Exxon Valdez Oil Spill
Restoration Project Final Report

Information Synthesis and Recovery Recommendations for Resources and Services Injured by the *Exxon Valdez* Oil Spill

Restoration Project 060783
Final Report

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October 2006

Exxon Valdez Oil Spill Trustee Council

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September 27, 2006

Dear Reader:

This report, **Information Synthesis and Recovery Recommendations for Resources and Services Injured by the *Exxon Valdez* Oil Spill**, was written by Integral Consulting Incorporated (Mercer Island, Washington) and funded by the *Exxon Valdez* Oil Spill Trustee Council as Project 060783. The findings and conclusions presented in this report are those of the authors and do not necessarily reflect the views of the Trustee Council. However, the Trustee Council will use this report, along with other scientific materials, as a source of information in revising the **Update on Injured Resources and Services**. The **Update on Injured Resources and Services** documents the position of the Trustee Council regarding the recovery status of resources and human services injured by the spill, and the most recent version can be viewed at www.evostc.state.ak.us/Habitat/injuredresources.htm.

Sincerely,

Michael Baffrey
Executive Director

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<u>Study History:</u> Restoration Project 060783 follows from Restoration Project 040776, which was initiated to provide the Trustee Council with an independent assessment of recent work on the nature and extent of lingering *Exxon Valdez* oil, an analysis of the ecological significance of lingering oil, a synthesis of relevant studies on resources classified in 2002 as "recovering" or "not recovering," and initial conclusions regarding the recovery status and general conditions of those resources. In addition to the resources addressed in Restoration Project 040776, Restoration Project 060783 addresses injured services (subsistence uses, passive uses, commercial fishing, and recreation/tourism) and resources currently classified as having an unknown recovery status (cutthroat trout, Dolly Varden, Kittlitz's murrelet, rockfish, and subtidal communities). This more comprehensive evaluation was conducted in consultation with agency and academic scientists who have been working in Prince William Sound over the past 17 years. Evaluation efforts are guided by the Exxon Valdez *Oil Spill Restoration Plan* (EVOS Trustee Council 1994), which provides long-term guidance for restoring the resources and services injured by the oil spill.

<u>Abstract:</u> This report summarizes and synthesizes restoration work performed to date; develops a scientifically sound process for objectively assessing the status of resources classified as injured; distinguishes (where possible) the contribution of other stressors to the condition of the resource; and provides recommendations to the Trustee Council on the recovery status of resources and services. As part of this evaluation, recovery objectives were reviewed and refined to ensure that the evaluation of the condition of the resources and services considers potential adverse effects from the spill and from other stressors. The resources and services addressed here were classified as "not recovering," "recovering," and "unknown" in the 2002 evaluation of recovery status (EVOS Trustee Council 2002b). This report provides the following recommendations to the Trustee Council on the recovery status of injured resource and services:

- **Recovered:** Subtidal communities, clams, mussels, the common loon, cormorants (3 spp.), rockfish, Dolly Varden, cutthroat trout, and harbor seals
- **Not recovering:** Pacific herring and the AT1 pod of killer whales
- **Recovering:** Wilderness areas, intertidal communities, harlequin ducks, sea otters, the AB pod of killer whales, and all services (subsistence uses, passive uses, commercial fishing, and recreation/tourism)
- **Unknown:** Marbled murrelet, Kittlitz's murrelet, and pigeon guillemot.

Recommendations on restoration and monitoring are also provided.

Key Words: Lingering oil, *Exxon Valdez*, EVOS, Prince William Sound, sediment quality, resource injury, service injury, sea otter, killer whale, harbor seal, seabirds, harlequin duck, Pacific herring, sediments, wilderness areas, intertidal communities, clams, mussels, cutthroat trout, Dolly Varden, marbled murrelet, Kittlitz's murrelet, common loon, pigeon guillemot, rockfish, subtidal communities, subsistence use, passive use, commercial fishing, and recreation/tourism

Project Data: No new data were collected for this project.

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ACRONYMS AND ABBREVIATIONS

95% CI	95 percent confidence interval
ADEC	Alaska Department of Environmental Conservation
ADFG	Alaska Department of Fish and Game
AHC	aliphatic hydrocarbon
AST	aspartate aminotransferase
BACI	before, after, control, impact (methodology)
CYP1A	cytochrome P450 1A
EROD	7-ethoxyresorufin-*O*-deethylase
EVO	*Exxon Valdez* oil
EVOS	*Exxon Valdez* oil spill
GGT	gamma glutamyl transferase
ha	hectare
IHC	immunohistochemical
LCI	lower Cook Inlet
LDH	lactase dehydrogenase
MLLW	mean lower low water
NOAA	National Oceanic and Atmospheric Administration
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PWS	Prince William Sound
SCAT	Shoreline Cleanup Assessment Team
SPMD	semipermeable membrane device
TPAH	total polycyclic aromatic hydrocarbon
USFWS	U.S. Fish and Wildlife Service

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This document represents our attempt to evaluate fairly and objectively a very broad body of work conducted in Prince William Sound and vicinity following the *Exxon Valdez* oil spill. The conclusions of this report represent those of Integral staff, and any errors and omissions are ours.

EXECUTIVE SUMMARY

This project was designed to synthesize restoration work performed to date; develop a scientifically sound process for objectively assessing the status of resources classified as injured; distinguish (where possible) the contribution of other stressors to the condition of the resource; and provide recommendations to the Trustee Council on the recovery status of resources and services. The resources and services addressed here were classified as “not recovering,” “recovering,” and “unknown” in the 2002 evaluation of recovery status (EVOS Trustee Council 2002b).

In preparing this report, we have considered a broad range of scientific studies, regardless of their funding source. The conclusions and recommendations provided in this report reflect the best professional judgment of Integral scientists.

BACKGROUND

EVOS occurred as a result of the grounding of the *T/V Exxon Valdez* on Bligh Reef on March 24, 1989. Approximately 11 million gallons of the tanker’s cargo of Alaskan North Slope crude oil was spilled into the open waters of PWS. The transport and fate of spilled *Exxon Valdez* oil (EVO) in open water in the first several days after the spill has been widely researched and is well documented in the open literature.

The periodic reassessment of the resources and services injured by EVOS is essential to understanding the effects of the original spill and lingering oil, documenting recovery of resources, and identifying new areas where additional restoration action or research may be needed. Communication to the Trustee Council and the public is a major part of this reassessment. Evaluation of the recovery status of injured resources has posed a challenge to scientists since 1994, when the Trustee Council first adopted an official list of injured species. As acknowledged in the original 1994 restoration plan and subsequent updates in 1999 and 2002 (EVOS Trustee Council 1994, 1999, 2002b), objective evaluation of resource recovery is complicated by uncertainties in population estimates, lack of pre-spill data, interaction of spill and natural factors, and the potential emergence of new and previously unidentified effects. As time passes, distinguishing the effects of EVOS from other stressors becomes even more challenging.

The 2006 assessment of injured resources and services was performed in consultation with a number of experts who have extensive experience in the assessment of resources and services adversely affected by EVOS. The approach to the evaluation included the following steps:

1. Identify all studies and reports funded by the EVOS Trustee Council
2. In consultation with experts, identify and prioritize those studies most relevant to the assessment of injured resource and services
3. Develop a systematic framework for evaluating biological resources

4. Develop and apply resource-specific evaluation matrices to summarize the scientific information available and the best professional judgment of resource experts
5. Conduct an evaluation of all resources and services classified as not recovering, recovering, and unknown.

A number of factors contribute to uncertainty in assessing the recovery status of resources and resource-dependent services. Sources of uncertainty include 1) uncertainties in population estimates, 2) lack of pre-spill data, 3) natural factors (climate variations, predator-prey relationships), 4) emergence of new effects, 5) difficulty in establishing causation, and 6) differences in the spatial and temporal scale of the different studies.

RESOURCES

Twenty-one resources were classified in 2002 as not recovering, recovering, or unknown (EVOS Trustee Council 2002b). Based on a comprehensive review of the most recent information on these resources, the following changes to recovery status are proposed:

	Resource	2002 Classification	Proposed 2006 Classification
Media			
	Sediment	Recovering	Recovering
	Wilderness areas	Recovering	Recovering
Intertidal and Subtidal Communities			
	Intertidal community	Recovering	Recovering
	Subtidal community	Unknown	Recovered
	Clams	Recovering	Recovered
	Mussels	Recovering	Recovered
Birds			
	Harlequin duck	Not recovering	Recovering
	Marbled murrelet	Recovering	Unknown
	Kittlitz's murrelet	Unknown	Unknown
	Common loon	Not recovering	Recovered
	Cormorants (3 spp.)	Not recovering	Recovered
	Pigeon guillemot	Not recovering	Unknown

	Resource	2002 Classification	Proposed 2006 Classification
Fish			
	Pacific herring	Not recovering	Not recovering
	Rockfish	Unknown	Recovered
	Dolly Varden	Unknown	Recovered
	Cutthroat trout	Unknown	Recovered
Mammals			
	Sea otter	Recovering	Recovering
	Harbor seal	Not recovering	Recovered
	Killer whale (AB pod and AT1 population)	Recovering (AB pod)	Recovering (AB pod) Not recovering (AT1 population)

It is recommended that the following monitoring and restoration actions be pursued:

- **Sediments—**Continue to monitor lingering oil in intertidal sediment, focusing on spatial extent, locations of hot spots, and loss rate. Consider supporting studies that may lead to more efficient ways of finding lingering oil, particularly outside of PWS.
- **Wilderness Areas—**Consider establishing a program to identify locations with lingering oil in wilderness areas, in coordination with studies described for sediments. Continue to communicate the progress being made toward recovery of resources important to wilderness areas.
- **Harlequin Ducks—**Continue to monitor exposure to lingering EVO through assessment of cytochrome P450 1A in harlequin ducks. Develop a population model to better understand the population dynamics and continue with population and demographic monitoring.
- **Seabirds—**Conduct population modeling to address uncertainty about the condition of the murrelet and pigeon guillemot populations, and consider methods to minimize incidental take of seabirds in gill nets.
- **Pacific Herring—**Direct research toward defining the relative contribution of predation and disease as limiting factors in recovery. Pursue the development and implementation of restoration projects related to herring enhancement.
- **Sea Otter—**Continue studies to better understand the condition of the sea otter population on Northern Knight Island.
- **Killer Whale—**Continue to monitor the population of the AB pod. Consider research to better understand the condition of the AT1 population and its relationship to stressors.

Additional detail on recommendations related to monitoring and restoration actions can be found in the individual resource sections.

SERVICES

Four services were classified in 2002 (EVOS Trustee Council 2002b) as recovering: commercial fishing, subsistence use, recreation, and passive use. Based on a comprehensive review of the most recent information on these resources, it is recommended that their recovery classifications remain the same.

It is also recommended that the following restoration actions be pursued:

- **Commercial Fishing—**See Pacific herring, above. In addition, consider involving herring fishermen (and their considerable expertise in vessel handling, marine equipment, and herring behavior) in projects to restore herring.
- **Subsistence Use—**Assess the status and relative importance of resources about which little is known. Develop strategies to address remaining food safety concerns. More outreach to help users understand and avoid diseases such as paralytic shellfish poisoning would help communities disassociate this disease from EVOS. Continue to incorporate subsistence users in resource stewardship and restoration to benefit cultural values and reconcile conflicts between spill-area users.
- **Recreation—**Continue to communicate the progress being made toward recovery of lingering oil in intertidal sediments.
- **Passive Use—**Continue to communicate the progress being made toward recovery for resources important to public perception. Recognize the importance of the ongoing presence of lingering oil and failed herring fishery to public perception.

Additional detail on recommendations related to monitoring and restoration actions can be found in the individual services sections.

1. INTRODUCTION

This project was designed to synthesize restoration work performed to date; develop a scientifically sound process for objectively assessing the status of resources classified as injured; distinguish (where possible) the contribution of other stressors to the condition of the resource; and provide recommendations to the Trustee Council on the recovery status of resources and services. As part of this effort, recovery objectives were reviewed and refined to ensure that in the evaluation of the condition of the resources and services, potential adverse effects both from the *Exxon Valdez* oil spill (EVOS) and from other stressors are considered. The resources and services addressed here were classified as “not recovering,” “recovering,” and “unknown” in the 2002 evaluation of recovery status (EVOS Trustee Council 2002b).

In preparing this report, we have considered a broad range of scientific studies, regardless of their funding source. The conclusions and recommendations provided in this report reflect the best professional judgment of Integral scientists, in consultation with technical experts.

1.1 STATEMENT OF PROBLEM

The periodic reassessment of the resources and services injured by EVOS is essential to understanding the effects of the original spill and lingering oil, documenting recovery of resources, and identifying new areas where additional restoration action or research may be needed. Communication to the Trustee Council and the public is a major part of this reassessment. Evaluation of the recovery status of injured resources has posed a challenge to scientists since 1994, when the Trustee Council first adopted an official list of injured species. As acknowledged in the original 1994 restoration plan (EVOS Trustee Council 1994) and subsequent updates in September 1996, March 1999, August 2002, and June 2003, objective evaluation of resource recovery is complicated by uncertainties in population estimates, lack of pre-spill data, interaction of spill and natural factors, and the potential emergence of new and previously unidentified effects. As time passes, distinguishing the effects of EVOS from other stressors becomes even more challenging.

1.2 BACKGROUND

EVOS occurred as a result of the grounding of the *T/V Exxon Valdez* on Bligh Reef on March 24, 1989. Approximately 11 million gallons of the tanker’s cargo of Alaskan North Slope crude oil was spilled into the open waters of Prince William Sound (PWS). The transport and fate of spilled *Exxon Valdez* oil (EVO) in open water in the first several days after the spill has been widely researched and is well documented in the open literature. In general, a number of widely accepted chemical and physical processes led to the relatively rapid evaporation, dissolution, dispersion, and degradation of EVO in the open water environment.

The initial spreading of EVO in open water was exacerbated by a series of significant storms resulting in the landing of EVO across shorelines of PWS over the course of a 2-month period. Several chemical and physical processes responsible for the transport and fate of EVO on these shorelines, particularly within the intertidal zone, have determined and continue to determine the nature and extent of remaining EVO. Seventeen years after the spill, EVO continues to persist to some degree in intertidal zones of the PWS shoreline and at patchy locations along the Gulf of Alaska shoreline southwest of PWS. This persisting EVO may act as a potential source of exposure to nonrecovering and recovering resources.

Initial efforts to address the impacts of the spill focused on rehabilitation of oiled birds and mammals and removal of oil from oiled shorelines. Efforts to remove oil from the shoreline using various treatment and removal techniques met with varying degrees of success. Subsequent restoration actions have been funded by the $900 million civil settlement paid by Exxon. Restoration activities have included habitat protection, research, monitoring, and general restoration. Protection of habitat through land acquisition ($406 million) has involved the purchase of important habitat to limit logging and development projects that could inhibit restoration of injured resources or services. Large parcels (greater than 1,000 acres) are purchased to protect key habitat throughout the spill region. Small parcels (less than 1,000 acres) are purchased typically to protect strategically located habitat, usually near coves, by important stretches of river, or adjacent to valuable tidelands. A portion of the settlement ($145 million) has been set aside as a restoration reserve, to fund long-term restoration efforts.

Natural recovery was selected as a preferred restoration method following the initial cleanup, which led to a comprehensive monitoring program to track the rate and effectiveness of natural recovery. Research was also directed toward restoration. Research and monitoring were primarily directed at tracking the recovery of resources following the spill and gaining a better understanding of the factors controlling the rate of recovery, the mechanism of impact, the nature of ongoing exposure, the location and bioavailability of pockets of residual EVO, and the interrelationships between injured and uninjured resources. Consideration of natural factors and other man-made influences (e.g., fishing, localized industrial releases) was needed to distinguish lingering impacts from the spill from those associated with other stressors. Three major ecosystem research programs were conducted: 1) the Sound Ecosystem Assessment project, which addressed factors that influence the productivity of Pacific herring and pink salmon; 2) the Nearshore Vertebrate Predator program, which evaluated factors affecting the recovery of four indicator species, river otters, pigeon guillemots (a seabird), harlequin ducks, and sea otters; and 3) the Alaska Predator Ecosystem Experiment, which evaluated the productivity and recovery of seabirds based on the availability of forage fish.

This most recent review and synthesis of the scientific research performed on resources injured by EVOS was initiated with Restoration Project 040776: *2005 Assessment of Lingering Oil and Resources Injuries from the Exxon Valdez Oil Spill* (Integral 2006). The primary purpose of the 2004/2005 assessment was to provide the Trustee Council with an independent analysis of the ecological significance of lingering oil and to provide an initial evaluation of the recovery status of injured resources classified as “recovering” or “not recovering.” The following resources were evaluated under Restoration Project 040776:

- Sea otter
- Harlequin duck

- Pacific herring
- Clams and mussels
- Intertidal communities
- Intertidal sediments, including shorelines in wilderness areas
- Killer whales
- Harbor seals
- Seabirds.

The results of the 2004/2005 evaluation were subjected to expert review in early 2006, as part of Restoration Project 060783.

The present synthesis report builds on resource evaluations performed in 2004/2005. Of the resources described above, significant additional effort was applied to the assessment of seabirds. Resources classified as unknown (subtidal sediments, Dolly Varden, cutthroat trout, and Kittlitz's murrelet) and services (commercial fishing, subsistence use, recreation and tourism, and passive use) were also evaluated. The synthesis of information and development of recovery recommendations for resources and services injured by EVOS that are provided in this report were initiated in October 2005 as Restoration Project 060783.

1.3 EVOS RESTORATION PLAN

Restoration efforts in PWS are guided by the Exxon Valdez *Oil Spill Restoration Plan* (EVOS Trustee Council 1994). The purpose of the restoration plan is to provide long-term guidance for restoring the resources and services injured by the oil spill. It contains policies for making restoration decisions and describes how restoration actions will be implemented. The plan also provides an official list of resources and services injured by the spill. For each resource, the plan identifies the following:

- **Recovery objectives—**An explicit statement of desired endpoints that would be achieved via implementation of a restoration strategy
- **Injury and recovery**—The nature of the injury to the resource and its current recovery status
- **Restoration strategy**—A resource-specific plan of action to achieve recovery.

The restoration plan acknowledges that all injuries to natural resources cannot be studied or fully documented, because of the size of the area affected by the spill, multiple habitat types, and large number of species affected. The lack of pre-spill baseline data is also a limiting factor. The list of injured resources and services provided in the restoration plan includes only those biological resources for which scientific research has demonstrated a population-level injury or continuing chronic effects. Periodic updates are provided when new information is available.

1.3.1 Goals and Objectives

The goals, objectives, and restoration strategies developed for injured resources and services (EVOS Trustee Council 1994, 2002b) are intended to provide the blueprint for restoring the spill area. The overall goal of restoration is recovery of all injured resources and services, sustained by healthy, productive ecosystems that maintain naturally occurring diversity (EVOS Trustee Council 1994). The objectives developed by the Trustee Council for the different resources and services are intended to be “measurable conditions that signal the recovery of individual resources or services. They are the yardsticks against which the success of the program is measured.” The overall recovery objective of injured resources is a return to conditions that would have existed had the spill not occurred (EVOS Trustee Council 1994, 2002b). Resource- and service-specific recovery objectives are in some cases refined in subsequent updates of the recovery status of injured resource and services (September 1996, March 1999, August 2002, and June 2003).

Many resources and services currently have as their recovery objective a “return to pre-spill levels” or “stable or increasing population trends.” These recovery objectives do not fully address the overall objective of a *return to conditions that would have existed if the spill had not occurred,* because they do not take into account other factors or stressors that can affect the population. For that reason, both resource-specific objectives and the overall objective of a return to conditions that would have existed had the spill not occurred are considered when evaluating the status of injured resources in this report.

1.3.2 Injury and Recovery Status

The underlying premise of the 1994 restoration plan is that the resources classified as injured were injured by EVOS. The 1994 injured species list included only those biological resources for which scientific research has demonstrated a population-level injury, or continuing chronic effects. In the years since the spill, other stressors have become increasingly important in determining the condition of a biological resource. As noted in the 2002 status update (EVOS Trustee Council 2002b), “analysis of these resources only pertains to recovery from the effects of the 1989 oil spill. Many of these resources are also experiencing the effects of other natural and human factors....”

In addition to the classification of “recovered,” the 1994 restoration plan defined three classifications for recovery status for injured resources:

- Recovering
- Not recovering
- Unknown.

These classifications were used to guide research and restoration strategies. Since 1994, a number of resources have been reclassified as recovered. Definitions for these different recovery classifications were not provided in the 1994 restoration plan. Some definitions were provided in the 2002 status update. Additional refinements to the definitions for the recovery classifications are provided in Section 2.3.1.

1.3.3 Restoration Strategy

The restoration plan includes five categories of restoration activities:

- General restoration
- Habitat protection and acquisition
- Monitoring and research
- Restoration reserve
- Public information, science management, and administration.

The restoration strategies developed under the 1994 restoration plan were tailored to each injured resource and its recovery status at that time (Table 1-1).

Table 1-1. *Exxon Valdez* Oil Spill Restoration Strategies, 1994.

	Restoration Actions				
	General Recovery				
Resource Category	Active Recovery	Natural Recovery	Habitat Protection and Acquisition	Monitoring	Research
Biological Resources					
Recovering		■		■	
Not Recovering	■		■	■	■
Unknown Recovery		■	■	■	
Other Resources					
Archeological	■		■		
Sediments	■	■		■	
Wilderness	← Dependant on recovery of other affected resources →				
Human Use Services[a]	← Dependant on recovery of other affected resources →				

[a] Commercial fisheries, passive uses, recreation, tourism, subsistence uses.
Source: EVOS Trustee Council (1994).

1.3.4 2002 Status of Injured Resources and Services

Twenty-one resources were classified in 2002 (EVOS Trustee Council 2002b) as not recovering, recovering, or unknown.

Not Recovering	Recovering	Unknown
Harlequin duck (Section 9)	Sediments (Section 3)	Subtidal communities (Section 6)
Cormorants (3 spp.) (Section 10)	Wilderness areas (Section 4)	Kittlitz's murrelet (Section 10)
Common loon (Section 10)	Intertidal communities (Section 5)	Rockfish (Section 12)
Pigeon guillemot (Section 10)	Clams (Section 7)	Dolly Varden (Section 13)
Pacific herring (Section 11)	Mussels (Section 8)	Cutthroat trout (Section 13)
Harbor seal (Section 15)	Marbled murrelet (Section 10)	
	Sea otter (Section 14)	
	Killer whales (Section 16)	

Four services were classified in 2002 (EVOS Trustee Council 2002b) as recovering: commercial fishing (Section 16), subsistence use (Section 17), recreation (Section 18), and passive use (Section 19).

1.4 DOCUMENT OVERVIEW

The approach to evaluating and classifying resources and services is provided in Section 2. Resources and services are evaluated in the following sections:

- **Resources**

  Section 3—Sediments

  Section 4—Designated wilderness areas

  Section 5—Intertidal community

  Section 6—Subtidal community

  Section 7—Clams

  Section 8—Mussels

  Section 9—Harlequin duck

  Section 10—Seabirds

  Section 11—Pacific herring

  Section 12—Rockfish

  Section 13—Dolly Varden and cutthroat trout

  Section 14—Sea otter

  Section 15—Harbor seal

  Section 16—Killer whale

- **Services**

  Section 17—Commercial fishing

  Section 18—Subsistence use

  Section 19—Recreation and tourism

  Section 20—Passive use

References cited are listed after these sections in addition to the following appendices:

- Appendix A—Summary of studies funded by the EVOS Trustee Council
- Appendix B—Resource evaluation framework
- Appendix C—Resource evaluation matrices
- Appendix D—Enzyme induction as a measurement of exposure.

2. APPROACH

The 2006 assessment of injured resources and services was performed in consultation with a number of experts with extensive experience in the assessment of resources and services adversely affected by EVOS (see list of experts in Appendix B). The approach to the evaluation included the following steps:

1. Identify all studies and reports funded by the EVOS Trustee Council
2. In consultation with experts, identify and prioritize those studies most relevant to the assessment of resources and services currently classified as injured
3. Develop a systematic framework for evaluating biological resources
4. Develop and apply resource-specific evaluation matrices to summarize the best professional judgment of resource experts
5. Conduct an evaluation of all resources and services classified as not recovering, recovering, and unknown
6. Subject resource and service evaluations to expert review.

Studies and reports funded by the Trustee Council are summarized in Appendix A. The reports and publications considered in the evaluation of resources and services are summarized in Section 20, "References." A more detailed evaluation of the nature and extent of lingering oil is provided in Integral (2006).

The decision framework, evaluation matrices, and evaluation process are described in the following sections. This section closes with a discussion of ecosystem and resource interconnectivity to provide a framework for considering potential cascading effects, when the condition of one resource affected by EVOS (or another stressor) may result in indirect effects on other resources.

2.1 DECISION FRAMEWORK FOR BIOLOGICAL RESOURCE ASSESSMENT

A decision framework, developed in consultation with technical experts, was constructed to provide a consistent and systematic evaluation process that could be applied to all resources (Figure 2-1). The recovery status of a resource population is determined by the magnitude of the initial impact of the EVOS, the population's intrinsic recovery potential, time since the spill, the magnitude of any continuing effects, and effects of other natural and anthropogenic stressors. Because the status of a population at any given time depends on a variety of life history traits, a simple measure of population abundance at any one time may not be a reliable indicator of future population viability. Population viability is a key measure of recovery status because it indicates the ability of the population to persist within a range of acceptable abundance levels in the future.[1] Therefore, the evaluation of recovery status should be based on those life history traits, spatial-temporal factors, physical-chemical characteristics, and other outside stressors that most heavily influence population viability:

- **Abundance and population growth**—The viability of a population, or conversely its risk of decline to undesirably low levels, depends on its abundance and productivity. Life history characteristics and food-web interactions combine to determine the potential viability of a population in a given habitat.
- **Genetic and phenotypic diversity**—Small populations may be at risk for loss of genetic diversity (Nelson and Soule 1987). High genetic diversity maximizes population persistence and productivity by allowing the population to use a wide range of habitats and environmental conditions (NRC 1996; McElhany et al. 2000).
- **Spatial–temporal structure of populations**—The evaluation of population spatial structure includes consideration of the amount of habitat available, the spatial organization and connectivity of habitat patches, and the overlap of the original spill and lingering oil with the population distribution. Temporal issues mainly relate to the amount of time since the spill in relation to generation time of a population, as well as seasonal migration behavior relative to the potential for release of lingering oil.
- **Physiological/behavioral metrics**—Physiological or behavioral metrics may be altered in response to an oil spill or other stressor, and be reflected in alterations in the general condition of the resource (e.g., changes in enzyme activity, or changes to activity-time budgets), which may be related to population level effects.
- **Habitat: Physical–chemical factors**—Habitat quality and extent clearly affect the recovery status of populations. In addition to spatial-temporal issues considered earlier from the standpoint of basic population ecology, the potential effects of lingering oil must be considered.
- **Confounding environmental factors—**Non-EVO-related stressors or natural disturbances may affect population recovery status.

The decision framework integrates both qualitative and quantitative information on multiple recovery metrics that pertain to population status. Details on the decision framework are provided in Appendix B.

2.2 EVALUATION MATRICES FOR BIOLOGICAL RESOURCES

In practice, information on a given resource is often incomplete. Evaluation matrices were developed for most[2] of the different biological resources using the recovery metrics described

[1] Although population viability is not a direct measure of recovery status, it is a useful concept for assessing the status of a population. If a population is not viable, then any recovery that may have occurred after EVOS is tentative.

[2] Matrices were not developed for subtidal communities or Dolly Varden.

above. Resource-specific evaluation matrices were modified, refined, and populated by experts in a series of meetings in 2005 and early 2006. These resource-specific matrices include information from existing scientific studies as well as best professional judgment of the participating experts, and represent the outcome of the meetings and discussions (Appendix C). They provide the foundation for making judgments about the existing status of the resources, but do not represent the final recommendations or conclusions of the resource assessments.

There are a number of sources of uncertainty in assessing resources and determining their recovery status. Sources of uncertainty[3] include the following:

- **Uncertainties in population estimates**—Because of the variability in animal distributions and the challenges of getting accurate counts, especially of highly mobile fish, birds, and mammals, most estimates of population size have wide ranges of uncertainty.
- **Lack of pre-spill data**—Many of the resources affected by the spill had limited or no recent data on their status in 1989. In addition, some of the available pertinent data was the result of limited sampling and had wide ranges in the population estimates. Data limitations made it difficult to assess initial injury accurately. In turn, any uncertainties in injury inevitably lead to uncertainties in estimating recovery.
- **Confounding of spill and natural factors**—It is increasingly difficult to separate what may be lingering effects from the spill from changes that are natural or caused by factors unrelated to the oil spill.
- **Emergence of new effects**—Because EVOS affected an area rich in wildlife and was so well studied, it would not be surprising that there are findings without precedent in the scientific literature.
- **Causation**—Establishing an unequivocal cause-and-effect relationship between a resource observed as impacted and EVOS may not be possible. For example, the level of biochemical alteration by oil in animals (e.g., cytochrome P450 1A [CYP1A] response) may be clearly linked to EVOS, but the degree to which it is detrimental to the population or to an individual is not known.
- **Scale—**The scale of an investigation must be considered when interpreting data. The 1994 plan identified injured resources based on scientific research that had demonstrated a population-level injury or continuing chronic effect. The overall goal of the restoration program is to restore a healthy and productive ecosystem. Many of the studies that address injured resources are conducted at large spatial scales to address these larger population and ecosystem concerns, and for practical reasons. Other studies focus on more localized areas (e.g., Northern Knight Island; localized “hot spots” of lingering oil).

[3] The first four bullets were described in the 2002 status update (EVOS Trustee Council 2002b).

2.3 EVALUATION PROCESS

Prior to evaluating the condition of a resource or service, it is important to 1) identify what constitutes recovery, and 2) define the terms used to classify ongoing injury. As described in Section 1, the recovery objectives developed by the Trustee Council were intended to be yardsticks against which recovery could be assessed. Because not all recovery objectives developed by the Trustee Council consider the impact of other stressors, the broader objective of a return to conditions that would have existed had the spill not occurred is also considered in this assessment. Definitions for the different recovery classifications are introduced here (Section 2.3.1) to clarify distinctions between the impacts from EVOS and those from other stressors, and to acknowledge different types of data limitations and uncertainty.

Information relevant to past and current conditions of the resource and related services were reviewed and evaluated to assess relative importance of 1) residual impacts from the spill, 2) recent and ongoing exposure to lingering oil, and 3) other stressors, in explaining the current conditions. Natural variability is also considered. Information is then subjected to a weight-of-evidence analysis to determine if it is more likely than not that the current condition of the resource (or related service) is related to EVOS.

The following sections describe refinements to the definitions for recovery classifications, principles of scientific proof that were considered when reviewing information, an overview of the evaluation process, and the weighing of evidence related to recovery.

2.3.1 Recovery Classification

An important challenge for this 2006 assessment of recovery status is to classify resources and services in a manner consistent with the original classification scheme, while acknowledging, when appropriate, our inability to distinguish potential residual impacts from the spill from the effects of other stressors. In 1994, this distinction was less of an issue. The spill was recent, dramatic in its impact, and in many cases, clearly linked to adverse effects in the biological resources and services classified as injured. In addition, it is important to retain a level of concern and scientific focus on an impaired resource while acknowledging that science may not always be able to identify a relationship between a resource condition and EVOS (or confirm the absence of a relationship).

Recovery objectives and restoration strategies for service categories historically have been dependent upon their respective biological resources, as well as traditional cultural values and the perceptions of the public. These dependencies do not change with this 2006 services evaluation. However, judgments concerning the recovery status of services will be affected by changes to the recovery status of related resources. To conduct a timely and current assessment of the status of services, we must rely on the recommendations related to resource recovery status provided in this report. In the case of subsistence use, this does not alter the 2002 recovery status (recovering) because other elements of the recovery objective for subsistence use have not been achieved. If the Trustee Council does not accept the recommendations on recovery status provided here for resources, the related recovery classifications for services may change.

Given the importance of other stressors, as well as the limitations of existing data, we have refined the definitions of recovery status in this 2006 assessment as follows:

2.3.1.1 Recovery Classifications for Resources

- **Recovered**—Recovery objectives have been achieved, and the current condition of the resource is unrelated to or is not adversely affected by EVOS.
- **Recovering**—Resources classified as recovering are making progress toward the recovery objective, but are still adversely affected by residual effects from the spill or have evidence of exposure to lingering EVO.
- **Not Recovering—**Resources classified as not recovering are showing no signs of recovery from EVOS injuries **or** are showing persistent impairment in the spill area that is unique, unprecedented, and of widespread concern to scientists and the public.
- **Unknown—**Biological resources classified as unknown have limited data on the life history and extent of injury **or** it is unclear if the condition of the resource can be attributed to other stressors or to residual effects from EVOS.

2.3.1.2 Recovery Classifications for Services

- **Recovered**—Recovery objectives have been achieved, and the current condition of the service is unrelated to or is not adversely affected by EVOS.
- **Recovering—**Services classified as recovering are making progress toward their recovery objective because the resource or resources on which they depend are making progress toward their recovery objective. Cultural values and human perceptions of resource recovery are also considered in the evaluation of recovery status of subsistence use, recreation, and passive use.
- **Not Recovering—**Services classified as not recovering depend solely on resources that are showing no signs of recovery from EVOS.

2.3.2 Principles of Scientific Proof

Principles of scientific proof are needed to ensure that information is objectively evaluated with respect to its strengths and weaknesses based upon accepted standards of conducting and interpreting scientific investigations. Moreover, the degree to which a study adheres to principles of scientific proof is important in a weight-of-evidence approach (Section 2.3.4 below) to assess potential cause-and-effect relationships between EVOS and recovery status.

Five principles were considered in the review of scientific reports and articles and throughout the course of communications with key scientific experts.

1. The use of formal hypothesis testing with standard statistical methods should be incorporated into the study design such that supportable inferences could be drawn from the observations and information obtained.
2. The use of generally accepted scientific methods to collect and analyze data samples and to analyze and present data is required.
3. Determination of the potential rate of error[4] associated with the data is required.
4. Use of a study design appropriate to address relevant scales of geography, time, and biological levels of organization is required.
5. The result should be peer reviewed and preferably accepted into a scientific publication.

2.3.3 Evaluation of Resources and Services

The current condition of the resources injured by the 1989 spill can potentially derive from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

Available information about the condition of the resource is assessed to determine the likely cause of the current condition. Information considered in assessing a resource includes the following:

- Population and community survey data compared with trends in reference areas
- Biomarkers of exposure (e.g., CYP1A)
- Tissue concentrations of polycyclic aromatic hydrocarbons (PAHs) as a marker of exposure to petroleum hydrocarbons
- Exposure potential
  - Distribution and concentrations of lingering oil
  - Overlap between spatial distribution of lingering oil and resource
  - Potential exposure pathways—Trophic, direct contact, ingestion of contaminated sediment
- Other sources of petroleum hydrocarbons and PAHs in PWS
- Effects of other stressors

[4] Rate of error is used in the discussion of principles of scientific proof to make implicit reference to the importance of understanding statistical error rates (i.e., assigned to α and β), which are important in hypothesis testing and interpretation of study results.

- Ecological significance of any demographic effects of initial impact of EVOS and of observed/predicted effects of lingering oil, including evaluation of spatial-temporal exposure, nature and magnitude of observed or predicted effects, and recovery potential.

Residual effects from the spill are assessed by evaluating the nature and magnitude of the initial impact from the spill, the life history of the resource and inherent ability of the population to recover from initial impacts, and current information about the condition of the resource. Long-lived resources that are slow to reproduce are most vulnerable to residual effects from the spill.

Ongoing exposure to lingering oil is assessed by considering the amount of lingering oil, its bioavailability and bioaccessibility, the degree to which there is spatial overlap between a given resource and lingering oil, the behavior of a resource that could result in ongoing exposure to lingering EVO, and the availability of information on biomarkers that indicate a greater degree of exposure in formerly oiled areas relative to unoiled areas. Potential exposure to lingering oil was the central focus of the initial assessment of resources (Integral 2006); evaluation of the nature, extent, bioavailability, bioaccessibility, and persistence of lingering oil relied heavily on recent work by Short et al. (2003a, 2004a, 2005, 2006). This more detailed assessment of lingering oil is incorporated into this report by reference. For resources that live or forage in the intertidal zone, exposure to localized areas of lingering oil is a concern, either through direct contact or through ingestion of contaminated prey.

All resources are subject to other stressors, and the role of other stressors is particularly important 17 years after the spill, when natural variability may obscure any residual effects of the spill.

The recovery of services is largely dependent upon their respective biological resources, as well as traditional cultural values and the perceptions of the public. These dependencies do not change with this 2006 services evaluation. However, judgments concerning the recovery status of services will be affected by changes to the recovery status of related resources. To conduct a timely and current assessment of the status of services, we must rely on the recommendations related to resource recovery status provided in this report. In the case of subsistence use, this does not alter the 2002 recovery status (recovering) because other elements of the recovery objective for subsistence use have not been achieved.

2.3.4 Weight of Evidence

The recovery status of a resource or service is determined using a weight-of-evidence approach in concert with the principles of scientific proof described above. Principles of scientific proof concern the scientific rigor, quality, and acceptability of information that can subsequently be used in a weight-of-evidence framework for judging recovery status. The weight-of-evidence approach involves reasonable scales for judging the information from multiple studies and making inferences concerning recovery, which are not strictly scientific. This weight-of-evidence approach incorporates multiple lines or sources of information to assess the current condition of resources. Multiple lines of evidence are used because an unequivocal cause-and-effect relationship between a resource observed as impacted and EVOS may not be possible or necessary to establish with certainty from a single study or line of evidence. In assessing the effects of contaminant spills, it is very difficult to establish a complete chain of cause and effect from the contaminant to its ultimate effects. For a variety of reasons, including a lack of pre-spill data, ignorance about the physiological effects of oil on key species of wildlife, and lack of knowledge of how sublethal doses of contaminants affect populations, there are few if any species for which we have complete knowledge of the original effects. Without such complete knowledge of effects, gauging recovery has some inherent uncertainties. Multiple lines of evidence are used to mitigate these uncertainties while acknowledging that unequivocal cause-and-effect relationships may not be demonstrable. In summary, the weight-of-evidence approach uses multiple lines of evidence to balance scientific proof and uncertainties, and incorporates professional judgment and inference (which are not strictly scientific) concerning whether it is more likely than not for resource recovery to have occured.

2.4 ECOSYSTEMS AND RESOURCE INTERCONNECTIVITY

It is important to consider the interrelationships among resources to assess potential cascading effects,[5] when the condition of one resource affects another. These relationships among resources may also result in indirect effects from EVOS, when one resource depends on another resource that is impaired by residual effects from the spill or exposure to lingering EVO.

PWS is a geologically and geographically complex semi-enclosed basin that supports a rich and diverse marine ecosystem. The ecosystem comprises a wide array of shoreline, nearshore, and open water habitats that range in elevation from the diurnally exposed upper intertidal zone to depths of 300 m or more. The numerous species and communities of organisms that are components of this ecosystem are connected through trophic[6] dependencies in a complex marine food web (Figure 2-2) and through non-trophic interactions that may involve social, competitive, or biological processes. Consequently, both natural perturbations and human disturbances such as EVOS can affect individual species not only directly but also indirectly through other interdependent species and ecosystem components (Peterson et al. 2003). In this section, we examine the potential for indirect interactions in the PWS ecosystem and the possible influence of such indirect effects on key biological resources. Whether EVOS caused injury through indirect effects and whether any observed indirect effects are ongoing will be addressed in later sections on individual recovering and nonrecovering resources.

Two kinds of indirect effects are considered:

- Trophic cascades and bottom-up effects mediated through food-web interactions
- Nontrophic cascades and bottom-up effects mediated through habitat provisioning or social or competitive interactions.

[5] Cascades occur when biotic or abiotic disturbances are expressed across more than one level of ecological organization (e.g., Peterson et al. 2003; Pace et al. 1999). Trophic cascades refer to effects on abundance or biomass across more than one link in a food web.

[6] Relating to processes of energy and nutrient transfer from one or more organisms to others in a food web, food chain, or food pyramid.

In addition to indirect effects mediated through species interactions, ecosystem forcing is considered as another factor that may affect populations and communities through basic habitat variables (e.g., physical mixing regimes, phytoplankton production, and climatic changes independent of EVOS).

Potential interaction webs are summarized graphically in Figures 2-3 through 2-5. Results of the evaluation of indirect effects on recovering and nonrecovering resources are provided in later sections of this report on individual resources.

Based on knowledge of the PWS system and other ecosystems of the Pacific Northwest, there are important species interactions that could lead to alternative community states after a perturbation such as an oil spill or climatic change. These interactions are best addressed through the perspective of the key resource species being considered in this report. For example, the following trophic and nontrophic cascades and bottom-up effects are possible after a perturbation:

2.4.1 Rocky Subtidal Habitat

- **Killer whale/sea otter/urchin/kelp trophic interactions—**Sea otters, through their effects on prey populations, are known to be a key species responsible for structuring rocky subtidal communities (Figure 2-3; Estes and Palmisano 1974). Declines in sea otters may result in increases in abundance and sizes of some invertebrate prey (clams, urchins). Increased grazing pressure could result in a decline in subtidal kelp populations. Transient killer whales may also be an important predator on sea otters and thereby initiate such a trophic cascade by consuming large numbers of otters when their larger marine mammal prey (harbor seal and sea lion) are less available (Estes et al. 1998; Springer et al. 2003).
- **Killer whale/seal and sea lion/herring trophic interactions—**A decline in transient killer whales due to a perturbation could cause increases in their marine mammal prey and a consequent decline in herring and other fishes eaten by the marine mammals. A similar cascade could result from a decline in resident killer whales that reduced predation pressure on their large-fish prey (e.g., salmon) and increased predation by salmon on herring (Figure 2-3; Peterson et al. 2003).
- **Bottom-up effects through food webs—**Loss of kelp through a perturbation may lead to declines in diverse communities associated with kelp beds. In particular, herring and other fishes that use kelp as substrate for spawning may be severely affected by a decline in a kelp population, potentially with subsequent indirect effects through food webs (Figure 2-3). In addition to a habitat-provisioning effect, any significant decline in a resource species at the base of a food web could lead to effects that propagate upwards through the web with subsequent changes in higher trophic-level species that are food-limited. In particular, significant declines in the herring population of PWS, whether they are due to EVOS or not, are of concern because herring is a key resource species for larger fishes, seabirds, and sea lions.

- **Social interactions among sea otters and among killer whales—**Loss of key older individuals in killer whale pods and in sea otter groups may lead to social disintegration, which would represent an indirect effect of an initial perturbation (Peterson et al. 2003).

2.4.2 Rocky Intertidal Habitat

- **Seabird and shorebird/crustacean and gastropod/algae trophic interactions—** Declines in harlequin ducks and other marine birds, or in oystercatchers and other shorebirds that prey on grazers such as gastropods and herbivorous crustaceans, could lead to increases in the grazer populations with subsequent decreases in edible algal species like *Ulva* and *Enteromorpha.* Similarly, a trophic cascade to benthic microalgae is possible through grazers such as periwinkles and limpets (Figure 2-4).
- **Bottom-up effects through food webs—**Loss of *Fucus* through a perturbation may lead to declines in diverse communities associated with *Fucus* beds in rocky intertidal habitat. In particular, loss of *Fucus* leads to declines in herbivorous crustaceans and gastropods that depend on *Fucus* for cover, potentially with subsequent indirect effects through food webs. In addition to habitat-provisioning effects, loss of *Fucus* results in increases in its subordinate competitors, the ephemeral green algae *Ulva* and *Enteromorpha* (Figure 2-5; Peterson et al. 2003). Any significant decline in a resource species at the base of a food web could lead to effects propagating upward through the web with subsequent changes in higher trophic-level species that are food-limited (Figure 2-4).

In rocky intertidal habitat, potential trophic cascades from higher-level predators through benthic filter-feeders to phytoplankton (Figure 2-4) are not a concern because is it unlikely that phytoplankton populations are limited by benthic filter-feeders.

Indirect effects of EVOS that are mediated through ecosystem connectivity may be affected by other stressors through ecosystem forcing variables. Potential mechanisms of ecosystem forcing in the PWS ecosystem include the following:

- **Climate—**Climatic factors, such as decadal-scale fluctuations in atmospheric pressure over the north Pacific or longer-term global warming, that alter physical oceanographic characteristics, including sea surface temperature, wind fields, current patterns, freshwater discharge, and nutrient regimes, act as stressors on the PWS ecosystem in addition to the potential effects of EVOS.
- **Alaska earthquake—**Changes in shoreline configuration created by uplift and tsunami during the great Alaska earthquake of 1964 could have caused heterogeneous conditions and consequently confound the evaluation of the effects of EVOS and recovery to pre-spill conditions.
- **Anthropogenic stressors—**In addition to EVOS, anthropogenic stressors on the PWS ecosystem may include human harvesting of marine mammals, fish, and shellfish; contamination of nearshore habitats by toxic chemicals; human-induced mortality of marine mammals; and disturbance of wildlife by human presence in their habitats.

Despite the potential for indirect effects of EVOS through trophic and nontrophic interactions between species, some researchers (e.g., Neff and Gilfillan 2004) have concluded that such effects after EVOS were insignificant. Clearly, EVOS and subsequent shore cleanup actions caused a decline in populations of the abundant and widespread alga *F. gardneri* in rocky intertidal habitat, leading to population instability. Regrowth of *Fucus* after the spill was dominated by a single-aged cohort, which led to a subsequent mass die-off of this species 4–5 years following EVOS (Paine et al. 1996). Cascades due to social disintegration of killer whale pods or sea otters remain an issue in PWS. One of the most persistent concerns is the potential relationship between EVOS and the decline in the herring population of PWS, leading to subsequent negative effects on other fish, seabirds, and sea lions that prey on herring. However, there is a large amount of scientific uncertainty in the linkage between the continuing reduction of the PWS herring population and EVOS.

Thus, any indirect linkage between seabird declines and EVOS via reductions in their herring prey resource is also highly uncertain. Direct and indirect effects of EVOS on resource species are discussed further in later sections of this report.

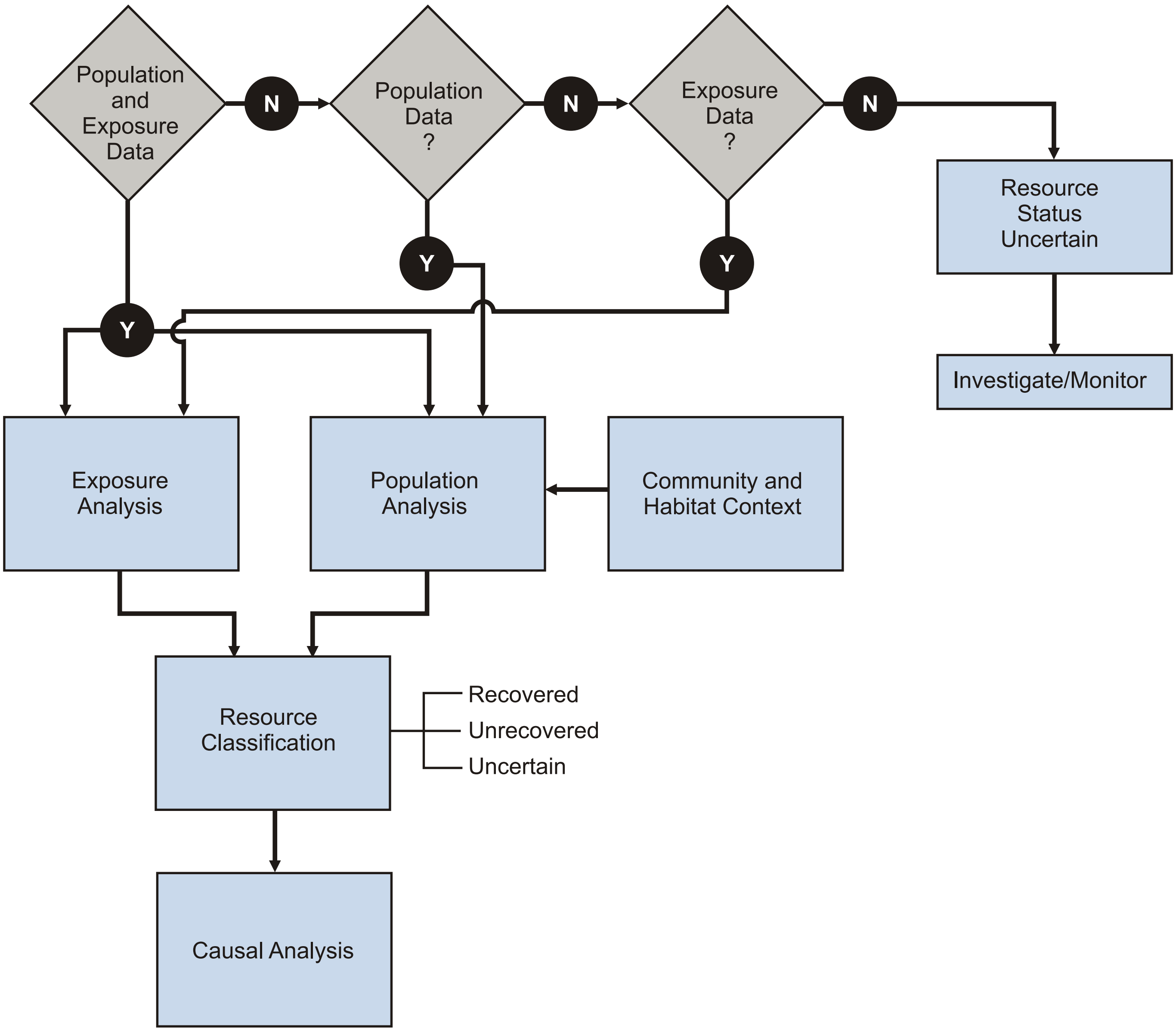
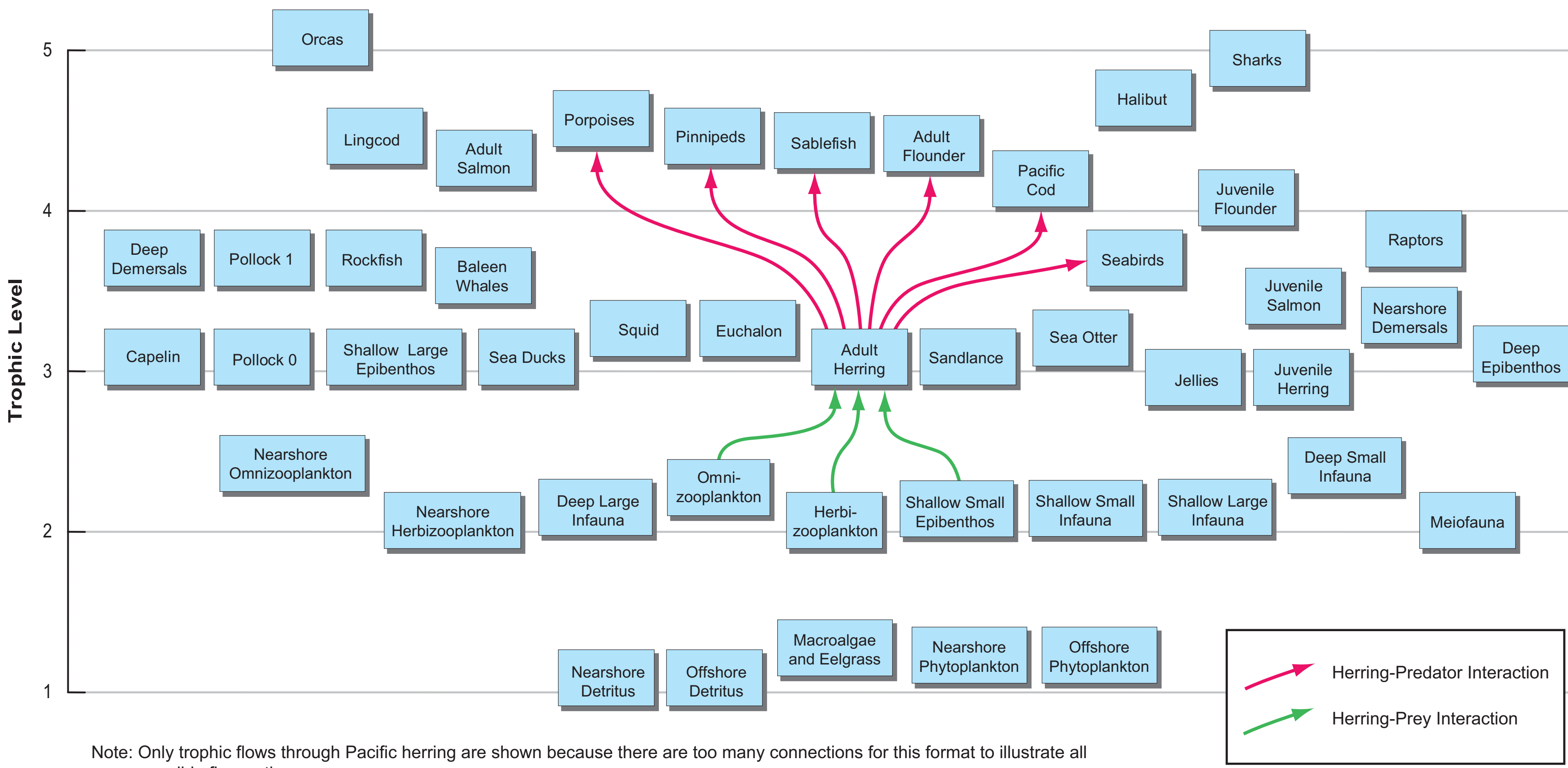


Figure 2-1. Overview of Evaluation of Resource Recovery Status for Population-Level Analysis



Note: Only trophic flows through Pacific herring are shown because there are too many connections for this format to illustrate all possible flow pathways.

Figure 2-2. Components of the Balanced Trophic Model of Prince William Sound, Alaska, Displayed on a Trophic Level Scale (adapted from Okey and Pauly 1999a).

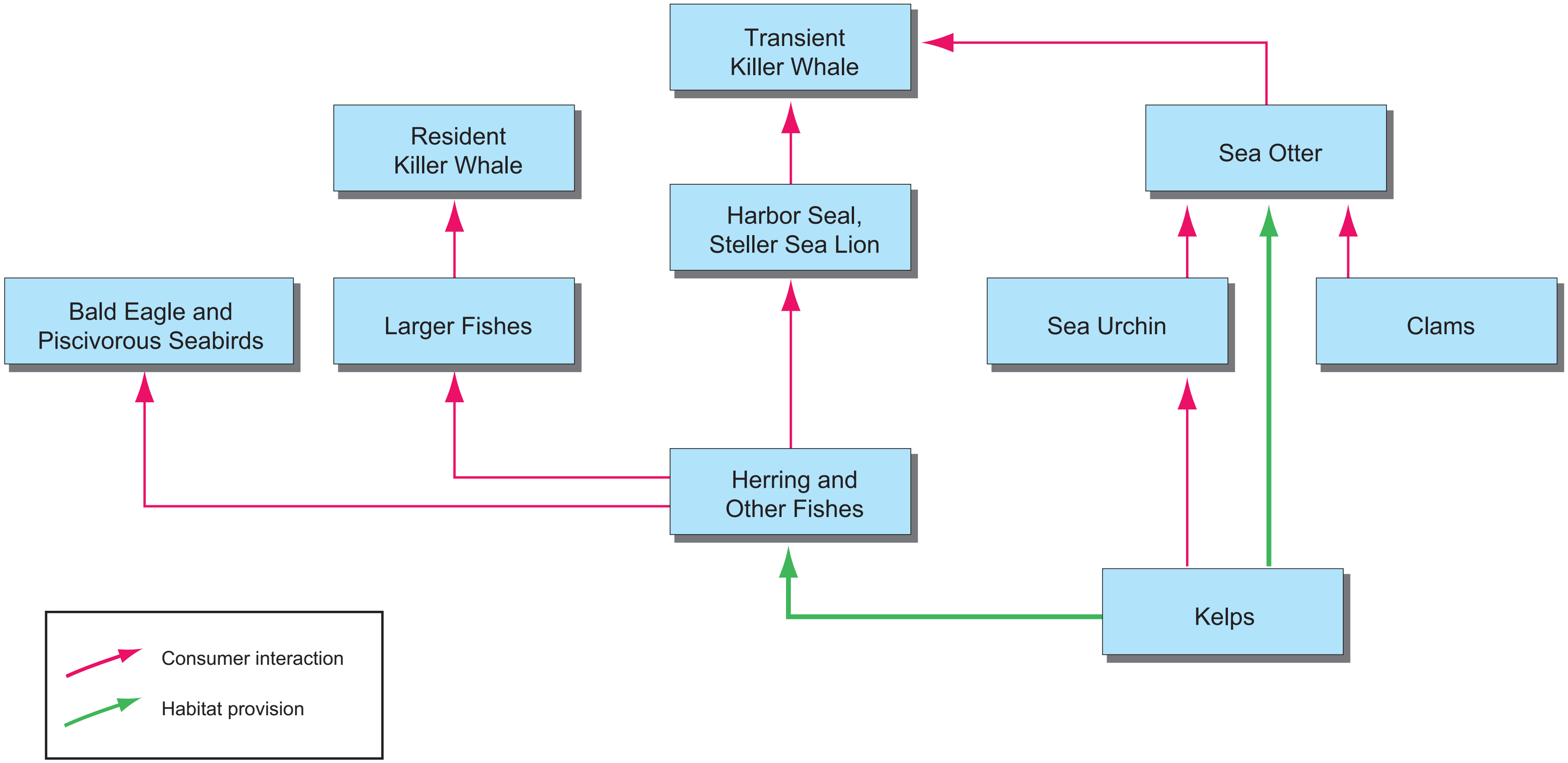


Figure 2-3. Primary Trophic Interactions in Rocky Subtidal Habitat of Prince William Sound (adapted from Peterson et al. 2003).

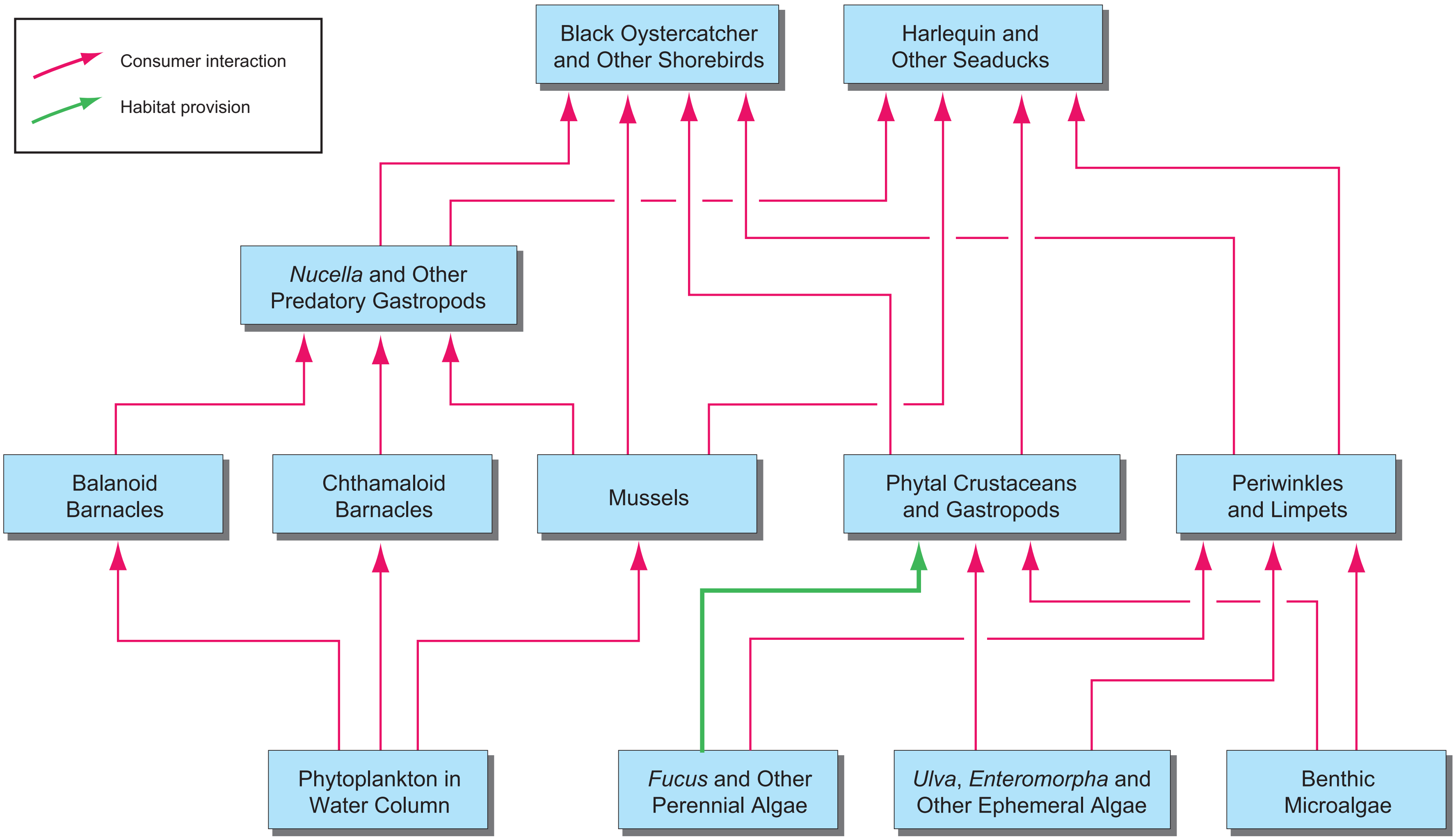


Figure 2-4. Primary Trophic Interactions in Rocky Intertidal Habitat of Prince William Sound (adapted from Peterson et al. 2003).

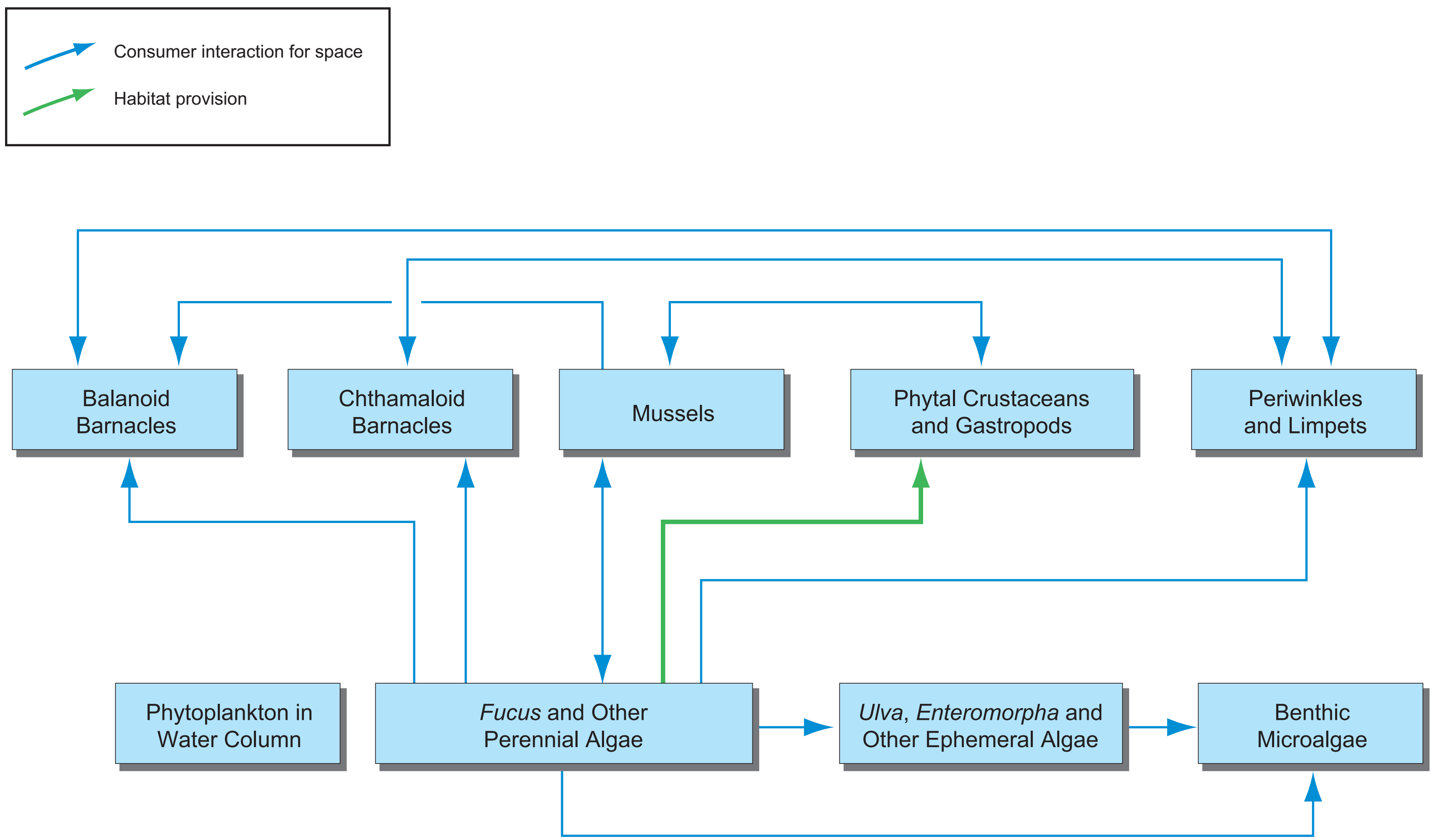


Figure 2-5. Primary Competitive Interactions in Rocky Intertidal Habitat of Prince William Sound (adapted from Peterson et al. 2003).

RESOURCES

3. SEDIMENTS

3.1 INTRODUCTION

On March 24, 1989, approximately 11 million gallons of Alaskan North Slope crude oil cargo from *T/V Exxon Valdez* was spilled into the open waters of PWS. Seventeen years after the spill, EVO continues to persist in intertidal zones of the PWS shoreline and along the shoreline southwest of PWS. Lingering oil in surface sediments occurs primarily in the form of highly weathered, solid asphalt-like material sporadically present in the upper intertidal zone of sheltered areas. In contrast, EVO that penetrated the intertidal matrix of cobbles, gravel, and finer sediments to subsurface depths is less susceptible to weathering processes.

The discussion in this section generally focuses on PWS because that is where the more complete and quantitative characterization of EVO in sediments has been performed.

3.1.1 Statement of Problem

Sediments were classified as "recovering" in the 2002 assessment of resource recovery status (EVOS Trustee Council 2002b) due to the presence of diminishing but persistent EVO residues. Sediments containing lingering EVO are currently limited to the intertidal portion of the shoreline. Much of the intertidal environment containing lingering oil can be considered "sediment" only in the broadest sense of the word. Shoreline geomorphology in PWS typically consists of exposed and sheltered rocky shores composed of bedrock, very large boulders (>50 cm diameter), boulder-cobble, or wave-cut platform; and coarse-textured beaches and exposed tidal flats comprising gravel, sand, and mixed gravel/sand.

3.1.2 Status of Injury and Recovery Classification

The recovery objective established in 1994 (EVOS Trustee Council 1994) was as follows:

> Sediment will have recovered when contamination causes no negative effects to the spill ecosystem.

By 2002 (EVOS Trustee Council 2002), this recovery objective had been refined to be:

> Sediments will have recovered when there are no longer significant residues of *Exxon Valdez* oil on shorelines (both intertidal and subtidal) in the oil spill area. Declining oil residues and diminishing toxicity are indications that recovery is underway.

In 2002, the EVOS Trustee Council (2002b, p. 21) concluded that "[s]ediments are considered to be recovering. However, the presence of surface and subsurface oil continues to compromise wilderness and recreational values, expose and potentially harm living organisms, and offend visitors and residents, especially those who engage in subsistence activities along still-oiled shorelines."

3.1.3 Overview of EVOS Trustee Council-Funded Restoration Efforts

The EVOS Trustee Council strategy for sediment restoration was to monitor recovery by monitoring concentrations of hydrocarbons in sediment and indices of petroleum exposure in flatfish, and to remove or reduce residual oil if treatment is cost-effective and less harmful than leaving the oil in place (EVOS Trustee Council 1994). Following the Shoreline Cleanup Assessment Team (SCAT) surveys conducted between 1989 and1993, most studies related to contaminated sediments focused on the resources that live in and on sediment or forage in sediments. However, starting in the early 2000s, the Trustee Council funded a number of National Oceanic and Atmospheric Administration (NOAA) studies that addressed the nature and extent of lingering oil. These studies are listed in Appendix A.

3.2 RESOURCE ASSESSMENT

The nature and extent of lingering EVO in shoreline sediments in PWS have been evaluated using visual surveys (SCAT surveys), probability-based sampling techniques to estimate spatial extent and volume, semipermeable membrane device (SPMD) techniques to address bioavailability, and specialized methods to evaluate the potential for lingering oil in intertidal sediment to induce an enzyme[7] indicating PAH exposure in living resources (Short et al. 2004a, 2006; Springman et al. in prep., 2005). These studies are described in the following sections.

3.2.1 Initial Impact from Spill (1989–1993)

Approximately 40–45 percent of the estimated 10.8 million gallons of crude oil spilled by the *Exxon Valdez* is estimated to have washed ashore in the intertidal zone of PWS (Wolfe et al. 1994). Aerial surveys conducted by the Alaska Department of Environmental Conservation (ADEC) showed that light to heavy deposits of EVO washed ashore on approximately 24 percent (446 km) of the 1,891 km of the PWS shoreline observed (Peterson 2001), and surveys in 1989 documented oil on 16 percent (783 km) of an estimated 5,000 km of PWS shoreline (Neff et al. 1995). Within the first few months following the spill, 89 percent (462) of the oiled beaches in PWS were cleaned using a variety of methods and techniques.

3.2.1.1 Shoreline and Intertidal Sediments

Following the initial spill in March 1989, a series of comprehensive ground surveys was performed to document the prevalence and magnitude of oiling present on beaches of PWS. The main surveys, referred to as SCAT surveys, were performed in 1989, 1990, 1991, 1992, and 1993. The goal of these surveys was to map the oil spill on shorelines and classify the shorelines according to extent and magnitude of oiling.

[7] CYP1A is an enzyme that is induced in organisms when they are exposed to certain types of chemicals, typically PAHs and PCBs.

The most extensive survey was conducted in September 1989, during which approximately 1,200 km of the 5,000 km PWS shoreline was walked and surveyed by SCAT members (see Figure 3-1). SCAT surveys conducted in subsequent years covered a smaller extent of PWS (1,100 km in 1990, 390 km in 1991, 32 km in 1992, and approximately 50 km in 1993), owing to reductions in oil attributable to natural processes (e.g., dispersion, weathering) and direct cleanup efforts performed chiefly by Exxon.

Because the methods used in SCAT surveys are predominantly based on visual observations, the emphasis of SCAT surveys was on surface oiling. Subsurface oiling was examined to a lesser extent and usually in an opportunistic fashion to augment visual assessments of the surface. A chief objective of the SCAT surveys was to direct cleanup efforts. The SCAT surveys also provided a mechanism by which the persistence of EVO over time could be monitored.

According to the SCAT surveys, the extent of oiled shoreline had decreased from 583 km to 10 km from the period of 1989 to 1992 (ASGDC 2005; Neff et al. 1995). These trends suggested that oil remaining after 1992 would soon further disperse to negligible amounts (Koons and Jahns 1992; Neff et al. 1995; Boehm et al. 1995; Gibeaut and Piper 1998; Gilfillan et al. 2000). At some locations, however, oil appeared to be more persistent (Hayes and Michel 1999; Brodersen et al. 1999; Carls et al. 2001a; Short et al. 2004a). For example, the 1993 SCAT survey suggested that the remaining oil might disperse more slowly because it was mostly in compartments such as sediments beneath armored beaches where it was protected, and it was no longer subjected to cleanup (Gibeaut and Piper 1998).

3.2.1.2 Subtidal Sediments

Little empirical data has been collected to provide a definitive estimate of the amount of EVO that was transported to subtidal communities after the initial spill. Lee and Page (1997) estimated that approximately 1–13 percent of the originally amount of EVO spilled was transported, whereas Wolfe et al. (1994) estimated a range of 12–13 percent. Koons and Jahns (1992) suggested that most of the nonvolatile portion of EVO was transported out of PWS into the Gulf of Alaska where waves and currents dispersed it into the open Pacific Ocean.

A sediment survey conducted by Wolfe et al. (1996) from 1989 to 1991 examined 18 oiled sites in shallow subtidal areas (0–6 m below mean low water). Locations were based on previous studies in which decreasing toxicity from direct oil contact was observed with increasing distance from the shoreline (Wolfe et al. 1996). Based on this survey, concentrations of petroleum hydrocarbons were greatest at depths between 0 and 3 m, while no significant difference in petroleum hydrocarbon concentrations was identified among oiled and reference sites for deeper waters (i.e., > 40 m in depth) (Wolfe et al. 1996). O’Clair et al. (1996a) examined subtidal sediment from 0 to 100 m mean low water depth in 1989, and observed that the greatest petroleum hydrocarbon concentrations were present at depths of 3–20 m. Jewett and Dean (1997) reported that average petroleum hydrocarbon concentrations in subtidal sediments adjacent to heavily oiled areas were > 4,900 ng/g versus < 1,200 ng/g in reference sites.

Sale et al. (1995) used sediment traps to assess potential nearshore to offshore transport of EVO. Oiled sediments were transported from the intertidal shoreline to adjacent subtidal areas and resulted in low and decreasing concentrations of petroleum hydrocarbons from 1989 to 1992 (Sale et al. 1995). Short et al. (1996) suggested that leaching of oil from intertidal sediments into the water column could also result in subsequent deposition to deeper water, although the exact transport mechanism was not stated.

By 1995, PAH concentrations in subtidal sediment were estimated to have decreased by 90 percent, leading to the recovery of most subtidal species (Jewett and Dean 1997). By 2001, little to no EVO was present in subtidal sediments (Short et al. 2003a). Lingering EVO in subtidal sediment is no longer a concern.

3.2.2 Other Sources of Petroleum

The vast majority of the area in PWS originally impacted by the spill is considered remote wilderness. Despite this remoteness, a variety of petroleum hydrocarbon and other PAH sources occur throughout PWS, including both natural and human sources. There are two major types of hydrocarbon sources in PWS and the surrounding Gulf of Alaska: petrogenic (produced from unburned petroleum) and pyrogenic (produced from the combustion of fossil fuels or organic matter). Prior to the spill, a major source of petrogenic hydrocarbons was the March 27, 1964, Alaska earthquake. The earthquake resulted in the rupturing of asphalt and fuel oil storage tanks in Valdez and other sites around the PWS and the Gulf of Alaska. These asphalt and fuel oil products originated from the California Monterey Formation oils, which are chemically distinct from EVO.

Hydrocarbons originating from background sources are present throughout PWS in subtidal sediments. Sources of background hydrocarbons include eroding petroleum “source rocks” derived from Tertiary shales in areas east of PWS, coals originating in the outcrops of the Kulthieth Formation east of PWS (including the Bering River coalfields), and natural oil seeps (of doubtful significance) that occur throughout the northern Gulf of Alaska, but that are absent in PWS itself. Additional sources of hydrocarbons are associated with human activity, including more recent, smaller oil spills, and activities at villages, sawmills, canneries, and camps where coal, oil, or wood were used or burned (Page et al. 1998; 2006).

3.2.3 Nature and Extent of Lingering EVO in Shoreline Sediments

This section describes the nature and extent of lingering oil. Processes responsible for determining the nature, extent, and current conditions of lingering oil are presented.

3.2.3.1 Surface EVO

At the surface, EVO has been susceptible to a number of chemical and physical weathering processes that have acted to limit (relative to subsurface) its nature and extent in the intertidal zone. For example, surface EVO was directly subjected to Exxon’s shoreline cleanup activities (e.g., bulk removal actions, hot-water washing) performed during the months after the spill. Some EVO remained on cobbles, gravel, and surficial sediments. This EVO was subsequently subjected to natural weathering and degradation processes, such as direct wave action and tidal flushing, evaporation, photolysis, and biodegradation. Over time, losses of EVO due to these processes have occurred at progressively slower rates, as the remaining hydrocarbon fractions gradually became less susceptible to weathering (Hayes and Michel 1999; Michel and Hayes 1999; Page et al. 2002b; Short et al. 2004a).

Under current conditions, surface EVO is present in a variety of weathered forms, including asphalt pavement/mousse, some tar balls and tar patties, and weathered surface oil residues (Gibeaut and Piper 1995; Short et al. 2002, 2004a). In addition, a small percentage of surface EVO consists of oil coats and oil films in the intertidal zone (Gibeaut and Piper 1995; Short et al. 2004a). NOAA researchers have recently estimated that approximately 4.13 hectares (ha) (10.2 acres) of surface EVO may remain in PWS, with the majority being present in the upper half of the intertidal zone (Short et al. 2004a). The majority of surface oil present in the intertidal zone consists of EVO, with less than 10 percent considered attributable to other sources (e.g., Monterey Formation petroleum products release from tanks during the 1964 earthquake) (Short et al. 2004a).

3.2.3.2 Subsurface EVO

In contrast with remaining surface EVO, EVO that penetrated the intertidal matrix of cobbles, gravel, and finer sediments to subsurface depths is less susceptible to weathering processes. At depth, particularly below armored beaches, EVO is not subject to the same degree of natural weathering that occurs at the surface. Subsurface EVO was also not directly subjected to the cleanup efforts performed by Exxon. The collective research suggests that less weathered subsurface EVO has been sequestered in beaches armored by boulders and cobbles (Hayes and Michel 1999; Michel and Hayes 1999; Page et al. 2002b; Short et al. 2004a), in low-angle middle intertidal areas (Short et al. 2004a), in finer sediments beneath mussel beds (Babcock et al. 1998), and in thick sediment veneers over bedrock (Hayes and Michel 1999). Subsurface EVO appears particularly evident in moderately to highly sheltered shorelines that were heavily oiled soon after the initial spill (Hayes and Michel 1999; Wolfe et al. 1994; Short et al. 2004a). Researchers have recently estimated that approximately 7.8 ha (19.3 acres) of subsurface EVO, located predominantly in the middle intertidal zone, may remain in PWS (Short et al. 2004a).

Despite being largely sequestered, subsurface EVO is nevertheless subject to some degree of weathering and other transformation/partitioning processes. These processes include dissolution into pore waters and metabolic transformation by microbial and other benthic organisms. Such processes are most likely to result in relatively slow weathering. More rapid changes to sequestered EVO may occur as a result of reintroduction to the sediment surface, where the more rapid transformation and weathering processes occur. Reintroduction may occur following storm events, which may produce significant erosion and changes in beach morphology. For example, such changes were observed following the vigorous storms of the winter of 1992–1993 (Babcock et al. 1998). Reintroduction of subsurface EVO by bioturbation by benthic invertebrates and digging activity of sea otters has also been proposed (Peterson et al. 2003; Rice and Peterson 2004).

3.2.3.3 Uncertainty in Lingering Oil Estimates

Because they were based on random sampling methods, estimates of the amount of lingering oil in intertidal sediments made by Short et al. (2004a, 2006) include explicit assessments of uncertainty. Beach segments previously classified as lightly oiled within PWS were not included in the Short et al. (2004a, 2006) surveys. Based on their 2001 survey, the point estimate of beach area contaminated by surface oil within PWS was 4.1 ha, and the associated 95 percent confidence interval (95% CI) for this estimate ranged from 2.1 to 7.7 ha (Short et al. 2004a). The corresponding estimate for subsurface area was 7.8 ha (95% CI: 4.1–12.7 ha). The amount of subsurface oil was also estimated as 55.6 tons (95% CI: 26.1–94.4 tons). The magnitude of these confidence intervals indicates that the likely upper and lower bounds of the estimates are within factors of 2 and 0.5, respectively.

The oiled beach areas were underestimated, because subsequent work showed that oil was more widespread than assumed for the 2001 study of Short et al. (2004a). The 2001 survey was limited to oil that was obvious in the upper half of the intertidal zone, and focused primarily on beaches that had been described as moderately or heavily oiled during surveys conducted from 1990 through 1993. Subsequent work indicated that the area of beach contaminated by subsurface oil in the lower half of the intertidal zone was approximately 36 percent of the amount in the upper half (Short et al. 2006). The amount of oil associated with beaches described as moderately oiled during the surveys conducted in the early 1990s was considerable, suggesting that additional oil may be associated with beaches described as lightly oiled during that period. These beaches were not considered for the 2001 survey. Accounting for these sources of underestimation suggests the point estimate of oiled beach areas should be increased by approximately 40 percent, with a corresponding increase of the oil amount to approximately 78 tons. Short et al. (2004a) suggested that accounting for surface oil would increase the point estimate of oil amount to approximately 100 tons, and if the 95 percent confidence intervals scale proportionately, an upper limit to the amount of oil remaining in 2001 would be approximately 200 tons.

Additional oil is present on beaches outside PWS (Irvine et al. 1999), but the quantity present is uncertain. Based on the mass balance estimates of oil fate presented by Wolfe et al. (1994), the amount of oil that initially beached outside PWS was about 18 percent of the oil that beached within PWS. If the oil within and outside PWS dispersed at similar rates, the amount remaining on beaches outside PWS would be approximately 18 tons, with an upper 95 percent confidence limit of approximately 36 tons. Such estimates are obviously very uncertain, because of the uncertainties in the amounts that beached outside PWS, the considerable differences in coastal geomorphology and oil viscosity on landfall between PWS and the more exposed Gulf of Alaska (Irvine et al. 1999), and possible differences in dispersion processes.

3.2.3.4 Bioavailability and Bioaccessibility

Based on the work of Short et al. (2004a), Page et al. (2002b), and others (e.g., Michel and Hayes 1999; Hayes and Michel 1999) and as described above, lingering oil in surface sediments occurs primarily in the form of highly weathered, solid asphalt-like material sporadically present in the upper intertidal zone of sheltered areas. Because it occurs at the surface, it is considered to be physically bioaccessible to resources. However, toxic components in weathered oil cannot readily dissolve into ambient seawater when the oil is in a solid, asphalt form, and therefore these components are not likely to be bioavailable.

In contrast with remaining surface oil, EVO that penetrated the intertidal matrix of cobbles, gravel, and finer sediments to subsurface depths is less susceptible to weathering processes and hence is less viscous, so that toxic components may dissolve more readily into seawater (Short et al. 2004a; Page et al. 2002b; Michel and Hayes 1999; Hayes and Michel 1999; Wolfe et al. 1994). Although it occurs at depth and may be less physically bioaccessible, this form of EVO is considered to be potentially more bioavailable than surface weathered oil.

Recent research conducted in 2004, using SPMDs[8] placed in the intertidal zone, indicates that where lingering subsurface oil is present, it is bioavailable to intertidal organisms, exists in a bioactive form that is capable of inducing CYP1A in fish, and is distinguishable from stressed reference locations that have sediments contaminated by other non-EVO-related sources of petroleum hydrocarbons (Springman et al. 2005; Short et al. 2005). Although such evidence for bioavailability exists, mussels tested near oil patches do not show elevated levels of PAHs (Page et al. 2005), and the benthic communities living on the oil patches are not significantly different from benthic communities found in unoiled areas (Day 2005). With respect to higher trophic level organisms, in particular harlequin duck and sea otter, CYP1A results indicate that exposure to EVO is declining, as evidenced by recent biomarker trends in oiled areas relative to unoiled. Additional details on the exposure and bioavailability of specific resources are discussed in subsequent sections of this report.

3.2.3.5 Estimate of EVO in Intertidal Sediments (2005)

Based on work performed in 2001, Short et al. (2004a) estimated that approximately 10 acres of surface EVO and 19 acres of subsurface EVO were present in PWS. Additional related work performed in 2003 (Short et al. 2006) demonstrated that lingering oil extended further into the lower intertidal zone than originally anticipated, suggesting that the original estimate may be low by as much as 30 percent. A recent Exxon-funded survey suggests that a smaller area than that estimated by Short et al. (2004a) may remain (Taylor and Reimer 2005). Consensus has been reached that whatever EVO does remain is a small fraction of the total area oiled in 1989.

In consultation with NOAA, a probabilistic technique was used to project the location of lingering oil in 2005, as well as the areal extent and volume (Integral 2006). Based upon a Monte Carlo analysis and an assumed annual loss rate of 20–26 percent, an estimated 4 acres of surface EVO and 7 acres of subsurface EVO were projected to be present in PWS in 2005 and less than 1 acre of EVO will be present in 2014 (i.e., 9 years). Based upon additional modeling using more conservative assumptions (i.e., a loss rate as low as 2.6 percent and 30 percent more lingering oil than originally estimated), a worst case estimate of approximately 35 total acres is predicted for 2005. Two locations were identified as areas of potential interest during the

[8] SPMDs are a biomimetic research tool that has been used to simulate water-mediated uptake and bioaccumulation potential of oil and other substances by aquatic organisms.

analysis. Northern Knight Island and Smith Island are two areas that were initially heavily impacted by the spill. Northern Knight Island has been the focus of additional investigation by NOAA during 2003 to evaluate further the presence of subsurface oil throughout the intertidal zone.

3.2.4 Restoration and Remedial Options for Lingering EVO in Sediments

Michel et al. (2005) evaluated potential technologies for the remediation of subsurface EVO in PWS. The technologies were initially screened on the basis of effectiveness, implementability, and operational considerations. Selected technologies were subsequently evaluated to consider a variety of environmental factors. Based on this evaluation, Michel et al. (2005) identified two restoration approaches as most viable: 1) natural recovery, and 2) nutrient enrichment. Natural recovery precludes active remediation in favor of allowing sediments to recover under normal environmental conditions. Nutrient enrichment is a treatment technique used to hasten the biodegradation of oil and thus, its removal from the environment. Michel et al. (2005) next evaluated these options with respect to both costs and environmental impacts.

Overall, Michel et al. found that:

- Natural recovery was the least expensive option. The predicted costs for natural recovery based on biannual monitoring were less than a million dollars.
- Natural recovery has fewer environmental impacts associated with implementation than nutrient enrichment.
- The costs associated with nutrient enrichment were predicted on the basis of extrapolated costs associated with treating an estimated 71,500 kg of subsurface EVO predicted for PWS, for a total cost of $50 million.
- Nutrient enrichment is predicted to cost approximately $700 per kilogram of subsurface EVO.
- Total costs for nutrient enrichment of subsurface EVO do not include finding the subsurface EVO prior to remediation, nor do they include project management and oversight by government agencies.
- Nutrient enrichment has greater environmental benefit, with benefit defined as removal of bioavailable oil.

Michel et al. (2005) acknowledged that the next step in the decision-making process is to conduct a detailed benefit-cost analysis, comparing the ecological benefits of removal of the lingering oil with the financial and ecological costs associated with remedial efforts.

Some uncertainty remains with respect to the likely effectiveness of the nutrient enrichment option. For example, this technology has not been applied to remove subsurface oils in the types of armored and rocky beaches prevalent in PWS. Because treatment scenarios are not directly applicable to the current subsurface oiling situation in PWS, additional research to identify factors limiting microbial degradation of subsurface oil and additional treatability studies would be necessary.

3.3 SUMMARY AND RECOMMENDATIONS

"Sediments will have recovered when there are no longer significant residues of Exxon Valdez oil on shorelines (both intertidal and subtidal) in the oil spill area. Declining oil residues and diminishing toxicity are indications that recovery is well underway" (EVOS Trustee Council 2002b). Declining oil residues have been well established, and declining toxicity corresponds to declining oil residues. The fundamental issue is one of significance. The remaining oil has limited ecological significance; however, it likely results in localized exposure and (possibly) adverse impacts to some resources that live in direct proximity to the remaining oil patches.

It is recommended that the Trustee Council classify sediments as "recovering." The following restoration activities are also recommended:

- Monitoring efforts that assess the recovery rate of intertidal sediments (i.e., the loss rate of EVO).
- Studies that may lead to efficient methods of finding the lingering oil, particularly in locations outside of PWS.
- If lingering oil is more persistent than anticipated, and if impacts to resources also persist, feasibility studies of remedial technologies that enhance the recovery of intertidal sediments.

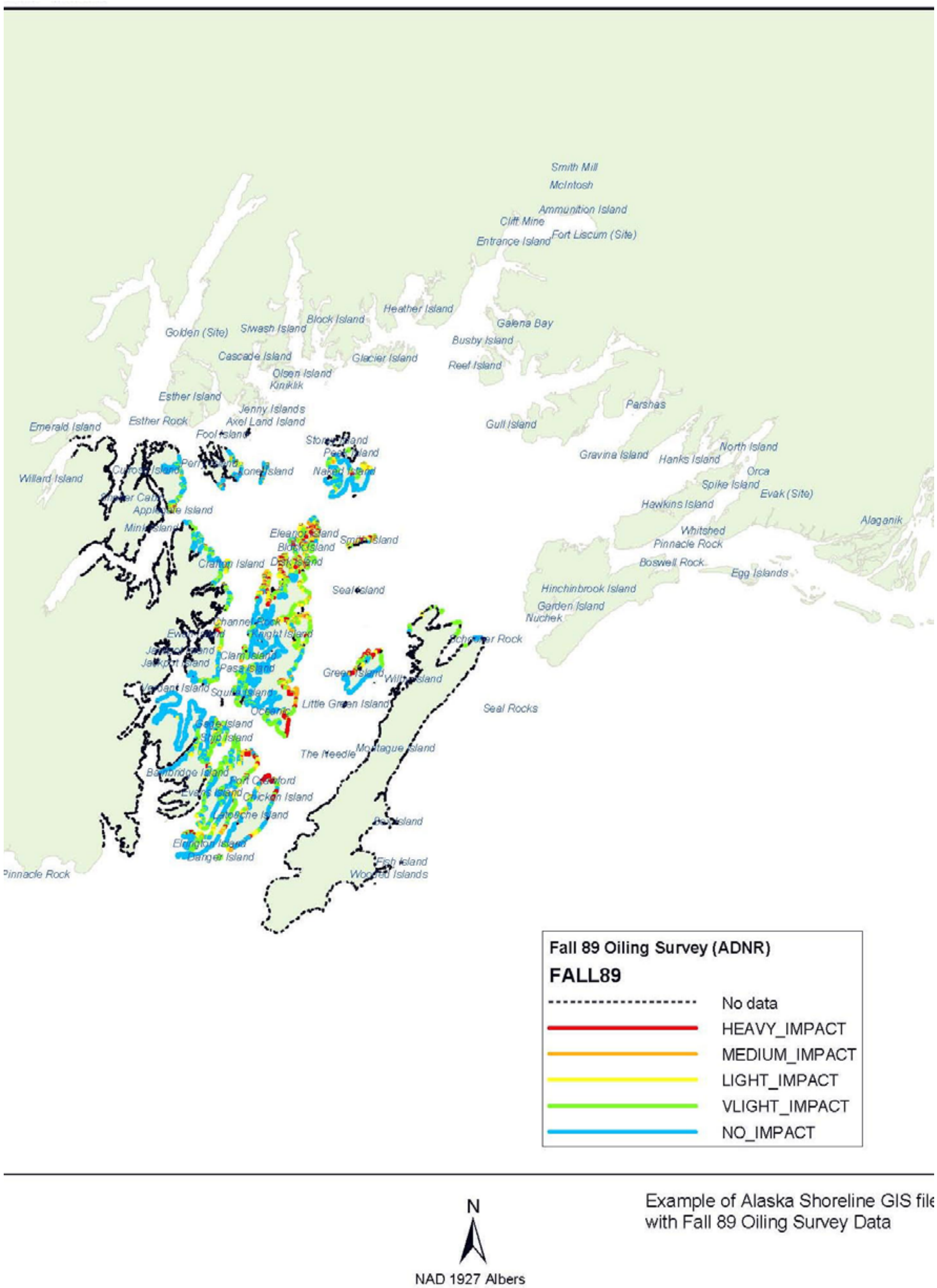


Figure 3-1. Depiction of Oiling in Prince William Sound According to Fall 1989 SCAT Survey.

4. DESIGNATED WILDERNESS AREAS

4.1 INTRODUCTION

EVOS resulted in the oiling of seven areas within the spill area designated as wilderness areas and wilderness study areas by Congress or the Alaska State Legislature. The presence of thousands of workers and their cleanup equipment during the 1989 and 1990 cleanup season also imposed an unprecedented amount of people, noise, and activity in this sparsely populated environment. The affected designated wilderness areas include Katmai National Park, wilderness study areas in the Chugach National Forest and Kenai Fjords National Park, and Kachemak Bay Wilderness State Park.

4.1.1 Statement of Problem

Wilderness areas were classified as "recovering" in the 2002 assessment of resource recovery status (EVOS Trustee Council 2002b) due to the presence of diminishing but persistent EVO residues. As is the case for sediment, lingering EVO in the intertidal shoreline is the portion of wilderness areas that continues to be of concern. Living resources associated with wilderness areas are also a concern.

4.1.2 Status of Injury and Recovery Classification

The recovery objective for wilderness areas established in 1994 (EVOS Trustee Council 1994) was as follows:

> Designated wilderness areas will have recovered when oil is no longer encountered in these areas and the public perceives them to be recovered from the spill.

This recovery objective was unchanged in the most recent assessment of resource recovery (EVOS Trustee Council 2002b). In 2002, the EVOS Trustee Council (2002b, p. 10) observed that significant quantities of oil were still present in wilderness areas in 2001, and concluded that wilderness areas were recovering but had not recovered from the oil spill.

4.1.3 Overview of EVOS Trustee Council-Funded Restoration Efforts

The EVOS Trustee Council restoration strategy for designated wilderness areas (EVOS Trustee Council 1994) was: "Any restoration strategy that aids recovery of injured resources, or prevents further injuries, will assist recovery of designated wilderness areas. No strategies have been identified that benefit only designated wilderness areas without also addressing injured resources." Few studies have been conducted that directly address wilderness areas outside of PWS; most studies have been focused on living resources in PWS. Studies funded by the EVOS Trustee Council are listed in Appendix A.

4.2 RESOURCE ASSESSMENT

The living resources that are integral to the recovery of wilderness areas are discussed in Sections 5 through 16. The evaluation of lingering EVO in the shoreline sediments of PWS, most relevant to Chugach National Forest, is discussed in Section 3. Outside of PWS along the Gulf of Alaska, a number of studies have been performed principally by the U.S. Geological Survey, the U.S. Fish and Wildlife Service (USFWS), and ADEC (e.g., Babcock et al. 1996, 1998; Irvine et al. 1999, 2002; Carls et al. 2001a) to evaluate lingering EVO on boulder armored beaches and mussel beds. These studies were performed along armored beaches at the Kenai Fjords and Katmai National Parks and the Kodiak Archipelago and for mussel beds along the Kenai and Alaska Peninsula coastlines.

In 1995, a shoreline survey team from ADEC visited 30 sites along the Kodiak Archipelago that had measurable or reported oiling in 1990 and 1991 (ADEC 1996). By 1995, no oil or only trace amounts of oil were observed. Along the Kenai Fjords and Katmai National Parks, the majority of armored beaches visited[9] (typically five of six beaches visited) had largely unweathered EVO present as mousse in the subsurface, while areas of surface oiling were largely absent. These study sites were characterized as being relatively low in geomorphological diversity, consisting of boulder-armored, gravel beaches, most with an underlying bedrock abrasion platform at shallow depth (Irvine et al. 2002). This low diversity stands in stark contrast to the high diversity in geomorphology along shorelines throughout PWS (Irvine 2005, pers. comm.). In sediments at mussel bed sites, EVO was generally found, but by 2002, the areal extent and concentration of EVO was found to have declined at most sites (Irvine et al. 2002). As of 2005, the decreasing trend in EVO present in sediments at mussel bed sites appears to be continuing in these remote areas (Irvine 2005, pers. comm.).

4.3 SUMMARY AND RECOMMENDATIONS

"Designated wilderness areas will have recovered when oil is no longer encountered in these areas and the public perceives them to be recovered from the spill" (EVOS Trustee Council 2002b). Declining oil residues have been well established (see discussion in Section 3); however, pockets of lingering oil remain. The absence of quantitative studies of lingering EVO outside of PWS is an important source of uncertainly when assessing the amount of lingering oil present in wilderness areas. Although lingering oil may be present in a relatively few, select locations within wilderness areas, it is unlikely to be encountered by most visitors because it is predominant in subsurface conditions, largely in the form of mousse under boulder-armored shorelines.

It is recommended that the Trustee Council classify wilderness areas as "recovering." Until the public perceives that lingering oil has diminished to levels that no longer adversely affect aesthetics, this resource cannot be considered recovered. It is also recommended that the following restoration actions be considered:

[9] Study sites included McArthur Pass, Cape Douglas, Kiukpalik Island, Ninagiak Island, Cape Gull, and Kashvik (Irvine et al. 2002).

- Consider supporting studies that may lead to efficient methods of determining the location and quantity of lingering oil in wilderness areas, in coordination with studies conducted to address lingering oil within PWS and outside of PWS (see recommendations for sediments, Section 3).
- Continue to communicate the progress being made toward recovery of resources important to public perception.

5. INTERTIDAL COMMUNITY

5.1 INTRODUCTION

EVOS resulted in the oiling of approximately 16 percent (783 linear kilometers) of an estimated 5,000 km of PWS shoreline (Neff et al. 1995). This event had major impacts on the intertidal communities, particularly to the upper intertidal zone (EVOS Trustee Council 2002a). Beach cleaning and associated physical impacts to intertidal communities also occurred within the first months after the spill. Following these events, intertidal habitat characteristics, biota mortality, and long-term changes in community composition were investigated to evaluate the impact of the spill and the various shoreline treatments used to remove oil (Houghton et al. 1996; Highsmith et al. 1996).

5.1.1 Statement of Problem

The intertidal community in PWS was classified as "recovering" in the most recent assessment of resource recovery status (EVOS Trustee Council 2002b). Information on the natural history of intertidal communities, nature and severity of impacts from the spill, and intertidal habitat and community characteristics are evaluated here to independently assess the current recovery status of intertidal communities.

Clams and mussels are independently classified as injured resources. Consequently, injury status and recovery of clams and mussels are addressed in separate sections of this report (Sections 7 and 8, respectively).

5.1.2 Natural History and Ecology

Exceptionally productive biological communities are found in intertidal zones, as a result of the confluence of nutrient runoff from the land and planktonic foods from the photic zone of the ocean pushed into the coastline by winds and waves. Intertidal communities are of intrinsic importance in PWS, providing important ecosystem services such as food resources for a wide variety of marine and terrestrial consumers. Consumers of intertidal flora and fauna include human subsistence users, bear, sea and river otters, marine crabs and shrimp, rockfish, cod, juvenile fish that use the intertidal zone for foraging and refuge, and a variety of birds, including black oystercatchers, harlequin ducks, and pigeon guillemots (EVOS Trustee Council 1994; Peterson 2001).

The intertidal communities of the Gulf of Alaska are characterized by a rich diversity of marine fauna and flora whose populations are governed by the physical and chemical gradients of their environment, as well as by biological forces including predation and competition (Foster et al. 1991; Houghton et al. 1997; Lindstrom et al. 1999). Important gradients that structure intertidal communities are exposure to air by tidal excursions, substrate type, and exposure to wave energy. These factors have led to a system of classification of intertidal habitat by its vertical position in relation to tidal elevations, substrate type, and degree of exposure to wave energy.

5.1.2.1 Vertical Gradients in Intertidal Habitat—Zonation

Tides in PWS are semidiurnal; two highs and two lows occur each lunar day, with successive high and low waters having different heights. Tidal heights vary depending on coastal geometry and are typically expressed relative to vertical distance above or below mean lower low water (MLLW). In PWS, the intertidal zone ranges from extreme low water (–1.4 m) to extreme high water (+5.1 m). However, these tidal extremes occur only a few times a year. The intertidal zone is more typically characterized by the semidiurnal fluctuations between the elevations of MLLW (0 m)[10] and mean higher high water (+3.8 m).

Within these few meters of vertical space, intertidal communities are shaped by a series of gradients that govern organism abundance and distribution, and result in often visually striking changes, or zonation, in the intertidal community. Vertical zonation is a prominent feature of Gulf of Alaska intertidal communities, particularly on rocky shores. Plants and animals of temperate rocky intertidal zones tend to exhibit strong patterns of vertical zonation. Physical factors, including temperature and emersion, strongly influence species' distribution at the upper limit of the intertidal zone, though shorebird predation can play an important role in limiting upper limits for some intertidal species (Irons et al. 1986; Feare and Summers 1986; Marsh 1986). Biological factors, particularly predation, often function to control the distribution of many plants and animals in the lower intertidal zone (Raffaelli and Hawkins 1996).

Although the exact terms used to describe vertical zonation patterns vary depending on researcher and geography, there is general agreement among descriptions of Pacific Coast intertidal communities that outlines distinct zones of communities along a vertical gradient. However, there is a variety of schemes for characterizing vertical gradients in the intertidal zone (Foster et al. 1990). Some are defined based on dominant taxa in the community. For example, Shigenaka (1997) defined lower, middle, and upper intertidal zones based on the distribution of rockweed (*Fucus*), which dominates the middle intertidal of rocky habitat. Other vertical classification schemes are based on the relative degree of exposure to air and position with respect to a fixed tidal benchmark. For example, Highsmith et al. (1996) defined zones based on vertical distance below the mean high water elevation. Consequently, low-, middle-, and high-intertidal zones may be defined differently depending on the objectives of a particular study. For this evaluation, we define a framework of three intertidal zones (high, middle, and low) divided evenly between extreme low water and extreme high water in PWS (Figure 5-1). Such a physically defined framework provides a common denominator for evaluating EVO, lingering oil, and resource injury for this highly complex and diverse community.

5.1.2.2 Horizontal Gradients in Intertidal Habitat—Substrate Type and Wave Energy

Substrate type is a major physical factor in shaping intertidal communities. Intertidal substrates range from bedrock or large boulder systems with little or no interstitial space, to cobble and mixed cobble/gravel beaches, to sandy beaches, and then mudflats. Rocky intertidal areas

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[10] The actual elevation of the MLLW benchmark can vary slightly from the ideal of 0 m depending on month-to-month and year-to-year variability in local conditions. For example, in 1989, the average monthly elevation of MLLW in PWS was +0.1 m.

provide a relatively stable substrate compared to gravel or sandy beaches where the substrate is more mobile and can shift due to wave action or other disturbance. However, animals found on gravel or sandy beaches are well adapted to this mobile substrate. The rocky intertidal area of the northeast Pacific is one of the best-studied marine ecosystems in the world, whereas research on sandy beach communities is less comprehensive.

Distinct changes in community composition are also seen along gradients of exposure to wave energy. High wave exposure results in a community dominated by algal species that can withstand abrasion and fast flow, and by animals such as mussels and barnacles that are resistant to detachment. In moderately wave-exposed areas, a broader array of more mobile fauna such as crabs and sea stars can be found using refuges such as rock overhangs to withstand wave exposure. A variety of more delicate plants and animals are found in more sheltered locations.

Based on beach geomorphology and degree of exposure, five principal intertidal habitats were identified for EVOS-related studies in PWS, the Kenai Peninsula, lower Cook Inlet (LCI), and Kodiak Island (Sundberg et al. 1996; Highsmith et al. 1996) (Figure 5-2):

- **Exposed rocky shores—**These shores are predominantly composed of bedrock, very large boulders (>50 cm diameter), boulder-cobble, or wave-cut platform habitats that are exposed to high energy waves. Disturbance, both physical and biological, and larval recruitment rates are among the factors that can modify the community composition and abundance of species. Because of the intense biological interactions among species, changes in the abundance or distribution of one or more species can have strong direct and indirect effects on other members of the intertidal ecosystem. Bedrock shores consist of a supralittoral *Verrucaria* fringe and a mid-intertidal *Fucus*-barnacle-mussel zone; the low intertidal zone is dominated by fleshy red algae at five of seven sites, with average cover exceeding 50 percent, although *Fucus* and a number of green algae are also diagnostic of these sites (Lindstrom et al. 1999). Boulder-cobble sites are characterized by *Acrosiphonia arcta*, *Fucus gardneri*, and "*Ralfsia*" sp. in the low zone; the mid-zone is mostly devoid of vegetation (Lindstrom et al. 1999).
- **Sheltered rocky shores—**These shores are bedrock shores of variable slope (from vertical cliffs to wide, rocky ledges) that are sheltered from exposure to most wave and tidal energy. Wide shores may have some surface sediment, but bedrock is the dominant substrate type. Species density and diversity vary greatly, but biota are often very abundant (NOAA 2000).
- **Coarse-textured beaches and exposed tidal flats—**These beaches and tidal flats comprise intermediate-sized substrates, including gravel, sand, and mixed gravel/sand < 5 cm diameter. Gravel and sandy beaches may occur on shorelines that are directly exposed to oceanic waves, and in more protected coastal areas. Coarse-textured beaches are dynamic habitats where the primary substrate can be easily moved by wave-generated currents; therefore, the biological community of these beaches must be adapted to a mobile, abrasive substrate. Mixed gravel/sand/silt (mixed-soft) sites are characterized by rockweed (*Fucus gardneri*), mussels, and barnacles in the mid-intertidal zone and by the green alga *Cladophora sericea*, *Fucus*, and the filamentous

brown alga *Pilayella littoralis* in the low intertidal zone; mussels and barnacles are common associates in the latter zone. The red alga *Polysiphonia aff. tongatensis* is found only at mixed-soft sites (Lindstrom et al. 1999).

- **Fine-textured beaches—**These beaches are generally flat and hard-packed. Though they are predominantly fine sand, there is often a small amount of shell hash. There can be heavy accumulations of wrack present. They are utilized by birds and turtles for nesting and feeding. Upper beach fauna are generally sparse, although amphipods can be abundant; lower beach fauna can be moderately abundant, but highly variable.
- **Sheltered estuarine shores (tide flats, marshes)—**Sheltered tidal flats are primarily composed of mud with minor amounts of sand and shell. They are present in calm-water habitats, are sheltered from major wave activity, and are frequently backed by marshes. The sediments are very soft and cannot support even light foot traffic in many areas (NOAA 2000). They can be sparsely to heavily covered with algae and/or sea grass. They can have very heavy wrack accumulations along the high-tide line. There can be large concentrations of shellfish, worms, and snails on and in the sediments. They are heavily utilized by birds and fish for feeding.

The majority (i.e., approximately 58 percent) of the shorelines present in PWS, the Kenai Peninsula, LCI, and Kodiak Island are composed of sheltered rocky shores and coarse-textured (gravel and mixed sand-gravel) beaches. Exposed rocky shores account for the majority of the remaining types of shorelines (Ford et al. 1996). Fine-grained beaches and sheltered estuaries are a small, but biologically important, component of the shoreline habitats. All but fine-textured beaches were evaluated for EVOS-related impacts in PWS.

5.1.2.3 Temporal Variation

In addition to variation at spatial scales, intertidal communities also vary over time. Temporal patterns are not obvious or well described, and few long-term studies exist to describe such patterns. A general seasonal summer maximum and winter minimum of growth may be typical of intertidal communities, and may be most pronounced in Alaska, where seasonal variation in light exposure is highly variable. For example, coverage of the intertidal zone by the annual brown alga *Alaria* sp. varied from 20 percent in winter to 100 percent in summer of one year (Foster et al. 1991). However, finding temporal patterns is vastly complicated by variability of offshore conditions, localized disturbance, and patterns of recruitment of the larvae of intertidal organisms.

Intertidal communities in PWS have also been influenced by periodic disturbance associated with geophysical processes. The Alaska earthquake of 1964 had profound, long-term effects on the intertidal biota of PWS. The entire spill zone is within the area that was uplifted up to 15 m, and in some areas subsided more than 1 m, from its original pre-earthquake elevation (Hanna 1971). In areas where uplift exceeded 3 m, more than one-third of the clam population and virtually the entire mussel community were destroyed. The earthquake also decimated grazing animals and displaced algal species (e.g., *Fucus*) that are important structural elements of the community. Subtidal biota were uplifted to intertidal elevations and perished within a year. The earthquake also affected the intertidal and subtidal benthic habitat. In some areas, the violent shaking and subsequent washing by tsunami or strong currents scoured much of the nearshore sediment and washed it to deeper water. In summary, the earthquake devastated the intertidal community, transformed much of the benthic habitat, and triggered an ecological succession of recruitment and recolonization that continued for many of the 25 years prior to the spill (Feder and Bryson-Schwafel 1988; Shigenaka 1997).

5.1.3 Status of Injury and Recovery Classification

The recovery objective established by the EVOS Trustee Council in 1994 was that "each intertidal elevation (lower, middle, or upper) will have recovered when community composition, population abundance of component species, age-class distribution, and ecosystem functions and services in each injured intertidal habitat have returned to levels that would have prevailed in the absence of the oil spill." The recovery objective was modified in 2002 to state that "intertidal communities will have recovered when such important species as *Fucus* have been reestablished at sheltered rocky sites, the differences in community composition and organism abundance on oiled and unoiled shorelines are no longer apparent after taking into account geographic differences, and the intertidal and nearshore habitats provide adequate, uncontaminated food supplies for top predators" (EVOS Trustee Council 2002b).

In 2002, the EVOS Trustee Council (2002b) concluded that there had been substantial progress towards recovery, but that recovery was incomplete because of the continued presence of residual oil in sediments and on exposed surfaces (e.g., beaches) in the intertidal zone, the lack of full recovery of some soft-sediment (mixed gravel-sand, sand, and sand-silt) intertidal invertebrates (e.g., clams), and the role of oil in initiating *Fucus* population instability.

5.1.4 Overview of EVOS Trustee Council-Funded Restoration Efforts

Strategies adopted by the Trustee Council to meet the recovery objectives were four-fold: 1) research into the causes of non-recovery, 2) restoration efforts to assist or accelerate recovery, 3) ongoing monitoring to determine recovery status, and 4) protection of intertidal communities through maintenance of water quality and reduction of disturbance (EVOS Trustee Council 1994). Projects funded by the EVOS Trustee Council are listed in Appendix A. Representative projects included multiple intertidal monitoring projects that focused on specific communities or areas (e.g., persistence of oil along the Kenai and Katmai coasts), development of monitoring methods, investigation of ecological factors that influence intertidal communities, and mapping of intertidal and subtidal shores in the coastal zone. Finally, habitat acquisition and restoration and reestablishment of clam populations were initiated at selected locations.

5.2 RESOURCE ASSESSMENT

The current condition of the intertidal community can potentially derive from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed on the basis of the intertidal community ecology and the inherent ability of these communities to recover from the initial impacts of the spill, the likelihood that the intertidal biota could be exposed to lingering EVO to a degree that could cause adverse effects and injury, and the nature and magnitude of other factors that could affect the condition of the intertidal communities.

5.2.1 Initial Impact from Spill

Approximately 40–45 percent of the estimated 10.8 million gallons of crude oil spilled by the *Exxon Valdez* is estimated to have washed ashore in the intertidal zone of PWS (Wolfe et al. 1994). Aerial surveys by the Alaska Department of Natural Resources showed that light to heavy deposits of EVO washed ashore on approximately 24 percent (446 km) of the 1,891 km of the PWS shoreline observed (Peterson 2001), and Exxon surveys in 1989 documented oil on 16 percent (783 km) of an estimated 5,000 km of PWS shoreline (Neff et al. 1995). Within the first few months following the spill, 89 percent (462) of the oiled beaches in PWS were cleaned using a variety of methods and techniques. Removal of the bulk of the oil in 1989 was followed by the use of more selective and less intrusive cleanup methods in 1990 and 1991 (Neff et al. 1995). The result was that intertidal communities were impacted by both the initial spill and subsequent treatment and cleaning efforts (see Section 5.2.1.2 below).

5.2.1.1 Effects of EVO

Initial impacts to intertidal organisms occurred at all tidal levels and in all types of habitats throughout the oil spill area. Direct assessment of spill effects included sediment toxicity testing, abundances of intertidal organisms, and ecological parameters of community structure.

Sediment toxicity tests were conducted to assess effects of EVO beginning in 1989 and continuing through 1991 (Page et al. 1995a, 2002b; Boehm et al. 1995; Wolfe et al. 1996). Toxicity tests were performed with representative benthic organisms[11] (the amphipods *Rhepoxynius abronius* and *Ampelisca abdita*, and Pacific oyster larvae *Crassostrea gigas*) using standard bioassay protocols. Test sediments were collected from various intertidal elevations in boulder/cobble, coarse-textured (pebble/gravel), and soft-bottom habitats. Comparisons with reference locations or controls indicated significant sediment toxicity in the *R. abronius* test in primarily the upper intertidal zone of both cobble/boulder and coarse-textured habitats in 1990. *R. abronius* toxicity was also present but at diminished levels in coarse-textured habitat in 1991. This pattern of diminished toxicity over time was also evident in tests with *Ampelisca abdita* and Pacific oyster larvae. In comparisons with reference locations, significant toxicity was only evident in the *Ampelisca abdita* test in 1990 (Wolfe et al. 1996).

[11] Additional toxicity testing has been conducted on eggs and embryos of Pacific herring (*Clupea pallasii*), which are deposited in the lower intertidal and nearshore subtidal areas. These data are discussed below in Section 11.

Dominant species of algae and invertebrates that were directly affected by the spill were common rockweed (*Fucus gardneri*), speckled limpet (*Tectura persona*), several barnacle species (*Chthamalus dalli*, *Balanus glandula*, *Semibalanus balanoides*), blue mussels (*Mytilus trossulus*), periwinkles (*Littorina sitkana*, *L. scutulata*), and oligochaete worms (Stekoll et al. 1996; Highsmith et al. 1996; van Tamelan and Stekoll 1996). Abundance of sediment infauna and clam densities at lower elevations on gravel and mixed sand/gravel beaches declined (Peterson 2001). Large numbers of dead and moribund clams documented on treated beaches suggest that they may have suffered toxic effects (Lees et al. 1996), but those effects are difficult to separate from the effects of hydraulic washing (see below). Intertidal fish were also affected. In a study conducted across a gradient of exposure and both rocky and coarse-textured habitats, Barber et al. (1995) found declines in density and biomass of fish at oiled sites relative to reference in 1990. The Barber et al. (1995) study does not provide pre-spill data because the first year of sampling was 1990, after the spill.

5.2.1.2 Effects of Cleaning Methods

Methods used to clean oiled beaches in PWS included manual, hydraulic, mechanical, chemical, and bioremediation techniques—most often in combination with one another (Mearns 1996; Lees et al. 1996; Driskell et al. 1996). With the exception of high-pressure, hot-water washing, most of the treatments had minimal short-term impacts or were tolerated by the biota that survived the initial oiling. However, the hydraulic techniques involving some combination of hot-water and high-pressure washing were highly destructive, eliminating as much as 90 percent of the biota that survived the initial oiling. High-pressure washing was conducted at 12 percent (61) of the oiled beaches and hot-water washing was conducted at an additional 35 percent (180) of the oiled beach segments in PWS. One exception to this widespread cleaning was in mussel beds, which were generally not hydraulically cleaned because of fear of killing this high-value resource (Peterson 2001).

On fine-grained and mixed sand/gravel beaches, cleaning treatments caused massive disturbance of sediment and transportation of sediment down-slope (Driskell et al. 1996). Following hydraulic cleaning, an immediate reduction in abundance of clam species *Protothaca staminea* and *Saxidomus giganteus* was documented (Driskell et al. 1996). An evaluation of injury to clams is provided in Section 7.

5.2.2 Residual Effects Following the Spill

Longer-term effects of EVO in the intertidal zone were expressed in terms of important ecological parameters such as percent cover and biomass of algal canopy, the total number of species present, total abundances of organisms, and overall diversity of biota. Most of the ecological characterization of the intertidal zone was conducted 1 or 2 years following the spill. Consequently, successional processes of habitat recolonization by affected species were under way when most of the ecological studies were conducted. Nevertheless, the Shoreline Ecology Program (Page et al. 1995a; Gilfillan et al. 1995) identified alterations in community level indices at low to mid-intertidal elevations of exposed bedrock communities and at low or high intertidal elevations in boulder cobble or pebble/gravel habitats. The Coastal Habitat Injury

Assessment identified significant alterations in canopy cover or in biomass of rockweed at all elevations in sheltered rocky and coarse-textured beach habitat, and at mid and upper intertidal elevations in exposed rocky and estuarine habitat (Highsmith et al. 1996; Stekoll et al. 1996; Stekoll and Deysher 2000; van Tamelan and Stekoll 1996). Post-spill studies on selected invertebrates conducted from 1990 to 1993 at Herring Bay showed that recovery had occurred by the end of 1993 at oiled sites in the lower and middle intertidal zones but remained incomplete in the upper intertidal zone for the speckled limpet at sheltered rocky and coarse-textured sites and for the Sitka periwinkle at sheltered rocky sites (Hooten and Highsmith 1996).

5.2.2.1 Changes in Community Structure

A variety of long-term indirect effects of trophic and interaction cascades were identified as a result of the initial spill and cleanup activities (Peterson et al. 2003). Indirect effects within the intertidal community were driven primarily by eradication of the *Fucus* canopy and most of the attached fauna, particularly in high-pressure and hot-water treated areas, which initiated an ecological succession. Loss of the *Fucus* canopy meant a loss of protection provided by this alga from predation, desiccation, and abrasion to many other intertidal community members, including molluscs, crustaceans, and *Fucus* germlings, slowing recovery for both *Fucus* and its associated community (Highsmith et al. 1996).

EVOS also initiated instability in populations of *Fucus*. Regrowth of this alga after the spill was followed 4–5 years later by a subsequent mass die-off of this species. Extensive denuding of the shoreline after the spill led to the establishment of large stands of *F. gardneri* that were all of a similar age class. The concurrent senescence of these single-aged stands is thought to be the reason for massive mortality of *Fucus* observed in 1994 and 1995 (Paine et al. 1996; Driskell et al. 2001). Such cycles could continue for several generations until a broader age-class distribution is achieved that would exhibit mixed-age, as opposed to evenly distributed age, patterns of cover.

EVOS, and the cleanup efforts following the spill, created a large-scale disturbance that reset ecological succession[12] in many areas of the intertidal zone. Mass mortality of established algal and invertebrate communities freed up space on the rocky substrate, a limiting resource in many intertidal communities. These clearings were quickly taken advantage of by early colonizers and species released from predation pressures (e.g., those with planktonic larvae). An initial bloom of ephemeral green algae was documented in the upper intertidal zone, probably facilitated by the loss of grazing molluscs that would normally limit the abundance of these algae (Stekoll et al. 1996). The upper-intertidal barnacle *Chthamalus dalli* was found much lower in the intertidal zone at oiled sites than unoiled ones. The increase in *C. dalli* in the mid-intertidal zone probably resulted from at least two spill-associated events: this species took advantage of lowered spatial competition from other barnacle species in denuded areas, and there was a reduction in mortality resulting from a decline in predatory molluscs (Highsmith et al. 1996). *F. gardneri* was found to take advantage of uncolonized substrates in the lower intertidal zone at oiled sites, outcompeting

[12] Ecological succession is a natural process whereby animal and plant communities replace each other over time in response to changing environmental conditions.

establishment of some of the annual algae that were removed as a result of oiling. *F. gardneri* establishment may have prevented the immediate recolonization of some annual algae, such as *Alaria*, that are normally common in the lower intertidal zone (Highsmith et al. 1996).

Increase in available space in the intertidal zone also favored species that could themselves quickly disperse or whose young were fast dispersers. The checkered periwinkle (*L. scutulata*), a strong disperser with planktonic larvae, was found in higher densities in EVOS-affected areas, while the Sitka periwinkle (*L. sitkana*), a poor disperser with crawl-away larvae, decreased at oiled sites (de Vogelaere and Foster 1994). Evidence that periwinkles with planktonic larval stages can rapidly recolonize was similarly seen after the *Torrey Canyon* spill, where the common periwinkle, *L. littorea,* which like *L. scutulata* has a planktonic larval stage, was one of the first littorines to recolonize oiled shorelines (Southward and Southward 1978).

5.2.2.2 Changes in Intertidal Populations

The majority of research published in the mid-1990s suggests that, at a regional level, population trajectories of affected species and intertidal communities at oiled but untreated sites in PWS had converged or were close to convergence with patterns of abundance and distribution in unoiled reference sites (Barber et al. 1995; Driskell et al. 1996; Highsmith et al. 1996; Houghton et al. 1997; Coats et al. 1999). However, recovery trends of populations of epibenthic biota and infauna at oiled and hydraulically treated beaches lagged that of oiled but untreated beaches. The impacts of cleaning on intertidal epibenthos persisted in the first few years following treatment (Houghton et al. 1996; de Vogelaere and Foster 1994). This difference in recovery trajectory between untreated and treated oiled sites suggests that the loss of fine sediments from hydraulic washing may delay recovery at treated sites (Peterson 2001). Hydraulic shoreline treatment exacerbated reductions in abundance and biomass of intertidal communities caused by the initial oiling, delaying recovery relative to untreated shores (Houghton et al. 1996). Some organisms in the middle intertidal zone appeared to recover particularly slowly from cleaning; for example, the red algal turf, including coralline algae, was slower to regrow than the *Fucus* canopy at some sites subjected to hot-water washing (Peterson 2001), although this recovery may also have been impeded by increased competition from *Fucus* as well (Driskell et al. 2001).

The long-term trends in recovery of intertidal biota are summarized by Houghton et al. (1997) for the years 1989–1996. Houghton et al. (1997) use several metrics to judge recovery:

- Simple comparisons between affected and reference sites, which assumes that the two types of sites were the same under pre-spill conditions
- Comparisons to the natural range in fluctuations[13] of the various assemblages or parameters used as indicators of stress.

Houghton et al. (1997) conclude that the grazer/rockweed association (i.e., periwinkles, limpets, and rockweed) in the middle rocky intertidal zone had not recovered by 1996 because fluctuations in this assemblage were greater at affected sites than at reference sites. Houghton et

[13] The natural range of fluctuations in functional and structural conditions of the community is based on the mean ±3 SE of the reference data averaged over the duration of the monitoring program.

al. (1997) surmise that within a few years, the oscillations in this assemblage should "dampen to within the range of natural variability" at reference sites in a process that is congruent with the natural cycle of growth and senescence in rockweed populations. Similarly, Houghton et al. (1997) conclude that lower intertidal infauna were on a recovery trajectory (but not yet complete) as indicated by trends in the total number of taxa, abundance, and diversity at affected sites—none of which were significantly different from reference areas in 1996.

These long-term trends and conclusions were revisited following the final year of intertidal monitoring in 1997 (Coats et al. 1999; Skalski et al. 2001). Incorporating the additional year of monitoring data and using multivariate statistics and "parallelism," Coats et al. (1999) and Skalski et al. (2001) suggested that intertidal epibiota and infauna had largely recovered by 1994 despite the lag in recovery at treated beaches. The parallelism method explores temporal trends in the ratio of the control to site data, where decreasing values over time indicate a recovery trend (i.e., the difference between affected and reference sites is diminishing). Recovery is inferred when there is a temporal trend of decreasing difference between control and site data that levels off and becomes constant over time. Thus, the differences noted by Houghton et al. (1997) in grazer/rockweed associations and the anticipated dampening of fluctuations seem to be confirmed in part by the multivariate statistical analyses and parallelism tests, which specifically address middle intertidal abundances of limpets, periwinkles, and rockweed.

The parallelism method is fundamentally different from simple control-to-impact comparisons because it does not assume *a priori* that the reference sites and affected sites are the same. Thus, parallelism can be achieved as long as differences between affected and reference sites are relatively constant over time. This is effectively similar to the notion of "natural fluctuations" expressed by Houghton et al. (1997) but allows for unanticipated bias in selection of reference stations. This is also a criticism of the method, which has led to its rejection in favor of the presumption that the available reference areas are truly the same as affected areas in the absence of the spill. Of course, there is no way that the assumption of this equality can be verified without pre-spill data, but it can be questioned by examining variability within the reference locations. Coats et al. (1999) note statistically significant differences among reference locations for some parameters (e.g., acorn barnacle cover), which suggests that similar heterogeneities could exist among reference and affected locations under pre-spill conditions. Consequently, the method of parallelism has merit and cannot be dismissed. Therefore, each method (i.e., convergence and parallelism) represents a different lens for viewing the intertidal monitoring data and each contributes to the weight-of-evidence evaluation of recovery status.

5.2.3 Impacts from Lingering Oil

Impacts to intertidal communities from lingering oil depend on 1) exposure to lingering oil, 2) the toxicity of lingering oil, and 3) the bioavailability and bioaccessibility of lingering oil.

5.2.3.1 Exposure to Lingering Oil

Information indicating ongoing potential exposure of intertidal communities to lingering oil draws upon horizontal and vertical patterns of their respective distributions. Post-spill studies of lingering oil indicate that it persists at depth (25–50 cm)[14] primarily in cobble/boulder, coarse-textured beach, or mussel bed habitats with sufficient armoring to protect sequestered oil from weathering by processes of physical or biological turbation (Hayes and Michel 1999; Irvine et al. 2002). Two studies of the distribution of lingering oil in the intertidal zone of PWS were conducted in 2001 and 2003. In 2001, Short et al. (2004a) surveyed a random selection of beaches in PWS that had been historically oiled for the presence of lingering oil in surface or subsurface sediments at intertidal elevations ranging from +1.8 to +4.8 m MLLW. Short et al. (2004a) indicated that the most heavily oiled beach segments are in sheltered embayments, but otherwise distinguished the distribution of lingering oil by elevation rather than by habitat type. The 2001 study results showed that lingering oil is present in the middle to upper intertidal zone on approximately 60 percent of the beach segments surveyed. However, the results also indicated that lingering oil has a limited patchy distribution on beaches where it is found. They showed that patches of lingering oil are present in the intertidal zone above +1.8 m MLLW, occurring on the surface most frequently at elevations of +2.8 to +3.8 m MLLW, and in the subsurface at elevations of +1.8 to +2.8 m MLLW (Short et al. 2004a). Opportunistic observations indicated that lingering oil also occurs below +1.8 m MLLW, but do not indicate the vertical extent of its distribution below this elevation (Short et al. 2004a).

NOAA returned to PWS in 2003 to conduct follow-on sampling in some of the most heavily oiled beaches characterized in the 2001 study (Short et al. 2006.). The 2003 investigation covered the full range of tidal excursions and assessed the presence of lingering oil in surface or subsurface sediments at intertidal elevations ranging from –0.2 to +4.8 m MLLW. The results of the study at northern Knight Island show that lingering oil is present throughout the intertidal zone, but occurs at less than half (44 percent) of the beaches sampled and has a distribution limited to less than 0.5 percent of the beach surface. Beaches sampled in the lower intertidal zone (0 to +1.8 m) accounted for approximately 36 percent of the oiling identified across all tidal elevations in 2003.

In each of the major investigations of intertidal communities, sampling was stratified among low, middle, and high tidal elevations within the range of +0 to +3.5 m MLLW (Figure 5-1) (Page et al. 1995a; Highsmith et al. 1996; Houghton et al. 1996). These studies were conducted several years before the surveys of lingering oil in 2001 (Short et al. 2004a) and 2003 (Short et al. 2006). Nevertheless, the patterns of recolonization and vertical zonation of intertidal communities observed in these studies clearly overlap with the distribution of lingering oil where it occurs in the intertidal zone. Because the intertidal community is ubiquitous throughout the various shoreline habitats of PWS, only a small fraction of these communities coincides with lingering oil. For example, assuming that the beach habitat itself defines the intertidal community in the broadest sense, then the 2003 survey results for northern Knight Island (Short et al. 2006) indicate that 1 percent or less[15] of the community would overlap with lingering oil depending on the embayment and elevation.

[14] Depths to which subsurface oil has been sampled by other researchers (10 cm by Page et al. [2002a] to 0.5 m by Short et al. [2004a]) have not provided sufficient information about vertical profiling of remaining oil to assess its depth distribution.

[15] The maximum probability of encountering either surface or subsurface oil is 0.0112 for the upper intertidal in Herring Bay and less than 0.006 for the remaining bays and locations (Short et al. 2006).

The 2001 (Short et al. 2004a) and 2003 (Short et al. 2006) studies of lingering oil focused exclusively on coarse beach habitat that could be excavated to assess lingering oil in the surface (0–5 cm) substrate as well as in the subsurface (5–50 cm) layer. However, almost half (49 percent) of the proposed sample locations in northern Knight Island were on impervious surfaces (e.g., bedrock cliffs or platforms) that could not be excavated. Lingering oil on the surface at these locations was not reported. Consequently, the degree to which surficial oil on these impervious surfaces overlaps with the distribution of the intertidal community adapted to hard-bottom habitat is not known. However, to the extent that lingering oil is present on hard-bottom habitat, it is unlikely to exist in a form that is readily bioavailable.

Current exposure to the intertidal community in coarse, permeable beach habitat depends on the vertical distribution of lingering oil in beach sediments, and on its bioaccessibility and bioavailability. Subsurface lingering EVO is not directly accessible to surface-dwelling intertidal organisms, including snails, crabs, and algae, which dwell almost entirely on the surface of the intertidal substrate, unless these organisms enter the subsurface, for example, to feed, or if there is a mechanism by which it is remobilized to the surface. If the depths reported by Hayes and Michel (1999) described above are predictive of the depths of remaining oil across PWS, it is unlikely that the majority of infauna, most of which occupies the top 10–15 cm of the substrate, will directly contact remaining oil, and exposure will instead depend on other transport mechanisms. Possible transport mechanisms include physical disturbances, such as storms, which remove covering sediments to expose the oil; hydraulic gradients that move subsurface EVO to the surface; bioturbation by foraging vertebrate predators; and bioturbation by deep colonizing infauna (Rice et al. 2003; Shigenaka 1997; Shigenaka and Henry 1995). That such transport mechanisms exist seems evident from studies of bioaccumulation. A 2004 study of chemical uptake using SPMDs deployed near oiled areas demonstrated the presence of bioavailable lingering oil in surface or shallow subsurface intertidal sediments (Short et al. 2005; Springman et al. 2005). Whether the bioavailable fraction is accumulated to levels sufficient to cause toxicity or impair intertidal community function is discussed below.

5.2.3.2 Acute and Chronic Toxicity of Lingering Oil

Past studies of acute toxicity have focused on tests[16] with representative benthic organisms. Results of these tests indicated that toxicity associated with oiled habitat was initially present, but diminished within a few years following the spill.

Short et al.'s (2004a) characterization of lingering oil in previously moderately to highly oiled locations suggests that sediment exposure and toxicity may be prevalent in discrete patches at these locations. This possibility was evaluated by Day (2005), who sampled five pairs of intertidal stations in the vicinity of lingering oil patches, each composed of one oiled and one nearby non-oiled station. These locations were evaluated for potential ecological impacts due to the lingering oil based on benthic community structure (see below) and sediment toxicity.

[16] More sensitive chronic toxicity tests using herring eggs and embryos have been developed in recent years and are discussed below in Section 11.

Sediments were not found to be toxic in the larval mussel bioassay using *Mytilus galloprovincialis*. Significant toxicity was noted in the 28-day survival and growth bioassay using the amphipod *Leptocheirus plumulosus*. None of the test amphipods survived exposure to sediments from the oiled sites, and amphipod survival ranged from 37 to 84 percent in sediments from the unoiled sites. Overall, amphipod survival from both oiled and unoiled locations was negatively correlated with sediment PAH concentrations. However, these results are complicated by additional stress that coarse-grained sediments may have imposed on the test organisms. USEPA (2001) recommends testing *L. plumulosus* in sediments that have greater than 5 percent silt-clay content. The substrate in PWS is exceptionally coarse and the silt-clay content expressed as percent fines was below this threshold at 8 of the 10 test sites. Consequently, low survival in some of the tests may be partially attributable to the coarse-grained nature of the sediments. Similar observations of grain-size effects in amphipod tests were made by Boehm et al. (1995). Nevertheless, the correlation with sediment PAH supports the idea that lingering oil may be a factor explaining the lack of amphipod survival at the oiled sites.

5.2.3.3 Bioavailability and Bioaccessibility of Lingering EVO

The majority of lingering EVO is subsurface, and subsurface EVO is generally less weathered and more bioavailable than lingering oil in surface sediments. The locations and depth of lingering oil indicate that it is unlikely that either infauna or epibiota will directly contact remaining oil, and exposure, if it occurs, will depend on other transport mechanisms. Such exposure has been investigated using sensitive biomarker techniques with intertidal fishes and SPMDs.

In 1990, studies of an intertidal fish, the high cockscomb prickleback (*Anoplarchus purpurescens),* in PWS showed elevated biomarkers (CYP1A) indicative of PAH exposure at EVOS-affected sites relative to that at unoiled sites (Woodin et al. 1997). In 1996, 1998, and 1999, similar follow-up studies of the biomarker were conducted with masked greenling (*Hexagrammos octagrammus*) collected subtidally and crescent gunnel (*Pholis laeta*) collected subtidally and intertidally (Jewett et al. 2002). In 1998, CYP1A induction in the intertidally collected crescent gunnel was elevated at Herring Bay, but not at the Bay of Isles in comparison with two unoiled control sites at Mummy Bay and Port Chalmers. In 1999, CYP1A induction was studied in crescent gunnel from eight oiled sites and a single control site (Barnes Cove). This study showed a wide range in CYP1A induction in which the control was statistically similar to all of the oiled sites. The only significant differences were among two locations with the highest CYP1A levels (oiled sites at Sleepy Bay and Herring Bay) and the lowest CYP1A levels (oiled site at Disk Island). The 1999 study results were confirmed with an independent measure[17] of CYP1A induction in which there were no statistically detectable differences among oiled or unoiled sites. Collectively, these results indicated that the CYP1A biomarker in intertidal fish was detectable in many oiled locations throughout the spill area, but Herring Bay in 1998 was the only location where it was distinguishable from unoiled locations.

[17] The 1996 and 1998 studies used immunohistochemical (IHC) analysis to assess CYP1A induction, and the 1999 study used IHC and another method based on the enzyme ethoxyresorufin-*O*-deethylase (EROD).

Bioaccessibility and bioavailability of lingering oil were also demonstrated in experiments conducted by Shigenaka and Henry (1995) 3 years following EVOS in which total polycyclic aromatic hydrocarbon (TPAH) concentrations were measured in SPMDs, sediments, water, and caged mussels placed on a previously heavily oiled beach on Smith Island and on an unoiled to lightly oiled beach also on Smith Island. Results of this study showed that TPAH concentrations were significantly correlated among the SPMDs, mussels, and sediments, further indicating the bioavailability of lingering oil to surface-dwelling organisms.

Higher vertebrate predators, including harlequin duck, Barrow's goldeneye, and black oystercatcher demonstrated exposure in 2004 and 2005 based on elevated CYP1A expression that is statistically distinguishable from background levels (Ballachey et al. 2006). All three of these species forage primarily on intertidal resources, supporting the possibility of ongoing exposure to oil in intertidal habitat.

Recent research conducted in 2004, using SPMDs placed in the intertidal zone, indicates that where lingering oil is present, it is still bioavailable to intertidal organisms, exists in a bioactive form that is capable of inducing CYP1A in fish, and is distinguishable from stressed reference locations that have sediments contaminated by other non-EVO-related sources of petroleum hydrocarbons (Springman et al. 2005; Short et al. 2005).

5.2.3.4 Effects on Reproduction and Other Population Parameters

Day (2005) evaluated benthic community structure in a focused study of lingering oil patches. Classification analysis indicated that community composition over all eight stations (four oiled and four unoiled stations) was relatively similar. Study results indicated that residual oil sequestered in intertidal sediments is not causing substantial community-wide effects though populations of sensitive species such as amphipods may be impaired. Given the patchy and limited distribution of lingering oil and the similarity in intertidal community structure between beaches with lingering oil and reference beaches, there is little conclusive evidence to suggest that lingering oil is influencing community succession or mature reestablished benthic communities.

5.2.4 Other Stressors

Other factors affecting intertidal communities that may confound an understanding of oil effects include natural variability associated with predation, natural disturbance, and recruitment. Reduction in predator numbers can result in changes in predation rates and thereby affect community composition, abundance, and size distributions (Fukuyama et al. 2000). Natural disturbances such as storms may have important localized effects in community structure and function. Localized disturbances play important roles in establishing community structural heterogeneity at the patch scale when sessile communities are cleared from the substrate, restarting ecological succession. Long-term variation in rocky intertidal communities is not well understood (Foster et al. 1990). These processes increase variability in population structure, distribution, and abundance that are a part of a naturally functioning intertidal community, and can increase the ecological "noise," or variation in data, when examining trajectories of intertidal community recovery. Finally, there is significant interannual variation in recruitment of intertidal invertebrates based on natural conditions, including temperature, nutrient levels, predation rates on plankton, and currents that are difficult to measure and predict. Considerable year-to-year variation in recruitment of some intertidal community members, such as algae, can complicate analysis of population trajectories following a large-scale disturbance (Foster et al. 1990).

5.3 SUMMARY AND RECOMMENDATIONS

The information provided in the previous sections was weighed to determine the recovery status of intertidal communities and to assess the need for additional restoration efforts. Clams and mussels are not evaluated in this section but are discussed separately in Sections 7 and 8.

The EVOS Trustee Council defined recovery of intertidal communities in 2002 as occurring "when such important species as *Fucus* have been reestablished at sheltered rocky sites, the differences in community composition and organism abundance on oiled and unoiled shorelines are no longer apparent after taking into account geographic differences, and the intertidal and nearshore habitats provide adequate, uncontaminated food supplies for top predators" (EVOS Trustee Council 2002b). Our recommendations for this two-part recovery objective are provided below, first for the composition of the community and second for its ability to provide uncontaminated food to higher trophic level vertebrate predators.

The weight of evidence of available data comparing oiled, oiled-and-treated, and unoiled sites supports the conclusion that intertidal communities impacted by the spill in 1989 and subsequent cleanup through 1991 had recovered by the mid-1990s. Although the most recent monitoring study in the mid-1990s noted statistically significant differences in intertidal community parameters among treated and untreated beaches, most if not all of these differences are likely to have decreased to *de minimis* levels in the 9 or 10 years since the last monitoring event. The processes of natural ecological succession are well established for intertidal communities. The likelihood of this recovery trajectory, coupled with the high interannual variability that is typical of these communities, makes it unlikely that future monitoring would yield differences that could be attributed to residual EVO effects and could be readily distinguished from other natural disturbances.

Sources of uncertainty in assessment of recovery in the intertidal community include 1) lack of pre-spill data for intertidal communities in the EVOS-affected area, 2) lack of data characterizing the intertidal community in the EVOS-affected area since the mid-1990s, 3) naturally high interannual variability of intertidal community demographics, and 4) the relatively low power[18] of most intertidal investigations to further detect statistically significant differences among sites. The lack of pre-spill data is always going to limit our ability to have the highest degree of certainty about recovery of intertidal communities and this will not be resolved by more study.

[18] The power of a statistical test is its ability to detect a true difference among two or more groups or populations. With low power of a test, there is a greater probability that even though two populations are in fact different, the test may not be able to identify this difference.

Although the recovery of the remaining direct damage to the intertidal communities and indirect damage has probably continued since the last period of monitoring in the mid-1990s, it is likely that the increment of any damage on the scale of initial impact is now indistinguishable from the year-to-year fluctuations in the these dynamic communities.

Recent studies indicate a potential for very small-scale impacts to sensitive organisms in patches of buried oil in beaches that were heavily and moderately oiled in 1989. Toxicity tests of sediments obtained from oiled areas indicated a relationship between PAH concentrations and amphipod mortality. However, grain size is an important confounding factor in this work, and such uncertainties limit the ability to identify ongoing effects even at this small patch scale.

The ability of intertidal and nearshore habitat to provide adequate, uncontaminated food supplies for top predators is another important consideration when assessing the recovery of these communities. Tissue data on PAHs in mussels indicates that bioaccumulation is no longer a concern for this resource. However, the most recent data on CYP1A in some bird species that forage in the intertidal zone suggests that they may be exposed to PAHs during feeding. Harlequin duck, black oystercatcher, and Barrow's goldeneye, all of which forage on intertidal resources, continued to demonstrate exposure in 2004 and 2005 based on ongoing elevated CYP1A expression that is distinguishable from background rates (Ballachey et al. 2006). The primary source of uncertainty with CYP1A measurements is the uncertain relationship between measurable exposure and individual- or population-level impacts to the resource.

Based on evidence that intertidal resources may not yet be providing uncontaminated food resources to higher trophic levels in the EVOS-affected area, it is recommended that the Trustee Council continue to classify intertidal communities as "recovering."

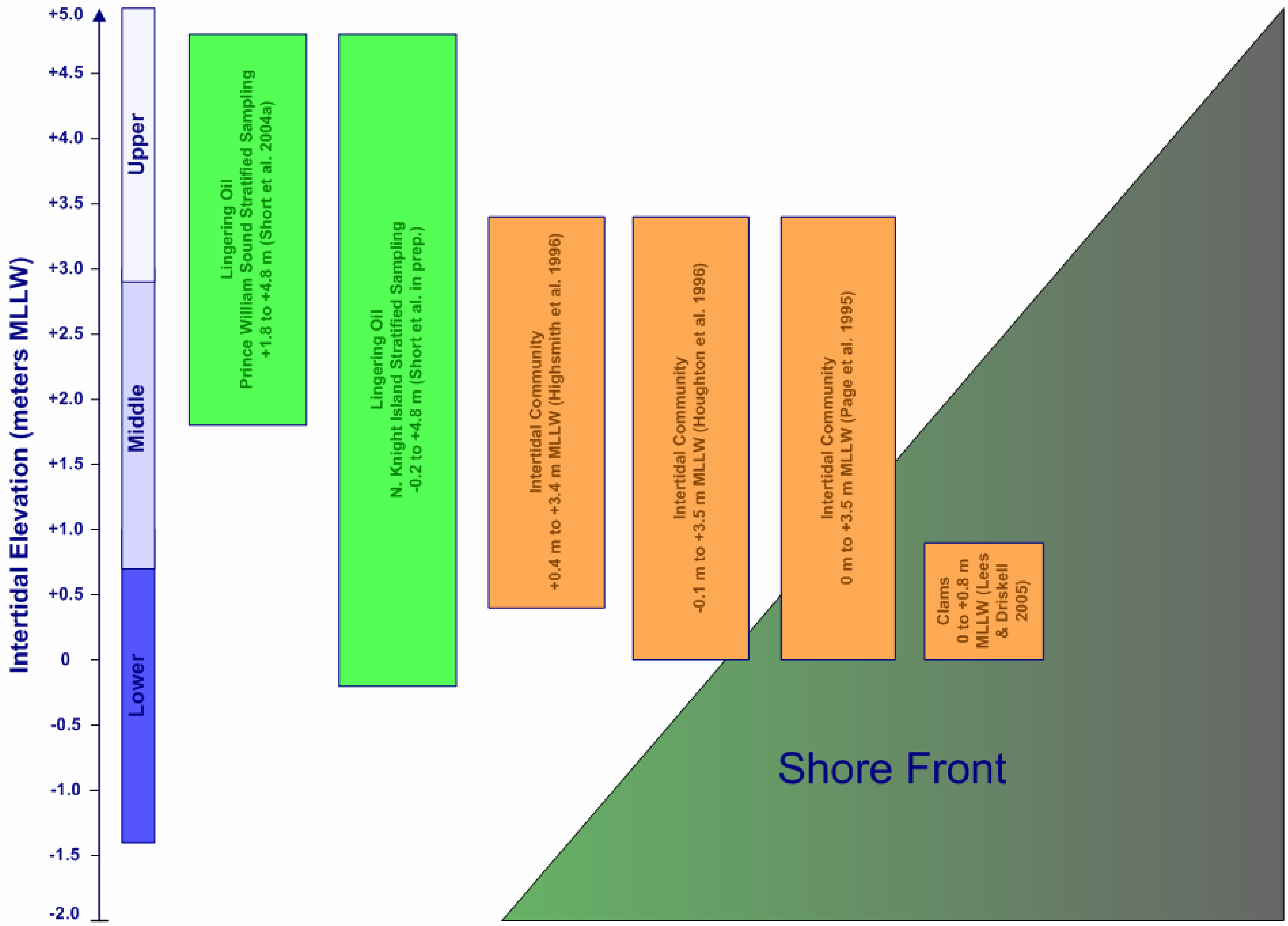

Figure 5-1. Sampling Elevations for Studies of Lingering Oil, Intertidal Communities, and Clams.

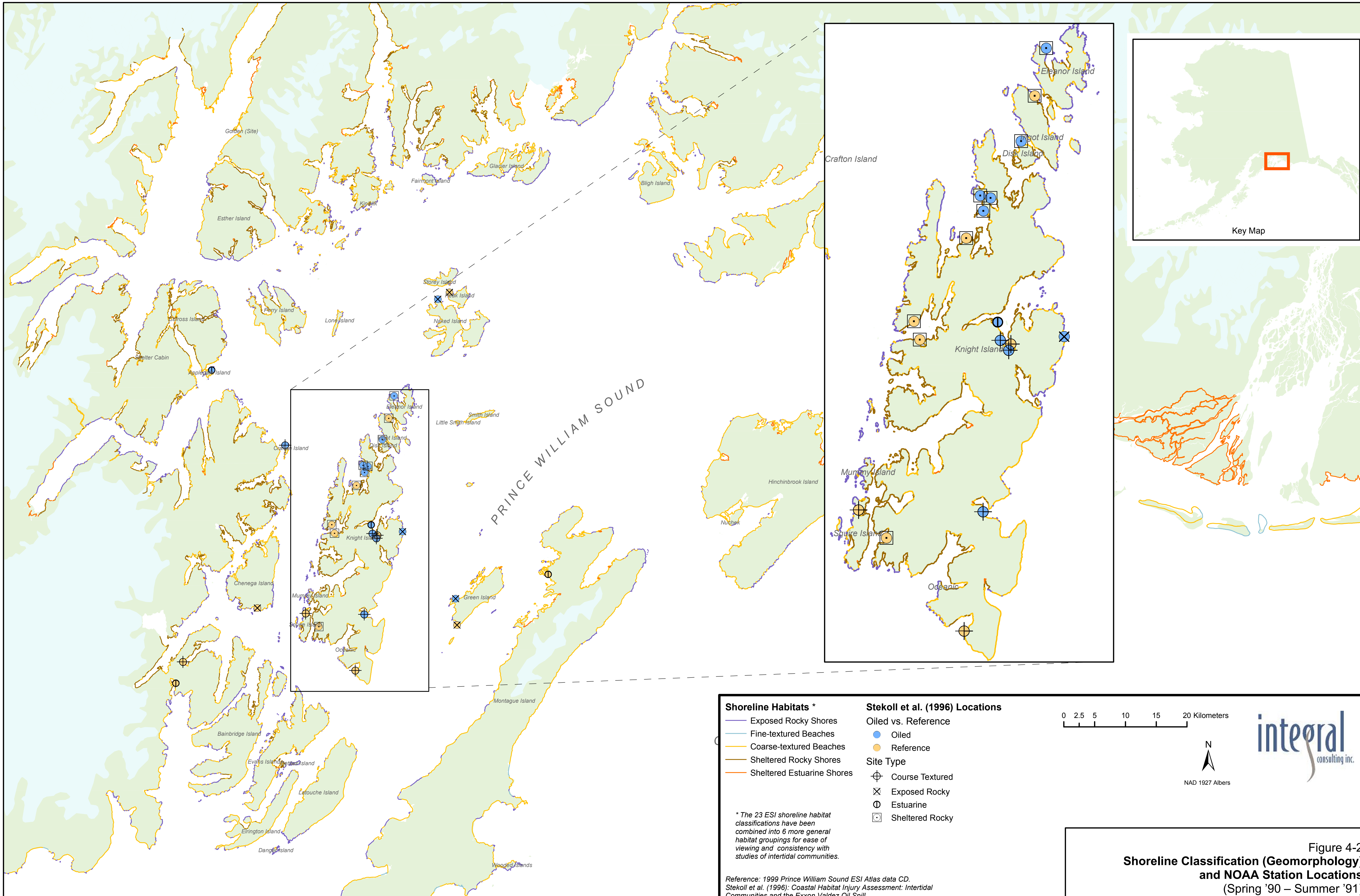

Figure 4-2
Shoreline Classification (Geomorphology) and NOAA Station Locations
(Spring '90 – Summer '91)

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6. SUBTIDAL COMMUNITY

6.1 INTRODUCTION

The subtidal habitat of PWS encompasses the entire seafloor that is not exposed by the tides, extending from the lowest intertidal elevation (see Section 5) to maximum depths approaching 800 m MLLW (Dean et al. 1996b; O'Clair et al. 1996a; Okey and Pauly 1999b). Following the initial spill, EVO was principally transported from the intertidal zone where it had washed ashore to subtidal environments through wave, tide, and storm energy as well as through beach cleaning activities. Other oil transport mechanisms (e.g., dissolution, sorption to suspended particulates and subsequent sedimentation, direct transport) leading to the subtidal seafloor are believed to be insignificant (Integral 2006).

Potential impacts of EVOS on the subtidal habitat were predominantly assessed through the evaluation of the depth distribution of EVO in sediments and direct measurements of toxicity or altered community composition to vertebrates and invertebrates constituting the subtidal community (O'Clair et al. 1996a,b; Wolfe et al. 1996; Jewett and Dean 1997). Additional studies examined the persistence of lingering oil in subtidal nearshore habitat (Short et al. 2003b), the potential influence of natural oil seeps and anthropogenic sources on subtidal sediment (Page et al. 1995b, 1996a, 1997, 2002b), and the influence of pressurized washing of PWS shorelines on subtidal communities (Houghton et al. 1996; Lees et al. 1996). Other studies examined deeper benthic community effects (Feder and Jewett 1987) as well as the influence of EVO on various eelgrass/shallow subtidal communities (Jewett et al. 1995; Jewett and Dean 1997; Dean and Jewett 2001).

6.1.1 Statement of Problem

The subtidal communities in PWS were classified as "unknown" in the most recent assessment of resource recovery status (EVOS Trustee Council 2002b). Overall, assessment of subtidal communities following EVOS has been difficult. The primary limitation is the absence of pre-spill data that would enable a before-after-control-impact (BACI) study design to evaluate the effects of the spill. Consequently, effects are necessarily inferred from post-spill comparisons that assume that there were no pre-existing differences among communities before the spill. Post-spill comparisons are further complicated by inherent practical limitations to conducting scientific research in deep water environments that can be used to effectively characterize and assess complex biological communities. Nevertheless, much post-spill data has been collected for sediments and certain benthic invertebrates, particularly in the nearshore, shallow (< 20 m MLLW) habitat that was most affected by EVO transported from the intertidal zone. For this assessment, information on the natural history of subtidal communities, rate of recovery from stressors, the nature and severity of impacts from the spill, the presence and concentrations of EVO in subtidal sediments, and subtidal habitat and community characteristics are evaluated to independently assess the recovery status of subtidal communities.

6.1.2 Natural History and Ecology

The subtidal communities of PWS consist of numerous vertebrate and invertebrate species that exhibit complex interactions with one another and their physical environment. These communities are characterized by a rich diversity of marine fauna and flora whose populations are governed by the physical and chemical gradients of their environment, as well as by biological forces including predation and competition. Subtidal communities are of intrinsic importance in PWS, providing important ecosystem services such as food resources for a wide variety of marine consumers.

The subtidal zone consists of different kinds of habitats and biological communities that depend on the kind of substrate (hard-bottom vs. soft-bottom) present and the depth. In PWS, shallow (<20 m MLLW) subtidal habitats are approximately 76 percent hard bottom and 24 percent soft-bottom (Okey and Pauly 1999b). However, sedimentation processes reverse this relationship with depth. The prevalence of hard-bottom habitat decreases to 10 percent at depths >100 m MLLW, with a corresponding increase in the prevalence of soft-bottom habitat. Infauna[19] (expressed as biomass) in soft-bottom communities are dominated by clams in the shallow subtidal, echinoderms (brittle stars and sea cucumbers) and clams at intermediate depths of 20–100 m MLLW, and polychaete worms and clams at depths greater than 100 m (Okey and Pauly 1999b). Epifauna of hard-bottom communities primarily consist of large sea stars and crabs and a diverse and spatially variable number of smaller invertebrate taxa. Vegetative communities in the shallow subtidal also vary by substrate with stands of attached kelp (e.g., *Laminaria saccharina*) common in hard-bottom habitat and meadows of eelgrass (*Zostera*) occasionally present on soft-bottom habitat. Other mobile organisms such as squid, juvenile fishes (including Pacific cod, herring, and salmon), sea otters, river otters, and marine birds frequent subtidal areas to prey upon food resources and/or to occupy habitat (Rosenthal et al. 1977; Feder and Jewett 1987; Jewett et al. 1996; Dean et al. 2000). In shallow subtidal communities (<20 m depth), young of the year Pacific cod have been observed to frequent eelgrass habitats, while kelp habitats throughout PWS include Arctic shanny and small sculpins (Laur and Halderson 1996). Flathead sole is also considered a ubiquitous representative of demersal fishes common throughout the shallow subtidal zone of PWS (Armstrong et al. 1995).

6.1.3 Status of Injury and Recovery Classification

The recovery objective established by the EVOS Trustee Council in 1994 stated that "subtidal communities will have recovered when community composition, age-class distribution, population abundance of component species, and ecosystem functions/services have returned to pre-spill levels" (EVOS Trustee Council 1994). The plan acknowledged that certain subtidal organisms initially harmed by EVOS (eelgrass, some algae) appeared to be recovering, while others (leather star and helmet crab) showed little sign of recovery through 1991. Because of this discrepancy, a general recovery condition of "unknown" was assigned to subtidal communities.

[19] Infauna refers to macrofauna and excludes the meiofauna, which are small organisms that will pass through a 1 mm mesh sieve. Meiofauna are not routinely sampled in macrofauna investigations such as those conducted pursuant to EVOS.

Dean and Jewett (2001) summarized recovery of shallow subtidal kelp and eelgrass communities. Kelp communities were largely recovered within a few years following the spill. However, recovery was slower in the soft-bottom eelgrass communities. Although many of the dominant taxa in eelgrass communities were recovered by 1995, a number of oil-sensitive species (such as phoxocephalid amphipods) were not recovering and the recovery of others was inconclusive. This resulted in the 1999 update's reclassification of subtidal communities as "recovering."

The 2002 update identified an additional study published in the peer reviewed literature that acknowledged the role that natural factors may be playing in the remaining differences in subtidal communities between oiled and unoiled bays. As a result, the 2002 plan again classified subtidal communities as "unknown." The recovery objective was also revised to state that recovery would be attained "when community composition in oiled areas, especially in association with eelgrass beds, is similar to that in unoiled areas or consistent with natural differences between sites such as proportions of mud and sand" (EVOS Trustee Council 2002).

6.2 RESOURCE ASSESSMENT

The current condition of the subtidal community can potentially derive from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed based on subtidal community ecology and the inherent ability of these communities to recover from the initial impacts of the spill, the likelihood that the subtidal biota and sediments could be exposed to lingering EVO present within the intertidal zone to a degree that could cause adverse effects and injury, and the nature and magnitude of other factors that could affect the condition of the subtidal communities.

6.2.1 Initial Impact from Spill

Little empirical data has been collected to provide a definitive estimate of the amount of EVO that was transported to subtidal communities after the initial spill. Lee and Page (1997) estimated that approximately 1–13 percent of the original amount of EVO spilled was transported, whereas Wolfe et al. (1994) estimated a range of 12–13 percent. Koons and Jahns (1992) suggested that most of the non-volatile portion of EVO was transported out of PWS into the Gulf of Alaska where waves and currents dispersed it into the open Pacific Ocean.

A sediment survey conducted by Wolfe et al. (1996) from 1989 to 1991 examined 18 oiled sites in shallow subtidal areas in the intertidal (mean low water[20]) as well as the shallow subtidal (≥3 m) zone. Locations were based on previous studies in which decreasing toxicity from direct oil contact was observed with increasing distance from the shoreline (Wolfe et al. 1996). Based on this survey, concentrations of petroleum hydrocarbons were greatest at depths between 0 and 3 m, while no significant difference in petroleum hydrocarbon concentrations was identified among oiled and reference sites for deeper waters (i.e., > 40 m in depth) (Wolfe et al. 1996). O'Clair et al. (1996a) examined subtidal sediment from 0 to 100 m depth in 1989, and observed the greatest petroleum hydrocarbon concentrations were present at depths of 3 to 20 m. Jewett and Dean (1997) reported that average petroleum hydrocarbon concentrations in subtidal sediments adjacent to heavily oiled areas were > 4,900 ng/g versus < 1,200 ng/g in reference sites. Based on these observations, this section focuses on shallow subtidal communities located in depths less than approximately 40 m MLLW.

Sale et al. (1995) used sediment traps to assess potential nearshore-to-offshore transport of EVO. Oiled sediments were transported from the intertidal shoreline to adjacent subtidal areas and resulted in low and decreasing concentrations of petroleum hydrocarbons from 1989 to 1992 (Sale et al. 1995). Short et al. (1996) suggested that leaching of oil from intertidal sediments into the water column could also result in subsequent deposition to deeper water, although the exact transport mechanism was not stated.

With respect to biological resources, initial injuries were observed for various nearshore subtidal organisms such as infaunal amphipods, infaunal bivalves, helmet crabs, and leather stars (Jewett et al. 1995; Dean et al. 1996b). In addition, stress-tolerant organisms (e.g., gastropods and mussels) were more abundant at oiled than unoiled sites (Jewett et al. 1995; Dean et al. 1996b). The most persistent injuries were most likely suffered by eelgrass and kelp communities, but it is unclear if this was the result of acute toxicity, sublethal effects, shoreline cleanup activities, or a combination (Dean et al. 1996a,b, 1998; Houghton et al. 1991; Jewett and Dean 1997). Based on a series of toxicity studies, Wolfe et al. (1996) showed significant sediment toxicity from 1989 to 1991 at oiled intertidal locations in comparison with reference stations but none at subtidal elevations.

Laur and Haldorson (1996) observed the effects of EVO on shallow subtidal fishes in depths < 20 m in oiled and reference sites. In both eelgrass and kelp habitats, oiled sites showed higher abundances of fishes due to greater young-of-year numbers versus unoiled locations, resulting from greater epifaunal prey abundance and diversity. Armstrong et al. (1995) measured elevated PAH levels in subtidal flathead sole in oiled sites from 1990 to 1991, and attributed them to elevated levels of PAH in clam prey. Jewett and Dean (1997) observed injuries to shallow subtidal eelgrass communities in heavily oiled regions immediately after the spill (1990) in which dominant taxa (amphipods, infaunal bivalves, helmet crabs, and leather stars) were more abundant in unoiled regions and average PAH concentrations in oiled regions exceeded 4,900 µg/kg.

[20] The Wolfe et al. (1996) and O'Clair et al. (1996a) studies reported their results in reference to the mean low water (MLW) tidal datum, which is approximately 1.8 m above the mean lower low water (MLLW) tidal datum adopted for this report.

6.2.2 Residual Effects Following the Spill

Longer-term effects of EVO in subtidal communities were predominantly assessed in terms of potential impacts to important ecological functions and processes. Dean et al. (1996b) hypothesized potential subtidal food chain impacts resulting from impacts to kelp and eelgrass, which offer habitat and food resources for various species.

Dean et al. (1996b) studied possible changes in subtidal macroalgal (primarily kelp) populations 1 year after the spill (1989–1990). No differences were observed between reference and oiled sites in density, biomass, or percent cover, suggesting that there were no long-term impacts to macroalgae. Smaller plants were observed at oiled versus reference sites, however, indicating recovery in recently disturbed areas, and supporting the notion that there were no apparent long-term impacts on subtidal populations (Dean et al. 1996b). Injury to eelgrass occurred in patchily distributed areas through 1995, and was most likely a result of shoreline cleanup efforts. The cleanup efforts consisted of pressurized washing of intertidal areas. The washing may also have directly transferred contaminated intertidal sediment to subtidal areas (Wolfe et al. 1994; Mearns 1996; Short et al. 1996).

Recovery of fishes and invertebrates within affected eelgrass communities was monitored from 1990 to 1995 (Jewett and Dean 1997; Jewett et al. 1999). In 1990, EVO-related effects were observed in 9 of the 33 taxa evaluated and were expressed in two ways, either as a significant decrease or as a significant increase in abundances at oiled sites in comparison with reference sites. Decreased abundances were particularly evident for pollution-sensitive amphipods. The high abundances of stress-tolerant taxa at oiled sites were presumably due to opportunistic recolonization of organically enriched substratum by these species. By 1995, PAH concentrations in subtidal sediment were estimated to have decreased by 90 percent, leading to the recovery of most, but not all, subtidal species—infaunal amphipods, bivalves, helmet crabs, and sea stars were still more abundant at reference than at oiled sites (Jewett and Dean 1997). EVOS-related effects and recovery of subtidal epibenthic invertebrates (primarily helmet crab and sea stars) were also evaluated within shallow bays and exposed points (Dean et al. 1996b). Lower densities of helmet crab and leather star were evident at oiled sites in 1990, but had disappeared by 1993.

Based on their investigation, as well as those of past oil spills, Jewett and Dean (1999) describe a multistep sequence of recovery process for benthic infaunal communities that consists of the following:

- Initial impacts associated with toxic effects and considerable mortality
- An organically enriched period in which opportunistic taxa become extremely abundant
- A period in which opportunists decrease in importance and fauna begin to return to conditions similar to adjacent unoiled areas or to a community characteristic of relatively undisturbed condition.

Jewett and Dean (1999) conclude that in 1995, these patterns of recovery were evident in the subtidal eelgrass communities in PWS, but that spill-related differences persisted. Based on studies of benthic communities in response to other oil spills, Jewett and Dean (1999) also indicate that recovery may take from 10 to 20 years following the spill to reach completion.

6.2.3 Current Exposure to Lingering Oil

By 2001, little to no EVO was present in subtidal sediments (Short et al. 2003b). Subtidal communities therefore are not currently being exposed to EVO *in situ*.

It is conceivable that some mobile subtidal to nearshore species, such as certain fish, may frequent intertidal areas where lingering EVO persists. Under current conditions, however, EVO is predominant in the intertidal zone as highly weathered asphalt-like material in surface sediments or is largely sequestered in subsurface sediments. Because subsurface sediments are not accessible to such species, exposure is minimal to most likely absent (see Section 5). This inference is supported by recent mussel watch data (Page et al. 2005), which can be used as a conservative estimate of PAH bioavailability to subtidal invertebrates because oil concentrations decrease from the intertidal to nearshore subtidal environments (Sale 1995). Mussels provide excellent insight on the bioavailability potential of oil because they do not metabolize PAHs rapidly, they are sessile organisms (thus reflecting steady exposure), and they characterize aqueous and solid phase exposure routes. The absence of elevated levels of PAHs in an indicator species such as mussels in the formerly heavily oiled portions of PWS indicates that PAHs are not bioavailable and supports the notion that conditions in the subtidal zone have sufficiently improved over the past 11 years.

6.2.4 Other Stressors

As described above, cleaning activities following the spill may have contributed to some impacts to subtidal communities, particularly eelgrass. Jewett and Dean (1997) also estimated sporadic influence of boat activity on eelgrass communities in the subtidal zone as a result of propeller interference, increased sedimentation, and small-scale fuel pollution.

Sources of PAHs not attributable to EVO may have also contributed to PAH levels in subtidal sediments. Natural oil seeps from the Gulf of Alaska and adjacent coal fields transport PAHs to PWS (Page et al. 1995b, 1996a, 1997; Bence et al. 1996; Short and Heintz 1998). Page et al. (1995b, 1996a, 1997) suggest that seeps from eastern areas including Katalla and Yakataga could influence subtidal sediment PAH concentrations in PWS. However, it is unlikely that these low natural background levels of PAH would cause adverse benthic effects. Short et al. (2004a) observed that these sources would represent an insignificant portion of hydrocarbons in the intertidal sediment of PWS as well as subtidal sediment (Short et al. 2004b).

6.3 SUMMARY AND RECOMMENDATIONS

The information provided in the previous sections was weighed to determine the recovery status of the subtidal community and to assess the need for additional restoration efforts. The recovery status of the subtidal community was previously classified as "unknown," reflecting limitations and uncertainties in the data available for assessment. To address data limitations, the evaluation performed here uses both direct and indirect information on the status of the resource.

The 1994 recovery objective states that the "subtidal communities will have recovered when community composition, age-class distribution, population abundance of component species, and ecosystem functions/services have returned to pre-spill levels." Because pre-spill conditions are not known for subtidal communities, this objective was revised in 2002 to state that recovery would be attained "when community composition in oiled areas, especially in association with eelgrass beds, is similar to that in unoiled areas or consistent with natural differences between sites such as proportions of mud and sand."

It is recommended that the Trustee Council classify the subtidal community as "recovered" from the effects of EVOS based on the following:

- Impacts on subtidal sediments and certain subtidal biological resources were reported in the first few years following the spill. Eelgrass and kelp bed communities were arguably the most affected subtidal communities, with impacts primarily attributable to toxic effects of EVO, pressurized washing of the coastline, or a combination of these processes. At the time of the spill, variable estimates ranging from 1 to 13 percent of total EVO are hypothesized to have initially penetrated subtidal sediment, with highest PAH concentrations occurring at water depths of 0–20 m.
- PAH concentrations in subtidal sediments decreased by more than 90 percent as of 1995.
- Affected epibenthic organisms outside of the eelgrass community were largely recovered by 1993.
- Direct residual impacts to eelgrass and macroalgae (primarily kelp) were minimal and non-detectable within a few years following the spill, indicating that these species had recovered from EVOS. Because eelgrass and macroalgae are foundational species in their respective communities there is no reason to suspect interaction cascades that would deter recovery of other species in these communities.
- Most fauna within the eelgrass community had recovered by 1995, although there were still noticeable differences between oiled and at reference sites. By 1995, some opportunistic and pollution-tolerant organisms prevailed in greater numbers at the oiled sites, while some pollution- or oil-sensitive taxa were more abundant at the unoiled reference locations. The pattern of recovery of subtidal fauna in eelgrass beds in PWS is not unique and follows successional patterns of recovery that have been noted for benthic communities in response to other spills. Based on these studies, the predicted time frame for recovery is 10 to 20 years (Jewett et al. 1999).
- Subtidal communities are now in their 17th year of recovery and nearing the end of the projected 10- to 20-year recovery period. It is highly likely that sufficient time has

elapsed since the 1995 studies (17 years) for processes of natural recovery and variability to have diminished any differences that might have existed at that time. Consequently, it is more likely than not that the subtidal communities have recovered from the effects of EVOS.

- Based on studies of intertidal sediments, lingering EVO at present is most likely not accessible to subtidal communities because it is either sequestered in subsurface intertidal sediments or occurs predominantly as a weathered solid in surface intertidal sediments and on shorelines. Significant food-chain exposures originating from persisting EVO in subtidal sediments are unlikely, and chances for lingering oil impacts to subtidal communities are very low.

This evaluation took into consideration the level of uncertainty associated with the available data. The primary uncertainty concerns the relatively low power of the subtidal monitoring program to distinguish differences among sites and to conclusively determine recovery status for some of the affected species (Dean and Jewett 2001). In 1995, the data were sufficient only to evaluate recovery for four of the nine eelgrass invertebrate and fish taxa that were affected in 1990. Of these four species, two had recovered and two had not. For the kelp community of invertebrates and fishes, additional post-1990 monitoring data were available for only four of the six affected taxa and were sufficient only to evaluate recovery for two taxa, both of which were recovered. Further studies have not been conducted to document recovery trends for those taxa that had not recovered by 1995 or which were categorized as inconclusive.

7. CLAMS

7.1 INTRODUCTION

Clams in PWS are important as prey for sea otters, seabirds, and many other predators, as well as subsistence use by native populations and recreational harvest. Within days of EVOS in March 1989, clams on beaches along the shoreline of PWS were exposed to the spreading oil slick. Initially, impacts of EVOS were identified by observations of clam mortality following the spill. Later assessments included comparison of growth rates, population trends, and tissue chemistry at oiled and unoiled sites.

7.1.1 Statement of Problem

Clams were classified as "recovering," but not yet fully recovered in the 2002 assessment of resource recovery status (EVOS Trustee Council 2002b). Although clam populations had largely recovered from the initial direct impacts of oiling by 1996, effects associated with physical disturbance from high-pressure, hot-water treatment were still evident (Driskell et al. 1996; Lees et al. 1996; Houghton et al. 1997; Coats et al. 1999; Skalski et al. 2001). Information on the life history of clams, severity and nature of impacts from the spill, and population trends are reevaluated here to independently assess the current recovery status of clams in PWS.

7.1.2 Natural History and Ecology

This assessment of clam resources in PWS focuses on two species: the littleneck clam (*Protothaca staminea)* and the butter clam (*Saxidomus giganteus*). These species are emphasized for several reasons. First, they are the most abundant and widely distributed large clam species in PWS. Second, these clam species are both important for subsistence use and are popular species for recreational harvest in PWS. Third, littleneck and butter clams are major prey items for numerous invertebrate and vertebrate species, including the sea otter and sea ducks.[21] Finally, for the above reasons, these species have been the focus of much of the research into the effects of oiling on clams in PWS, and in the case of the littleneck clam, studies in other areas.[22] Key elements of the natural history of littleneck and butter clams are summarized in the following sections.

[21] Because of their small size, sea ducks like the harlequin duck, Barrow's goldeneye, lesser scaup, and surf scoters, may forage on smaller clams from younger year classes, which may dwell closer to the surface than older clams (Richman and Lovvorn 2004; Lewis et al. 2005).

[22] There are many other species of clams (e.g., *Macoma* spp.) in PWS and the western Gulf of Alaska that were not targeted for EVOS work (Feder and Jewett 1987; Feder and Blanchard 1998).

7.1.2.1 Life Cycle

Embryonic development and early life history stages are similar for littleneck clams and butter clams. For each species, sexes are separate, and eggs and sperm are released into the water where mass fertilization takes place. The timing of spawning depends on temperature. In PWS, the littleneck clam spawning period may last for up to 4 months and generally occurs between July and September (Chew and Ma 1987). Butter clam spawning also occurs in summer. After fertilization, the eggs divide rapidly, develop into trochophore larvae in about 12 hours, and then reach the veliger larval stage within the following 24 hours (Chew and Ma 1987). The eggs and larvae are planktonic, drifting with local currents and feeding on phytoplankton in the water column. After about 3 weeks, the littleneck clam larvae settle onto the substrate where they change from larvae into young clams known as "spat." Development is similar for butter clams, with planktonic larvae that settle to the bottom 4–6 weeks after fertilization.

Young littleneck clam spat can move about; butter clam larvae do not have this ability and do not move once they settle (Chew and Ma 1987). Recruitment (i.e., addition of new individuals to a population, typically by reproduction or immigration) for all clam species is highly variable, and there is significant interannual variation in littleneck clam recruitment in PWS (Paul and Feder 1973). Environmental factors affecting recruitment include temperature, food supply, predation, and favorable conditions for settlement (Paul and Feder 1973).

Littleneck clams reach maturity at 2–3 years (Chew and Ma 1987). Some littleneck clams spawn in their second year but most spawn at the end of the third year, depending on size and maturity (Chew and Ma 1987; Ricketts and Calvin 1968). Butter clam spawning typically first occurs at the end of the third year (Ricketts and Calvin 1968). In PWS, the maximum life span is 15 to 16 years for littleneck clams, and may be up to 20 years for butter clams (Morris et al. 1980). Adult clams are sedentary, although they may re-burrow.

Littleneck clam growth rates in PWS are relatively slow (approximately 2–5 mm/year) when compared with other populations of this species in British Columbia (Paul and Feder 1973; Chew and Ma 1978), but vary both spatially and temporally. Factors influencing growth rates include food supply and location (including currents, protection from storms, substrate, and tidal level). Some researchers observed higher growth rates for littleneck clams on beaches with strong tidal currents compared to quiet bays and suggested that increased currents may increase food supply (Chew and Ma 1987). Others report slower clam growth rates in exposed areas compared to protected sites (McCrae 1995).

7.1.2.2 Abundance and Distribution

Littleneck and butter clams are widely distributed in PWS. They are most abundant in the lower intertidal to subtidal zones of sheltered beaches with gravel, sand, or mixed substrate. The preferred substrate for littleneck clams is coarse sand or fine gravel with mud (Paul and Feder 1973; Chew and Ma 1987). Butter clams are observed in a variety of substrates, preferring porous mixtures of gravel, broken shells, mud, and sand (Kozloff 1976; Morris et al. 1980).

Abundance and distribution of clams are strongly influenced by recruitment processes. Larval dispersion, which is dependent on environmental conditions including current patterns and strength, and larval settling patterns establish initial patterns of sessile clam abundance and distribution that are subsequently shaped by factors including abiotic stressors and predation, which dominate post-settlement success (Olafsson et al. 1994). Whereas butter clam spat are not mobile, the young littleneck clam can to some extent migrate laterally by pedal movements and can therefore move around on the substrate to locate a suitable surface after settling (Chew and Ma 1987).

Adult littleneck and butter clams have limited mobility and so cannot easily relocate in large distances in response to changes in environmental conditions. In Simpson Bay of PWS, butter clams were found in the lowest part of the middle intertidal zone and in the lower intertidal zone usually between –0.9 and +1.2 m MLLW, and littleneck clams were found between –0.6 and 1.5 m MLLW (Chew and Ma 1987).[23] Maximum butter clam density in the same study was observed at the 0 ft tide level, and maximum littleneck clam was observed at the +0.3 m (+1 ft) MLLW tide level (Chew and Ma 1987). In Galena Bay of PWS, few littleneck clams were found above +0.43 m (+1.4 ft) MLLW (Paul and Feder 1973). Butter clams are also abundant in the lower intertidal zone, and while they may be co-located with littleneck clams, they are often found at somewhat lower elevations (Morris et al. 1980; Chew and Ma 1987).

The vertical distributions of littleneck and butter clams within the sediment can also overlap, although butter clams are generally found somewhat deeper. Adult littleneck clams are shallow burrowers and are commonly within 15 cm of the surface; they may burrow to a maximum depth of 20 cm (Chew and Ma 1987). In Galena Bay of PWS, most littleneck clams were found within 3.8 cm of the surface (Paul and Feder 1973). Butter clams can burrow as much as 25 to 30 cm deep, although they are more frequently found closer to the surface (Kozloff 1976).

The Alaska earthquake of 1964 and the uplift of the shoreline in PWS had a major impact on the distribution of intertidal resources, including clams (Hanna 1971; Baxter 1971). At some locations, the magnitude of the uplift was great enough to elevate portions of the intertidal habitat to levels that were above the water depth needed to sustain the clam communities. In some areas, the violent shaking and subsequent washing by tsunami or strong currents scoured much of the nearshore sediment and washed it to deeper water, significantly altering the intertidal habitat. The combined influence of uplift and tsunami scour set into motion successional processes that involved sedimentation, recruitment, and recolonization by clams. Feder and Bryson-Schwafel (1988) note that sedimentation processes in the heavily scoured intertidal zone affected community succession in some areas through 1982, 18 years after the earthquake.

7.1.2.3 Feeding

Adult and larval littleneck clams are filter feeders, feeding on plankton and suspended organic matter in the water. There is no evidence for food selectivity.

[23] Based on elevations at Cordova, Alaska, approximate intertidal zone elevations are lower intertidal –1.45 to +0.75 m, middle intertidal +0.75 to +2.95 m, and upper intertidal +2.95 to +5 m.

7.1.2.4 Natural Mortality and Predation

Highest clam mortality is observed in larval stages and during the first year. Early survival depends on temperature, food supply, predation, currents, and substrate (McCrae 1995). In addition, clams are prey for many predators, including crab, octopus, and sea ducks. In PWS, clams are a preferred food item of sea otters (Fukuyama 2000; Van Blaricom et al. 2002; Dean et al. 2002) and may account for as much as 60–70 percent of the otter diet (Bodkin and Ballachey 1997).

Human use can contribute to clam mortality in some intertidal areas. Both butter and littleneck clams are important for subsistence use. In PWS, both species are harvested recreationally year-round, although most clamming occurs from April through September (ADFG 2006a). There is no limit on the number of clams that can be collected, but they must be harvested by hand or using a rake, shovel, or other manually operated tool.

7.1.3 Status of Injury and Recovery Classification

The specific recovery objective described by the Trustee Council in 1994 was a return to populations and productivity that would have prevailed in the absence of the oil spill (pre-spill data or unoiled control sites) (EVOS Trustee Council 1994). This objective was refined in 2002 to state that "clams will have recovered when population and productivity measures (e.g., size and distribution) at oiled sites are comparable to populations and productivity measures at unoiled sites, taking into account geographic differences" (EVOS Trustee Council 2002b).

In 2002, the Trustee Council concluded that clam populations continue to recover, but are not yet fully recovered from the effects of the oil spill (EVOS Trustee Council 2002b). This conclusion was based on observed differences through 1997 in clam populations among unoiled, oiled-and-untreated, and oiled-and-treated sites, as well as differences between study locations in clams available as prey to sea otters.

7.1.4 Overview of EVOS Trustee Council-Funded Restoration Efforts

The EVOS Trustee Council's strategy for clam restoration relies on natural recovery, monitoring, and protection of clam beds (e.g., maintain water quality, reduce disturbance). Other restoration efforts have focused on research to better understand the impacts of the spill on clams. The EVOS Trustee Council has funded numerous projects toward these restoration efforts (see Appendix A).

7.2 RESOURCE ASSESSMENT

The current condition of clam populations can potentially derive from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed on the basis of the clam life histories and inherent ability of clam populations to recover from the initial impacts of the spill, the likelihood that their behavior could result in ongoing exposure to lingering EVO to a degree that could cause adverse effects and injury, and the nature and magnitude of other factors that could affect the condition of these populations.

7.2.1 Initial Impact from Spill

In the first days to weeks following the initial spill, EVO was distributed both in open water and along the shoreline of PWS. The Trustee Council (2002b) reported that "the magnitude of immediate impacts on clam populations varied with the species of clam, degree of oiling, and location." In addition to the immediate impacts of the oil, cleanup operations immediately following the spill also affected clam populations. Cleanup technologies included pressure washing of intertidal areas using cold or hot water, as well as manual and mechanical removal of oil and tar, and manual removal of oiled sediments. Driskell et al. (1996) indicate that the initial oiling independent of the cleanup operations had minor impacts on bivalves as indicated by rich infauna and an abundance of littleneck clams on the heavily oiled, but untreated beach at Block Island in 1994. By contrast, the extreme temperatures and physical displacement of the high-pressure and hot-water treatment of oiled beaches resulted in substantial impacts to clams (Lees et al. 1996).

7.2.2 Residual Effects Following the Spill

7.2.2.1 Population Effects

Spatial and temporal patterns of impact and recovery of clam populations were investigated as part of the NOAA injury assessment (Driskell et al. 1996; Houghton et al. 1996, 1997; Lees et al. 1996) (Figure 7-1). Prior to 2002, these investigations included comparison of impacts and rates of recovery among oiled-and-untreated, oiled-and-treated, and unoiled reference locations. With the exception of high-pressure, hot-water washing, most of the treatments had minimal short-term impacts or were tolerated by the biota that survived the initial oiling (Driskell et al. 1996). Infaunal assemblages that were not treated by high-pressure hot-water washing were generally indistinguishable from those at unoiled reference sites by mid-summer 1991. Hot water pressure washing, however, caused thermal stress, oil dispersion, animal displacement and burial, and the transport of finer-grained sediments from the upper intertidal into the lower intertidal zone. The results of this treatment included reductions in bivalve abundance observed on treated beaches 1–3 years after EVOS (Peterson 2001). Although recruitment and abundance were similar between unoiled and oiled-but-untreated sites, clam abundance was low on oiled-and-treated beaches (Driskell et al. 1996). Further monitoring indicated that lower recruitment and abundances of littleneck clams persisted at oiled-and-treated beaches in comparison to reference or oiled-and-untreated beaches through 1996 (Houghton et al. 1997).

Recent monitoring data from 2002 compares trends in clam populations in oiled-and-treated and reference[24] areas (Lees and Driskell, in prep.). This report has not been finalized pursuant to peer review and has not been published in a peer-reviewed scientific journal. Consequently, the salient information and conclusions provided by Lees and Driskell (in prep.) are summarized below. This summary is followed by a brief review of the uncertainties in the report that may affect scientific confidence based on standards of proof and its subsequent usability in a weight-of-evidence approach to judging recovery (see Sections 2.3.2 and 2.3.4 for a discussion of the principles of scientific proof and weight-of-evidence approaches).

Lees and Driskell (in prep.) studied bivalve assemblages at 23 oiled-and-treated locations and 17 reference sites in PWS[25] to assess residual impacts of cleanup activities on mixed-soft beach habitat and its resident infaunal bivalve community in the lower intertidal zone. Two bivalve assemblages were studied at each location: large bivalves were excavated to 15 cm within a 0.0625 m^2 quadrat and small bivalves were sampled to the same depth with a 0.009 m^2 corer. For each sampling location, physical sediment characteristics, individual species abundances, total bivalve abundances, species richness, and two indices of diversity[26] were determined.

The Lees and Driskell (in prep.) investigation shows that median particle grain size at the oiled-and-treated areas (10.3 mm) was significantly higher ($p<0.1$) than that at the reference locations (6.8 mm). Overall, Lees and Driskell (in prep.) believe that the difference among locations in particle grain size was small and not attributable to shoreline washing. Their analysis indicates that differences in particle grain size (percent fines) are largely determined by hydrodynamic processes as indicated by the degree of beach exposure to open water and wind (fetch). Other sediment habitat characteristics (silt-clay, organic carbon, nitrogen, and carbon/nitrogen ratios) were highly intercorrelated, but nonetheless similar among oiled-and-treated and reference sites.

Differences for each kind of assemblage were also identified. For the large-quadrat bivalve assemblage, abundances of butter clams, abundances of littleneck clams, total abundances, and species richness were higher at reference locations than in oiled-and-treated locations. For the small-corer bivalve assemblage, abundances of butter clams and overall bivalve diversity were higher in reference locations than in the oiled-and-treated locations. As indicated in Figure 7-1, the differences in abundances and species richness noted between oiled-and-treated and reference locations in 2002 appear to be consistent (neither increasing nor decreasing) in comparisons with those noted in 1997.

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[24] Reference locations in the 2002 study by Lees and Driskell (in prep.) consisted of beaches that had not been oiled and those that had been oiled but untreated by high-pressure hot-water washing. This was done because of differences between unoiled and oiled-but-untreated beaches had diminished by 1997 (Houghton et al. 1997).

[25] Lees and Driskell also sampled three treated sites and one reference site known from previous NOAA studies, but excluded these locations from their quantitative evaluation of the data.

[26] The Shannon-Weiner diversity index (H') and Simpson's inverse diversity index.

Influence of sediment grain size on the bivalve community is also apparent from strong negative correlations between particle grain size and many of the biological parameters including individual abundances, total abundances, and species richness for both the large-quadrat and small-corer assemblages. The authors also note that large, long-lived clams in the small-corer assemblage at oiled-and-treated locations were about one-third as abundant as those in reference locations. Lees and Driskell (in prep.) note that the observed differences in bivalve assemblages at oiled-and-treated sites in comparison with reference sites follow the same pattern that was noted in NOAA's post-spill investigation.

Lees and Driskell (in prep.) concluded that sediments have recovered from the disturbance associated with high-pressure, hot-water washing, but the bivalve assemblages lag and will not attain full recovery for many years. However, they also noted appropriately that "the results of this study do not provide conclusive evidence that [oiled and] treated sites have not recovered from the effects of the HP-HW [high-pressure hot-water] washing" because of uncertainties in the following:

- Classification of study sites as either reference locations or oiled-and-treated locations. In some instances, historical information was insufficient to predict with confidence whether a particular location had been oiled-and-treated or whether it could be considered as a reference location.
- Recovery rates that may vary substantially among oiled-and-treated sites. This limitation suggests that some oiled-and-treated sites may have recovered while others may have not.

The omission of replicate information for individual beaches and an incomplete assessment of the role of physical factors introduce additional uncertainty into the Lees and Driskell (in prep.) study, which need to be weighed before judging recovery status of clams.

Although beaches are the appropriate unit for the kinds comparisons made by Lees and Driskell (in prep.), the omission of replicate information from the resampling procedure introduces an additional uncertainty because it imputes significance to the magnitude of the differences detected between reference and oiled-and-treated beaches that may be within the realm of ecological variability (e.g., Cade et al. 2005). Our understanding of the study design is that three randomly placed 0.0625 m^2 quadrat samples and five randomly placed 0.009 m^2 cores were sampled from randomly placed 30-m transects on each beach. The replicates for each sampling device were later pooled to generate a single value for each beach. This single value was then used in the statistical resampling procedure to generate comparisons among beaches. The concern is that the resampling procedure should include the inherent within-beach variability that is represented by the replicate data rather than the single values generated by pooling the replicate data.

A further uncertainty concerns the importance that physical factors may have on structuring habitat and which may have been influential in the trajectory of the spill and the locations at which it landed. Lees and Driskell (in prep.) point out that 36 percent of the treated sites had fetches of 9.1 km or greater compared to only 6 percent of the reference sites and that beaches with longer fetch (mostly treated sites) have a tendency toward lower silt content and less organic nitrogen than beaches with short fetches. These observations suggest that physical factors that were influential in the trajectory of the spill and the locations at which it landed may also define important differences in habitat characteristics that may have been extant prior to the spill (see Peterson 1993).

Lees (2006, pers. comm.) provided a supplemental evaluation of factors that may influence exposure to physical wave action. Lees' (2006, pers. comm.) analysis suggests that wave exposure has a positive influence in terms of abundances or numbers of species on reference beaches, but a negative influence on previously oiled-and-treated beaches. However, here too there are numerous uncertainties that require further substantiation as scientific tools and preclude making judgments. These uncertainties include the following:

- Development of several ordinal indices for wave exposure. The various indices appear to represent a new method that has not been fully calibrated or validated and should be subjected to peer review by experts in coastal sedimentary geology and physical oceanography.
- Averaging of these multiple ordinal scales into a single composite index. Whether such a composite index can be used meaningfully as a predictor of physical wave action deserves explanation and should also be the subject of peer review by experts in coastal sedimentary geology and physical oceanography.
- Statistical regression[27] of clam data onto the composite ordinal index for wave exposure. Although ordinal data can be used in a regression analysis, it is an advanced topic that requires careful analysis and specialized statistical methods to assure meaningful interpretation and should be peer reviewed by an expert in advanced statistical procedures.
- Inherent bias in regression analysis due to unequal sample sizes. The regression data for the oiled-and-treated beaches are weighted toward the high end of the exposure scale with 10 of the 20 beaches represented by an exposure index ≥8. On the other hand, only 4 of the 17 untreated beaches are represented by an exposure index ≥8. Such unequal distribution of sample points favors finding a significant regression for one group but not the other, suggesting that the comparisons may not be valid.
- Use of regression to impute significant differences where none were evident from the original statistical analysis based on re-sampling techniques. For example, Lees (2006, pers. comm.) regresses microbivalve abundance, microbivalve richness, and macrobivalve[28] diversity on the composite exposure index to identify and explain the influences of wave exposure at reference and oiled-and-treated sites. However, none of these parameters differed significantly in Lees and Driskell's (in prep.) original comparisons between reference and oiled-and-treated beaches. Hence, breaking down

[27] Regression is a statistical technique to show a linear relationship of a dependent variable (the "y" axis) on an independent variable (the "x" axis). Where such relationships can be proven (i.e., are significant), part of the variability in the dependent variable is not random, but can be explained by the independent variable.

[28] In the supplemental analysis provided by Lees (2006, pers. comm.) "microbivalve" and "macrobivalve" are new terms introduced to describe clams that have been previously designated by Lees and Driskell (in prep.) as those from infaunal or excavation samples, respectively.

non-significant differences between treatments into significant trends within treatments seems to make little sense without further analysis. The presence of a significant regression within a treatment group suggests that the original statistical comparisons may have been flawed by uncontrolled sources of variation, such as hydrodynamic setting. Consequently, an outcome of the regression procedure should be to stratify the data by exposure category and repeat the statistical comparisons of reference and oiled-and-treated beaches independently for each exposure stratum.

7.2.2.2 Toxicity

Several field studies examined the effect of EVO toxicity on clam mortality; no laboratory experiments evaluating the effects of EVO on clams have been reported. Mortality of clams transplanted from oiled areas 5–7 years after the spill was higher than that of clams from clean areas, even among animals moved from the oiled to the clean areas, suggesting residual effects on clams with longer-term exposure to the oil. Significant differences in clam mortality were observed 2 years, but not 1 year, after transplanting clams to oiled areas, suggesting that perhaps longer term exposure may affect mortality (Fukuyama 2000).

Possible sublethal effects of hydrocarbon exposure include shallower and slower burrowing, reduced siphon activity, and decreased growth rates. Reduced clam growth rates due to oil exposure are the most frequently observed result of oiling (Fukuyama et al. 2000; Trowbridge et al. 2002). Experiments by Roesijadi et al. (1978) using large littleneck clams did not show significant differences in growth rate due to exposure to oiled sediment (887 μg/g), but other experiments with small littleneck clams and PWS field experiments have clearly shown decreased growth associated with hydrocarbon exposure. There were several observations of decreased growth rates in PWS in the years immediately after EVOS. In PWS in 1990 and 1991, growth of littleneck clams at oiled sites was less than at control sites, and the growth of littleneck clams increased as the concentration of EVO decreased from 1990 to 1991 (Trowbridge et al. 2002). In transect sampling, clam growth rates in PWS decreased as PAH concentrations increased (Trowbridge et al. 2002). PWS clams transplanted from unoiled to oiled areas 5–7 years following EVOS had significantly reduced growth rates, but these rates were still within the range seen in previous studies in PWS (Fukuyama 2000).

7.2.3 Exposure to Lingering Oil

7.2.3.1 Distributions of Clams and Lingering Oil

Exposure of clams to subsurface lingering oil depends on overlap in the distributions of clams and lingering oil. There are three components to clam and oil distribution: physical habitat characteristics (including substrate type and degree of physical disturbance), intertidal elevation, and depth below the surface. Available data on each of these three elements are discussed in the following paragraphs.

The recent study of lingering oil by Short et al. (2004b) was based on the likelihood that most lingering oil occurs in the middle and upper intertidal zone of previously heavily to moderately oiled beaches. Based on Short et al.'s (2004a) study, Integral (2006) confirmed that the probability of lingering oil in beaches that were lightly oiled by the original spill (<0.7 percent) is much less than that for the moderately to heavily oiled beaches (1.6–3.9 percent). Consequently, it is likely that clam exposure to lingering oil conforms to these predictions. The locations of habitats conducive to clam beds and locations with potential lingering EVO are shown in Figure 5-2.

Habitat characteristics such as exposure, disturbance frequency, and geomorphology or substrate affect distribution of clams and lingering oil. Both littleneck and butter clams are most commonly found in protected beaches and bays. They are found in a variety of substrates, but prefer coarse sand and gravel beaches. Butter clams typically occur in beaches with a porous mixture of sand, broken shell, and small gravel; littleneck clams prefer coarse sand to firm gravel. Persistent EVO was found in sheltered bays and on beaches with boulder/cobble surface armoring or a thick sediment veneer over bedrock (Short et al. 2004b). Neither boulder/cobbles nor bedrock is the type of substrate preferred by clams.

Overlap in the tidal elevations at which lingering oil and clams are found is also required for exposure. Two studies of the distribution of lingering oil in the intertidal zone were conducted in 2001 (Short et al. 2004b) and 2003 (Short et al. 2006). The 2001 study results show that lingering oil is present in the middle to upper intertidal zone on approximately 60 percent of the beach segments surveyed. However, the results also indicate that lingering oil has a limited patchy distribution on beaches where it is found. The 2003 investigation covered the full range of tidal excursions at three locations on northern Knight Island and assessed the presence of lingering oil in surface or subsurface sediments at intertidal elevations ranging from –0.2 to +4.8 m MLLW. The results of this study show that lingering oil is present throughout the intertidal zone, but occurs at less than half (44 percent) of the beaches sampled, has a distribution limited to less than 0.5 percent of the beach surface, and can be found at tidal elevations ranging from –0.2 to +4.8 m MLLW.

Lower intertidal elevations are preferred by littleneck and butter clams, and they are not found in the upper intertidal zone. Littleneck clams are distributed between –0.9 and +1.2 m MLLW. In PWS, the greatest littleneck clam abundance was found at 0 m MLLW (Chew and Ma 1987). Consequently, although lingering oil is limited and patchy in its distribution, it can overlap with the distribution of littleneck and butter clams in the lower intertidal zone in those areas in which it occurs.

Finally, the depth of lingering oil could also determine if there is potential clam exposure. Juvenile clams are found at the surface, within the upper inch of sediment, and so are unlikely to be exposed to subsurface lingering EVO. However, as the young clams develop and begin burrowing, there is exposure to subsurface sediments that could contain lingering oil. Adult littleneck and butter clams may burrow 8 to 12 in. deep, respectively, and so would encounter any subsurface oil at these depths. Subsurface oil may have a greater effect on clams than surface oil. Littleneck clams exposed to a surface layer of oiled sediments for 1 year did not contain detectable amounts of petroleum components, but clams in sediments mixed with oil did accumulate contaminants (Anderson et al. 1983).

7.2.3.2 Bioavailability and Bioaccessibility of Lingering EVO

The primary routes for littleneck clams to accumulate hydrocarbons are direct uptake from water ventilated by the animals or ingestion of contaminated food or particulate matter. Filter or suspension feeders like littleneck clams appear to take up hydrocarbons from seawater (and interstitial water) at a slow rate until equilibrium is reached (Roesijadi et al. 1978). Although bivalves have limited ability to metabolize hydrocarbons, several studies indicate that clams are able to depurate hydrocarbons to some degree when the hydrocarbon source is removed (Fukuyama 2000). Trowbridge et al. (2002) observed EVO in bivalves collected from various oiled sites in 1989[29] following the spill, but reported a general absence of EVO or weathered EVO in bivalves collected in 1990, possibly indicating some level of depuration.

If clams and lingering oil co-occur, it is likely that elevated PAH concentrations may be present in clam tissue or adhered to the shells of clams. Neff and Gilfillan (2004) investigated PAH concentrations in clams from beaches on Smith Island in PWS that contained subsurface lingering oil. In 2002, clams were collected in the mid-lower intertidal areas below the upper tidal elevations where lingering oil was documented. Clam TPAH ranged from <10 to approximately 400 ng/g dry weight; TPAH in clams from a reference area were <10 to approximately 200 ng/g dry weight (estimated from graph presented by Neff and Gilfillan 2004).

Bioaccessibility and bioavailability of lingering oil were also demonstrated in experiments conducted by Shigenaka and Henry (1995) 3 years following EVOS in which TPAH concentrations were measured in SPMDs, sediments, water, and caged mussels placed on a previously heavily oiled beach on Smith Island and on an unoiled to lightly oiled beach also on Smith Island. Results of this study showed that TPAH concentrations were significantly correlated among the SPMDs, mussels, and sediments, further indicating the bioavailability of lingering oil to surface-dwelling organisms.

Recent research conducted in 2004 using SPMDs placed in the intertidal zone indicates that where lingering oil is present, it is still bioavailable to intertidal organisms, exists in a bioactive form that is capable of inducing CYP1A in fish, and is distinguishable from stressed reference locations that have sediments contaminated by other non-EVO-related sources of petroleum hydrocarbons (Springman et al. 2005; Short et al. 2005).

7.2.3.3 Bioaccumulation

Trowbridge et al. (2002) sampled bivalves, including littlenecks and butter clams, at oiled and unoiled sites in PWS, Cook Inlet, the outer Kenai Peninsula, and around Kodiak Island, between 1989 and 1991 to examine hydrocarbon concentrations in sediment and bivalves. In 1989, elevated levels of TPAH were documented in bivalve tissues. By 1990, weathered EVO was tentatively detected[30] in clam tissue at only 3 of 18 sites sampled, at levels ranging between 630

[29] PAH concentrations in clam tissue ranged from less than 4,000 to 34,357 ng/g dry weight.

[30] Detected oil was described by the authors as too weathered to confirm identity of the oil, but relative abundances of remaining PAH were consistent with extremely weathered EVO.

and 1,230 ng/g. Histopathological results were not significantly different between oiled and unoiled sites in either year of sampling, and there was no strong evidence that clam tissues were severely affected by EVO based on the presence of lesions or parasites.

7.2.4 Other Stressors

Other factors potentially affecting clam populations are predation, natural disturbance, and natural variability.[31] Changes in predator (e.g., sea otter) numbers can result in changes in predation rates, affecting clam population attributes such as population abundance and size distributions (Kvitek et al. 1992; Van Blaricom et al. 2002). Natural disturbances such as storms may have localized effects but are unlikely to contribute to overall population variability. There is also significant interannual variation in clam recruitment based on natural conditions that are difficult to measure and predict (Chew and Ma 1987).

Studies of changes in sea otter predation pressure following the spill suggest a possible role of the oil spill in cascading effects on clam populations. Van Blaricom et al. (2002) compared clam abundance in oiled and unoiled intertidal and subtidal areas as part of their evaluation of sea otter populations in 1996–1998. The authors predicted that, consistent with general ecological theories of predator-prey relationships, a release in predation pressure following the decline in sea otter populations resulting from the spill might lead to an increase in size and abundance of preferred prey such as clams. Some findings, including an increase in mean size of littleneck and butter clams at Knight Island where sea otter abundance was significantly reduced after the spill, supported this theory (Van Blaricom et al. 2002; Dean et al. 2002). However, other results, including densities of both littlenecks and butter clams, were not different between areas, inconsistent with the theory of cascading effects of predation pressure release. The authors concluded that the relationship was not a simple causal relationship between predator and prey and suggested that other factors, including abiotic stressors and invertebrate predators, play an important role in moderating the relationship between sea otter and bivalve prey.

7.3 SUMMARY AND RECOMMENDATIONS

The information provided in the previous sections was weighed to determine the overall recovery status of clams and to assess the need for additional restoration efforts. This included assessment of the current condition of clams and consideration of factors contributing to their current condition.

The 1994 recovery objective for clams was a return to populations and productivity that would have prevailed in the absence of the oil spill (pre-spill data or unoiled control sites). This objective was refined in 2002 to state that “clams will have recovered when population and productivity measures (e.g., size and distribution) at oiled sites are comparable to populations and productivity measures at unoiled sites, taking into account geographic differences.”

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[31] The clam species of concern in this evaluation are filter feeders, ingesting plankton or other particles of suitable size in the water column. There is no evidence that EVO has affected plankton abundance or distribution or changed the availability or quality of food available to clams.

It is recommended that the Trustee Council reclassify clams as "recovered" from the effects of EVOS based on the following:

- Studies conducted in the early to mid 1990s show that direct impacts of EVO to clam populations on oiled-but-untreated beaches were minimal and could no longer be discerned from unoiled reference beaches by 1997. Consequently, clams have recovered from the direct effects of EVOS.
- The spatial and temporal distribution of lingering EVO suggests that ongoing exposure to lingering oil and related impacts to clams are localized, limited, and patchy.
- By contrast, the extreme temperatures and physical displacement of the high-pressure and hot-water treatment resulted in substantial impacts to clams at oiled-and-treated beaches that were diminishing but still evident in 1997.
- In the most recent 2002 sampling, there were discernible differences between oiled-and-treated and reference beaches[32] in species richness, diversity, and abundances of a few species. However, there is considerable uncertainty in these observations, and the differences noted may be explained by inherent physical factors and exist within the realm of ecological variability.
- Clam populations have been on a recovery trajectory since the early 1990s (Figure 7-1).[33] It is likely that the recovery trajectory observed through 1997 has continued through processes of natural recovery and ecological succession, and that recovery of clams 17 years after the spill is more likely than not.
- Recovery of clams is consistent with the final summary of the intertidal monitoring program (Coats et al. 1999; Skalski et al. 2001), which showed that by 1997, the infaunal benthic community, including bivalves, had stabilized and that differences between oiled-and-treated sites and reference locations (including oiled-but-untreated sites) were largely determined by physical differences in the environment.

This evaluation took into consideration the level of uncertainty associated with the available data. Sources of uncertainty include the strength of scientific proof and consequently the weight of evidence associated with the most recent 2002 sampling. Uncertainties associated with this study preclude meaningful judgment about the factors responsible for those differences. These uncertainties include the following:

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[32] Reference locations in the 2002 study by Lees and Driskell (in prep.) consisted of beaches that had not been oiled and those that had been oiled but untreated by high-pressure hot-water washing. This was done because of differences between unoiled and oiled-but-untreated beaches had diminished by 1997 (Houghton et al. 1997).

[33] Figure 7-1 is taken from Lees and Driskell (in prep.) and is somewhat misleading because the recovery line is missing the years between the last monitoring event in 1997 and the most recent study in 2002. Inclusion of these years would provide a more accurate depiction of the recovery trend over time, but would not affect the relative differences between data points and their error bars. Also, the 2002 data presumably represent all of the stations that were sampled in that year and are inclusive of some of the historical NOAA sites that were sampled in previous years.

- **Classification of study sites as either reference locations or oiled-and-treated locations—**In some instances historical information was insufficient to predict with confidence whether a particular location had been oiled-and-treated or whether is could be considered as a reference location.
- **Recovery rates that may vary substantially among oiled-and-treated sites—**This limitation suggests that some sites may have recovered while others may have not.
- **Omission of replicate data—**Omission of replicate data imputes significance to the magnitude of the differences detected between reference and oiled-and-treated beaches that may be within the realm of ecological variability.
- **The importance of physical factors—**Physical factors play an important role in structuring habitat, which may have been influential in the trajectory of the spill and the locations where it landed.

These uncertainties in the 2002 study make it difficult to judge within the current principles of scientific proof the magnitude of the remaining injury or the extent to which the condition of the resource can be attributed to other stressors or to residual effects from EVOS. Consequently, judgment of recovery is weighted towards the recovery trajectory observed through 1997 and the likelihood that it has continued through processes of natural recovery and ecological succession. Finally, an additional but related uncertainty concerns the equality of reference and oiled-and-treated locations. To the extent that such physical differences between these locations persist and exist naturally or cannot be attributed to EVOS, further convergence to the 2002 recovery objective may be an unrealistic goal, particularly when the available monitoring tools are already near their limits of resolution.

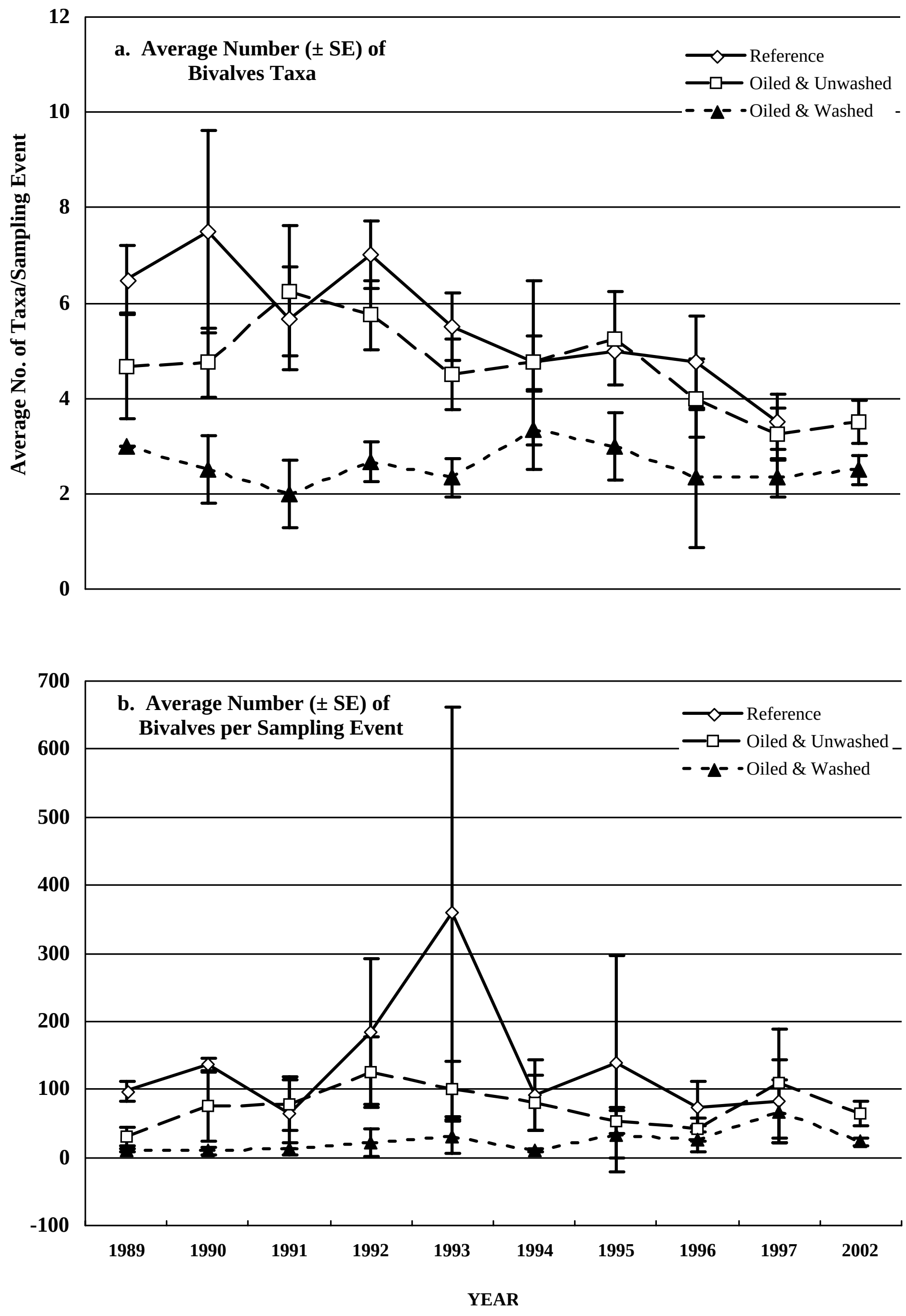

Figure 7-1. Average numbers of bivalve taxa and individuals by treatment category (Source: Lees and Driskell in prep.).

8. MUSSELS

8.1 INTRODUCTION

Mussels (*Mytilus trossulus*) in PWS are important prey items for harlequin ducks, black oystercatchers, juvenile sea otters, river otters, and many other species. They are also a key component of the intertidal habitat, providing physical stability and habitat for other organisms. Within days of EVOS in March 1989, mussels on beaches along the shoreline of PWS were exposed to the spreading oil slick. Abundance, density, and tissue chemistry of mussels from oiled and unoiled beaches were compared to determine if there were changes following the spill.

8.1.1 Statement of Problem

The EVOS Trustee Council's (2002b) current recovery objective is "mussels will have recovered when concentrations of oil in the mussels reach background concentrations and mussels do not contaminate their predators." In the 2002 assessment of resource recovery status, mussels in PWS were classified as "continuing to recover, but not yet fully recovered" (EVOS Trustee Council 2002b). Information on the life history and ecology of mussels, severity and nature of impacts from the spill, population trends, and tissue chemistry are evaluated here to independently assess the recovery status of mussels. The evaluation presented here is more comprehensive than an evaluation of tissue chemistry, which is the only one of these measurements that is directly relevant to the current recovery objective.

8.1.2 Natural History and Ecology

8.1.2.1 Life Cycle

Mussels have separate sexes, and spawning in PWS runs from late February into August (Thomas et al. 1999). Eggs and sperm are released directly into the water column. Within 24 hours of fertilization, the embryo develops into a free-swimming larva. Within the next 24 hours, the larva grows into the more advanced veliger stage. The veliger has a ciliated velum that gives it more control in swimming and gathering food. In 2–3 weeks, veligers change from a swimming larva to a bottom-dwelling juvenile mussel (i.e., spat or seed). The newly settled mussels attach to substrates with byssal threads. Young mussels can detach and crawl or drift to a different location to seek a more favorable substrate.

Recruitment of mussels is highly variable from year to year (Gosling 1992). Growth rates are variable, depending on many factors, including temperature and the quantity and quality of food (Skidmore and Chew 1985; Gosling 1992). The life span of mussels ranges from 3 to 12 or more years, but mussels in PWS rarely live longer than 9 years (Seed 1976).

8.1.2.2 Feeding

Mussels are suspension feeders and filter a wide variety of food from the water column, including bacteria, phytoplankton, fine organic detritus, and inorganic material (Gosling 1992). Mussels feed only when submerged, so periodic inundation is a requirement for feeding and growth.

8.1.2.3 Abundance and Distribution

M. trossulus is the dominant species of mussel found in PWS and the surrounding area. It is abundant in middle and lower tidal zones[34] of protected bays (Houghton et al. 1997; Lindstrom et al. 1999). The upper elevation is ultimately set by physical factors such as exposure to air and desiccation; predation is important in determining lower elevation limits (Seed 1976; Gosling 1992). Sampling elevations reported for mussel collection in PWS are primarily in the mid-low to low intertidal zones, between 0 and +2 m MLLW (Highsmith et al. 1996), but have been reported as low as –0.8 m MLLW (Houghton et al. 1997).

Mussel habitat in PWS includes exposed and sheltered bedrock and boulder shoreline, but mussels also form dense beds on soft (i.e., gravel) sediment. An overview of common intertidal habitats occupied by mussels (exposed and sheltered rocky shores, coarse-textured beaches) is shown in Figure 5-2. There are no comprehensive data for mussel distribution or abundance throughout PWS.

Although mussels can occur as either beds or small patches or solitary organisms, the focus of most studies in PWS has been on mussel beds. This is primarily because these dense aggregations can sequester oil, which can act as a source of contamination to the community supported by the mussels. The beds are composed of interconnected living and dead mussel shells and accumulated sediments and debris, and provide structural habitat for a wide variety of other intertidal flora and fauna. The beds can be up to 10 to 20 cm thick, as younger mussels settle and accumulate on established beds of older mussels. The mussels' byssal threads can be so closely intertwined that it is possible to tear the bed away from the underlying sand or gravel in a solid mass (Rickets and Calvin 1968). Mussel bed sizes can range from 20 to 2,200 m^2 or more and beds may cover up to 60–100 percent of the sediment surface (Boehm et al. 1996; Lindstrom et al. 1999; Carls et al. 2001a). Reported mussel densities in PWS ranged from 20 to more than 10,000 individuals/m^2 (Babcock et al. 1996, 1998; Boehm et al. 1996; Carls et al. 2001a).

The Alaska earthquake of 1964 and the uplift of the shoreline in PWS had a major impact on the distribution of intertidal resources, including mussels (Hanna 1971). The entire spill zone is within the area that was uplifted up to 15 m from its original pre-earthquake elevation (Hanna 1971). At some locations, the magnitude of the uplift was great enough to elevate portions of the intertidal habitat to levels that were above the water depth needed to sustain the mussel communities. Substrate changes also resulted, as subtidal soft sediments were uplifted and

[34] Approximate intertidal zone elevations are shown in Figure 5-1.

exposed, and nearshore sediments were scoured by tsunami or strong currents and washed into deeper waters.

8.1.2.4 Natural Mortality and Predation

Mussels are prey for a variety of vertebrate and invertebrate predators. They are a common food item for many seabirds (including harlequin ducks and black oystercatchers), river otters, and juvenile sea otters, as well as gastropods, crabs, and sea stars. Sea stars have been shown to be a major predator of *Mytilus,* strongly influencing the distribution and abundance of the mussel at the lower intertidal elevations (Gosling 1992).

8.1.3 Status of Injury and Recovery Classification

The EVOS Trustee Council (2002b) defines the recovery goal for mussels as "a return to conditions that would have existed had the spill not occurred." The original recovery objective described by the EVOS Trustee Council in 1994 stated "mussels will have recovered when their populations and productivity are at prespill levels and they do not contain oil that contaminates higher trophic levels." This recovery objective was revised in 2002 to state that "mussels will have recovered when concentrations of oil in the mussels reach background concentrations and mussels do not contaminate their predators" (EVOS Trustee Council 2002b).

As of 1995, some mussel beds in PWS still contained EVO, although more than half of the sites surveyed showed significant natural declines in oil concentrations (Carls et al. 2001a). While hydrocarbon concentrations in mussels from some sites were expected to reach background concentrations in a few years, contamination was expected to persist in mussels at other sites that were well protected or where oil penetrated into underlying sediments. In addition, there were concerns about continued hydrocarbon exposure to sea otters and harlequin ducks, although the pathway of exposure was not known. In 2002, the EVOS Trustee Council (2002b) reviewed the status of mussels in PWS and concluded that mussels were continuing to recover, but were not yet fully recovered from effects of the spill.

8.1.4 Overview of EVOS Trustee Council-Funded Restoration Efforts

The original restoration strategy relied on cleaning oiled mussel beds, monitoring, and measures to protect mussels and their habitat (EVOS Trustee Council 1994). Subsequent restoration efforts focused on research to better understand the impacts of the spill on mussels, active cleaning and restoration of some beds, and acquisition of habitat important to mussels. Restoration projects funded by the EVOS Trustee Council are listed in Appendix A.

8.2 RESOURCE ASSESSMENT

The current condition of mussel populations can potentially derive from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed on the basis of the mussel life history and inherent ability of mussel populations to recover from the initial impacts of the spill, the likelihood that there could be ongoing exposure to lingering EVO to a degree that could cause adverse effects and injury, and the nature and magnitude of other factors that could affect the condition of these populations.

8.2.1 Initial Impact from Spill

In the first days to weeks following the initial spill, EVO was distributed both in open water and along the shoreline of PWS. Mussels at all tidal levels and substrates were directly exposed to EVO as oil coated mussels and penetrated the underlying mat of dense mussel beds. Cleanup operations immediately following the spill included pressure washing of intertidal areas using cold or hot water, as well as manual and mechanical removal of oil and tar, and manual removal of oiled sediments. However, dense mussel beds on unconsolidated substrates were generally not cleaned following the spill so that the stability and habitat they provide would be preserved.

Mussels were initially exposed to EVO through direct contact and ingestion of particulate oil. Petroleum hydrocarbons were initially accumulated as whole particulate oil rather than by absorption of hydrocarbons dissolved in seawater or associated with suspended sediment or particulates (Short and Babcock 1996). Petroleum hydrocarbon concentrations in mussels sampled in the spill area immediately following EVOS were much higher than in mussels sampled outside the spill area (Babcock et al. 1996). In addition, hydrocarbon concentrations in mussels immediately following the spill (1989) were higher than in mussels sampled prior to the spill (1977–1979). Mussels collected from 13 heavily oiled intertidal locations in PWS 6 weeks after EVOS had total petroleum hydrocarbon concentrations of up to 100,000 µg/kg dry weight compared to mean hydrocarbon concentrations of 143 to 544 µg/kg dry weight before EVOS (Short and Babcock 1996).

8.2.2 Residual Effects Following the Spill

8.2.2.1 Bioaccumulation

In many areas, the initial high petroleum hydrocarbon concentrations in mussel tissue began declining soon after EVOS.[35] Hydrocarbon concentrations in mussels on hard rock substrate had generally returned to background levels shortly after the spill. However, mussel populations from many areas with coarse-textured soft substrate still showed significant differences compared to reference locations and compared to mussels sampled prior to the spill (Highsmith

[35] Mussels will rapidly depurate PAH if not chronically exposed to hydrocarbons in water or sediment.

et al. 1996; Babcock et al. 1996). Numerous investigations since the mid-1990s documented elevated PAH concentrations in mussels at some oiled beaches compared to mussels at unoiled locations or pre-spill levels (Carls et al. 2001a). While PAH concentrations in mussels declined in PWS and the Gulf of Alaska, some beaches remained contaminated 10 years after the spill (Carls et al. 2001a, 2004; EVOS Trustee Council 2002b).

Carls et al. (2001a) studied mussel beds at 80 beaches in PWS and 18 beaches in the Gulf of Alaska over four years from 1992 to 1995. By the end of the study in 1995, TPAH in mussels declined at many locations, but remained significantly greater than background concentrations (90 µg/kg dry weight) at six locations. In a subsequent study, Carls et al. (2004) noted that by 1999, TPAH concentrations in mussels were below background levels at all but one of seven restored mussel beds and that TPAH concentrations in mussels had generally declined to background levels throughout PWS. Carls et al. (2004) found that TPAH concentrations in mussels were initially reduced by beach restoration, but rebounded in subsequent years, suggesting that transport mechanisms invaded the restored sediments and recontaminated the mussels. In a separate 1999 study of residual oiling of armored beaches and mussel beds in the Gulf of Alaska, Irvine et al. (2002) measured TPAH in mussels from six locations. Tissue concentrations were less than background levels established by Carls et al. (2001a, 2004) at five of these locations and were less than twice background at the remaining site. Twice background is a benchmark established by Carls et al. (2001a, 2004) below which concentrations were not considered to be significantly elevated.

The PWS Regional Citizens' Advisory Committee long-term environmental monitoring program documented a return of PAH and AHC [aliphatic hydrocarbons] levels in mussel tissue in PWS to background levels by 2003 (Payne et al. 2005). With the exception of two sites, the Alyeska Marine Terminal site and the Gold Creek site in Port Valdez, 10 regional sites did not show elevated concentrations of hydrocarbons. At the two elevated sites, where PAH and AHC contaminants from the Alyeska Marine Terminal Ballast Water Treatment Facility were detected, concentrations were small and the authors suggested that PWS is not heavily contaminated from ongoing anthropogenic activities (Payne et al. 2005).

By 1999, Carls et al. (2004) reported that TPAH concentrations in mussels were below background levels at all but one of seven restored mussel beds and that TPAH concentrations in mussels had generally declined to background levels throughout PWS. In 2002, Boehm et al. (2004) measured TPAH concentrations in composite samples of mussels from beaches identified by Short et al. (2002) as having lingering oil. Mean tissue TPAH in composite mussel samples from lingering oil beaches were comparable to levels in beds not exposed to EVO.[36] In a separate 1999 study, Irvine et al. (2002) measured TPAH in mussel beds from six locations in the Gulf of Alaska, all of which were either below or not significantly elevated in comparison to background levels.

[36] These results were from composite samples based on a sampling grid and, in contrast to Carls et al. (2001a, 2004), did not target areas where lingering oil was visibly present or elevated.

8.2.2.2 Population and Physiological Measures

The lack of baseline information on mussel population abundance in PWS prior to the spill prevents direct assessment of potential changes in mussel populations due to oil. Initial decreases in mussel abundance were observed in spill areas (Houghton et al. 1991; Highsmith et al. 1996), particularly in areas that had been treated with high-pressure hot-water washing (Houghton et al. 1996). However, post-spill comparison of localized mussel densities at oiled and unoiled sites indicated that, by 1991, significant differences in abundance and biomass were not apparent in sheltered rocky and PWS estuarine habitats (Short and Babcock 1996). Mussel populations from coarse-textured Cook Inlet area habitats still showed significant differences (Highsmith 1996). A study of intertidal epibiota in PWS found no statistically significant difference for mussels between oiled and unoiled sites by 1992 (Houghton et al. 1996).

Physiological effects from EVO were also examined. Many physiological responses in mussels were not correlated with oil exposure 3–4 years after EVOS. In a 1992 study by Thomas et al. (1999), total PAH tissue concentrations[37] in mussels ranged from 0 to 6,000 µg/kg dry weight and were significantly different between mussels from oiled and non-oiled beaches. However, there was no significant difference in byssal thread production, condition index, feeding rate, or glycogen content between mussels from oiled beaches and those from reference locations, or between mussels from beds overlying oiled sediment and from nearby hard substrate.

Mussels collected at oiled locations in PWS in 1993 (Morado et al. 1998; Shigenaka 1997) showed changes in histopathology compared to mussels from an unoiled control site. Although sampling was limited, observations indicated that mussels from the oiled locations had increased digestive gland metaphasia, increased brown cells, decreased abundance of storage cells, and increased hemocytic infiltrates in gonads compared to controls.

Shigenaka (1997) noted that there was some indication of offset reproductive timing in oil-exposed mussels collected at Smith Island in 1993, but no further information was located. Although there are data on mussel abundance, mussel recruitment patterns can exhibit large temporal and spatial variability (Gosling 1992), making it difficult to assess the extent to which local reproduction contributes to local recruitment and abundance. Therefore, effects on reproduction may not be discernible from local patterns of adult mussel abundance.

8.2.3 Exposure to Lingering Oil

Despite the direct measurements described above, the extent and magnitude of the current exposure of the mussel populations in PWS to lingering subsurface oil cannot be directly quantified. Investigations assessing PAH concentrations in mussel tissue have been based on non-random sampling and many targeted known or visibly oiled locations, and often the "most oiled" portions of mussel beds (Babcock et al. 1996). Therefore, they do not allow estimates of the current extent of mussel exposure to lingering oil relative to the overall mussel population in

[37] Nondetected values in this study were reported as zero.

PWS. However, available information on the relative distributions of mussels and lingering oil as well as the bioavailability of lingering oil is provided below.

8.2.3.1 Distribution of Lingering Oil and Mussels

Two studies of the distribution of lingering oil in the intertidal zone were conducted in 2001 (Short et al. 2004b) and 2003 (Short et al. 2006). The 2001 study was a stratified random survey of lingering oil that did not include all mussel habitat. The 2001 study shows that lingering oil is present in the middle to upper intertidal zone (+1.8 to +4.8 m MLLW) on approximately 60 percent of the beach segments surveyed. However, the results also indicate that lingering oil has a limited patchy distribution on beaches where it is found. In comparison, mussels are most abundant at lower intertidal and lower-mid intertidal elevations. The 2003 investigation covered the full range of tidal excursions (from –0.2 to +4.8 m MLLW) at three areas on northern Knight Island. The results of this study showed that lingering oil was present at less than half (44 percent) of the beaches sampled, had a distribution limited to less than 0.5 percent of the beach surface, and was found at tidal elevations ranging from –0.2 to +4.8 m MLLW.

Lingering oil is clearly present in surface and subsurface sediments in the lower intertidal zone and was historically observed below mussel beds (Short et al. 2004b; Short and Babcock 1996; Carls et al. 2001a). Researchers agree that the total area of oil-contaminated mussel beds as a percentage of all mussel beds in PWS was small in the 1990s (Boehm et al. 1996; Carls et al. 2001a; Babcock et al. 1996). Mussels are widely distributed on both hard and soft coarse substrates throughout PWS, including areas such as Smith Island and northern Knight Island that were moderately to heavily oiled by EVOS. Using estimates of habitat types and mussel densities in the different habitats, Boehm et al. (1996) estimated that fewer than 3 percent of the mussels in PWS were exposed to lingering subsurface oil, and more recently reduced the estimate to ~0.1–0.2 percent (Boehm et al. 2004). Other mussel and subsurface oil sampling investigations (e.g., Carls et al. 2001a, 2004) have not used random sampling and so cannot be used to estimate the proportion of the mussel population in PWS potentially affected by lingering oil. Finally, in a recent review, Page et al. (2005) summarized mussel data for PWS for the years 1990, 1991, 1993, 1998, 1999, 2000, 2001, and 2002. These results show that PAHs from EVOS residues that remain buried in shoreline sediments after the early 1990s are in a form and at locations that provide low accessibility to mussels living in the intertidal zone.

Outside of PWS along the Gulf of Alaska, a number of studies have been performed to evaluate lingering EVO on boulder armored beaches or mussel beds at the Kenai Fjords and Katmai National Parks and the Kodiak Archipelago. Although measurable oiling was reported along the Kodiak Archipelago in 1990 and 1991, no oil or only trace amounts of oil were observed in 1995. Along the Kenai Fjords and Katmai National Parks, the majority of armored beaches visited had largely unweathered EVO present as mousse in the subsurface, while areas of surface oiling were largely absent. EVO was generally found in sediments at mussel bed sites, but by 2002, the areal extent and concentration of EVO declined at most sites (Irvine et al. 2002). As of 2005, the decreasing trend in EVO present in sediments at mussel bed sites appears to be continuing in these remote areas (Irvine 2005, pers. comm.).

8.2.3.2 Bioaccessibility and Bioavailability

The primary route for mussel exposure to subsurface lingering EVO is ingestion of petroleum hydrocarbons in water (Carls et al. 2001a; Boehm et al. 1996). Mussels are found on the sediment surface, and there is little direct contact with subsurface lingering oil. Mussels are suspension feeders and filter large volumes of seawater. Oil from contaminated subsurface sediment may enter interstitial or overlying water with suspended sediment or as dissolved hydrocarbons (Carls et al. 2001a). Both particulate and dissolved hydrocarbons are ingested by mussels as they filter seawater.

At present, the very small quantities of lingering oil have a patchy distribution and limited bioaccessibility to mussels in PWS (see "Effects Following Spill" and "Current Exposure to Lingering Oil" sections above). Where it was present in the past, there is evidence that subsurface oil is unevenly distributed within mussel beds (Harris et al. 1996). Factors such as the original degree of oiling, differences in exposure and water flow over the bed, grain size, and the strength of periodic disturbances by storms all affect the distribution and potential mobilization of subsurface oil within a mussel bed (Irvine et al. 2002). Carls et al. (2001a) and Irvine et al. (2002) express concern that episodic storm-generated remobilization of oil from sediments and uptake by mussels may be a significant exposure mechanism. However, documentation of such mechanisms has proved elusive, and hypothesized differences noted in seasonal or interannual trends in the data were not statistically significant (Carls et al. 2001a).

Although bioaccessibility is low, subsurface lingering oil remains in a bioavailable state as indicated by the continued presence of elevated hydrocarbons in some mussel beds with lingering oil (Carls et al. 2001a). Bioaccessibility and bioavailability of lingering oil were also demonstrated in experiments conducted by Shigenaka and Henry (1995) 3 years following EVOS in which TPAH concentrations were measured in SPMDs, sediments, water, and caged mussels placed on a previously heavily oiled beach on Smith Island, and on an unoiled to lightly oiled beach also on Smith Island. Results of this study showed that TPAH concentrations were significantly correlated among the SPMDs, mussels, and sediments, further indicating the bioavailability of lingering oil to surface-dwelling organisms.

In 2002, Boehm et al. (2004) measured TPAH concentrations in composite samples of mussels from beaches identified by Short et al. (2002) as having lingering oil. Mean tissue TPAH in mussel samples from lingering oil beaches were 54 µg/kg dry weight compared to mean concentrations of 28 and 106 µg/kg dry weight in beds not exposed to EVO.[38] These results were from composite samples based on a sampling grid and, in contrast to Carls et al. (2001a, 2004), did not target areas where lingering oil was visibly present or elevated.

The 2001 (Short et al. 2004b) and 2003 (Short et al. 2006) studies of lingering oil in the intertidal zone (described above) confirmed its presence in patchy localized areas in the middle to lower intertidal zones inhabited by mussels. Recent research conducted in 2004 using SPMDs placed

[38] Boehm et al. (2004) report TPAH concentrations minus parent naphthalene. The two reported PAH levels are the mean value for sites not associated with human and industrial use, and the mean for sites associated with human and industrial use, respectively.

in the intertidal zone indicates that where lingering oil is present, it is still bioavailable to intertidal organisms, exists in a bioactive form that is capable of inducing CYP1A in fish, and is distinguishable from stressed reference locations that have sediments contaminated by other non-EVO-related sources of petroleum hydrocarbons (Springman et al. 2005; Short et al. 2005).

8.2.4 Other Stressors

There are a large number of natural factors contributing to mussel population variability, including predation, food supply, competition for food and space, currents and larval dispersion, storm disruption, and climatic factors. Estimates of the time for mussel recovery (e.g., PAH tissue concentrations declining to background or pre-spill levels) have varied widely (Babcock et al. 1996; Carls et al. 2001a; Page et al. 2005). Natural factors will affect recovery rates. For example, Irvine et al. (2002) suggested that disturbance by storms or mussel mortality could be important factors in determining the recovery of mussel beds. Between 1995 and 1999, they observed greater decreases in subsurface oil concentrations in mussel beds compared to armored beaches. This observation could be due to more frequent or severe disturbance in the mussel beds (i.e., death of mussels in beds), although there are also differences in the tidal elevations. In addition, based on unpublished data, Carls et al. (2004) reported that there was evidence of unexplained regional declines in mussel populations in the last decade, but no supporting information or evidence was provided.

8.3 SUMMARY AND RECOMMENDATIONS

The information provided in the previous sections was weighed to determine the overall recovery status of mussels and to assess the need for additional restoration efforts. This included assessment of the current condition of mussels and consideration of factors contributing to their current condition.

The recovery objective for mussels is defined as a return of petroleum hydrocarbon concentrations to background levels in mussels such that mussels do not contaminate their predators. Therefore, tissue PAH concentrations were the primary data considered in the recovery evaluation. Other evidence considered in the evaluation included changes in mussel populations and the potential for oil exposure (from the initial spill and current exposure to lingering oil), and effects of other stressors.

It is recommended that the Trustee Council reclassify mussels as "recovered" from the effects of EVOS based on the following:

- Within 6 weeks of EVOS, mussels from heavily oiled areas had hydrocarbon tissue concentrations several orders of magnitude higher than mussels from outside the spill area or before EVOS. However, mussels rapidly depurate hydrocarbons once exposure to oil ceases, and hydrocarbon concentrations in mussels declined rapidly after the initial spill.

- Comparison of mussel densities at oil and unoiled sites in PWS 2 to 3 years after the initial spill did not show statistically significant differences in mussel abundance or biomass.
- By the late 1990s to 2003, multiple investigations reported that PAH concentrations in mussels had returned to background levels at those sites within PWS that have been sampled.
- Lingering oil in sediments is not impacting mussels because the bioavailable oil is in subsurface sediments and is not accessible to the surface-dwelling mussels.
- Although lingering oil has been observed below mussel beds, the total area of mussel beds with lingering oil is a very small percentage of all mussel beds in PWS (perhaps 0.1–0.2 percent).
- Lingering EVO in sediments at mussel bed sites appears to be declining. It is unlikely that the few localized areas where lingering oil remains could contaminant mussels at levels that would result in unacceptable risk to predators.

This evaluation took into consideration the level of uncertainty associated with the available data. Sources of uncertainty include natural variability and study design (e.g., non-random sampling), potential for remobilization by storm disturbance, and the absence of baseline data on mussel populations before EVOS that could be used directly to assess changes in mussel population abundance in PWS due to oil. Despite these concerns, the overall uncertainty associated with the primary line of evidence, mussel tissue PAH concentrations, is low as evidenced by the multiple investigations and researchers that report similar conclusions despite different study designs and sampling locations. There is greater uncertainty associated with information on mussel populations and the extent of oil exposure due to the absence of pre-spill data, and non-random study designs.

9. HARLEQUIN DUCK

9.1 INTRODUCTION

Harlequin ducks (*Histrionicus histrionicus*) are present year-round in the nearshore environment of PWS. They are at maximum density during the winter, and thus the full population was present in March 1989, when EVOS occurred. Ducks in the path of the oil slick became coated with oil, and an estimated 7 percent (range = 3–12 percent) of the wintering population of PWS and a higher percentage of those wintering in oiled areas suffered acute mortality from oiling (Piatt 2005, pers. comm.). In the years following the oil spill, population counts were variable by season and year; no clear trend of increasing population was established.

9.1.1 Statement of Problem

Harlequin ducks were classified as "not recovering" in the 2002 assessment of resource recovery status (EVOS Trustee Council 2002b). Information on the life history of the harlequin duck (e.g., foraging behavior), biomarker data on PAH exposure (i.e., CYP1A), population trends, and other measures of the health of individuals and the population are evaluated here to assess the current recovery status of harlequin ducks.

9.1.2 Natural History and Ecology

Harlequin ducks are found throughout PWS, where they occupy shallow subtidal and intertidal zones, rich with benthic invertebrate food sources. They are seasonal migrants, with the wintertime population of roughly 15,000 in PWS (average abundance during 1990–2004 winters from Sullivan et al. 2005) reduced by more than half in June, when breeding birds have flown to their freshwater breeding grounds on inland rivers and streams.

9.1.2.1 Life History

Harlequin ducks are a relatively long-lived waterfowl with a diverse, primarily invertebrate diet that uses both fresh- and saltwater habitats over its lifecycle. The coastal breeding range of harlequin ducks extends from northern California to Alaska including the Aleutians. Females become reproductively mature at 2 years of age, but have low reproductive success until 5 years of age (Robertson and Goudie 1999). A harlequin duck of at least 10 years of age was identified in British Columbia, suggesting the life span is at least this long or longer (Robertson and Goudie 1999). Low annual productivity is compensated for by relatively high adult survival (Esler et al. 2002b). Population change is most sensitive to changes in adult female survival (Robertson and Goudie 1999). Because of limited dispersal, immigration to an area after a population decreases due to some natural or anthropogenic factor may be limited. Recovery time from a perturbation like an oil spill may be extended by demographic lags associated with low immigration rates, high site fidelity, and low reproductive rates.

9.1.2.2 Seasonal Behavior and Habitat

Harlequin ducks nest inland, but they overwinter in coastal, marine waters. They are known for their high site fidelity (philopatry[39]) on both wintering and breeding areas (Robertson and Goudie 1999; Patten et al. 2000). PWS is prime wintering habitat and is one of the northernmost wintering areas in the species' range (Esler et al. 2002b). Harlequin ducks in PWS exhibit a high degree of fidelity to specific wintering areas (Iverson et al. 2004) (e.g., within approximately the same few kilometers of shoreline).

Wintertime activity is focused on foraging (Robertson and Goudie 1999). During the day, harlequin ducks remain close to shore, spending most of their time foraging in shallow subtidal and intertidal waters (Robertson and Goudie 1999). At night, they often "raft-up" offshore in small groups to rest (Robertson and Goudie 1999; Rizzolo 2004).

Pairs form on winter range as early as October, and pair formation continues through spring (approximately May) until breeding birds depart for their nesting grounds farther inland (Robertson and Goudie 1999). Some nonbreeding individuals remain on marine waters over summer. Breeding males remain on the nesting grounds for only a short period, departing sometime during egg incubation (which is carried out by the female), and arriving back on their wintering grounds around the end of June (Robertson and Goudie 1999). Females with broods appear some time in late August or September. Wing molting, during which adult and juvenile birds (but not fledglings) are flightless, occurs in the summer and early fall on marine waters.

Most of the breeding locations for the PWS wintering population are unknown. Rosenberg and Petrula (1998) conducted post-spill brood surveys and concluded that breeding habitat in the PWS watershed is limited and that most harlequin ducks leave the area to breed. A few harlequin ducks breed locally on streams draining into PWS and rear their broods in estuaries where they feed on salmon roe and intertidal invertebrates.

9.1.2.3 Diet

During the winter, harlequin ducks feed on small (≤ 25 mm) intertidal and subtidal invertebrates (Esler et al. 2002b). North American winter diets were found to consist of 57 percent crustaceans (decapods, amphipods, isopods, and barnacles), 25 percent molluscs (snails, limpets, chitons, and bivalves [especially blue mussel]), 10 percent insects, and 5 percent echinoderms and fish (Robertson and Goudie 1999). Local diets of harlequin ducks in PWS were quantified after EVOS in 1989–1990. They consisted of 20 percent snails of the genus *Littorina*, 18 percent snails of the genus *Lacuna*, 12 percent blue mussels (*Mytilus* sp.), and 10 percent limpets (*Lottia*); the remaining 40 percent consisted of 24 different taxa, all in small amounts (Patten et al. 2000). Harlequins were observed grazing, dabbling, and diving for invertebrates, at or near the surface of the water in the intertidal zone (Patten et al. 2000).

Diets of harlequin duck in PWS are supplemented in summer with seasonally available salmon eggs and in spring with herring roe (Patten et al. 2000). Breeding birds forage on freshwater

[39] The tendency of an individual to return to, or stay in, its home area or another adopted locality.

aquatic insects, including midge larvae, caddis flies, stone flies, and mayflies (Robertson and Goudie 1999).

9.1.2.4 Predators and Disease

Predation on harlequin ducks occurs on both wintering and breeding grounds. Bald eagles occur in PWS and are known to prey on harlequin ducks. They attack aggressively by swooping repeatedly and causing the ducks to dive until exhausted (Robertson and Goudie 1999). On breeding grounds, predators include mink, martens, hawks, great horned owls, arctic foxes, and common ravens (Robertson and Goudie 1999). There is no evidence to evaluate the degree to which predation limits the size of wintering populations of harlequin duck (Rosenberg and Esler 2005, pers. comm.).

Studies of disease suggest that harlequin ducks do not have parasite loads as heavy as those of other sea ducks (Robertson and Goudie 1999). Feather lice, acanthocephalan worms, and trematodes have been identified as parasitic organisms on harlequin ducks, and one trematode, *Paramonostomum histrionici*, appears to be unique to harlequin ducks, not having been identified in any other host species (Robertson and Goudie 1999).

9.1.3 Status of Injury and Recovery Classification

The EVOS restoration plan (EVOS Trustee Council 1994) provides long-term guidance for restoring resources injured by the 1989 spill. The 1994 recovery objective for harlequin ducks was stated as:

> Harlequin ducks will have recovered when breeding and post-breeding season densities and production of young return to estimated prespill levels, or when there are no differences in these parameters between oiled and unoiled areas.

By 2002 (EVOS Trustee Council 2002b), this objective had been refined to be:

> [H]arlequin ducks will have recovered when breeding- and nonbreeding-season demographics return to prespill levels and when biochemical indicators of hydrocarbon exposure in Harlequins in oiled areas of PWS are similar to those in Harlequins in unoiled areas"

In 2002, the Trustee Council concluded that "[a]lthough some of the indicators show signs of recovery, the majority of the indicators do not indicate recovery. Taken together, the population census trends, survival measures, and indicators of exposure suggest that the Harlequin Duck has not recovered from the effects of the oil spill."

A modified recovery objective was used in the evaluation presented to better reflect the available information and to better consider the effects of other stressors that may affect the population:

> Harlequin ducks will have recovered when breeding- and nonbreeding-season demographics[40] and biochemical indicators of hydrocarbon exposure in harlequin ducks in oiled areas of PWS are similar[41] to those in unoiled areas, taking into account geographic differences that are not related to EVO.

9.1.4 Overview of EVOS Trustee Council-Funded Restoration Efforts

The EVOS Trustee Council strategy for harlequin duck restoration was to conduct research to find out why harlequin ducks are not recovering; initiate, sustain, or accelerate recovery of harlequin ducks; monitor recovery; and protect harlequin ducks and their habitat (EVOS Trustee Council 1994). Since the early 1990s, the EVOS Trustee Council has funded numerous projects toward these restoration efforts (see Appendix A). Most restoration efforts have focused on research to better evaluate harlequin duck recovery and mechanisms of injury. The most important of these studies was the Nearshore Vertebrate Predator project, a 5-year study of factors limiting recovery of four indicator species that used coastal lands and waters. The project focused on two fish eaters—river otters and pigeon guillemots—and two species that feed on shellfish and other invertebrates—harlequin ducks and sea otters. This project spawned follow-on studies that continue to look at oil exposure as a potential factor for the lack of recovery of sea otters, harlequin ducks, and pigeon guillemots, but also at such natural factors as food availability.

9.2 RESOURCE ASSESSMENT

The current condition of the harlequin duck population in PWS can potentially derive from one or more of the following:

- Residual effects from the original spill, including reduced abundance due to demographic lags
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed on the basis of life history of the harlequin duck and the inherent ability of the population to recover from the initial impacts of the spill, the nature and degree of ongoing exposure to lingering EVO that could cause adverse effects, and the nature and magnitude of other factors that could affect the condition of the population.

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[40] Demographics in the context of this report section is a technical term adopted from the original research cited and is used to indicate the number of breeding pairs, age and sex composition of the population, molt chronology, number of broods, and annual counts of individual harlequin ducks.

[41] The word "similar" in this context is adopted from the original research and expresses the idea of confirmation of the null hypothesis where there is no statistical difference in demographic parameters between study or treatment groups (e.g., between eastern PWS vs. western PWS).

9.2.1 Initial Impact from Spill

EVOS occurred in March, when the full wintering population of harlequin ducks was present in PWS. Harlequins and other sea ducks are among the most vulnerable to oil spills because they spend most of their time in nearshore waters where they feed on benthic invertebrates (Piatt et al. 1990). Within days of the spill, hundreds of harlequin ducks became coated with oil and suffered acute mortality due to loss of insulation (caused by oiled feathers) and subsequent hypothermia. Most carcasses recovered were completely coated with oil. Others may have suffered from ingestion of oil and subsequent toxicological effects (Esler et al. 2002b; Patten et al. 2000). Patten et al. (2000) found hydrocarbon metabolites in 4 percent of harlequin ducks collected (shot) from oiled areas in 1989 and 1990, consistent with exposure to oil. Using an estimated carcass recovery rate of 15 percent, harlequin duck mortality for the years 1989 and 1990 was estimated at 1,413 for the entire spill area and 980 in PWS, which is about 7 percent of the wintering population (Piatt and Ford 1996; Esler et al. 2002b). Rosenberg et al. (2005) estimated 3,199 ducks in the spill area of PWS based on an average of 6 years of counts in west PWS and 5 years of counts in southwest PWS, plus a 20 percent estimate to cover areas not surveyed, yielding an estimate of 31 percent of harlequin ducks in the spill area of PWS killed by oiling (980 out of 3,199).

9.2.2 Residual Effects Following the Spill

Residual effects of the EVOS on harlequin ducks in PWS have been studied by comparing duck populations in oiled and unoiled areas, including analyses of long-term trends in the population abundances. Insights into potential recovery times from initial perturbations may also be gained by analysis of life history characteristics, toxicity to individuals, and demographic measures.

9.2.2.1 Impacts on Population

Population trend data are complicated by two main factors aside from sampling design issues: 1) a lack of pre-spill data, and 2) temporal variation (seasonal and annual) in populations. Population trends of harlequin ducks in PWS prior to EVOS are unknown. The only pre-spill population data available were collected in July and March 1972 and August and March 1973 (Klosiewski and Laing 1994) and in the summers of 1984 and 1985 (Irons et al. 2000). There is relatively little breeding activity that occurs within the PWS watershed; thus, pairs begin leaving for breeding grounds in May, and individuals return to PWS from June through August or September. Breeding propensity, phenology, and success may vary from year to year, making annual comparisons of spring and summer data difficult and as a result, summer data have been of lesser value for comparison to post-spill populations. By September, most birds have returned to PWS, although some movements (redistribution) may occur following molt. Winter populations are the most stable (Rosenberg and Petrula 1998; Esler et al. 2002b), and therefore winter population data should provide the best indicator of overall population trends in PWS.

Comparisons of population trends in oiled vs. unoiled portions of the spill area have been made by Murphy et al. (1997), Rosenberg and Petrula (1998), Agler and Kendall (1997), Lance et al. (2001), Irons et al. (2000), Wiens et al. (2004, 2005), Sullivan et al. (2005), and Rosenberg et al. (2005, in review). Our summary of analyses of temporal trends and comparisons between areas will generally focus on winter data because several investigators (e.g., Esler et al. 2002b and Rosenberg and Petrula 1998) believe winter is the best time to survey for population comparisons. The only long-term information available is provided by the most recent analysis of population data by USFWS (Sullivan et al. 2005). The statistical limitation of field surveys of duck populations is their inability to detect relatively small changes (e.g., < 10 percent) in abundance, even over many years of surveys, if annual variability is high or sample size is low. Not all population studies reached similar conclusions and studies that provided more powerful assessments of population status were given more weight.

Rosenberg and Petrula (1998) found a decline in harlequin duck populations in western PWS during the period 1995–1997, whereas none was detected in eastern PWS. They believe the decline is due to lower survivorship in western PWS, not due to lower recruitment. Based on their data on population structure and size, Rosenberg and Petrula (1998) concluded "[the harlequin duck] population in oiled areas of WPWS [western PWS] has the potential to recover from the effects of the EVOS. However, our trend analysis indicates that the population in oiled areas is still declining."

Several population studies using overlapping data sets have found some time periods within which the harlequin duck population in oiled areas of PWS increased (e.g., Agler and Kendall [1997] for the March population in 1990, 1991, 1993, 1994, and 1996; Lance et al. [2001] for the March population in 1990–1998). However, the analysis by Sullivan et al. (2005) of USFWS long-term data on the harlequin duck population of PWS showed that the overall winter population trend of harlequin ducks in oiled areas of PWS from 1989 through 2004 has been stable since EVOS despite some evidence of an increase in the population from March 1990 to March 1996. According to the analysis by Sullivan et al. (2005), there is no evidence of increasing populations in oiled areas or PWS as a whole over the full time period (1990–2004).

Esler et al. (2002b) concluded that harlequin duck populations had not recovered by 1998 and that adverse effects from oil continued for at least 9 years after the spill. Their conclusion is based on the following:

- Elevated CYP1A in ducks wintering in previously oiled areas compared with those wintering in unoiled areas
- Lower winter survival of adult females in previously oiled areas compared with those in unoiled areas
- A declining trend in oiled areas from 1995 to 1997 based on fall population surveys by the Alaska Department of Fish and Game (ADFG)
- Lower population densities in oiled areas in 1996 and 1997 than would be expected based on habitat.

Sullivan et al. (2005) found no population trends for harlequin duck in oiled portions of PWS surveyed in March and July and no absolute difference in trends relative to unoiled areas. Given the overall lower abundance of harlequin duck in oiled areas compared with unoiled areas after the EVOS, Sullivan et al. (2005) interpret[42] the absence of a difference in population trends between oiled and unoiled areas of PWS to be an absence of evidence of a recovering population. Rosenberg et al. (2005) conducted a more comprehensive analysis of sex and age composition and population trends in PWS, and concluded that harlequin duck demographics in oiled areas of PWS are similar to that elsewhere in their range and populations in oiled areas are stable.

Wiens et al. (2004) evaluated habitat use by small numbers of harlequin ducks in transitory habitat and determined that harlequin duck populations in oiled areas were not adversely impacted relative to unoiled areas. In addition, Wiens et al. (2004) surveyed harlequin duck populations during summer only, which may not be the best time of year to detect impacts of EVOS.

Despite extensive evaluations of population survey data and winter survivorship of harlequin ducks in PWS, as discussed above, there has been no detailed demographic modeling to assess the significance of the initial mortality due to the spill. Moreover, modeling to estimate recovery time after the initial impact and the effect of demographic lags has not been conducted. Life history analysis of the harlequin duck suggests that recovery of a population after a perturbation like EVOS could be extended (e.g., 10 years or more) because naturally they are relatively long-lived birds (up to 12 years) with high survival and low reproduction rates. Their low productivity is associated with a late age at first breeding, a small average clutch size, and a high proportion of non-breeding birds in some years (Canadian Wildlife Service 2006). Dispersal and immigration rates are thought to be low (Iverson et al. 2004). Thus, lowered survivorship over a several year period (as observed by Esler et al. 2002b after EVOS) could have an extended effect on a population.

9.2.2.2 Acute and Chronic Toxicity to Individuals

In 2000–2002, Bodkin et al. (2003) conducted experimental feeding of hydrocarbon-contaminated food to captive harlequin ducks. The researchers measured CYP1A levels as an indicator of exposure in their experimental and control populations. They also observed behavior and measured food consumption, body mass, and metabolism at two levels of contamination in their experimental population and in a control group. Results of this unpublished study showed that CYP1A was induced at levels greater than in the control population. However, there were no significant differences in any of the parameters that would indicate effects of ingestion of contaminants on either behavior or energetics in the experimental population. These results are difficult to compare with wild populations of harlequin ducks potentially exposed to lingering oil because the degree of exposure in the wild population is unknown. Improvement in winter female survival coincided with reduced exposure, as indicated by CYP1A levels, in oiled areas (see "Biomarker Measurements," below) but lower survival probability was still correlated with greater oil exposure (D. Esler, unpubl. data). No studies

[42] To test whether the populations in east and west PWS were changing at different rates, Sullivan et al. (2005) examined the homogeneity of the slopes of the logarithms of the densities over time between the oiled and the unoiled areas using linear models. They concluded that significantly different slopes indicated that densities of a species or species group in the oiled area were changing at a different rate than in the unoiled area.

were conducted in 2005 to evaluate the relationship between increased oil exposure (see "Biomarker Measurements," below) and survival.

Another potential cause of mortality is oiling of plumage, which can lead to ingestion of oil and possibly effects on behavior and physiology, as well as hypothermia. Plumage-oiling reduced feeding in captive wild ducks although inferences to behavioral effects on birds in the wild are uncertain (Bodkin et al. 2003). Although contact of harlequin duck with lingering oil is possible (see below), the probability of plumage oiling has not been assessed.

9.2.2.3 Effects on Reproduction and Other Population Parameters

Rosenberg and Petrula (1998) compared demographics of harlequin ducks in oiled western PWS with unoiled eastern PWS during surveys conducted in both spring and fall from 1995 to 1997. They found more males than females in both areas. They found no major differences in recruitment between the two areas as evidenced by similar proportions of subadults in the population. Few broods were observed in eastern PWS and no broods were observed in western PWS, leading them to conclude that breeding habitat is limited in PWS, and most pairs go elsewhere to breed and fledge their young. Overall, they did not detect any substantial differences in population, age, and sex structure between eastern PWS and western PWS that would indicate effects of oil on demographics (but see discussion of results of Esler et al. [2000a] below for information on winter survivorship). However, despite similarity in population structure, they did find that harlequin duck populations were declining in western PWS and when interpreted in context with other EVOS studies (Esler et al. 2002a), attributed this decline to EVO exposure.

In 1995–1997, Esler et al. (2000a) compared harlequin duck densities on oiled Knight Island and unoiled Montague Island. They examined the relationship between habitat variables, food availability, and oiling history on densities of wintering harlequin ducks. After accounting for differences in habitat, they found densities were lower in oiled than unoiled areas.

Esler et al. (2000b) also found winter survival of females to be lower in previously oiled areas in western PWS than on unoiled Montague Island. Kaplan-Meier estimates of survival were 78 and 84 percent, respectively, during the winters of 1995–1996 and 1997–1998 (data from all three years were pooled). The study projects annual population growth of 0.5 percent for the unoiled sites on Montague Island, and a population decrease of 5.4 percent annually for the oiled areas. In contrast, Lance et al. (2001) measured overall winter population increases in the oiled area during an overlapping time period (1990–1998). The winter survival study was repeated in 2000–2003 (Bodkin et al. 2003). Preliminary findings of this unpublished study indicate that there are no significant differences in cumulative winter survival of female harlequin ducks between previously oiled (81 percent survival) and unoiled (84 percent survival) areas. Female survival was not reevaluated in 2005 when exposure levels were higher in oiled areas than in unoiled areas (see Section 9.2.2.2, "Acute and Chronic Toxicity to Individuals," above).

Rosenberg et al. (2005) conducted a more comprehensive analysis of sex and age composition and concluded that harlequin duck demographics in oiled areas of PWS are similar to that elsewhere in their range, and that age ratios, which were used as an index of recruitment, are similar in oiled and unoiled areas, indicating that productivity has not been adversely affected. They noted that the lower proportion of females in oiled areas is a concern, but concluded that based on demographic data, the outlook for full recovery is good.

9.2.3 Exposure to Lingering Oil

9.2.3.1 Bioavailability and Bioaccessibility of Lingering EVO

Lingering oil buried in the sediment may be bioaccessible to harlequin ducks to the extent that it can migrate to the sediment–water interface through physical processes or be exposed through the burrowing or foraging activities of organisms. Physical transport of lingering oil to the sediment–water interface was demonstrated in experiments conducted by Shigenaka and Henry (1995) 3 years following EVOS. Shigenaka and Henry (1995) assessed bioavailability of lingering oil using SPMDs. SPMDs are a research tool that has been used to simulate water-mediated uptake and bioaccumulation potential of oil and other substances by aquatic organisms. Shigenaka and Henry (1995) measured TPAH concentrations in SPMDs, sediments, water, and caged mussels placed on a previously heavily oiled beach on Smith Island and on an unoiled to lightly oiled beach also on Smith Island. Results of this study showed that TPAH concentrations were significantly correlated among the SPMDs, mussels, and sediments, further indicating the bioavailability of lingering oil to surface-dwelling organisms. Preliminary results demonstrating the bioavailability of lingering EVO and its ability to induce CYP1A has recently been demonstrated by Short et al. (2005), who compared the potential for CYP1A induction in PAHs collected by SPMDs deployed in different part of PWS where different types of petroleum contamination were known to occur. Extracts were injected into trout fry (Springman et al. 2005) and EVOS was demonstrated to be a potent inducer of CYP1A, unlike samples collected from human use sites or other area-wide sources.

Harlequin ducks forage on small invertebrates that are either attached to or sequestered beneath coarse gravel, cobble, or larger sediments. Consequently, bioturbation of surficial sediments during foraging and ingestion of contaminated prey are two mechanisms that have been hypothesized for exposure to lingering oil (Esler et al. 2002b; Bodkin et al. 2003). Plumage oiling through contact with oiled sediments may also occur, but the importance of this mechanism is unknown.

Harlequin ducks are well distributed throughout PWS; however, there is a small geographical overlap between shorelines used by harlequin ducks and shorelines with EVO (Figure 9-1). Bird surveys published in the PWS Environmental Site Investigation Data Atlas, supplemented by additional data provided by D. Rosenberg, indicate that concentrations of harlequin duck within the oiled area (1989–2001 oil data) of PWS are distributed over approximately 1,800 km of shoreline. Approximately 15 km (0.8 percent) of this distribution coincides with previous heavily to moderately oiled areas where lingering oil has been identified. Harlequin ducks could be exposed to lingering oil in this area through ingestion of contaminated prey. They could also be exposed through contact with sediments while foraging beneath rocks in the intertidal zone (Esler et al. 2002b). Harlequin ducks may have occurred in heavily oiled areas and have not successfully returned to (recolonized) these areas (at least in former densities) since the spill due to effects of lingering oil.

9.2.3.2 Biomarker Measurements

Trust et al. (2000) measured CYP1A levels in harlequin ducks and Barrow's goldeneyes in 1998 as an indicator of exposure to oil constituents 9 years after the spill. CYP1A is a liver enzyme that is induced in many vertebrate species following exposure to PAHs (Golet et al. 2002) and polychlorinated biphenyls (PCBs) (Trust et al. 2000).

Trust et al. (2000) sampled harlequin ducks in March–April of 1998 at oiled sites (Crafton Island and Main Bay) and unoiled Montague Island. They collected liver samples from 37 harlequin ducks (19 from oiled sites, 18 from unoiled sites) and assessed them for CYP1A induction by measuring 7-ethoxyresorufin-*O*-deethylase (EROD) activity. EROD activity was significantly ($p<0.001$) higher in the ducks from the oiled sites. Levels of PCB congeners suspected of inducing CYP1A in birds did not differ between oiled and unoiled populations. One particular congener (PCB congener 138) was measured above detection limits in all samples and was positively related to EROD activity, although it did not differ between the populations at oiled and unoiled sites. PCB congener 138 was present at elevated levels in only four blood plasma samples. After accounting for variation due to this congener, Trust et al. found that birds from oiled areas still had significantly ($p<0.001$) higher EROD activity than those from unoiled areas. In other words, CYP1A was higher in the oiled population even after the effects of PCB congeners were taken into account.

CYP1A testing in harlequin ducks has continued since the 1998 studies reported above (Bodkin et al. 2003). Results from studies conducted in 2000–2002 initially indicated that levels in the oiled population have converged with levels in the unoiled population (Bodkin et al. 2003). However, the preliminary results for CYP1A data collected in March 2005 (Ballachey et al. 2006.) indicate that levels were significantly higher in harlequin ducks collected from oiled areas relative to unoiled areas. The difference in the CYP1A results between the 2000–2002 time period and the 2005 results is partly because the variance of the mean for the 2005 data sets (oiled and unoiled treatment means) was much lower than that for the 2000–2002 data sets. A lower variance implies greater statistical power, which lowers the minimum detectable difference between samples. Nevertheless, a trend of decreasing CYP1A induction over time is evident in the oiled areas, with the level of CYP1A induction in oiled areas being about double that of unoiled areas in 2005 (see Section 9.2.2.3, "Effects on Reproduction and Other Population Parameters," above).

9.2.3.3 Indirect Effects of Lingering Oil

Studies have been done to determine whether EVO has affected the availability of prey for harlequin duck. Both Esler et al. (2000a) and Holland-Bartels (2000) reported that the availability of prey was the same between oiled and unoiled sites during 1996 and 1997. Prey availability does not appear to be a factor in female winter survival (Esler et al. 2000b). Similar body mass between females from oiled and unoiled sites also indicates that food is not limited for the population in the oiled area (Esler et al. 2000b). There is no evidence indicating harlequin ducks have altered their use of habitats or their migratory behavior subsequent to the spill.

9.2.4 Other Stressors

There are numerous environmental stressors that can affect harlequin duck populations and complicate interpretation of their recovery status. Rosenberg and Petrula (1998) identified seasonal, interannual, and spatial factors that affect reproductive fitness and success. Influencing factors include variability in the quality of winter habitat, immigration/emigration particularly for unmated bachelor males, disease, and predator–prey cycles. There is no evidence to suggest that any of these factors cause any differences between harlequin duck populations in oiled and unoiled areas of PWS or account for the observed population trends.

Bald eagles are natural predators of harlequin ducks, and some subsistence harvest by Native Americans may contribute to mortality. However, predation on harlequin ducks in PWS has not been quantified, and there are no data to assess whether lingering oil has affected predation levels on harlequin duck. Mortality and survival studies (Esler et al. 2000a) do not provide data on the amount of mortality that is due to predation or the relative amounts of predation between oiled areas in PWS and unoiled areas on Montague Island.

9.3 SUMMARY AND RECOMMENDATIONS

Information on harlequin duck population parameters, habitat, exposure to lingering oil, and behavioral/physiological indicators was weighed to assess the current condition of the harlequin duck and its relationship to EVO.

Many population demographic attributes of harlequin ducks in oiled areas of PWS are similar to those in unoiled areas of PWS and western Canada, but it remains uncertain if numbers have increased to former levels. A stable population in the oiled area, similar age ratios (a measure of recruitment), and converging values in over-winter female survival rates are positive signs for recovery. However, a lower proportion of females in the oiled area may be a lingering effect from initial spill mortality and lower female survival in oiled areas (1995–1998) and remains a concern.

The USFWS marine bird surveys indicate a population increase in the oiled areas from 1990 to 1998, although lacking precision. They did not observe an increase in the oiled areas relative to unoiled areas. Concurrently, observed differences between oiled and unoiled areas in female winter survival rates, densities, and population trends (declining in oiled areas) from 1995 to 1998 were linked to observed differences in contaminant exposure. Collectively, these latter studies supported the conclusion that harlequin duck populations had not recovered from the spill as of 1998. More recent surveys indicate populations have been stable in oiled and unoiled areas from 1997 to the present. There is no certainty that oiled populations have increased sufficiently to account for initial and chronic spill mortality.

The persistence of bioactive EVO in intertidal sediments is expressed in elevated CYP1A in harlequin ducks collected from oiled areas. Since 1998, CYP1A levels have fluctuated, but most recent assays (2005) indicated significantly higher oil exposure levels in female harlequin ducks in oiled areas than in unoiled areas of PWS. However, statistical reanalysis accounting for interannual variation has indicated that exposure has generally declined since 1998 (see Section 9.2.3.2, "Biomarker Measurements"). Regardless, this pattern was also found in 1998 and 2000. Barrow's goldeneyes, another sea duck occupying similar habitats, also exhibited greater exposure to PAHs in oiled than unoiled areas coincidental to population declines in oiled areas relative to unoiled areas from 1990 to 2004. Food supply (prey biomass) does not appear to be limiting recovery. A source of uncertainty in the assessment of CYP1A in harlequin ducks is the uncertain relationship between current exposure (as measured by CYP1A) and population-level effects.

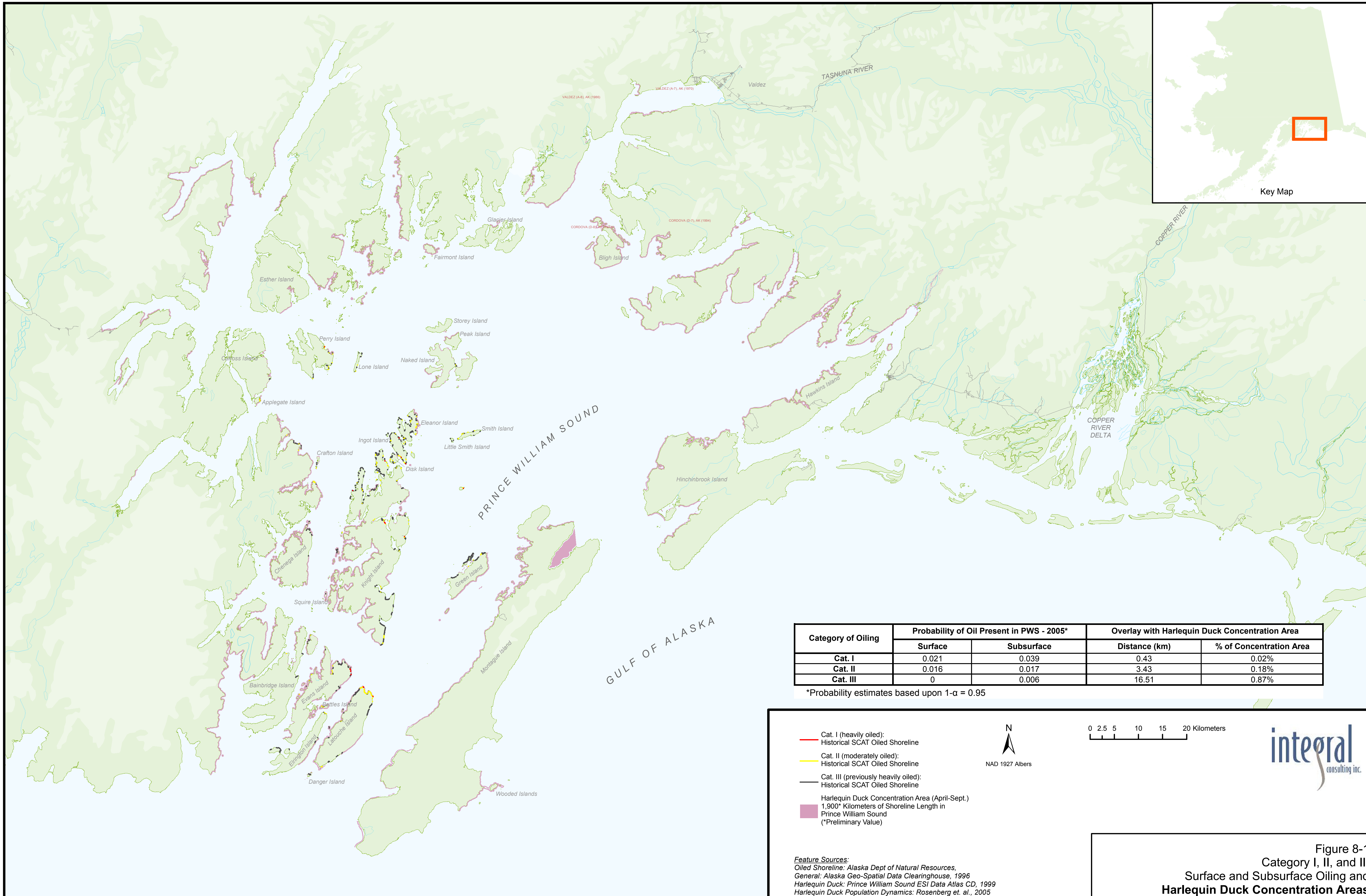
Harlequin ducks have naturally low rates of annual recruitment and dispersal, suggesting a population may require many years to replenish birds lost from a major perturbation. High initial mortality plus effects from lingering oil and cleanup activities on habitat condition and survival will likely delay full recovery until long after all spill effects have abated. This is a valid hypothesis but has not been tested by population modeling.

It is recommended that the Trustee Council classify the harlequin duck population in PWS as "recovering," based on evidence that direct effects are diminishing. It is also recommended that the recovery objective for harlequin duck be revised to eliminate the reference to pre-spill conditions. The recommended recovery objective is as follows:

> Harlequin ducks will have recovered when breeding- and nonbreeding-season demographics and biochemical indicators of hydrocarbon exposure in harlequin ducks in oiled areas of PWS are similar to those in unoiled areas, taking into account geographic differences that are not related to EVO.

The following monitoring and restoration actions are recommended:

- Continue to monitor levels of CYP1A in harlequin ducks from oiled and unoiled areas until levels are the same.
- Consider an integrated study of CYP1A exposure, oil in sediments, and oil in prey items of harlequin ducks.
- Support development of a population model to better understand the population dynamics of harlequin ducks and assess the potential for constraints in recovery based on population demographic characteristics and impacts from lingering oil.
- Continue population and demographic monitoring.



Category of Oiling	Probability of Oil Present in PWS - 2005*		Overlay with Harlequin Duck Concentration Area	
	Surface	Subsurface	Distance (km)	% of Concentration Area
Cat. I	0.021	0.039	0.43	0.02%
Cat. II	0.016	0.017	3.43	0.18%
Cat. III	0	0.006	16.51	0.87%

*Probability estimates based upon 1-α = 0.95

Cat. I (heavily oiled): Historical SCAT Oiled Shoreline

Cat. II (moderately oiled): Historical SCAT Oiled Shoreline

Cat. III (previously heavily oiled): Historical SCAT Oiled Shoreline

Harlequin Duck Concentration Area (April-Sept.) 1,900* Kilometers of Shoreline Length in Prince William Sound (*Preliminary Value)

Feature Sources:
Oiled Shoreline: Alaska Dept of Natural Resources,
General: Alaska Geo-Spatial Data Clearinghouse, 1996
Harlequin Duck: Prince William Sound ESI Data Atlas CD, 1999
Harlequin Duck Population Dynamics: Rosenberg et. al., 2005

Figure 8-1
Category I, II, and III
Surface and Subsurface Oiling and
Harlequin Duck Concentration Areas

\\Mi-goocks\GIS_projects\C113_EVOS_NRTEVOS_Oiling-Probability-Resource-B-map_GJC-updated_11x17_12-02-05.mxd RN / GJC @ 04-05-06

10. SEABIRDS

10.1 INTRODUCTION

Approximately 1 million seabirds inhabited the oil spill area prior to EVOS, an estimated 100,000 to 300,000 of which died initially due to the spill in 1989 (Piatt et al. 1990). These birds were most likely exposed to EVO through direct contact with oil and consumption of contaminated prey. With respect to lingering oil present in PWS today, both mechanisms represent potential pathways of continuing exposure. Potential impacts of EVOS on seabirds were assessed through evaluation of direct mortality and breeding effects following the spill (e.g., Piatt et al. 1990; Irons et al. 2000; Oakley and Kuletz 1996; Kuletz 1996). Subsequent studies of longer-term population trends and potential food source contamination were performed across several years following the initial spill (Klosiewski and Laing 1994; Agler et al. 1994; Agler and Kendall 1997; Lance et al. 2001; Murphy et al. 1997; Irons et al. 2000; Golet et al. 2002; Wiens et al. 2004; Sullivan et al. 2005). This section synthesizes these data and other lines of information in a weight-of-evidence framework to assess the current recovery status of seabirds.

10.1.1 Statement of Problem

As of 2002, the following seven seabird species had not yet met the recovery objectives of the update to the EVOS restoration plan (EVOS Trustee Council 2002b):

- Pigeon guillemot (*Cepphus columba*)
- Marbled murrelet (*Brachyramphus marmoratus*)
- Double-crested cormorant (*Phalacrocorax auritus*)
- Pelagic cormorant (*Phalacrocorax pelagicus*)
- Red-faced cormorant (*Phalacrocorax urile*)[43]
- Common loon (*Gavia immer*)[44]
- Kittlitz's murrelet (*Brachyramphus brevirostris*).

The goal of this evaluation was to assess the current status of seabirds based on the best available data and expert analysis. To achieve this goal, information on seabird natural history and ecology, historical and ongoing impacts of EVOS to seabirds and their prey, and other potential stressors was assembled and synthesized. Specific information on species' feeding and foraging

[43] The vast majority (approximately 99 percent) of cormorants observed in PWS are pelagic cormorant (Irons 2006, pers. comm.). Any text hereinafter that refers in general to cormorants is based on knowledge of pelagic cormorant biology.

[44] Although loons are not specifically seabirds, the similarity of their feeding mechanism and prey preferences allows them to be grouped with seabirds for this discussion.

behavior was used to evaluate the likelihood of historical and current effects of EVOS on both seabirds and their prey. Breeding ecology, reproductive parameters, and other population data were used to evaluate intrinsic recovery potentials of seabirds in the spill area. Comparisons of population trends between oiled and unoiled areas were used to assess potential ongoing effects of EVOS in previously oiled areas. Where available, data related to biochemical responses to EVO ingestion were used to examine continued exposure to lingering oil. Finally, the importance of additional exogenous factors in influencing seabird populations was considered. The collective information was then evaluated in a weight-of-evidence synthesis framework to determine the current recovery status of the seven seabird species.

Achievement of this goal was difficult for a number of reasons. First, not all seabirds have been studied to the same extent. For example, many studies focused on pigeon guillemots, whereas fewer investigated cormorants. The varied extent to which these seabirds have been investigated complicates the evaluation of these species as a collective group (i.e., seabirds). Second, there are challenges associated with drawing reliable inferences related to the health of certain seabird populations given the complexities of population biology and differences across study designs. Third, as in all population studies, there are underlying uncertainties in population measures throughout all studies that need to be acknowledged.

10.1.2 Natural History and Ecology

Pigeon guillemots, marbled murrelets, Kittlitz's murrelets, cormorants, and common loons all spend a significant portion of their life histories in the nearshore waters of PWS. All except loons are seabirds, spending 80 percent of their lives at sea and coming ashore for a few weeks during the breeding season to nest. All seven species forage for fish or benthic invertebrates in nearshore waters[45] of PWS. Each seabird group's feeding habits, wintering and breeding habitats, and reproductive parameters were considered to understand to what degree these intrinsic characteristics might affect the magnitude and duration of potential exposure and subsequent injury attributable to EVO.

10.1.2.1 Feeding and Foraging Behavior

Pigeon Guillemot—Pigeon guillemots feed by diving and probing the seabed with their bills. They are generalist feeders, targeting mid-water schooling fish and bottom-dwelling organisms (Ewins 1993). Their optimal foraging habitat is water 10–20 m deep, usually over rocky substrate (Ewins 1993). Breeding birds forage within 0.2 to 7 km of their colonies (Ewins 1993). They select prey from a wide variety of fish and benthic invertebrates, presumably based on availability (Ewins 1993). In Alaska, the adult diet is primarily Pacific herring (*Clupea pallasi)*, Pacific sand lance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), other smelts (family Osmeridae), cods (*Gadus* sp.), sculpins (family Cottidae), gunnels (family Pholidae), pricklebacks (family Stichaeidae), and flounders (families Bothidae and Pleuronectidae; Kuletz 1983; Golet et al. 2000). Primary invertebrate prey include red rock crab (*Cancer productus*),

[45] For the purposes of this evaluation, nearshore water refers to waters within 1 km of shoreline (i.e., the waters most commonly utilized by the majority of seabird species in PWS).

shrimp (family Pandilidae), and occasionally polychaetes, gastropods, and bivalve molluscs (Kuletz 1983; Ewins 1993). In Alaska, chicks are fed primarily Pacific sand lance, Pacific herring, capelin, gadids (family Gadidae), gunnels, pricklebacks, and other fish 6–15 cm in size (Golet et al. 2000). Changes in availability of schooling fish (e.g., Pacific herring) could potentially have affected pigeon guillemot populations.

Because a certain proportion of the diet of pigeon guillemot is obtained from prey residing within or frequenting benthic environments, including the intertidal zone, there is some potential for current exposure to lingering oil through prey (see Section 10.2.4.1 below).

A summary of feeding and foraging behavior for pigeon guillemot is presented in Table 10-1.

Table 10-1. Weight-of-Evidence Information Used to Assess Recovery Status of Pigeon Guillemot.

Natural History and Ecology					
Breeding Habits				Feeding	
Age at First Reproduction (Lifespan)	Clutch Size	Fledgling/ Nesting Success	General Population Growth Rate	Dietary Composition	Behavior
2–5 (14+) (Ewins 1993)	1–2, some replacement clutches (Ewins 1993)	0.36–1.48 (Kuletz 1983; Oakley 1990)	Variable and uncertain: declined in PWS from 1979 to 1997 (Kuletz 1998)	In PWS, small fish. High lipid fish include sand lance (primarily) and herring. Many pigeon guillemot specialize on non-schooling fish. Invertebrates are eaten during winter (Golet et al. 2002).	Dives. Prefers rocky substrates. Forages 0–15 km from land. Feeds mostly on epibenthic or benthic fish and invertebrates. Probes bottom when feeding.

Exposure and Impacts from EVO			
Initial Impacts	Effects Following Spill	Potential for Current Exposure	Toxicity of Lingering EVO
600 carcasses, estimated 2,000–6,000 total dead (Piatt et al. 1990). Estimated mortality counts are based on a calculation of recovered pigeon guillemot carcasses divided by a 10% and 30% carcass recovery rate.	Initial higher rate of population decrease in 1989–1990 (Murphy et al. 1997)	Remotely possible and more so in adults than in chicks (Seiser et al. 2000)	Probably yes (Golet et al. 2002)

Population Trends				
Oiled vs. Unoiled		Other	Issues Related to Prey Availability	Other Stressors
Summer	Winter			
There was no difference in trends between oiled and unoiled areas (Sullivan et al. 2005).	There was no difference in trends between oiled and unoiled areas (Sullivan et al. 2005).	Highly uncertain and variable data, but no dramatic declines documented elsewhere in Alaska (Ewins 1993).	Fewer high-quality fish possibly due to EVOS (Golet et al. 2002). Food availability is probably a limiting factor in population growth (Ewins 1993).	Decrease in nest site availability (Kuletz 1998). Decreased food availability (Ewins 1993).

Marbled Murrelet—Marbled murrelets are generalist feeders, consuming a variety of small fish and invertebrate species depending on season and prey availability (Nelson 1997; Kuletz 2005). Murrelets forage 0–15 km from shore and dive up to 50 m in search of prey. In PWS, radio-tagged murrelets have been observed foraging 5–40 km from suspected nest sites (Kuletz 2005). Marbled murrelets usually feed within 1 to 2 km of shore; in PWS, the greatest densities of marbled murrelets forage within 1 km of shore (Kuletz 1997, 2005). Though most of their feeding occurs near the surface or in the water column, murrelets will occasionally take prey from the bottom environments (Nelson 1997).

Murrelets consume a large variety of fish throughout the summer, including Pacific sand lance, Pacific herring, capelin, northern anchovy (*Engraulis mordax)*, walleye pollock (*Theragra chalcogramma*), and sea perch (*Sebastes alutus)*, as well as various other smelt and gadid species (Nelson 1997). Primary winter prey include capelin, surf smelt (*Hypomesus pretiosus*), and Pacific herring (Nelson 1997), while various invertebrates such as krill and amphipods account for a smaller proportion of the diet (Krasnow and Sanger 1982; Nelson 1997). During the breeding seasons, murrelets target high quality prey such as Pacific sand lance and Pacific herring to meet the energetic requirements of their chicks (Kuletz 2005). Summer foraging behavior and associated diet vary with prey availability (Kuletz 2005).

Unlike pigeon guillemots, marbled murrelets are unlikely to experience continued exposure to lingering oil, because they primarily feed on fish species above the benthos. Any current impact to this species would therefore be related to the degree to which, if any, EVOS may have played a role in prey availability.

A summary of feeding and foraging behavior for marbled murrelet is presented in Table 10-2.

Kittlitz's Murrelet—Kittlitz's murrelets consume mostly fishes including Pacific sand lance and herring (Day et al. 1999). Their diet contains more invertebrates including euphausiids, amphipods, and zooplankton than does the diet of the marbled murrelets (Day and Nigro 2000; Vermeer et al. 1987). Kittlitz's murrelet feeding frequency is approximately three times higher in nearshore versus offshore (< 200 m vs. > 200 m) microhabitats (Day and Nigro 1999). They capture prey underwater by using their wings for propulsion (Day et al. 1999). Foraging effort varies seasonally; the numbers of feeding Kittlitz's murrelets increase from the beginning to the end of summer (Day and Nigro 2000).

For the purposes of this evaluation, the dietary habits of Kittlitz's murrelets were considered comparable to that of marbled murrelets. As is the case with marbled murrelets, Kittlitz's murrelets are unlikely to experience continued exposure to lingering oil. Any current impact to this species would therefore be related to the degree to which, if any, EVOS may have played a role in prey availability.

A summary of feeding and foraging behavior for Kittlitz's murrelet is presented in Table 10-3.

Table 10-2. Weight-of-Evidence Information Used to Assess Recovery Status of Marbled Murrelet.

Natural History and Ecology					
Breeding Habits				Feeding	
Age at First Reproduction (Lifespan)	Clutch Size	Fledgling/ Nesting Success	General Population Growth Rate	Dietary Composition	Behavior
2–4 (unknown) (Nelson 1997)	1 per season (Nelson 1997)	0.28 (Nelson 1997)	Slow: many individuals do not nest every year, high nest failure rate (Nelson 1997)	Abundant nearshore fish including capelin, sand lance, and Pacific herring in Alaska (Burkett 1995)	Dives to 50 m, feeds mostly near surface or in water column. Ranges 0–15 km offshore (Nelson 1997).

Exposure and Impacts from EVO			
Initial Impacts	Effects Following Spill	Potential for Current Exposure	Toxicity of Lingering EVO
870 carcasses, estimated 2,900-8,700 total dead out of spill-area population of 140,000 (6% mortality) (Carter and Kuletz 1995; Piatt et al. 1990)	Indirect population effects from initial breeding population die off (Carter and Kuletz 1995)	No data, negligible	No data, possibly yes

Population Trends			Issues Related to Prey Availability	Other Stressors
Oiled vs. Unoiled		Other		
Summer	Winter			
There was no difference in population trends between oiled and unoiled areas (Sullivan et al. 2005). Sullivan et al. (2005) made no distinctions among murrelet species; comparisons represent trends in overall murrelet populations.	There was no difference in population trends between oiled and unoiled areas (Sullivan et al. 2005). Sullivan et al. (2005) made no distinctions among murrelet species; comparisons represent trends in overall murrelet populations.	Decreased 4–6% throughout Alaska and North America (Beissinger 1995). Gulf of Alaska populations may have declined 50–73% from 1977 to 1997 (Nelson 1997).	Possibly fewer high-lipid schooling fish available than before EVOS (Golet et al. 2002).	Possible climate-related shifts in prey species populations. Loss of nesting habitat throughout range (McShane et al. 2004).

Pelagic, Double-Crested, and Red-Faced Cormorants—The foraging behavior and diets of cormorants are similar to those of other seabirds. Cormorants are opportunistic feeders that dive for prey in the water column, on the bottom, and by rooting in sediment (Hatch and Weseloh 1999). Primarily, they consume fish ranging from 3 to 40 cm in length, but they do eat invertebrates as well (Causey 2002; Hatch and Weseloh 1999; Hobson 1997). Pelagic cormorant chicks are fed mainly fish, including Pacific sand lance, gunnels, pricklebacks, and sculpins, and shrimp (Hobson 1997). Red-faced cormorants eat predominantly demersal fish including smelt, Pacific sand lance, flounder, and sculpin (Causey 2002). Cormorants are all nearshore feeders, but differ in their foraging habitat preferences. Like pigeon guillemots, red-faced and pelagic cormorants primarily forage over rocky bottoms, while double-crested cormorants preferentially forage over sandy bottoms. Consequently, pelagic cormorants' diets overlap nearly 100 percent

Table 10-3. Weight-of-Evidence Information Used to Assess Recovery Status of Kittlitz's Murrelet.

Natural History and Ecology					
Breeding Habits				Feeding	
Age at First Reproduction (Lifespan)	Clutch Size	Fledgling/ Nesting Success	General Population Growth Rate	Dietary Composition	Behavior
2–4 (unknown) (Day et al. 1999)	1 per season (Day et al. 1999)	Unknown (Day et al. 1999)	Slow; many females do not breed each season (Day et al. 1999)	Small fishes and zooplankton (capelin, sand lance, herring, and crustaceans) (Day et al. 1999)	Dives. Feeds mostly near surface or in water column. Usually forages within 200 m of shore (Day et al. 1999).

Exposure and Impacts from EVO			
Initial Impacts	Effects Following Spill	Potential for Current Exposure	Toxicity of Lingering EVO
Estimated 370 killed directly by oil spill (Kuletz 1996)	Unknown	No data, negligible	No data, possibly yes

Population Trends			Issues Related to Prey Availability	Other Stressors
Oiled vs. Unoiled		Other		
Summer	Winter			
There was no difference in population trends between oiled and unoiled areas. Sullivan et al. (2005) made no distinctions among murrelet species; comparisons represent trends in overall murrelet populations.	There was no difference in population trends between oiled and unoiled areas. Sullivan et al. (2005) made no distinctions among murrelet species; comparisons represent trends in overall murrelet populations.	Uncertain (Day et al. 1999)	Possibly fewer high-lipid schooling fish available than before EVOS (Golet et al. 2002).	Possible climate-related shifts in prey species populations (Piatt and Anderson 1995).

with that of pigeon guillemots in some locations and only 20 percent with that of double-crested cormorants (Hobson 1997).

Cormorants' continued exposure to EVO is considered limited given that they focus primarily on fish, which do not bioaccumulate oil to any great degree (Varanasi et al. 1989). As with other species that rely on Pacific sand lance, herring, and other schooling fish, cormorants are vulnerable to shifts in prey availability. Any current impact to this species would therefore be related to the degree to which, if any, EVOS may have played a role in prey availability.

A summary of feeding and foraging behavior for cormorants is presented in Table 10-4.

Common Loon—In the marine environment, common loon foraging activity occurs primarily nearshore, in the upper 5 m of the water column, though they may dive to 60 m in clear water (McIntyre and Barr 1997). Loons visually locate prey, and often probe vegetation and sediment

Table 10-4. Weight-of-Evidence Information Used to Assess Recovery Status of Cormorants.

Natural History and Ecology					
Breeding Habits				Feeding	
Age at First Reproduction (Lifespan)	Clutch Size	Fledgling/ Nesting Success	General Population Growth Rate	Dietary Composition	Behavior
3 (~18) (Causey 2002; Hatch and Weseloh 1999; Hobson 1997). Life parameters were averaged from all three species data.	1–7 (Causey 2002; Hatch and Weseloh 1999; Hobson 1997). Life parameters were averaged from all three species data.	~2.0 (Causey 2002; Hatch and Weseloh 1999; Hobson 1997). Life parameters were averaged from all three species data.	Variable, but potentially high (3.28 young/bird in double-crested cormorant) (Hatch and Weseloh 1999).	Fish (3–40 cm). In Alaska, mostly sand lance, herring, smelt, and bottom fish (Causey 2002; Hatch and Weseloh 1999; Hobson 1997). Life parameters were averaged from all three species data.	Dives for fish in water column, on bottom, and by rooting in sediment (Causey 2002; Hatch and Weseloh 1999; Hobson 1997). Life parameters were averaged from all three species data.

Exposure and Impacts from EVO			
Initial Impacts	Effects Following Spill	Potential for Current Exposure	Toxicity of Lingering EVO
875 carcasses recovered, estimated 2,900–8,800 total dead. Estimate derived from cormorant carcasses recovered multiplied by total carcasses recovered before August 1, 1989, from Table 1 in Piatt et al. 1990, and carcass recovery rates of 10–30%.	Demonstrating possible oiling effects through 1998; possibly recovered earlier (Irons et al. 2000; Wiens et al 2004).	No data, negligible	No data, possibly yes

Population Trends				
Oiled vs. Unoiled		Other	Issues Related to Prey Availability	Other Stressors
Summer	Winter			
There was no difference in population trends between oiled and unoiled populations (Sullivan et al. 2005).	There was no difference in population trends between oiled and unoiled populations (Sullivan et al. 2005).	Overall increasing, but locally variable (colonies relocate) (Causey 2002; Hatch and Weseloh 1999; Hobson 1997). Life parameters were averaged from all three species data.	EVOS effects on schooling fish (Golet et al. 2002). Opportunistic feeders, less reliant on specific prey (Causey 2002; Hatch and Weseloh 1999; Hobson 1997). Life parameters were averaged from all three species data.	Climatic changes possibly affecting some prey species availability (Golet et al. 2002).

while feeding (McIntyre and Barr 1997). Feeding activity usually occurs near suitable small fish habitat including shoals, islands, outcrops, and entrances to tributaries (McIntyre and Barr 1997). Wintering loons often feed in the same locations each day (McIntyre and Barr 1997). The common loon's diet consists primarily of small fish (up to 25 cm long), including eels, herring, sand lance, pipefish, goby, and sculpin (McIntyre and Barr 1997). As opportunistic feeders, they also eat aquatic invertebrates such as crustaceans and molluscs, and even vegetation (Barr 1996).

Common loons are unlikely to be exposed to significant amounts of oil at present, because they feed primarily on fish. As with other species that rely on sand lance, herring, and other schooling fish, cormorants are vulnerable to shifts in prey availability. Any current impact to this species would therefore be related to the degree to which, if any, EVOS may have played a role in prey availability.

A summary of feeding and foraging behavior for common loon is presented in Table 10-5.

Table 10-5. Weight-of-Evidence Information Used to Assess Recovery Status of Common Loon.

Natural History and Ecology					
Breeding Habits				Feeding	
Age at First Reproduction (Lifespan)	Clutch Size	Fledgling/ Nesting Success	General Population Growth Rate	Dietary Composition	Behavior
4–7 (25–30) (McIntyre and Barr 1997)	1–3 (McIntyre and Barr 1997)	0.81(McIntyre and Barr 1997)	Slow: delayed breeding, low productivity (McIntyre and Barr 1997)	Primarily small fish (up to 25 cm) (McIntyre and Barr 1997)	Dives and probes vegetation and sediment while feeding (McIntyre and Barr 1997)

Exposure and Impacts from EVO			
Initial Impacts	Effects Following Spill	Potential for Current Exposure	Toxicity of Lingering EVO
Approximately 216 common loon carcasses recovered; estimated between 720 and 2,160 total dead. Estimate derived from common loon carcasses recovered reported in EVOS Trustee Council (2002b) and estimated carcass recovery rates of 10-30% (Piatt et al. 1990).	Possible oiling effects present in 1989 and 1993, no discernible effects in following years (Day et al. 1997; Irons et al. 2000).	No data, negligible	No data, possibly yes

Population Trends			Issues Related to Prey Availability	Other Stressors
Oiled vs. Unoiled		Other		
Summer	Winter			
There was no difference in population trends between oiled and unoiled populations (Sullivan et al. 2005).	There was no difference in population trends between oiled and unoiled populations (Sullivan et al. 2005).	Loon populations increased rapidly from 1969-1989 throughout North America, and have generally stabilized (McIntyre and Barr 1997).	Feed seasonally on high-lipid schooling fish, which may have been affected by EVOS (Golet et al. 2002).	Climatic changes possibly affecting some prey species availability (Golet et al. 2002).

10.1.2.2 Habitats and Breeding

The northern Gulf of Alaska, including PWS, contains important seabird breeding and wintering territory. The breeding seasons for all seabird species discussed here occur approximately from May through August. Pigeon guillemots and marbled murrelets nest on land close to coastal feeding areas and disperse following the breeding season. Cormorants are year-round residents as they nest and winter along the seaward edge of PWS and on coastal islands in the Gulf of Alaska. Common loons breed inland on freshwater lakes, but winter in coastal marine regions including PWS. Wintering and breeding habits of seabirds were used to evaluate potential short-term and long-term effects of EVOS. Information on breeding and wintering habitats lend insight on the potential overlap with historical and current extent of EVO. Other breeding characteristics, such as reproductive potential, lend crucial insight on a species ability to rebound following an acute population hit, such as that which may have occurred following EVOS.

Pigeon Guillemot—Each May in PWS, pigeon guillemots establish pair bonds and nest in small colonies (Ewins 1993). They nest in cavities or burrows on rocky coastlines, often on islands which afford protection from predators (Ewins 1993). Only 25–50 percent of the summer pigeon guillemot population overwinters in PWS; the remainder disperse to unknown wintering areas (Sullivan et al. 2005). In general, pigeon guillemots relocate from exposed coastline to sheltered inshore waters for winter (Ewins 1993); in PWS, they nest in sheltered fjords and bays and migrate in fall (Kuletz 2006, pers. comm.). Little is known about the extent of their winter range.

Most breeding pairs lay a clutch of one to two eggs though there are occasional replacement clutches. Fledging success ranges from 0.36 to 1.48 fledgling per pair, and the overall population growth rate is highly variable. Pigeon guillemot populations may have begun to decline in PWS before EVOS (Oakley and Kuletz 1996) and continued to decline through 2004 (Sullivan et al. 2005). The population growth rate of pigeon guillemots is variable and most likely limited by nest site and food availability (Ewins 1993). Population modeling has not been performed for this species and could lend some insight on population recovery potential following EVOS.
A summary of breeding habits for pigeon guillemot is presented in Table 10-1.

Marbled Murrelet—From northern California to Alaska, marbled murrelets nest in coastal forests, laying single eggs on the ground or, more commonly, on the moss-covered branches of large trees (Piatt and Ford 1993; Marks and Kuletz 2001). It is likely that murrelets choose nest sites near favorable foraging areas (Piatt and Ford 1993; Marks and Kuletz 2001). The northern Gulf of Alaska area contains relatively high concentrations of marbled murrelets, but only about 25 percent of the summer population of marbled murrelets in PWS remain through the winter (Agler et al. 1998; Kuletz 1997).

Marbled murrelets are long-lived birds with low productivity. Their fledging success is low at an estimated 0.28 chicks fledged per nest. This is in part because many individuals forego nesting each year, and the rate of nest failure is high (Nelson 1997). Marbled murrelet populations are decreasing throughout North America, and have decreased 50–73 percent in several areas of the Gulf of Alaska, although they have increased along the southern Kenai Peninsula (Van Pelt and

Piatt 2003. In the southern portion of marbled murrelet range, nesting habitat loss may be the primary cause for this decrease (Nelson 1997; Ralph et al. 1995). Given their low productivity, the maximum population growth rate for marbled murrelets is estimated to be low. Recovery from an acute population loss could therefore take decades (Nelson 1997; Piatt et al. 1990).

A summary of breeding habits for marbled murrelet is presented in Table 10-2.

Kittlitz's Murrelet—The Kittlitz's murrelet is perhaps the most poorly understood seabird nesting in North America. Few studies of Kittlitz's murrelets have been published, and most focus on foraging behavior and nesting habitat (e.g., Kishchinskii 1968; Day et al. 1983; Day 1995; Piatt et al. 1999). Kittlitz's murrelets nest in areas of glacial outcropping from May to August (Day 1996). Though migration habits of Kittlitz's murrelets are incompletely known, Kittlitz's murrelets probably reside within PWS until September-October each year (Day et al. 1999). However, detailed surveys indicate that Kittlitz's murrelets leave the inner fjords and bays of PWS by mid-August (Kuletz et al. 2003) and few or none are present during March (Sullivan et al. 2005). In winter, they have been observed at low densities in offshore waters throughout the Gulf of Alaska (Day et al. 1999). In particular, Kittlitz's murrelets have been observed to winter in the mid-shelf regions of the northern Gulf of Alaska (Day and Prichard 2001). The majority of birds migrate back to PWS in April and May (Day et al. 1999).

Each female lays one egg per year sometime from June to August (Table 10-3; Day 1996; Day and Prichard 2001). Based on an unsuccessful search for juvenile birds at sea, Kittlitz's murrelets had very low reproductive output in 1996 in PWS (Day 1996). Because few juveniles are observed at sea, it has been suggested that breeding failures are not uncommon with this species (Day 1996; Day and Nigro 1999). For these reasons, the population growth rate of Kittlitz's murrelets is thought to be low. Kittlitz's murrelets' low productivity and population growth rate are indications that the species is likely to recover slowly from an acute population loss.

A summary of breeding habits for Kittlitz's murrelet is presented in Table 10-3.

Pelagic, Double-Crested, and Red-Faced Cormorants—Pelagic cormorants are resident from the Bering Strait to Baja, California, including the Gulf of Alaska (Hobson 1997). Their colonies are often located on cliffs in forested, grassy, and rocky headlands and islands (Hobson 1997). Double-crested cormorants breed and winter from the Aleutian Islands to Mexico. They nest in trees or on the ground, preferably on small islands (Hatch and Weseloh 1999). The majority of cormorants in PWS overwinter near their breeding areas (Agler et al. 1994). The winter range of red-faced cormorants probably overlaps with their breeding range, but is not well-documented (Causey 2002).

All three cormorant species are stochastic breeders with potentially high reproductive success. They lay clutches of one to seven eggs, and have an annual fledging success of approximately two chicks per nesting pair (Table 10-4). Double crested cormorants in particular are successful breeders, producing approximately 3.3 young per adult. Given their relatively high reproductive success, cormorant populations are likely capable of rebounding relatively quickly following an acute population loss.

A summary of breeding habits for cormorants is presented in Table 10-4.

Common Loon—The common loon is widely distributed across North America, breeding on the shores of freshwater lakes (McIntyre and Barr 1997). Although they are freshwater breeders, most loons winter in coastal waters, generally inshore, over shoals, and in sheltered bays, inlets, and channels (McIntyre and Barr 1997). Specific locations of loons wintering in PWS are unknown (EVOS Trustee Council 2002b).

Loons are long-lived, delayed breeders with low productivity. Each breeding pair produces one to three eggs per year with a fledging success of approximately 0.81 chicks per pair. Their maximum population growth is low; common loon populations took nearly 30 years to recover from past depressions (McIntyre and Barr 1997). Low population growth rate is an indication that the species is likely to recover slowly from an acute population loss. However, another important consideration is that loons breed and feed on inland freshwater bodies, so, among affected seabirds, their breeding habitat is the least vulnerable to effects of EVOS.

A summary of breeding habits for common loon is presented in Table 10-5.

10.1.3 Status of Injury and Recovery Classification

Of the seven species of seabirds addressed in this evaluation, none was considered to have met the recovery objectives of the restoration plan (EVOS Trustee Council 2002b). For each of the seven species, the 2002 recovery plan update states the following:

Pigeon Guillemot—"Boat surveys have indicated that numbers of guillemots in the summertime continue to decline along both oiled and unoiled shorelines in the PWS through 2000. March surveys reveal no significant trends in abundance although the data appear to suggest a decline at this time of year as well. For these reasons the pigeon guillemot is still considered to be not recovering from the effects of the oil spill." (EVOS Trustee Council 2002b, p. 17)

Marbled Murrelet—"The summertime marbled murrelet population is not stable or increasing, but the March population is stable over time. Marbled murrelet productivity, as measured by surveys of adults and juveniles on the water in PWS, appears to be within normal bounds. Based on these results, it appears that the marbled murrelet is at least recovering from the effects of the oil spill, but clearly has not yet recovered." (EVOS Trustee Council 2002b, p. 15)

Kittlitz's Murrelet—"The population data, indications of low reproductive success, and affinity to tidewater glaciers (of which the lower elevation glaciers are receding rapidly) are reasons for concern about the long-term conservation of Kittlitz's murrelets. Specifically, with reference to the effects of the oil spill, however, the original extent of the injury and its recovery status are still unknown and may never be resolved. Therefore, this species is in the recovery unknown category." (EVOS Trustee Council 2002b, p. 15)

Pelagic, Double-Crested, and Red-Faced Cormorants—"More recent surveys (through 2000) have not shown a significant increasing population trend since the oil spill, and, for that reason, these species are considered to be not recovering." (EVOS Trustee Council 2002b, p. 9)

Common Loon—"One year of high counts in the unoiled areas is insufficient to indicate that recovery has started. Thus the common loon is considered still not to have recovered from the effects of the spill" (EVOS Trustee Council 2002b, p. 8).

10.2 RESOURCE ASSESSMENT

The current condition of seabird populations in PWS may result from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed on the basis of the life histories and inherent abilities of these populations to recover from the initial impacts of the spill, the likelihood that behavior and habitat preferences of these species prolong exposure to lingering EVO to a degree that could cause adverse effects and injury, and the nature and magnitude of other potential factors affecting the condition of the populations.

10.2.1 Initial Impact from Spill

An immediate effect of EVOS on local seabird breeding populations was a loss of breeding adults for 1989 and future years due to direct mortality (Piatt et al. 1990). Of the approximately 1 million seabirds inhabiting the oil spill area prior to EVOS, an estimated 100,000 to 300,000 died initially from acute effects of oiling (Piatt et al. 1990). The most vulnerable seabirds included loons, grebes, sea ducks, and alcids (including murres, auklets, puffins, murrelets, and guillemots) because flocks of these birds occupied spill area's waters (Piatt et al. 1990). Oil caused direct mortality either by coating feathers and causing fatal hypothermia or through toxicity of ingested oil. Murres accounted for 74 percent of injured seabirds recovered after the spill, followed by other alcids (7 percent) and sea ducks (5.3 percent; Piatt et al. 1990). As indicated by these numbers, alcids are usually the most susceptible to oil spills, largely because they spend most of their time on the surface of the water, often in dense aggregations (King and Sanger 1979; Piatt et al. 1990).

Except where noted, initial mortality among seabird groups is based upon carcass recovery data provided in Table 1 of Piatt et al. (1990). These data are presented in summary form for each of the seabirds in Tables 10-1 through 10-5. Piatt et al. (1990) attributed the deaths of seabirds recovered before August 1 to direct effects of EVOS, and estimated that between 10 and 30 percent of dead birds were recovered. The total number of dead birds was in most cases extrapolated explicitly by Piatt et al. (1990) from the numbers of recovered carcasses and the assumed 10–30 percent carcass recovery rate.

A decline in seabird prey availability in PWS is another potential immediate effect of EVOS. Soon after the spill, populations of Pacific herring and Pacific sand lance may have declined. The potential effects of EVOS on Pacific herring are discussed in Section 11 of this report. Some researchers speculated that populations of Pacific sand lance in PWS declined in response to EVOS and subsequently affected seabird productivity (Golet et al. 2002; Litzow et al. 2002). No studies have addressed this hypothesis, and data on pre-spill Pacific sand lance populations are lacking.

Pigeon Guillemot—Estimates of pigeon guillemot mortality directly attributable to EVOS vary widely by area. For the entire spill area, Piatt et al. (1990) recorded 2.2 percent of recovered oiled bird carcasses as unspecified guillemots. On a local scale, Oakley and Kuletz (1996) attributed a 43 percent population decline in pigeon guillemots to the spill and other factors at a cluster of islands in central PWS containing nearly 25 percent of the PWS breeding population. Based on pre-spill and post-spill population statistics, initial impacts of the spill were more pronounced for pigeon guillemots than for any other seabird (Golet et al. 2002; Murphy et al. 1997). Based on the work of Piatt et al. (1990), an estimated 2,000–6,000 pigeon guillemots were killed as a result of EVOS.

Marbled Murrelet—PWS contains high concentrations of marbled murrelets, the most abundant seabird in PWS (EVOS Trustee Council 2002b). Estimates of initial mortality vary. Kuletz (1996) estimated 7–12 percent (12,800–14,800 individuals) of 183,000 marbled murrelets in the spill area died as a direct result of the spill, whereas Piatt et al. (1990) estimated losses to range from 2,900 to 8,700 birds (approximately 6 percent of 140,000 birds). Further immediate EVOS effects were evident in aliphatic liver compound analysis of murrelets indicating oil ingestion. In addition, murrelet foraging patterns may have been disrupted during the cleanup effort as indicated by reduced numbers of murrelets in busy cleanup areas (Kuletz 1996).

Kittlitz's Murrelet—Few species-specific data are available with which to estimate the total number of Kittlitz's murrelets that died immediately following EVOS. Seventy-two Kittlitz's murrelet carcasses were positively identified following the spill (EVOS Trustee Council 2002b). Estimates of total dead Kittlitz's murrelets varied depending on whether the estimate incorporated unidentified murrelet carcasses or was based on a percentage of total birds and a simple carcass count. For example, Van Vliet and McAllister (1994) estimated 1,000–2,000 dead, Kuletz (1996) estimated 370 dead, and Carter and Kuletz (1995) estimated 255 dead. Van Vliet and McAllister (1994) further suggested that Kittlitz's murrelets were severely affected, proposing a 5–10 percent world population decrease as a result of EVOS, although this range has never been confirmed.

Pelagic, Double-Crested, and Red-Faced Cormorants—Approximately 875 cormorant carcasses were recovered as an immediate result of EVOS (Piatt et al. 1990). From this sample, direct EVOS-related cormorant mortality was estimated to be between 2,900 and 8,800 deaths.

Common Loon—Loons in the spill area may have suffered high losses relative to their population sizes (Piatt et al. 1990). From a recovered 216 carcasses, an estimated 720–2,200 common loons died immediately following EVOS (EVOS Trustee Council 2002b).

10.2.2 Effects Following the Spill

Comparisons of population trends in oiled vs. unoiled portions of the spill area were performed by Sullivan et al. (2005), Wiens et al. (2004), Irons et al. (2000), Murphy et al. (1997), and Klosiewski and Laing (1994). The first attempt to examine population trends of seabirds in PWS, and differences between oiled and unoiled areas of PWS, were by Klosiewski and Laing (1994). In their analysis, they compared population trends in both oiled and unoiled areas between 1972–1973 and 1989–1990 data sets. Although surveys were conducted in 1984–1985, only shoreline zones were surveyed, and only the July 1984 data were adequate for comparison with the other data (Klosiewski and Laing 1994). Because of differences in defining nearshore and shoreline zones in 1972–1973, the 1984 data could be compared only with the 1989–1990 data (Klosiewski and Laing 1994). Therefore, these data could not be used for examining population trends, only to determine if there were fewer birds than expected in the shoreline of the oiled zone than in the unoiled zone before and after EVOS (Klosiewski and Laing 1994). Furthermore, this could be done only for the western half of PWS, which limited the number of available oiled transects for comparison (Klosiewski and Laing 1994). Thus, determinations of population trends between 1972 and 1989 were primarily based on inferences from the large observed differences in population sizes between 1972 and 1989 data versus the estimated EVOS mortality of individual species, not on the results of the 1984–1985 survey (Klosiewski and Laing 1994). Also, the authors did not detect significant differences in expected declines in population numbers in 1984 and 1989 between oiled and unoiled areas or in population levels before and after EVOS, though some species showed differences in expected declines in 1972 versus 1990 or 1991 populations (Klosiewski and Laing 1994). These conclusions were based on limited numbers of transects in unoiled areas of western PWS. The authors performed power analyses and concluded that additional population data would improve the power to detect differences between oiled and unoiled areas (Klosiewski and Laing 1994). Subsequent reports would be able to take advantage of the power afforded them by additional years of data.

More recent comprehensive evaluations of the relationship between EVOS and seabird populations in the years following the spill were summarized in Irons et al. (2000), Wiens et al. (2004), and Sullivan et al. (2005). All of these studies accepted a high probability (alpha [α] = 0.20) of committing statistical Type I errors (i.e., rejecting the null hypothesis when the null hypothesis is correct) in order to conservatively detect impacts. By using a high α-level in statistical studies of multiple comparisons such as those of Irons et al. (2000), Wiens et al. (2004), and Sullivan et al. (2005), the authors accepted that one in five of their comparisons would result in a Type I error (i.e., detecting an effect [either positive or negative] where none in fact existed). As a result, the authors based their conclusions more on observational trends than statistical findings, and acknowledged uncertainty in their conclusions. An additional potential concern in comparing population trends is that many seabird species migrate during March or April (Klosiewski and Laing 1994). Therefore “winter” surveys, which occurred in March, may not be relevant for gauging recovery of species such as marbled murrelets, which potentially alter migration timing in response to climate changes (Kuletz 2006, pers. comm.).

Irons et al. (2000) used a methodology known as BACI (before, after, control, impact) on population data collected from 1985 to 1998 from 187 to 212 shoreline transects[46] in PWS. The BACI design assumed that 1) birds in the reference locations were not affected by the spill, 2) bird populations in the spill area and reference area were closed populations, and 3) changes in bird density in the reference area reflected changes that would have occurred in the oiled area had the spill not taken place.[47]

Wiens et al. (2004) conducted surveys in 10 bays in 1989–1991, 1996, 1998, and 2001 and assessed potential ongoing impacts based on abundance and habitat change. The authors evaluated bird abundance, as estimated by nearshore and offshore surveys and habitat data, by 1) using oil as a quantitative variable with and without habitat measures as covariates to assess spill effects and their changes over time, and 2) using oiling as a categorical variable (oiled vs. unoiled) to conduct between-year, repeated-measures analysis with 1984 data as baseline. Results were combined in a weight-of-evidence interpretation for each bird species.

Sullivan et al. (2005) estimated population numbers and densities of seabirds in PWS using survey data collected through 2004, and compared winter and summer density trends in oiled areas versus unoiled areas. The purpose of their study was to assess whether recovery was taking place by measuring population densities in oiled and unoiled sites. Species demonstrating significant increasing population densities at oiled sites or at oiled sites relative to unoiled sites were considered to be recovering (Sullivan et al. 2005). In cases where decreasing or stable population trends were comparable between sites, recovery was judged to be not occurring. This approach for determining recovery was based on the judgment of the authors, and not necessarily on standard statistical methods for comparing impacted (e.g., oiled) versus reference (e.g., unoiled) environmental data.[48]

Summary information on population trends is presented for each of the seabirds in Tables 10-1 through 10-5.

Pigeon Guillemot—Significant declines were found between pre- and post-spill July populations of pigeon guillemots in PWS (1972 data versus 1989–1990 data; Klosiewski and Laing 1994). Population declines were noted in both oiled and unoiled areas (1972 data versus 1989 data; Klosiewski and Laing 1994). The PWS pigeon guillemot population has continued to decline since EVOS (Agler et al. 1994; Sullivan et al. 2005). This population trend, the 17-year gap between pre- and post-spill estimates, and spatial and temporal differences among studies are potential confounding factors in evaluating long-term effects of EVOS on pigeon guillemot populations. From 1989 to 1991, pigeon guillemot abundance decreased, more in oiled areas than in unoiled areas, demonstrating potential effects of EVOS (Murphy et al. 1997). Pigeon guillemots continued to exhibit negative effects in oiled areas in most years through 1998

[46] In the 1984/1985 survey, 772 transects were surveyed.

[47] The authors noted that assumptions 1 and 2 were probably not met, but argued this would bias the interpretation to be more conservative (i.e., underpredict impacts).

[48] Based on standard statistical methods, if steady population trends were observed in both oiled and unoiled sites, it would be inferred that no difference exists between populations of seabirds attributable to oiling.

according to BACI analysis (Irons et al. 2000). In contrast, after statistically controlling for habitat differences, Wiens et al. (2004) concluded that pigeon guillemot populations in oiled areas suffered initial adverse impacts relative to unoiled areas, but were likely demonstrating recovery from oiling effects by 1991. The authors acknowledged, however, that lower abundance of pigeon guillemots in oiled areas in 1996 and 2001 might be evidence of delayed and inconsistent spill effects (Wiens et al. 2004). Sullivan et al. (2005) found no differences in pigeon guillemot population trends between oiled and unoiled sites but found a significant decline in the oiled area populations, and therefore concluded that populations were not recovering. Pigeon guillemot populations were speculated to have been decreasing in PWS prior to EVOS (Klosiewski and Laing 1994; Oakley and Kuletz 1996). There were no complete population estimates between 1972–1973 and the time EVOS occurred to confirm this speculation. In summary, though pigeon guillemot populations are not recovering in the spill area, the long-term effects of EVOS on their populations amidst other factors are uncertain.

Marbled Murrelet—The marbled murrelet is listed as a threatened species in California, Oregon, and Washington (McShane et al. 2004) and in British Columbia (Burger 2002). Due in part to the large differences in population estimates between 1972 and post-spill surveys, murrelet populations, like those of pigeon guillemots, may have been declining prior to EVOS (Klosiewski and Laing 1994; Kuletz 1996). Murrelet populations continued to decline afterwards (Agler et al. 1994; Sullivan et al. 2005). Summer murrelet populations in PWS declined from an estimated 304,000 birds in 1972 to 97,000 birds shortly after the spill (Klosiewski and Laing 1994). With the exception of an unusually high population estimate in 1993, the overall murrelet population continued to decrease between 1989 and 2004 (Sullivan et al. 2005). This overall population decline makes discerning long-term oil-related effects difficult. Irons et al. (2000) compared July murrelet populations pre- and post-spill in oiled and unoiled areas and concluded that populations increased in oiled areas relative to unoiled areas in 1993 to 1998, and speculated that this was due to increased prey availability. Similarly, Agler and Kendall (1997) compared July population trends for Kittlitz's murrelets in oiled and unoiled areas from 1989 to 1996 and concluded that the overall population decreased during these years, but that numbers in oiled areas increased due to population shifts. Wiens et al. (2004) concluded that marbled murrelet populations in oiled areas were not adversely affected relative to unoiled areas. Sullivan et al. (2005) also found no differences in population density trends between oiled and unoiled areas in 2004.

One factor to consider in assessing long-term effects of EVOS on marbled murrelets is that murrelets' widespread nesting distributions and foraging ranges make it difficult to separate murrelets into oiled or unoiled areas. More importantly, declines in marbled murrelet breeding populations were documented in both oiled and unoiled areas. The similar population trends throughout PWS suggest that other factors in addition to EVOS, such as prey availability, may be influencing the murrelet population (EVOS Trustee Council 2002b). In summary, though marbled murrelet populations are not recovering in the spill area, the long-term effects of EVOS on their populations amidst other factors are uncertain.

Kittlitz's Murrelet—Throughout its range, Kittlitz's murrelet is a candidate for listing under the Endangered Species Act (USFWS 2006). Most of the referenced studies do not distinguish between Kittlitz's murrelets and other murrelet species when assessing long-term effects of

EVOS on murrelet populations. Many conclusions regarding marbled murrelets probably apply to Kittlitz's murrelets, but a lack of species-specific data for Kittlitz's murrelets increases the level of uncertainty. To address the problem of species identification, USFWS contracted with WEST Inc. to model population trends of both marbled and Kittlitz's murrelets with the apportionment of "unidentified" murrelets (Kuletz 2005). Kittlitz's murrelet populations have declined 99 percent from 1972 to 2004, and 88 percent from 1989 to 2004 (Kuletz 2005). While the decline probably began prior to EVOS, the rate of decline was 17.7 percent per year since 1972, but 30.8 percent per year since 1989 (Kuletz 2005). Assessing the reasons behind the declines in numbers of Kittlitz's murrelets is complicated by apparent concurrent shifts in murrelet distribution and their association with tidewater glaciers, most of which are receding in PWS (Kuletz et al. 2003). For these reasons, the long-term effects of EVOS on Kittlitz's murrelet populations remain unknown.

Pelagic, Double-Crested, and Red-Faced Cormorants—Conclusions on the effects of EVOS on cormorant populations differ. Murphy et al. (1997) found an overall decrease in pelagic cormorant abundance from 1989 through 1991, with a greater decrease in oiled vs. unoiled areas. Similarly, cormorant populations responded negatively to oiling in most years from 1989 to 1998 (Irons et al. 2000). More recently, after controlling for habitat differences between oiled and unoiled sites, Wiens et al. (2004) concluded that pelagic cormorant populations in oiled areas were initially adversely affected relative to unoiled areas, but that pelagic cormorants were recovering by 1991. Sullivan et al. (2005) found no differences in cormorant population trends between oiled and unoiled areas in 2004, although the authors noted that summer cormorant populations in oiled areas were increasing. Based on these analyses, cormorant populations in oiled areas appear to have been reduced for several years after the spill, but are increasing in oiled areas. There is no documented evidence that EVOS continues to affect cormorant populations in the spill area.

Common Loon—In 2000, there was evidence of an increase in PWS winter population density of common loons consistent with recovery, but no evidence of summer population recovery (Sullivan et al. 2005). Sullivan et al. (2005) tentatively concluded that winter populations of loons may be recovering based on significantly increased winter population density in 2000.

Common loons exhibited declines in population numbers and habitat usage in oiled areas in 1989 but not in 1990 (Day et al. 1997; Irons et al. 2000). Irons et al. (2000) found a weak negative effect of oiling on population numbers again in 1993, but not in 1996 or 1998. Wiens et al. (2004) did not examine loon populations. Sullivan et al. (2005) found no differences in loon population density trends between oiled and unoiled areas, and noted increased winter loon populations in 2004. Post-spill winter population counts of common loons have met or exceeded available pre-spill counts for all years except 1993 (Sullivan et al. 2005). Sullivan et al. (2005) tentatively concluded that winter populations of loons may be recovering. Evidence of increased common loon populations and the absence of differences between population trends in oiled versus unoiled areas indicate that there is no evidence of continuing effects of EVOS on common loon populations.

10.2.3 Potential Impacts on Seabird Food Sources

EVOS had the potential to cause indirect effects to seabirds by damaging important prey resources. All of the seabird species depend to some extent on herring or other high-lipid, schooling fish as food. For example, juvenile herring and Pacific sand lance are important in murrelet and other seabird chick diets, and adult Pacific herring and Pacific sand lance are important components of the adult diets of all species (Kuletz 2005; Litzow et al. 2002). The potential extent to which EVOS resulted in the decline of herring or sand lance in PWS could indirectly affect seabirds that rely upon these prey resources. However, there is a large amount of scientific uncertainty in the linkage between reductions in prey and EVOS.
For example, sand lance spawn in fine gravels or sand near shore, and burrow in intertidal sediment to avoid predators (Hobson 1986; Golet et al. 2002). Pacific sand lance are sensitive to oil contamination and avoid contaminated substrate, but are vulnerable to predation when they remain in the water column (Pearson et al. 1984; Golet et al. 2002). There is some possibility that lingering oil increases predation pressure on Pacific sand lance and subsequently affects seabirds that rely on sand lance for food (Golet et al. 2002). No direct evidence of this mechanism has been produced. Similar uncertainty exists with respect to the impact of EVOS on decreases in Pacific herring. As discussed in Section 11 of this report, other factors such as disease and climate shifts may play a significant or cumulative role in observed trends.

10.2.4 Impacts from Lingering Oil

Impacts to seabirds from lingering oil depend on 1) exposure to lingering oil, and 2) toxicity of lingering oil.

10.2.4.1 Exposure to Lingering Oil

While initial seabird mortalities caused by oil were through direct contact (i.e., coating of feathers with oil and eventual death from hypothermia) or through ingestion, the likeliest pathway for exposure to remaining oil is through food chain transfer from invertebrate prey (Golet et al. 2002). This pathway was suggested following the discovery of elevated CYP1A in adult pigeon guillemots from oiled sites (Golet et al. 2002). The authors assumed the transfer occurred from invertebrates rather than fish prey because 1) fish-eating chicks did not exhibit elevated CYP1A, whereas fish-and-invertebrate-eating adults did, and 2) invertebrates are more likely to sequester PAH compounds and pass them on through the food chain whereas fish more readily metabolize them (Golet et al. 2002).

Pigeon Guillemot—As a continuation of work by Seiser et al. (2000) on activity of liver enzymes in pigeon guillemot, Golet et al. (2002) found significantly higher hepatic CYP1A activity in the livers of pigeon guillemots from oiled parts of PWS compared to pigeon guillemots from unoiled parts. These findings indicated pigeon guillemots in oiled areas experienced higher exposures to CYP1A inducers (such as PAHs associated with EVO) than those in unoiled areas (Golet et al. 2002). Even in oiled populations, however, absolute CYP1A activity was low, indicating a low-level of exposure. The authors attributed this finding to the patchy distribution of lingering oil, and differences in oil ingestion based on different foraging patterns among individuals (Golet et al. 2002). No differences were found between CYP1A levels in chicks from oiled and unoiled sites (Golet et al. 2002). This finding was explained by the fact that pigeon guillemot chicks are fed primarily fish, while adults eat a substantial amount of invertebrates (Golet et al. 2002). Invertebrates are more likely to sequester petroleum compounds, whereas fish metabolize them (Golet et al. 2002). Data collected in 2004 indicated that there were no difference in the CYP1A levels in pigeon guillemots collected in oiled and unoiled parts of PWS (Ballachey et al. 2006). In addition, our evaluation of overlap of local pigeon guillemot foraging areas with areas of lingering oil found no evidence of exclusive or extensive overlap. However, by the nature of pigeon guillemots' opportunistic nearshore feeding habits, such an overlap could exist. There may be a seasonal component to potential oil exposure as well. Ewins (1993) summarized data suggesting that pigeon guillemots focus on invertebrate prey for only a portion of the year, demonstrating spring and winter preferences for invertebrate prey; this would further decrease overall exposure of pigeon guillemots to oil. However, adult pigeon guillemots collected in the summer at Naked Island, PWS, contained high proportions of shrimp, crab, and other invertebrates (Eldridge and Kuletz 1980), which may indicate similar exposure to oil through consumption of invertebrates throughout all seasons.

No research has been conducted to provide direct evidence of the invertebrate pathway of PAH-transfer to pigeon guillemots or the other seabirds discussed here, but they should be considered for the future. Studies designed to examine such pathways have been performed on other species. For example, Andres (1999) examined the effects of persistent shoreline oil on black oystercatchers in PWS in 1992 and 1993. Andres evaluated the diets, foraging behavior, and habitat use of oystercatchers nesting and feeding on oiled and unoiled beaches (Andres 1999). He found some differences between his populations including slower chick mass gains and elevated hydrocarbon indices in chick feces in the oiled sample (Andres 1999). Overall, however, he found that the patchiness of lingering oil led to exposure for only a relatively few individuals and concluded that lingering oil presented little risk to the PWS oystercatcher population as a whole (Andres 1999).

The diversity of fish and invertebrate prey consumed by seabirds, combined with the large extent of foraging territories (extending to several kilometers offshore) suggest that lingering oil in prey would affect only a fraction of the diet of birds residing in oiled areas. More specific studies examining pigeon guillemot diets and levels of PAHs in invertebrate prey could address these data gaps. Based on the recent absence of differences between CYP1A levels in oiled and unoiled pigeon guillemot populations and the overall low estimated probability of birds encountering lingering oil, lingering oil is considered a negligible risk to pigeon guillemot populations.

Other Seabird Species—Evidence of ongoing exposure to lingering EVO by other seabird species is absent. Collectively, the existing information suggests that negligible overlap in both time and space exists between lingering EVO and seabirds. It is acknowledged that there is uncertainty due to the lack of hydrocarbon ingestion data in murrelet, cormorant, and loon populations. However, given that these species have predominantly piscivorous diets combined with their limited chances of encountering lingering oil strongly suggests that exposure to lingering EVO is negligible.

10.2.4.2 Toxicity of Lingering Oil to Seabirds

Pigeon Guillemot—Seiser et al. (2000) measured blood parameters in pigeon guillemot populations of oiled vs. unoiled portions of PWS in 1997. An objective of this study was to identify evidence of toxic responses to oil contamination in both chicks and adults. Seiser et al. (2000) concluded there was little evidence of chicks being impacted by lingering oil. Preliminary data from adults, however, indicated elevated aspartate aminotransferase (AST) activity in oiled populations. This finding is an indication of hepatocellular injury, which would be consistent with continued exposure to lingering oil (Seiser et al. 2000). Seiser et al. (2000) additionally suggest that further research be conducted to evaluate fully the health of adult pigeon guillemots residing in oiled areas.

Golet et al. (2002) also tested blood parameters in guillemots. There were significant differences between birds from oiled vs. unoiled sites, but not consistently across years. For example, guillemots at the oiled site had higher concentrations of the enzyme lactate dehydrogenase (LDH) in both 1998 and 1999 than guillemots at unoiled sites. In 1999, guillemots at the oiled site also had elevated AST activity. The combined effect of elevated LDH and AST is indicative of toxicological response (Golet et al. 2002), but this effect was present only in 1999 and not 1998, when there was no difference between AST levels at oiled vs. unoiled sites (Golet et al. 2002).

Other Seabird Species—Although toxicity studies were done solely on pigeon guillemots, similar mechanisms of toxicity, if it occurs at all, could exist for any of the other six species considered in this evaluation.

10.2.5 Other Stressors

Ocean climate in the Gulf of Alaska cycles between warm and cold regimes approximately every 20–30 years (Anderson and Piatt 1999). In 1977, the regime shifted from warm to cold. This shift was followed by marked changes in fish and shellfish community structure (Anderson and Piatt 1999). For seabirds, this meant a decline in capelin, a high-energy, fatty forage species. By 1988, many seabirds had shown a shift in diet from primarily capelin to primarily sand lance and juvenile pollock (Piatt and Anderson 1995). It also signaled an increase in predatory groundfish (such as cod, flounder, and halibut), which compete with marine birds for smaller forage fish (Piatt and Anderson 1995). Population declines in many marine bird species have occurred coincident with these climatic and ecological shifts in the Gulf of Alaska (Piatt and Anderson 1995; Agler et al. 1999). Despite the apparent coincidence, the precise timing of seabird declines relative to the 1977 regime shift is unknown because most seabird censuses did not begin until the mid-1970s or later, and those that occurred in earlier years are generally considered unreliable.[49]

The decline in seabird populations of PWS could also be related to decreases in their key food resources (see Sections 10.2.3 and 10.2.4 above). Along the southern coast of Alaska, climatic

[49] Personal communication from A. Springer (University of Alaska) to L. Jacobs (Integral Consulting Inc.); e-mail dated May 12, 2006.

shifts may have caused changes in the abundance of high quality forage fish such as capelin, Pacific herring, and Pacific sand lance upon which murrelets and other seabirds depend (Kuletz et al. 1997; Agler et al. 1999; Anderson and Piatt 1999). Declines in Pacific herring and other forage fish in PWS could account for a decline in marbled murrelets, because juvenile herring are historically important components of murrelet chicks' diets (Kuletz 2005). Similarities in the rates and percentages of herring and murrelet population declines suggest a link between the two (Kuletz 2006, pers. comm.). Golet et al. (2002) discussed the importance of herring and sand lance together as "high-lipid" food resources for guillemots and other seabirds. Whether the decline in herring in PWS is related to EVOS is inconclusive (see Section 11, "Pacific Herring"). Thus, the link between the declines in seabird populations and EVOS through an indirect effect on their key food resources cannot be determined at this time. Golet et al. (2002) speculated that sand lance populations may have declined in response to EVOS, and subsequently impacted seabird productivity through decreases in high quality forage fish availability. Studies have not been done to confirm this speculation, and pre-spill data on Pacific sand lance populations are lacking. In any case, prey species availability must be considered a factor in seabird population changes.

Pigeon Guillemot—An apparent increase in nest predation of pigeon guillemot chicks and incubating adult birds occurred after the spill (Hayes and Kuletz 1997; Golet et al. 2002). A proposed hypothesis was that, after the spill, predators such as river otters and minks preyed more heavily on nesting guillemots due to heavy oiling of their customary shellfish prey (Hayes and Spencer 1997). Pigeon guillemots are also caught and drowned incidentally in gill nets (Wynne et al. 1991, 1992; Manly et al. 2003). These factors may contribute to the observed declines in pigeon guillemot populations throughout the spill area.

Marbled Murrelet—Marbled murrelet populations have declined throughout the species' range. South of the spill zone, the primary cause is considered to be loss of old growth nesting habitat (McShane et al. 2004), although prey availability is also important for reproductive success (Peery et al. 2004; Kuletz 2005). During the early 1990s, Carter et al. (1995) estimated from limited data that mortality through incidental capture in gill nets was about 3,300 individuals in Alaska annually. Murrelets were one of the most commonly caught seabirds in gill nets in PWS (Wynne et al. 1991, 1992) and Kodiak (Manly et al. 2003). Population trends projected from demographic analyses suggest that populations are declining in California, Oregon, Washington, and British Columbia as much as 4–7 percent per year (Beissinger 1995). In Alaska, declines have occurred in four areas (including PWS) though at varied rates (Van Pelt and Piatt 2003), and an increase occurred in the Kenai Fjords (Van Pelt and Piatt 2003). There are no trend data for southeast Alaska, the largest region, which may support more than 60 percent of the world's marbled murrelet population (McShane et al. 2004). Given the declining trend for marbled murrelet throughout much of its range and the potential for cumulative impacts from multiple stressors in PWS, it is unlikely that, even in the absence of residual or lingering oil spill impacts, this species could achieve the recovery objective listed in the 2002 status assessment.

Other Seabird Species—The factors discussed earlier for all seabirds, including gill net bycatch, the change in the ocean climate in the Gulf of Alaska, and declines in the herring population of PWS potentially linked to the EVOS, may contribute to population trends in other seabirds. Specific evidence of the action of other factors on these species is lacking.

10.3 SUMMARY AND RECOMMENDATIONS

The information provided in the previous sections was weighed to determine the overall recovery status of seabirds and to assess the need for additional restoration efforts. The goal of this evaluation was to assess the current status of seabirds based on the best available data and expert analysis. To achieve this goal, information on seabird natural history and ecology, historical and ongoing impacts of EVOS to seabirds and their prey, and other potential stressors was assembled and synthesized. The collective information was then evaluated in a weight-of-evidence synthesis framework to determine the current recovery status of the seven seabird species.

Overall, it is unlikely that seabirds are continuing to experience any direct adverse effects from EVOS or from lingering EVO in the intertidal zone. There is currently minimal potential for exposure to lingering EVO in the intertidal zone, and it is likely that sufficient time has passed for most populations to have recovered from the initial acute mortalities caused by the spill. However, potential links between the oil spill and declining populations of sand lance and herring may be having a long-lasting, indirect effect on some seabirds in PWS. Moreover, population modeling to evaluate the effects of EVOS and the recovery potential of seabirds has not been performed.

10.3.1 Pigeon Guillemot Recovery Status

Pigeon guillemot populations are declining, although the difference between populations in oiled and unoiled areas is no longer significant. Pigeon guillemots rely on forage fish such as Pacific herring and Pacific sand lance, which may be declining in the spill area due to various reasons, including a possible link to EVOS. In the past, pigeon guillemots have been exposed to oil likely through invertebrate prey, but recent CYP1A data indicate that exposure between oiled and unoiled populations is no longer different. Overall, the chances of encountering lingering EVO is negligible for pigeon guillemots.

The recovery objective for pigeon guillemots is *increasing or stable populations*. This evaluation of pigeon guillemot also took into consideration the relative importance of EVOS and other stressors in influencing the current condition of the population. To ensure that a broader range of factors that may affect pigeon guillemot populations are considered in future resources status assessments, it is recommended that the Trustee Council change the recovery objective for pigeon guillemot to the following:

> Pigeon guillemots will have recovered when a weight-of-evidence analysis of population trends, life history and ecology, exposure to EVO, and other stressors indicates that they are no longer adversely affected by residual effects of the spill or lingering EVO.

It is recommended that the Trustee Council classify the pigeon guillemot as “unknown” because it is unclear if the current condition of the pigeon guillemot population can be attributed to other stressors or to residual effects from EVOS. This relationship is unclear for the following reasons:

- There is no information relating the previously elevated levels of CYP1A in pigeon guillemot to adverse effects in individuals or the population
- There is no information that confirms or refutes a definitive link between reduced populations of herring or sand lance and the decline in pigeon guillemot populations
- Although a great deal of effort has been directed at assessing the link between EVOS and Pacific herring, there is no information that confirms or refutes a definitive link between EVOS and the current condition of the herring populations
- There is no information that confirms or refutes a definitive link between EVOS and the current condition of sand lance populations
- Population modeling, which could be used to assess the inherent ability of the population to recover from the initial impact of EVOS, has not been conducted.

It is recommended that population modeling be conducted to determine if population recovery would have occurred in the absence of other stressors. It is further recommended that restoration actions be considered, such as enhancing herring in PWS, reducing incidental take of seabirds in gill nets, and monitoring watercraft traffic in sensitive areas.

10.3.2 Marbled Murrelet Recovery Status

Marbled murrelet populations are declining throughout much of the spill area including LCI and PWS, but are increasing in the Kenai Fjords. They have low intrinsic productivity and a slow population growth rate. There are no differences in population trends between oiled and unoiled areas. Marbled murrelets rely on forage fish such as Pacific herring and Pacific sand lance, which may be declining in the spill area due to various reasons including a potential link to EVOS. Their dietary preferences and foraging areas afford them negligible contact with lingering oil. Exogenous factors such as climatic factors, decreases in habitat availability, and shifts in forage fish populations are the most likely drivers of murrelet population dynamics. Murrelets are one of the most commonly caught seabirds in gill nets in PWS.

The recovery objective for marbled murrelets is an *increasing or stable population*. This evaluation of marbled murrelets also took into consideration the relative importance of EVOS and other stressors in influencing the current condition of the population. To ensure that a broader range of factors that may affect marbled murrelet populations is considered in future resource status assessments, it is recommended that the Trustee Council change the recovery objective for the marbled murrelet to the following:

> Marbled murrelets will have recovered when a weight-of-evidence analysis of population trends, life history and ecology, exposure to EVO, and other stressors indicates that they are no longer adversely affected by residual effects of the spill or lingering EVO.

It is recommended that the Trustee Council classify the marbled murrelet as “unknown,” because it is unclear if the current condition of the marbled murrelet population can be attributed to other stressors or to residual effects from EVOS. This relationship is unclear for the following reasons:

- There is no information that confirms or refutes a definitive link between reduced populations of herring or sand lance and the decline in marbled murrelet populations
- Although a great deal of effort has been directed at assessing the link between EVOS and Pacific herring, there is no information that confirms or refutes a definitive link between EVOS and the current condition of the herring populations
- There is no information that confirms or refutes a definitive link between EVOS and the current condition of the sand lance populations
- There is no information that confirms or refutes a definitive link between other stressors (e.g., incidental catch in gill nets) and the current condition of the marbled murrelet population
- Population modeling, which could be used to assess the inherent ability of the population to recover from the initial impact of EVOS, has not been conducted.

It is recommended that population modeling be conducted to determine if population recovery would have occurred in the absence of other stressors. It is further recommended that restoration actions be considered, such as enhancing herring in PWS, reducing incidental take of seabirds in gill nets, and monitoring watercraft traffic in sensitive areas.

10.3.3 Kittlitz's Murrelet Recovery Status

Little is known about Kittlitz's murrelets, and therefore conclusions are based on a degree of acknowledged uncertainty. Kittlitz's murrelets continue to decline in PWS, and USFWS is currently proposing to list them under the Endangered Species Act. Kittlitz's murrelets appear to have low intrinsic productivity and a slow population growth rate. They suffered a relatively small estimated initial loss from EVOS, although it may have been relatively high compared to the total population within the spill area. No species specific data are available comparing growth trends between oiled and unoiled populations. Like the other seabirds, Kittlitz's murrelets are likely dependent on the availability of high-lipid forage fish such as sand lance and herring, the population declines of which bear an unsubstantiated link to EVOS. Their known dietary habits probably result in a negligible risk of encountering lingering oil through contact or ingestion.

No recovery objective has been identified for Kittlitz's murrelet. This evaluation of Kittlitz's murrelet considered the relative importance of EVOS and other stressors in influencing the current condition of the population.

It is likely that Kittlitz's murrelets are affected by the same stressors as marbled murrelets, in which case climatic factors (specifically, glacial recession), prey availability, and gill net mortality probably play major roles in influencing current populations. The potential linkage between forage fish decline and EVOS could affect Kittlitz's murrelets as well, but is unproven.

For the same reasons as indicated for the marbled murrelet, it is recommended that the Trustee Council classify the Kittlitz's murrelet as "unknown." Kittlitz's murrelet was classified as "unknown" in the 2002 status update.

10.3.4 Pelagic, Double-Crested, and Red-Faced Cormorants Recovery Status

Cormorant populations are increasing throughout their range, and seem to be increasing in the spill area as well. As in other seabirds, cormorants' population growth relies on the availability of prey fish, some of which may have been affected by EVOS. Cormorants are opportunistic feeders with the ability to take larger fish than murrelets, and are probably not affected by declines of Pacific herring and Pacific sand lance populations to the extent that smaller seabirds are, but may be affected nonetheless.

The recovery objective for cormorants is a *return to pre-spill levels in the oil spill area*. This evaluation of cormorants also took into consideration the relative importance of EVOS and other stressors in influencing the current condition of the population.

It is recommended that the Trustee Council classify cormorant species as "recovered" because the current condition of cormorant populations is unrelated to or is not adversely affected by EVOS. Furthermore, it is highly likely that cormorants have achieved a *return to pre-spill levels in the oil spill area*. A classification of "recovered" is supported by the following:

- Cormorants have a high intrinsic growth rate. They are stochastic breeders that can lay large clutches, which gives them the potential to recover relatively quickly from population losses when conditions are favorable.
- Cormorant populations are increasing throughout their range, and are probably increasing in the spill area as well. Cormorant population estimates are highly variable throughout their range, mostly because of cormorants' ability to relocate colonies between breeding years. Within this level of uncertainty, cormorant populations in PWS have apparently recovered to levels within the 95 percent confidence interval of 1972 populations.[50]
- Cormorants' primarily piscivorous diet and generally flexible foraging behavior suggest that their ongoing exposure to lingering oil is negligible.

10.3.5 Common Loon Recovery Status

Common loons have low productivity, but have recovered successfully from past population declines in the southern portions of their range. Their piscivorous dietary habits and temporary seasonal residence in the spill area expose them to a negligible risk of encountering lingering oil through contact or ingestion. Similarly, although loons may be affected to a small extent by declines in forage fish availability, which may or may not be related to EVOS, breeding pairs

[50] Estimated 1972 cormorant population levels ranged from approximately 10,000 to 30,000 birds; the 2004 summer population was estimated to range from 9,000 to 11,000 birds (Sullivan et al. 2005).

most likely feed outside of the spill region during the nesting season, mitigating impacts of saltwater forage fish declines.

The recovery objective for loons is a *return to pre-spill levels in the oil spill area.* This evaluation of loons also took into consideration the relative importance of EVOS and other stressors in influencing the current condition of the population.

It is recommended that the Trustee Council classify common loons as "recovered" because the current condition of common loon populations is unrelated to or is not adversely affected by EVOS. Furthermore, it is highly likely that loons have achieved a *return to pre-spill levels in the oil spill area*. A classification of "recovered" is supported by the following:

- There is uncertainty in loon population counts, but available data support that wintering populations of common loons have likely exceeded pre-spill levels in PWS for all years except 1993 (Sullivan et al. 2005)
- Although they have low productivity, reversals of population decline have been documented for loons
- The seasonal residence of loons in the spill areas means that they had a limited and seasonal exposure to forage fish population declines
- Based on their foraging behavior, loons have a negligible probability of encountering lingering oil.

11. PACIFIC HERRING

11.1 INTRODUCTION

Pacific herring (*Clupea pallasii*) are of both ecological and commercial importance in PWS. Not only are they central to the marine food web, providing food to marine mammals, birds, and invertebrates, but herring are also fished commercially for food and bait, sac-roe, and spawn on kelp. Pacific herring populations in PWS were increasing in the late-1980s before EVOS, and record numbers were reported immediately after EVOS primarily due to the strong recruitment of the 1988 (pre-spill) year class. Within a week of the EVOS in March 1989, Pacific herring and eggs deposited on beaches were exposed to the spreading oil slick in open water and along the shoreline. Although egg mortality and larval deformities were documented, the population level effects of these injuries were not clearly established.

11.1.1 Statement of Problem

The EVOS Trustee Council (1994, 2002b) classified Pacific herring as a non-recovering resource based on population trends that became evident 4 years after the spill in 1993. Pacific herring populations in PWS were increasing in the late 1980s before EVOS, and record numbers for the modern fishery were available for harvesting prior to the spill in 1989. However, in 1993, the Pacific herring fishery collapsed: the overall 1993 harvest was only 14 percent of the 1992 harvest (Pearson et al. 1999) and the 1989 year class was one of the smallest cohorts ever to return to spawn (EVOS Trustee Council 1998; Brown et al. 1996).[51] The Pacific herring fishery in PWS was closed from 1994 to 1996. Pacific herring populations in PWS began increasing in 1997 and 1998, but numbers leveled off beginning in 1999 and the fishery was again closed, which has continued through 2006.

Despite the fact that a number of studies have been directed at understanding the toxicity of oil to Pacific herring, the cause(s) of the highly depressed population, which has closed the fishery for all but 6 of the 17 years since the spill,[52] are not well understood. As of spring 2006, ADFG (2006e) reported that Pacific herring biomass in PWS remained below the minimum threshold of 22,000 tons for establishing a Pacific herring fishery in PWS and the fishery will remain closed through 2006. Combinations of poor recruitment, disease, and predation appear to suppressing the population from a robust recovery.

11.1.2 Natural History and Ecology

Pacific herring are of both ecological and commercial importance in PWS. Not only are they central to the marine food web, providing food to marine mammals, birds, and invertebrates, but

[51] Recruitment of the 1989 year class was also low in other Alaskan herring stocks (Funk 1995).

[52] The fishery was open in 1990, 1991, 1992, 1993, 1997, and 1998 (Johnson et al. 2002).

they are also fished commercially for food and bait, sac-roe, and spawn on kelp (Thomas and Thorne 2003). Key elements of Pacific herring natural history in PWS are summarized in the following sections.

11.1.2.1 Life Cycle and Distribution in PWS

There are four Pacific herring life stages—eggs, larvae, juveniles, and adults—and all are found in PWS at various seasons and locations (Brown and Carls 1998). Spawning in PWS typically takes place in April and the spawning season varies from 5 days to 3 weeks. Pacific herring typically spawn along the same beaches each year, although the volume of eggs and shoreline distance varies (Brown and Carls 1998; Carls et al. 2002). For example, from 1994 to 1997, the annual spawning beach length ranged from 23.3 to 68.5 km (Willette et al. 1998). Figure 11-1 shows Pacific herring spawning beds located throughout PWS based upon 1989–1998 data provided by ADFG (Moffitt 2004, pers. comm.). During spawning, the eggs attach to eelgrass, rockweed (i.e., *Fucus*), and kelp in shallow subtidal and intertidal areas. The eggs hatch in May, about 24 days after spawning depending on temperature (Hart 1973; Brown and Carls 1998).

After hatching, the larval herring migrate to the surface, congregate nearshore and continue to grow. Initially, the larvae have yolks that will last a few days, are poor swimmers, and currents significantly affect their distribution. The larvae become juveniles in July, about 10 weeks after hatching. In the fall, the juveniles move into deeper water but nearshore habitat remains important for at least the first year, and they may spend up to 2 years in nearshore areas or bays before joining the adult population residing in deeper waters (Brown and Carls 1998).

In PWS, adult Pacific herring rarely spawn before their third year and may live up to 12 years. After spawning in the spring, adult Pacific herring disperse from the spawning aggregations to multiple schools in deeper waters, presumably close to the entrances of PWS (Brown and Carls 1998). In the fall, adult and 2-year old Pacific herring return from summer feeding areas and overwinter in central and eastern PWS.

11.1.2.2 Feeding

Newly hatched larvae carry a yolk sac that is typically depleted in the first week. The earliest larval stages begin feeding on invertebrate eggs and small zooplankton such as copepods. While the larval Pacific herring grow and congregate nearshore through their first summer, they continue to live mainly on copepods but may also eat other crustaceans, barnacle larvae, mollusc larvae, or young fishes (Brown and Carls 1998). As they move into deeper water, copepods remain an important food for both juvenile and adult Pacific herring, but adults also feed on larger crustaceans and small fish. During winter, as temperature and light decrease, food supply becomes limited and both young and adult year classes stop feeding functionally. Survival of young herring through the winter depends on the amount of food that was available in the preceding summer and their ability to store sufficient lipid reserves to sustain them over the winter. For the older age classes, winter is less limiting on direct survival, but may affect their reproductive condition and spawning capacity in the spring (Carls et al. 2001b).

11.1.2.3 Natural Mortality

All Pacific herring life stages are important prey items in the marine food web (Hart 1973). Egg mortality caused by foraging birds or wave scouring can be as high as 90 percent in the intertidal zone. In addition, up to 50 percent of eggs that do hatch may exhibit morphological abnormalities due to natural factors (Carls et al. 2002). Newly hatched larvae are preyed on by invertebrates and fish and can be swept away by currents. Juvenile and adult Pacific herring are a critical food resource for salmon, seabirds, and marine mammals (Brown and Carls 1998). In recent years, PWS herring have been plagued by continuing disease problems that appear to be the major factors limiting their recovery. In addition, Pacific herring and their eggs are an important commercial fishery in PWS with most harvest occurring in the spring (Pearson et al. 1995).

11.1.3 Status of Injury and Recovery Classification

The Pacific herring population in PWS is depressed, and has been since the 1993 crash, with no evidence of recovery trends. Based on the 1993 decline in the Pacific herring population, and the speculative relationship between this decline and EVO, the EVOS Trustee Council (1994) established recovery objectives and defined a restoration strategy for Pacific herring in PWS. The recovery objective was defined as a return to healthy and productive pre-spill herring population abundances. Research into the cause(s) of the Pacific herring decline, monitoring, and habitat protection were adopted as the restoration strategies that would be implemented to meet the recovery objective.

In 2002, the EVOS Trustee Council (2002b) reviewed the status of the Pacific herring in PWS and concluded that it could not be considered to be recovering. The Pacific herring population had still not met the recovery objective of recruitment of the next highly successful year class into the population, although there were indications that the population was increasing.[53] The recovery objectives were modified to specify that Pacific herring will have recovered when the next highly successful year class is recruited into the population and when other indicators of population health (such as biomass, size-at-age, and disease expression) are within normal bounds in PWS. The restoration strategy was not modified.

ADFG (2006e) reported that the spring 2006 Pacific herring biomass in PWS remained slightly below the minimum spawning biomass threshold (i.e., 22,000 tons) for establishing a Pacific herring fishery in PWS and the fishery was again closed and will remain closed in 2006.

11.1.4 Overview of EVOS Trustee Council-Funded Restoration Efforts

Because of its importance near the base of the nearshore marine food web and its value as a commercial fishery, numerous projects have been initiated to evaluate and restore Pacific herring populations. Injury and restoration projects include research on the mechanisms limiting

[53] In 2002, 70 percent of the population was composed of young, 3-year old fish suggesting that the next large year class was present in the population and that recovery was under way.

recovery, surveys to collect information for fisheries management, investigation of ecological factors governing herring populations, and acquisition of habitat protective of herring. Appendix A provides a summary of these projects.

11.2 RESOURCE ASSESSMENT

The current condition of Pacific herring population can potentially derive from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed based on the Pacific herring life history and inherent ability of the population to recover from the initial impacts of the spill, the likelihood that the behavior of Pacific herring could result in ongoing exposure to lingering EVO to a degree that could cause adverse effects and injury, and the nature and magnitude of other factors that could affect the condition of the population. The results of that evaluation are provided in the following sections. While ongoing exposure to lingering oil is not suspected of being a significant contributor to the lack of recovery of PWS herring, the other factors are complex and have a significant element of uncertainty in their evaluations and consequences.

11.2.1 Initial Impact from Spill

In the first days to weeks following the initial spill, EVO was distributed both in open water and along the shoreline of PWS. As such, it is reasonable to presume that most life stages of Pacific herring were exposed to EVO to some degree following the initial spill. The spill occurred a few weeks before Pacific herring spawned in PWS, so eggs and adults were exposed directly to EVO, ranging from oiled habitat to dissolved concentrations of the oil in the water column. Larval contact with EVO also probably occurred given that EVO was distributed in nearshore areas for several months following the spill and was often resuspended in the water column as a result of the large cleaning effort transpiring in multiple areas and bays throughout PWS. Because there are similarities in the mechanisms of uptake and toxicological modes of action are comparable during these life stages, it is difficult to separate impacts of exposure as larvae from earlier exposure as eggs. Observations of juvenile Pacific herring exposure to EVO are anecdotal, based on observations of juveniles in contaminated intertidal habitat (Carls et al. 2001b). Although larvae may also have been exposed to EVO through ingestion of oil-contaminated food,[54] this was not a significant route of exposure (Kline 1999). Prespawning adults in nearshore areas generally do not feed and so did not ingest EVO or oil-contaminated food.

The early life stages are the most sensitive to the effects of oil. Based on the extent of visible oil on beaches observed during initial surveys conducted in 1989, Pearson et al. (1995) estimated

[54]Copepods, one of the major herring prey items, have been shown to accumulate and concentrate petroleum hydrocarbons (EVOS Trustee Council 1998; Brown et al. 1996).

that 4–10 percent of the total Pacific herring spawn length in PWS occurred along shorelines with oil. In addition, EVO contaminants were shown by researchers to be available in open water along shorelines where oiling was not directly evident. Using PAH accumulation in mussels from spawn beaches as an index of oil exposure, Brown et al. (1996) estimated that 40–50 percent of the eggs were exposed to EVO in 1989. By combining mussel accumulation data with the timing of the egg deposition at various spawn sites, Carls et al. (2002) refined this estimate down to 25–32 percent of the 1989 eggs that were exposed to EVO. While Pacific herring did not spawn on the most heavily oiled beaches, they did spawn on shorelines considered lightly to moderately oiled (Brown et al. 1996).

Pacific herring larvae from eggs from oiled beaches showed increased sublethal impacts and mortality compared to eggs from non-oiled beaches (Hose et al. 1996; McGurk and Brown 1996). Given the fragile nature and vulnerability of herring larvae, sublethal laboratory effects are very likely to be lethal in the wild. Both field and laboratory studies demonstrated sublethal impacts that included premature hatching, low larval weights, reduced growth, and increased incidence and severity of morphological deformities and genetic abnormalities (McGurk and Brown 1996; Marty et al. 1997; Norcross et al. 1996; Brown and Carls 1998; Carls et al. 1999). Of the embryos present in PWS in 1989, 25–32 percent may have been damaged (Carls et al. 2002). Larvae drifting into oiled areas and under slicks would have added to these numbers. By 1991, sublethal larval measurements had returned to probable baseline levels (Hose et al. 1996).

There is no direct measurement of the percentage of the adult population that encountered EVO. Severe lesions and elevated PAH levels were observed in some adult Pacific herring from oiled areas (Brown and Carls 1998; Marty et al. 1999). Herring typically rise to the surface after darkness and would have had increased exposure probability at this time. Laboratory studies showed abnormalities and possible depressed immune functions in Pacific herring exposed to oil (Carls et al. 1999, 2001b). Significant adult mortality was not observed in 1989 (Carls et al. 2002), but this would not be unexpected given the heavy predation or scavenging by different groups of predators.

11.2.2 Residual Effects Following the Spill

EVO exposure was suspected as a potential cause of the herring population decline in 1993. However, numerous other reasons could also explain this decline: disease aggravated by high population density, food scarcity, and poor ocean conditions (EVOS Trustee Council 1999; Brown et al. 1996). It is likely that no single factor explains the 1993 population decline.

Whether the initial spill continues to exert residual effects on Pacific herring populations is unknown and is the subject of an ongoing review and research (Rice et al. 2005). This research, which is scheduled for completion in June 2006, will focus on uniqueness of the PWS herring stocks relative to oil, disease, recruitment success, and resiliency through genetic diversity. The task group involved with this project met in October 2005 to discuss their preliminary findings. Preliminary (unpublished) findings into residual effects of EVO focused on four areas of investigation:

- **Persistent toxicological mechanisms—**Two mechanisms that could promote long-term multigenerational toxicity were discussed: long-term immunosuppression to disease from initial exposures in 1989, and effects from lingering oil exposures that cause continuing or cascading effects. Neither mechanism was considered plausible. The overlap between herring use and lingering oil does not exist.
- **Fish pathogens—**Disease associated with two fish pathogens (viral hemorrhagic septicemia virus and *Icthyophonus hoferi*[55]) continue to be the leading suspected cause for limiting recovery of Pacific herring. The time period over which these two diseases have been limiting recovery appears to be unique and is on the order of a decade. The cause of the continuing disease problem is unknown.
- **Population dynamics—**In a recent retrospective study, it was hypothesized that the decline in Pacific herring populations was initiated by the spill in 1989, but was not detectable until 1993 (Thomas and Thorne 2003; Thorne 2005). Two independent measures of spawning success were used in a population model to test this idea but yielded contradictory results. Resolution of these competing hypotheses does not appear possible.
- **Genetic diversity—**It was hypothesized that historical fishing practices coupled with the population crash in 1993 resulted in a population with low genetic diversity that limits its ability to tolerate disease or other environmental stressors. Preliminary review indicates that genetic diversity in Pacific herring from PWS is relatively high and no different from that in other populations along the Pacific Coast of North America.

Based on these preliminary findings, the cause of the continued depressed Pacific herring population in PWS is linked to continuing disease problems (see "Other Stressors" below).

More recently, Brown (2005) has constructed a conceptual model and a hypothesis linking EVO and other environmental stressors (e.g., viral hemorrhagic septicemia virus and decreased abundance of zooplankton food) in a unique combination of events to explain the current and persistent status of Pacific herring populations. In Brown's (2005) opinion, the net result of EVO and other environmental factors is a small population of Pacific herring in PWS that is perpetually held in check by its chief predator, the humpback whale. Although intriguing, Brown's (2005) hypothesis lacks supporting data in many instances[56] and therefore has not yielded sufficient weight of evidence to conclusively confirm or deny a causative relationship to EVO.

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[55] A fungus-like organism associated with massive mortalities in herring in the Atlantic Ocean, and has recently been reported to cause disease in wild Pacific herring from Washington through Alaska.

[56] Elements of the model that could benefit from more explicit quantification include mechanisms for activation, susceptibility, and immunoresistance to viral hemorrhagic septicemia virus among the various cohorts of Pacific herring leading to the 1993 crash; spatially significant patches of oil at the sea surface as late as 1991, resulting in overlapping distributions of oil, herring, and zooplankton prey; exposure to juvenile herring via consumption of contaminated zooplankton prey in 1991; EVOS related trophic cascades that suppressed predation on 1987 and 1988 cohorts of herring; and population trends of herring in relation to population levels of its predators, including humpback whales.

Recent research results (Marty 2006, pers. comm.) using a histopathology biomarker (pigmented macrophage aggregates) as an indicator of environmental stress in Pacific herring populations suggest that EVOS stress was not detectable in the 1988 year class of herring, but that stress associated with disease in the 1993 collapse was evident in the 1988 year class. Although these findings suggest a preeminent role of disease in the collapse of the herring fishery, the linkage to oil cannot be proved or disproved.

In the final analysis, predation and disease may be linked and inseparable as controlling factors in Pacific herring recovery. Predation may weed out a higher proportion of diseased animals, leading to underestimates of the significance of disease. These two factors introduce uncertainty into estimates of herring survival and the significance of each as a contributing factor in limiting recovery.

11.2.3 Exposure to Lingering Oil

While lingering oil exists in some parts of PWS, particularly in the intertidal zone of the northern Knight Island area, there is little to no overlap with this habitat and herring spawning areas. Lingering oil is not likely to directly affect spawning adults, eggs, or larvae of Pacific herring nor is it likely to indirectly affect other critical life history characteristics such as availability of food, offshore foraging habitat, or migratory behavior (Integral 2006). Consequently, lingering oil is also unlikely to be a cause for poor recovery following the 1993 population crash.

11.2.4 Other Stressors

Natural environmental factors are also associated with population variability of Pacific herring. However, the reasons and mechanisms for this natural variability are poorly understood. Predation, disease, food availability, intertidal exposure of eggs to air and larval drift are all examples of natural factors contributing to the large natural variability observed in Pacific herring populations (Pearson et al. 1999; Carls et al. 2001b; Marty et al. 2003b; Rooper et al. 1999; Sturdevant et al. 2001). These factors are dynamic and vary among each life stage, and over time (both seasonally and annually). The population at any one time represents the collective influence of all of these factors in a complex environmental mosaic that cannot be precisely understood or predicted with certainty.

Climate, as it affects food availability, also affects Pacific herring populations (Brown 2002; Schweigert et al. 2002). Brown (2002) noted that trends in abundance of Pacific herring in the northern Gulf of Alaska appear to be in phase with decadal-scale climate indices, which may also affect growth and spawn timing. Schweigert et al. (2002) reported that herring stocks throughout British Columbia and Alaska have shown a decline since the late 1970s that may result from climatic conditions and declining food availability.

In a synthesis of the literature, Carls et al. (1999, 2001b) surmise that the combination of high population density, poor nutrition, and epidemic infection by viral hemorrhagic septicemia virus caused the collapse in a boom-and-bust cycle typical of Pacific herring populations in the Gulf of Alaska and elsewhere. Pearson et al. (1999) also concluded that a combination of increasing biomass and decreasing food supply led to poor Pacific herring condition and the 1993 decline. Both studies acknowledged that natural factors and variability could explain the population decrease, and a clear link between EVOS and the 1993 population decline was not established, nor eliminated. Disease in the Pacific herring population in PWS continues and it appears to be a limiting factor in the recovery today.

There is evidence that declines in Pacific herring biomass in PWS are attributable to disease (viral hemorrhagic septicemia virus, *Ichthyophonus hoferii)*, and that disease is a significant variable in population fluctuations (Johnson 2002; Marty et al. 2003b, 2004; Quinn et al. 2001). Marty et al. (2004) concluded that disease is the most important variable limiting recovery of the Pacific herring populations in PWS and predicted that Pacific herring in PWS will not recover until both viral hemorrhagic septicemia virus and *I. hoferii* are at background levels for several years. These disease factors are common to Pacific herring throughout its range, but appear to have a unique controlling influence on Pacific herring populations in PWS.

The Pacific herring population began increasing in 1997 following the 1993 decline, and the fishery was opened in 1997 and 1998. However, the population increase stalled in 1999, and recent research by Thomas and Thorne (2003) have speculated that the opening of the fishery in 1997 and 1998 stressed the already weakened population and contributed to the 1999 decline, when the fishery was again closed.

Although Pacific herring are renowned for their high interannual variability in so-called boom-or-bust cycles of productivity, the persistence of the 1993 crash appears unprecedented and is of concern because upward swings in the population characterize this species in other locations in Alaska (Figure 11-2). Worldwide, herring populations show large fluctuations, with crashes followed by periods of recovery that may take a decade or longer (Hay et al. 2001). However, only a single stock of Pacific herring has shown an extended collapse. Pacific herring from the Hokkaido-Sakhalin region in the western Pacific was once one of the world's largest fisheries, but collapsed for unknown reasons and has remained depressed for more than 40 years most likely due to uncontrolled fishing pressure (Hay et al. 2001).

11.3 SUMMARY AND RECOMMENDATIONS

The information provided in the previous sections was weighed to determine the overall recovery status of Pacific herring and to assess the need for additional restoration efforts. This evaluation included assessment of the current condition of herring and consideration of factors contributing to that condition. Key evidence weighed in the recovery evaluation included population survey data, other indicators of population health, the nature and magnitude of the initial impact of EVOS, the potential for exposure to lingering EVO, and effects of other stressors.

Pacific herring have played a fundamental role in the PWS ecosystem, serving as primary forage species to sustain numerous higher trophic level predators like seabirds and sea lions, as well as important fisheries. Consequently, the initial exposure to EVO immediately following the spill in 1989 and the collapse of the fishery in 1993 have been and remain a major concern both from the point of view of overall ecosystem integrity and the viability of a sustainable fishery.

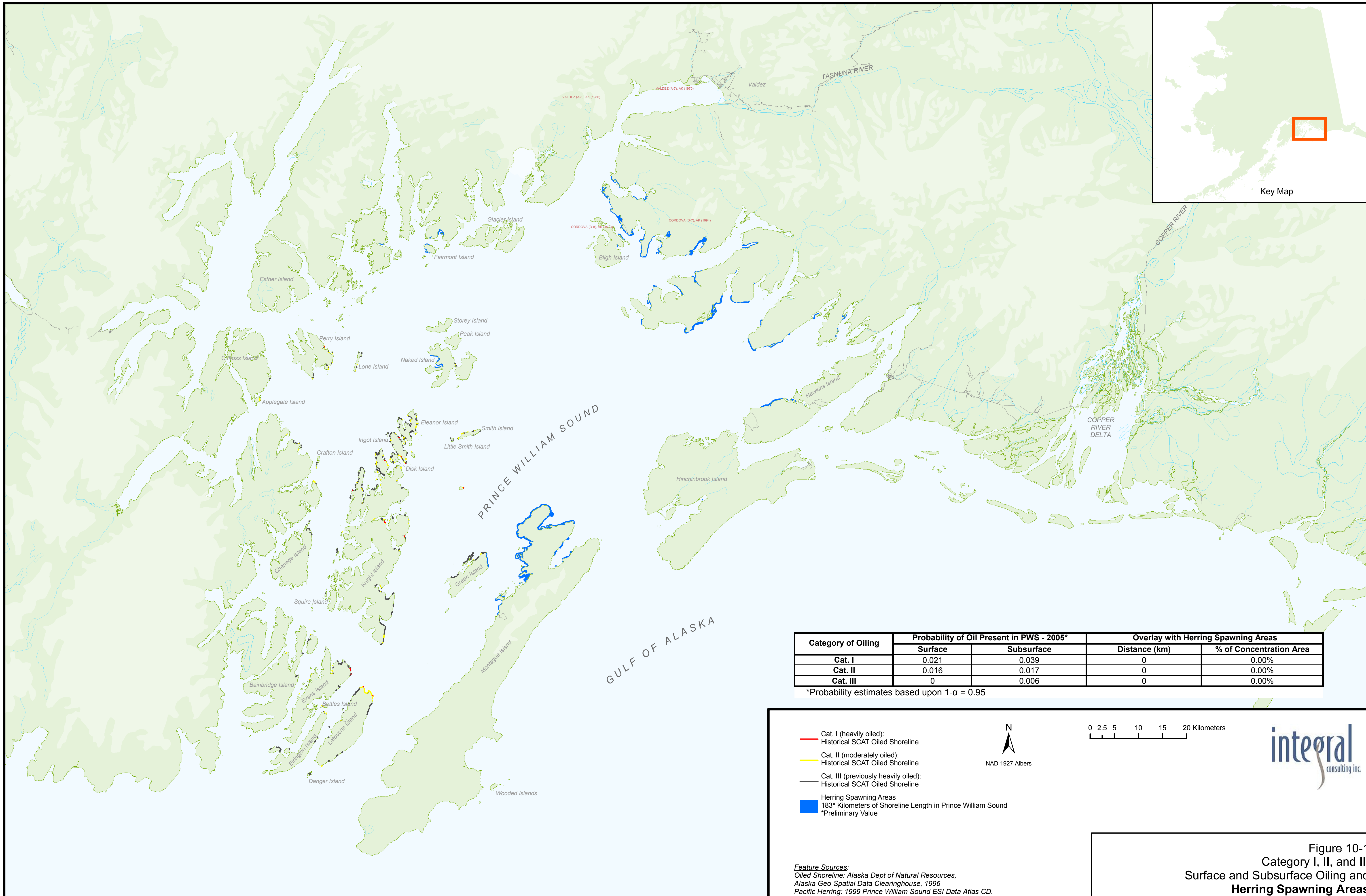
The 2002 recovery objective states that "Pacific herring will have recovered when the next highly successful year class is recruited into the population and when other indicators of population health (such as biomass, size-at-age, and disease expression) are within normal bounds in PWS." This evaluation of herring also took into consideration the relative importance of EVOS and other stressors in influencing the current condition of the population.

It is recommended that the Trustee Council classify Pacific herring as "not recovered" because herring are showing persistent impairment in the spill area that is unique, unprecedented, and of widespread concern to scientists and the public.
It is likely that no single factor explains either the collapse of the Pacific herring population in 1993 or its continuing depressed status in PWS. There is little evidence linking the depressed herring population to residual effects from the spill, though it cannot be eliminated. More recently, an expert group has been convened to address broader issues associated with the depressed herring population in PWS. Preliminary findings of the expert group indicate that the cause of the continued depressed Pacific herring population in PWS is apparently linked to continuing disease problems. The continuing limiting of the population by disease is a unique situation, and while these diseases are ever present in all populations of herring (and other species), they are seldom suspected of limiting populations over an extended period of time. No other North American population has suffered acute population losses like those in 1993, nor has any other population suffered from chronic disease issues.

The roles and relative contributions that other environmental stressors such as predation, climate, and nutrition may have on recovery are not precisely known and contribute to the complexity and uncertainty of understanding Pacific herring population cycles. These factors further complicate attempts at understanding causality and any linkages associated with the dual challenges of EVOS exposure followed by debilitating infectious disease associated with multiple pathogens. However, none of these uncertainties are sufficient to overwhelm the fundamental conclusion that Pacific herring remain persistently impaired in the spill area in a situation that is unique, unprecedented, and of widespread concern to scientists and the public.

The following research and restoration actions should be considered:

- Direct research toward defining the relative contribution of predation and disease as limiting factors in recovery. Reestablish disease monitoring incidence in PWS and reference populations, at all age classes.
- Pursue the development and implementation of restoration projects related to herring enhancement.



Category of Oiling	Probability of Oil Present in PWS - 2005*		Overlay with Herring Spawning Areas	
	Surface	Subsurface	Distance (km)	% of Concentration Area
Cat. I	0.021	0.039	0	0.00%
Cat. II	0.016	0.017	0	0.00%
Cat. III	0	0.006	0	0.00%

*Probability estimates based upon 1-α = 0.95

Cat. I (heavily oiled):
Historical SCAT Oiled Shoreline

Cat. II (moderately oiled):
Historical SCAT Oiled Shoreline

Cat. III (previously heavily oiled):
Historical SCAT Oiled Shoreline

Herring Spawning Areas
183* Kilometers of Shoreline Length in Prince William Sound
*Preliminary Value

N
NAD 1927 Albers

0 2.5 5 10 15 20 Kilometers

integral consulting inc.

Feature Sources:
Oiled Shoreline: Alaska Dept of Natural Resources,
Alaska Geo-Spatial Data Clearinghouse, 1996
Pacific Herring: 1999 Prince William Sound ESI Data Atlas CD.

Figure 10-1
Category I, II, and III
Surface and Subsurface Oiling and
Herring Spawning Areas

\\Mi-gcocks\GIS_projects\C113_EVOS_NRTEVOS_Oiling-Probability-Resource-B-map_GJC-updated_11x17_12-02-05.mxd RN / GJC @ 04-05-06

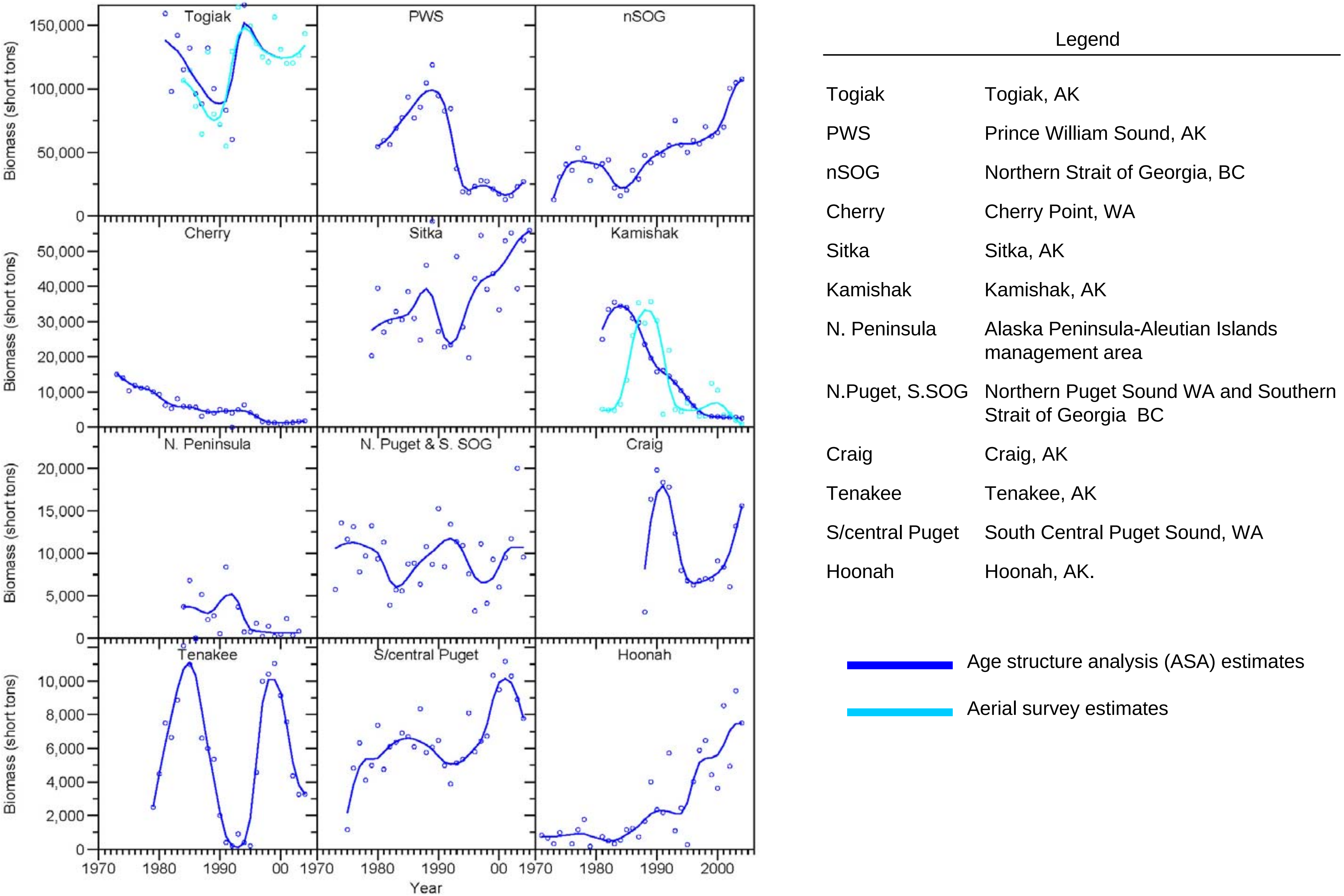


Figure 11-2. Trends in Pacific Herring Populations from Washington, British Columbia, and Alaska.
Source: Carls 2006 (pers. comm.)

12. ROCKFISH

12.1 INTRODUCTION

Rockfish (*Sebastes* spp.*)* are bottom-dwelling fish residing throughout PWS and much of the North Pacific. Rockfish residing within PWS all belong to the family Scorpaenidae and the genus *Sebastes* (Kendall 2000). Common PWS species include canary rockfish (*S. pinniger*), tiger rockfish (*S. nigrocinctus*), and yelloweye rockfish (*S. ruberrimus*). Following EVOS, a focused number of studies were conducted to evaluate the initial impacts from the spill to rockfish. These included studies on petroleum hydrocarbon levels in rockfish from 1989 to 1991 (Hoffmann and Hansen 1994; Marty et al. 2003a), biochemical responses in rockfish from petroleum hydrocarbon exposure during 1999–2000 (Huggett et al. 2003; Page et al. 2004), and general stock trends of rockfish throughout the Gulf of Alaska (NMFS 2005).

12.1.1 Statement of Problem

Rockfish were classified as “unknown” in 2002 due to a lack of information on pre-spill conditions and current species abundance and composition (EVOS Trustee Council 2002b). Information on natural history, potential EVOS impacts on fish health and behavior, and the potential influence of EVOS on rockfish habitat are evaluated here to assess the recovery status of *Sebastes*. Among these key sources, there is little information available with which to develop a meaningful assessment of pre-spill conditions of rockfish health relative to post-spill conditions. Absent this information, other sources of information related to the potential for current exposure to EVO and the overall health of rockfish stocks are considered.

12.1.2 Natural History and Ecology

Approximately 20 individual rockfish species are believed to reside throughout the waters of PWS, all with similar morphology (Orr et al. 2000) and life history. Alaskan rockfish are found in a variety of habitats including demersal (bottom-dwelling) and pelagic (open-water) varieties. Demersal fish usually reside near rocky reefs or boulder fields, but can also occupy other nearshore subtidal areas such as kelp beds (Hoffmann and Hansen 1994; NMFS 2005). Pelagic species are usually found in large schools in the open water column, typically above or near rocky areas on the continental shelf (NMFS 2005). Rockfish give birth to hundreds of larval fish through internal fertilization and embryo development, as opposed to reproduction through spawning and external fertilization of eggs (NMFS 2005). Once larvae are released, they may disperse widely throughout the water column, or they may instead opt to occupy a certain vertical segment of the water column (e.g., demersal, pelagic) (Love et al. 2002). Great annual variability in larval recruitment occurs in PWS. This variability is largely seen as a function of variable flow dynamics driving larval transport. In terms of general PWS circulation, an inward flow of water continues through Hinchinbrook Entrance in the southeast, while an outward flow through PWS continues through Montague Strait in the southwest (Norcross and Frandsen 1996). Freshwater flow from streams and glacial melt also contributes to larval dispersal, and it is important to note that at the time of EVOS, the lowest recorded freshwater discharge was observed in almost 60 years (Norcross and Frandsen 1996). Rockfish are planktivorous as larvae, evolving to planktivores and invertivores (e.g., copepods) as juveniles, and finally to invertivores and predominantly piscivores (e.g., sand lance, herring) as adults (Orr et al. 2000; NMFS 2005).

Rockfish also exhibit very slow growth and high longevity relative to other bony fishes. Yelloweye rockfish, for example, can live more than a 100 years, and a 205-year old rougheye rockfish was observed in southeastern Alaska in 2000 (Munk 2001). In addition, greater maximum ages are generally observed between demersal species versus pelagic (Munk 2001). In general, rockfish experience low natural mortality, great longevity (typically up to 30–50 years, and possibly longer), and sexual maturity at older ages than most bony fish. For example, rockfish reach sexual maturity typically between the ages of 4 and 10, depending on sex and species (Love et al. 2002).

Adult rockfish also have recreational and commercial value. The NMFS Gulf of Alaska Groundfish Plan Team assessed size of rockfish populations from 1980 to 2005 using bottom trawls to 700 m depths (NMFS 2005). Historically, there appears to be a steady increase in Gulf of Alaska rockfish biomass from 1980 to 2005, with approximately 7 million tons recently estimated. Rockfish biomass in 2005 increased by 7 percent from the previous year, and increases in recruitment and catch were observed as well.

12.1.3 Status of Injury and Recovery Classification

The 1994 plan included a discussion on rockfish mortality and sublethal impacts following EVOS. No recovery objective was defined with natural processes serving as the sole means of recovery (EVOS Trustee Council 1994). The plan also stated the need to assess damage and to collect other data to define a restoration objective and a strategy (EVOS Trustee Council 1994).

The 2002 plan developed a recovery goal for *Sebastes* as "return to conditions that would have existed had the spill not occurred." Again, no recovery objective was offered due to a lack of basic pre-spill information and knowledge of current recovery status. Consequently, there was a need to know basic information about abundance and species composition in spill areas to foster evaluations of injury and recovery.

12.1.4 Overview of EVOS Trustee Council-Funded Restoration Efforts

Since the early 1990s, the Trustee Council has funded a focused number of projects for evaluating rockfish since the original spill (see Appendix A). The remainder of this section provides a brief summary of these projects and their overall findings.

Norcross and Frandsen (1996) examined the spatial and temporal distribution of various larval fish genera (including rockfish) to assess general injury to larval fish in PWS in 1989. This study observed no net larval growth of rockfish numbers between April and September probably because of sequential birthing by many species. No impacts directly associated with EVOS were identified.

Hoffmann and Hansen (1994) examined injury to demersal rockfish and shallow reef habitats in PWS from 1989 to 1991. In addition to observed rockfish mortality in areas within the spill zone, higher petroleum hydrocarbon concentrations in rockfish from oiled areas versus reference sites were observed. Hoffman and Hansen (1994) suggested that because demersal rockfish reside near rocky reefs or boulder fields where oil entrapment is likely, continued exposure would be possible.

Marty et al. (2003a) conducted a fish histopathological damage assessment of various fish species (rockfish included). Fish sampled in oiled and reference sites between 1990 and 1991 were inspected for microscopic lesions. No definitive link between EVO exposure and incidence of lesions was identified (Marty et al. 2003a).

12.2 RESOURCE ASSESSMENT

The current condition of rockfish populations in PWS can potentially derive from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed based on the life history and inherent ability of rockfish to recover from the initial impacts of the spill, the likelihood that the behavior and habitat preferences of these species could result in ongoing exposure to lingering EVO to a degree that could cause adverse effects and injury, and the nature and magnitude of other factors that could affect the condition of the populations.

12.2.1 Initial Impact from Spill

Immediately following the spill in 1989, dead rockfish were observed throughout PWS. However, the absolute number of dead rockfish was never documented. Samples of dead rockfish had a significantly higher incidence of hydrocarbons in oiled areas than did samples from reference sites (Hoffmann and Hansen 1994). Subsequent analysis in 1990–1991, however, showed the presence of hydrocarbons in both oiled and reference sites (Hoffmann and Hansen 1994). Marty et al. (2003a) further concluded that although demersal rockfish were exposed to EVO in 1989, old age and species differences were the cause for higher hydrocarbon metabolites and microscopic lesions in 1990–1991, not continual exposure to EVO. Norcross and Frandsen (1996) conducted field studies in 1989 to determine spatial and temporal variation of fish larvae in PWS in the months following EVOS. Most larval fishes were in the upper 50 m of the water column and were either concentrated in the oiled western portions of PWS or were transported through this portion of the sound by the same processes that moved EVO. However, an effect of EVO on rockfishes was not detected.

12.2.2 Residual Effects Following the Spill

Relatively few studies were conducted to examine residual effects of EVO on rockfish. Key studies include biomarker studies by Huggett et al. (2003) and Page et al. (2004). Biomarker analyses were performed on rockfish samples from 1999 to 2000 to compare hydrocarbon levels in fish from previously oiled sites with reference sites (Huggett et al. 2003; Page et al. 2004). Huggett et al. (2003) observed comparatively low hydrocarbon levels across all sample sites (previously oiled as well as reference), suggesting natural oil seeps as the contamination source of demersal habitats. Page et al. (2004) showed rockfish in PWS embayments had liver CYP1A levels positively correlated with background sources of PAH. Traces of EVO residues detected in site sediment at nearshore sites in the spill path were also observed, but biomarkers in fish were not elevated relative to other sites (Page et al. 2004). Overall, both studies observed similarly low hydrocarbon levels across reference and oiled sites, suggesting that hydrocarbon exposure is probably due to background sources instead of lingering EVO.

12.2.3 Exposure to Lingering Oil

At the time of the spill in 1989, contact with EVO on the sea surface, dissolved EVO in the open water column, and EVO residues in subtidal sediments were predominant environmental pathways of most concern for rockfish. These pathways and routes of exposure are not significant today. Except for occasional sheens from beaches, lingering oil does not occur in surface water, but rather is predominant in the intertidal zone as highly weathered asphalt-like material in surface sediments or is largely sequestered in subsurface sediments. It is conceivable that some invertebrate prey items utilized by immature rockfish could contain residues of petroleum hydrocarbons attributable to EVO. However, the preponderance of data indicates that benthic invertebrates, such as mussels, no longer accumulate appreciable residues of petroleum hydrocarbons attributable to EVO (Page et al. 2005). In addition, food-chain exposures are unlikely because fish are known to metabolize PAHs rapidly (Lawrence and Weber 1984; Eisler 2000). A lack of exposure has also been demonstrated for rockfish and halibut residing in offshore to nearshore areas and preying upon benthic organisms (Page et al. 2004).

In summary, none of the exposure pathways and routes considered at the time of the spill is present today. Because lingering EVO is sequestered in subsurface sediments or occurs predominantly as a weathered solid in surface sediments of the intertidal zone, it is not directly accessible to rockfish. Significant food-chain exposure is unlikely because fish metabolize PAHs rapidly and significant bioaccumulation in prey is unlikely. Based on the low likelihood of exposure and the low accessibility of oil, chances for lingering oil impacts to these species are very low.

12.2.4 Other Stressors

The dominant environmental stressor that could potentially influence rockfish recruitment is the dynamic current circulation conditions that occur throughout PWS. These conditions are suspected to have a significant impact on larval dispersal and survival (Norcross and Frandsen 1996). Another potential stressor is the commercial and recreational fishing of rockfish throughout PWS and elsewhere in Alaska. AMCC (2005) has identified four stressors associated with fisheries impacts:

- Habitat destruction caused by impacts of fishing gear on the seafloor
- Bycatch mortality associated with embolisms in fish brought from depth and discarded
- Localized depletions of populations in intensely fished areas
- Altered age-structure caused by selective fishing techniques.

Analyses of stock trends of Gulf of Alaska rockfishes over the past 25 years have shown relatively steady to rising biomass with recent increases in recruitment and catch (NMFS 2005). The rockfish fishery for PWS is reviewed by Berceli et al. (2005) and summarized below in Section 17.2.1.4 (Services – Commercial Fishing, Rockfish). Rockfish harvest in 1988 was 113,000 lb. Subsequent to EVOS, annual rockfish harvests in PWS during 1989–2000[57] ranged from 60,539 lb in 1999 to 489,154 lb in 1990. The peak harvest in 1990 was attributed to market conditions that encouraged targeting of rockfish. Although the harvest data are not a direct measure of the rockfish population, they nevertheless indicate that the population was viable and sufficient to support the fishery to the levels observed in 1988.

12.3 SUMMARY AND RECOMMENDATIONS

The information provided in the previous sections was weighed to determine the recovery status of rockfish and to assess the need for additional restoration efforts. The recovery status of rockfish was previously classified as "unknown," reflecting limitations and uncertainties in the data available for the assessment. To address data limitations, the evaluation performed here uses both direct and indirect information on the status of the resource. Factors considered in our evaluation were immediate post-spill trauma to fish, biomarker evidence of hydrocarbon exposure, possible hydrocarbon contamination of rockfish habitat, impacts to sensitive larval life stages, and population viability as indicated by fisheries statistics.

Immediately following the spill in 1989, dead rockfish were observed throughout PWS with significantly higher incidences of hydrocarbons occurring in oiled versus reference sites. Hydrocarbon exposure from 1990 to 1991, however, is believed to stem more so from species diversity and old age than from continual exposure to EVO (Marty et al. 2003a). In addition, biomarker analyses from 1990 to 1991 showed comparably low hydrocarbon signatures in previously oiled and reference sites, suggesting a natural background source of hydrocarbons (Huggett et al. 2003; Page et al. 2004).

Because little to no rockfish habitat contains lingering EVO, ongoing exposure is believed to be low to nonexistent. None of the exposure pathways present at the time of the spill are present today (appreciable amounts of EVO on surface waters, dissolved EVO in the water column,

[57] Fishery management regulation for rockfish changed following the 2000 harvest year. Consequently, beginning in 2001, landings statistics represent differences in these regulations and reporting and are not comparable to the pre-2001 era.

EVO residue in subtidal sediments). Because fish are known to rapidly metabolize PAHs (Lawrence and Weber 1984; Eisler 2000), food chain exposure is also unlikely.

Rockfish are generally very long lived with relatively low fecundity and recruitment (AMCC 2005). Consequently, small impacts to the reproducing adult population could have very long-term consequences, which might be observed as decreases in larval fish recruiting to the population or as declining adult populations and diminished fisheries. Surveys of larval fish in PWS in 1989 indicated that rockfish larvae occurred within the footprint of the spill trajectory or were transported through this portion of the sound by the same processes that moved EVO. However, an effect of EVO on larval rockfishes was not detected after the spill. Periodic NMFS–Gulf of Alaska stock assessments show that recruitment and catch of rockfish have recently increased while biomass has remained relatively steady. Also rockfish populations have been robust enough since the spill to sustain fisheries at or above 1988 levels in 8 of the 12 years from 1989 to 2000. In summary, the available exposure, life history, and fishery information suggests that the initial impacts were inconsequential, that larvae were not affected, and that the population's ability to sustain a fishery was not altered.

It is recommended that the Trustee Council classify rockfish as "recovered."

13. DOLLY VARDEN AND CUTTHROAT TROUT

13.1 INTRODUCTION

Dolly Varden (*Salvelinus malma,* southern form) and cutthroat trout (*Oncorhynchus clarkii*)[58] are iteroparous[59] members of the salmon family with similar, complex migrations between salt- and freshwater throughout PWS. Because these species have similar natural histories, habits, and distribution, they are evaluated together in this section. Initial impacts of EVOS were assessed primarily through tagging and recapture studies to evaluate potential injury to both fish species as individuals moved into and out of oiled areas (Hepler et al. 1996; Trotter 1989; McCarron and Hoffmann 1993; Collier et al. 1996). Other studies evaluated potential biochemical responses to EVO exposure (Collier et al. 1996), population distributions and genetics (Schelske et al. 1998; Currens et al. 2003), potential impacts on migratory and foraging behavior (Jewett et al. 1996), and the role of sport fishing on stock abundance (McCarron and Hoffmann 1993).

13.1.1 Statement of Problem

Dolly Varden and cutthroat trout were classified as "unknown" in the 2002 assessment of resource recovery status (EVOS Trustee Council 2002b). Information on natural history, potential EVOS impacts on fish health and behavior, potential biochemical responses to EVO exposure, potential EVOS impacts to prey items, and information on genetic and population differences are evaluated here to assess the current recovery status of each species. Among these key sources, information garnered from genetic and population differences indicate that several subpopulations of each species may exist across PWS. The presence of subpopulations across geographic locales complicates the overall assessment on of these resources throughout PWS as a whole.

13.1.2 Natural History and Ecology

Most Dolly Varden and most cutthroat trout in PWS are members of two anadromous[60] subspecies. The southern form of Dolly Varden extends from the southern arc of the Aleutian Peninsula east and south across PWS, through southeast Alaska, and into Canada, while range of the cutthroat trout extends north from Oregon along the coast to PWS, but no farther (Hart 1973; Morrow 1980; Trotter 1989). Schelske et al. (1998) identified undocumented populations of Dolly Varden and cutthroat trout in 1996 and 1997 and concluded that both species are more widely distributed throughout PWS streams than previously thought. Additional migratory

[58] For the purposes of this evaluation, this designation additionally includes the coastal cutthroat trout (*Oncorhynchus clarki clarki*).

[59]Adults may spawn over one or more years.

[60]Living mostly in the sea, with spawning occurring in fresh water.

populations of Dolly Varden (23) and cutthroat trout (21) were discovered in lakes and streams to supplement Hepler et al.'s (1996) initial observations of five Dolly Varden and three cutthroat populations from 1989 to 1991. Six additional resident (nonanadromous) populations were also observed in freshwater for both species, respectively. Generally, Dolly Varden and cutthroat trout are not commercially valuable species, but both are heavily sought-after sport fish in Alaska and elsewhere.

Adults of both species in PWS spawn in natal streams with most survivors overwintering in lakes and the rest returning to sea (Trotter 1989; Bernard et al. 1995). Dolly Varden spawn mid-August through November and cutthroat trout May through June. Smolt of both species migrate to sea in summer after reaching approximately 150 mm in length after 2 to 4 years in freshwater (Morrow 1980; Trotter 1989). During their first summer at sea, juveniles of both species move along shorelines entering streams in search of prospective watersheds to spend the following winter. Migrations of Dolly Varden are more extensive than those of cutthroat trout with the former regularly crossing straits and passages and the latter more inclined to follow the shoreline (Armstrong 1974; Hepler et al. 1996). Once a suitable lake has been found for overwintering, individuals of both species home to that watershed each winter that they do not remain at sea. Dolly Varden reach sexual maturity in 3–6 years in PWS and cutthroat trout in 5–7 years. Most adults and all juveniles of both species were in freshwater at the time that EVOS occurred; adults, immature individuals, and smolt migrated into waters with EVO shortly thereafter.

The dietary habits of both species reflect their migratory life histories. Crustaceans and other small invertebrates (amphipods, euphausiids, megalopae, polychaetes) are the preferred diets of immature Dolly Varden and cutthroat trout, while adults consume mostly fish (sand lance, herring, greenling, and small salmon) (Armstrong 1971; Narver and Dahlberg 1965).

13.1.3 Status of Injury and Recovery Classification

Following the spill in 1989, Dolly Varden and cutthroat trout were regarded as resources that "have grown more slowly in oiled areas than in unoiled areas [but] [i]nsufficient data are available to determine whether they are recovering" (EVOS Trustee Council 1994). In the 1994 restoration plan, the recovery objective for both species was defined as the "maintenance of adequate water quality, riparian habitat, and intertidal habitat for spawning and rearing" (EVOS Trustee Council 1994). Full recovery was defined as "when growth rates within oiled areas are comparable to those for unoiled areas" (EVOS Trustee Council 1994).

The 2002 plan stated full recovery would exist for both species when "growth rates within oiled areas are comparable to those for unoiled areas after taking into account geographical differences" (EVOS Trustee Council 2002b). The 2002 recovery classification was "unknown" for both species, pending additional genetic characterization of subpopulations occurring throughout PWS. Currens et al. (2003) is the most recent report available on genetic differentiation of coastal cutthroat trout and Dolly Varden char populations throughout PWS. This report detailed genetic characterization information for both species based on 1996 and 1997 tissue samples with genetic analyses performed from 1997 to 1999. Griswold (2002) provides further analysis of genetic diversity in coastal cutthroat trout and Dolly Varden in PWS.

These studies are preliminary investigations, and while the need for follow-on genetics work has been raised by some researchers, no subsequent work has been conducted to date.

13.1.4 Overview of EVOS Trustee Council-Funded Restoration Efforts

The EVOS Trustee Council restoration strategy for Dolly Varden and cutthroat trout restoration was to monitor the recreational success of each species through sport fishing (EVOS Trustee Council 1994). Since the early 1990s, the Trustee Council has funded a focused number of projects toward these restoration efforts (see Appendix A). The remainder of this section provides a summary of these projects and their overall findings.

Survival and growth of anadromous Dolly Varden and cutthroat trout were evaluated in oiled versus unoiled areas of PWS by Hepler et al. (1996). Generally, decreased survival and growth was observed for both species from 1989 to 1990, though only differences in growth were statistically significant. This observation is consistent with studies of pink salmon where differences in growth of juvenile salmon were apparent following the spill in 1989 and diminished in subsequent years of the study in 1990 and 1991 (Willette 1996). Poor juvenile growth of pink salmon was also correlated with lower survival in adults in 1989, but not in the follow-up studies of the 1990 and 1991 juvenile cohorts.

Definitive conclusions regarding the extent of exposure of anadromous Dolly Varden and cutthroat trout to EVO were hampered by the inability to ascertain the precise areas frequented by studied fish. Because salmonids can detect aromatic hydrocarbon concentrations down to minute levels (i.e., a few parts per million) in water, these species might be able to selectively avoid oil patches, thereby limiting long-term effects on populations (Hepler et al. 1996). This possibility is suggested by patterns of distribution of juvenile pink salmon along PWS shorelines in 1989–1991 where the proportion of juvenile salmon present along oiled shorelines was less than that along unoiled shorelines (Wertheimer and Celewycz 1996).

Currens et al. (2003) investigated potential differences in genetic characteristics among anadromous and freshwater resident populations within PWS for both species. Genetic variation was observed between populations of cutthroat trout in which divergence increased with distance. Because of this divergence in genetic makeup across the species, prior evaluations of population recovery following the spill became somewhat uncertain. The assessment process described in this report is utilized to add clarity to the evaluation of the recovery status of these resources.

13.2 RESOURCE ASSESSMENT

The current condition of Dolly Varden and cutthroat trout populations in PWS can potentially derive from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed based on the life history and inherent ability of these populations to recover from the initial impacts of the spill, the likelihood that the behavior and habitat preferences of these species could result in ongoing exposure to lingering EVO to a degree that could cause adverse effects and injury, and the nature and magnitude of other factors that could affect the condition of the populations.

13.2.1 Initial Impact from Spill

The initial impact of EVOS on these species was likely delayed based on their timing of migration to the ocean. Hepler et al. (1996) hypothesized that heavy oiling of the intertidal and adjacent estuarine waters may have impacted anadromous Dolly Varden and cutthroat trout leaving freshwater habitats by late April (the typical timeframe during which return to the ocean occurs for both species). After departing from their freshwater spawning areas in April, Dolly Varden and cutthroat trout primarily rely upon shallow nearshore environments for feeding (Armstrong 1970; Trotter 1989). Within the spill area, such environments may have contained EVO. If direct exposure did occur, it likely occurred at the sea surface or in the open water column over a relatively brief period of time. Such direct exposures would not be expected to be long term because EVO underwent rapid volatilization at the water's surface immediately after the spill, and because concentrations in the open water column rapidly diminished within the first months after the spill (Galt et al. 1991; Neff et al. 1995; Neff and Stubblefield 1995; Wells et al. 1995). Direct exposure would also be expected to be relatively transient over space, given that both species are highly mobile and were likely to move in and away from areas in which EVO could be encountered.

Despite the limited potential for direct exposure, some impacts to Dolly Varden and cutthroat trout were identified shortly after the spill. Hepler et al. (1996) documented that fish emigrating to and from oiled areas from 1989 to 1990 exhibited decreased growth compared to those in unoiled areas (20–25 percent less for Dolly Varden; 35–45 percent less for cutthroat trout). Examination of scales from cutthroat emigrating in spring 1989 prior to their exposure to EVO showed growth rates for this species had been similar across PWS in prior years (no similar comparison was possible for Dolly Varden). Growth differences between fish associated with oiled and unoiled parts of PWS persisted through 1991 for cutthroat trout. Differences across PWS in growth of Dolly Varden disappeared by 1991 because growth in fish associated with unoiled areas unexpectedly slowed. In subsequent studies, Collier et al. (1996) examined levels of biliary fluorescent aromatic hydrocarbons and aromatic hydrocarbon metabolizing enzymes such as CYP1A in Dolly Varden captured in nearshore environments following the spill. Both biochemical responses were elevated in 1989 compared to the baseline, but these values were considerably reduced by 1990. Collier et al. (1996) further found that stomach contents of Dolly Varden were free of hydrocarbons, suggesting adsorption through the open water column, not consumption of prey, as a major exposure pathway.

Decreased prey availability and/or alterations in prey composition initially after the spill could also potentially have impacted Dolly Varden and cutthroat trout. For example, in benthic areas influenced by petrogenic hydrocarbons, invertebrate communities have been shown to shift away from dominance by amphipods toward smaller epifauna (Teal and Howarth 1984). Based upon the work of Jewett et al. (1996), this phenomenon occurred throughout PWS in 1989 and 1990, and may have resulted in lost prey availability for immature Dolly Varden and cutthroat trout. It is also conceivable that a shift in benthic communities could subsequently result in a shift in small fish communities, which serve as a prey base for mature Dolly Varden and cutthroat trout, though no data exist to definitively demonstrate this occurrence.

13.2.2 Effects Following the Spill

Persisting impacts to Dolly Varden and cutthroat trout populations following the spill were not likely to have occurred beyond 1991. As described above, growth differences occurred between oiled and unoiled areas through 1991 for cutthroat trout, but not Dolly Varden (Hepler et al. 1996). In addition, biochemical responses to aromatic hydrocarbon exposures were low as shortly after the spill as 1990 (Collier et al. 1996).

13.2.3 Current Exposure to Lingering Oil

At the time of the spill in 1989, contact with EVO on the sea surface and dissolved EVO in the open water column were two predominant environmental pathways of most concern for Dolly Varden and cutthroat trout. These pathways and routes of exposure are not significant today, except for occasional sheens from beaches. Lingering oil does not occur in surface water, but rather is found in the intertidal zone at the surface as highly weathered asphalt-like material. In the subsurface, EVO is more moderately weathered and is sequestered at depth below sediments and armoring at the surface. It is conceivable that some invertebrate prey utilized by immature Dolly Varden and cutthroat trout could contain residues of aromatic hydrocarbons attributable to EVO. However, the preponderance of data indicates that benthic invertebrates, such as mussels, are not under present conditions accumulating appreciable residues of aromatic hydrocarbons attributable to EVO (Page et al. 2005). In addition, food-chain exposures are unlikely because fish are known to rapidly metabolize PAHs (Lawrence and Weber 1984; Eisler 2000).

In summary, none of the exposure pathways and routes considered at the time of the spill is present today. Because lingering EVO is sequestered in subsurface sediments or occurs predominantly as a weathered solid in surface sediments of the intertidal zone, it is not directly accessible to Dolly Varden or cutthroat trout. Significant food-chain exposure is unlikely because fish metabolize PAHs rapidly and significant bioaccumulation in prey is unlikely. Based on the low likelihood of exposure and the low accessibility of oil, chances for lingering oil impacts to these species are very low.

13.2.4 Other Stressors

Because Dolly Varden and cutthroat trout are fished for sport, fishing pressures may be a potential factor inhibiting successful recruitment of both species. In addition, competition for prey and habitat may exist between these species and coho salmon in freshwater systems, which additionally could result in reductions in recruitment (Gillikin 2000). Habitat alteration, such as that which occurs from poor logging practices, may pose a significant impact on these species particularly that portion of their lives spent in freshwaters. Although impacts from these other stressors are conceivable, definitive data for their impacts on Dolly Varden and cutthroat trout populations within PWS are not available.

13.3 SUMMARY AND RECOMMENDATIONS

The information provided in the previous sections was weighed to determine the recovery status of Dolly Varden and cutthroat trout and to assess the need for additional restoration efforts. The recovery status of Dolly Varden and cutthroat trout was previously classified as "unknown," reflecting limitations and uncertainties in the data available for assessment. To address data limitations, the evaluation performed here uses both direct and indirect information on the status of the resources.

It is recommended that the Trustee Council classify Dolly Varden and cutthroat trout as "recovered" from the effects of EVOS based on the following:

- In the first few years following the spill, impacts on the growth and survival of Dolly Varden and cutthroat trout in oiled areas were reported. Heavy oiling of the intertidal zone and estuarine habitats immediately following the spill could have adversely impacted both species leaving freshwater environments in late April. Decreased growth rates of both species migrating through oiled areas were observed from 1989 to 1991, although none of the differences in growth were statistically significant.
- In Dolly Varden captured in nearshore environments following the spill, biochemical indicators of exposure (levels of biliary fluorescent aromatic hydrocarbons, CYP1A) were elevated in 1989 compared to the baseline, but these values were considerably reduced by 1990.
- Dolly Varden and cutthroat trout are highly mobile, indicating that potential movement to areas with EVO would be transient.
- The dominant EVO exposure pathway for these fish was oil in the water column and on the surface. Rapid volatilization of PAHs months after the spill resulted in short-term oil exposure.
- Because lingering EVO is predominantly sequestered in subsurface sediments of the intertidal zone, it is not directly accessible to Dolly Varden or cutthroat trout, and is also unlikely to contaminate their prey. In addition, significant food-chain exposures are unlikely because fish are known to metabolize PAHs rapidly.

The primary source of uncertainty for Dolly Varden and cutthroat trout is the absence of recent information on the condition of these resources. Both of these species are also conceivably influenced by sport fishing pressure and competition with Coho salmon in freshwater habitats, but PWS data are not available to assess these impacts.

14. SEA OTTER

14.1 INTRODUCTION

Prior to EVOS, sea otters populated the nearshore marine environment of PWS. This species had made a dramatic comeback from the brink of extinction in the early 1900s, when fur hunting had reduced the numbers to perhaps no more than a few hundred throughout their North Pacific range. By 1985, the estimated population in PWS was 5,800 (Irons et al. 1988), and at the time of the spill, Garrott et al. (1993) estimated the western PWS sea otter population size at 6,546 and still growing. Hundreds of sea otters became coated with oil in the days following the spill. Higher than normal mortality in sea otters after the spill, particularly in older adults, was evident through at least 1998 (Monson et al. 2000a). By the mid 1990s, the sea otter population of western PWS showed population growth, but elevated mortality and emigration continued to constrain population growth in heavily oiled areas for at least a decade after the spill (Bodkin et al. 2002). Specifically, there was no evidence of population growth through 2005 in the heavily impacted subpopulation[61] at northern Knight Island (Bodkin et al. 2002; Ballachey and Bodkin 2006).

14.1.1 Statement of Problem

Sea otters were classified as "recovering" in the 2002 assessment of resource recovery status (EVOS Trustee Council 2002b). Information on the life history of the sea otter (e.g., foraging behavior), biomarker data on PAH exposure (i.e., CYP1A), population trends, and other measures of the health of individuals and the population are evaluated here to assess the current recovery status of sea otters.

14.1.2 Natural History and Ecology

Sea otters were originally widespread throughout the northern Pacific, inhabiting nearshore marine environments in northern Japan, Russia, Alaska, Canada, the continental U.S., and northern Mexico. Their thick pelts were highly sought after by fur traders, who began hunting them in Alaska in the 1740s (Riedman and Estes 1990). By the end of the 19th century, the worldwide population of sea otters was nearly extinct. In 1911, sea otters came under protection of the International Fur Seal Treaty. Since then, populations have increased and through translocations and dispersal, much of their former range has been recolonized.

A remnant population of sea otters survived the fur harvest in southwestern PWS. The population increased through the 1950s, and began to expand north and eastward through the 1970s. By the time of EVOS, the sea otter population in western PWS had been established for at least 25 years. Before the spill occurred, this population was likely near equilibrium density,

[61] Subpopulation is a geographically distinct group of individuals that interbreeds with other groups within a larger population through immigration and emmigration.

and limited by prey availability, although some habitat in northwest PWS was below carrying capacity (Estes et al. 1981; Garshelis et al. 1986).

14.1.2.1 Food and Foraging

Sea otters forage in the benthos of rocky and soft-sediment communities, as well as within the algal understory and canopy (Riedman and Estes 1988). They forage most often in subtidal zones, although the intertidal is used as well (Riedman and Estes 1988). In PWS, the percentage of intertidal foraging dives varies among individuals, ranging from less than 5 to more than 30 percent of total dives (Ballachey and Bodkin 2006).

Sea otter prey preferences are largely determined by the availability of prey species, which varies with geographic location and habitat and the length of time that the area has been occupied by sea otters (Riedman and Estes 1988). Sea otters prey on calorie-rich sea urchins where they are available, particularly in rocky habitats, but studies have shown that they can deplete an area of their preferred prey and then switch to other, less energetically profitable prey (Kvitek et al. 1993). Studies in PWS have shown clams (including *Saxidomus giganteus* and *Mya truncata*) to be their primary prey, as well as the most abundant food resource (Riedman and Estes 1988; Dean et al. 2002). It has been reported that 60–80 percent of the diet is clams, while mussels constitute 10–20 percent (Garshelis et al. 1986; Doroff and Bodkin 1994; Dean et al. 2002). In specific areas, however, mussels may account for a larger proportion of the diet. Estes et al. (1981) found mussels and clams equally common in diets at Green Island, an area long occupied by sea otters and possibly depleted in its clam population. In 1991, juvenile sea otters in PWS foraged more frequently on mussels in the intertidal zones, whereas adults foraged more on subtidal clams (Doroff and Bodkin 1994). During 1996–1997, clams accounted for 72–80 percent and mussels 9–14 percent of the sea otters'diet in western PWS (Dean et al. 2002).

14.1.2.2 Reproduction

Female sea otters begin breeding as early as age 2, and by age 3, most females are reproductively mature (Bodkin et al. 1993). Pups are usually born singly and can be born in any month; however, a peak in pupping occurs in PWS in April and May (Ballachey et al. 2003). Within about 6 months, pups are independent of their mothers. Dominant adult males establish and defend territories that provide access to females (Riedman and Estes 1990). Male territories vary in size, averaging about 75 acres (Riedman and Estes 1990). Some males have been observed to move between their breeding territory and locations of all-male aggregations (Garshelis et al. 1986). Non-territorial males live in those same all-male aggregations, which are often established adjacent to areas where reproductive females and territorial males occur (Riedman and Estes 1990). Home range or use estimates for sea otters from the northern Knight Island subpopulation average 23 km^2 for males and 21 km^2 for females (Ballachey and Bodkin 2006).

14.1.3 Status of Injury and Recovery Classification

The EVOS restoration plan (EVOS Trustee Council 1994) provides long-term guidance for restoring resources injured by the 1989 spill. The 1994 recovery objective for sea otters was stated as:

> Sea otters will be considered recovered when population abundance and distribution are comparable to pre-spill abundance and distribution, and when all ages appear healthy.

By 2002 (EVOS Trustee Council 2002b), this objective had been refined to be:

> "[S]ea otters will have recovered when the population in oiled areas returns to its prespill levels and distribution, and when biochemical indicators of hydrocarbon exposure in otters in the oiled areas are similar to those of otters in unoiled areas."

In 2002, the Trustee Council concluded that "[s]ea otter recovery is underway for much of the spill-affected area, with the exception of subpopulations at the most heavily oiled bays in western PWS. For this reason, sea otters continue to be in the recovering category."

14.1.4 Overview of EVOS Trustee Council-Funded Restoration Efforts

The EVOS Trustee Council strategy for sea otter restoration was to conduct research to find out why sea otters are not recovering; initiate, sustain, or accelerate recovery of sea otters; monitor recovery; and protect sea otters and their habitat (EVOS Trustee Council 1994). Since the early 1990s, the EVOS Trustee Council has funded numerous projects toward these restoration efforts (see Appendix A). Most restoration efforts have focused on research to better evaluate sea otter recovery and mechanisms of injury. The most important of these studies was the Nearshore Vertebrate Predator project, a 5-year study of factors limiting recovery of four indicator species that relied largely or exclusively on nearshore marine habitats. The project focused on two fish eaters—river otters and pigeon guillemots—and two species that feed on shellfish and other invertebrates—harlequin ducks and sea otters. A major conclusion of the project was that invertebrate predators were failing to recover from EVOS, and continued exposure to oil was a factor contributing to delayed species and ecosystem recovery (Peterson et al. 2003). This project generated follow-on studies that continue to look at oil exposure as a potential factor for the lack of recovery of sea otters, harlequin ducks, and pigeon guillemots.

14.2 RESOURCE ASSESSMENT

The current condition of the sea otter population in PWS can potentially derive from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed on the basis of sea otter life history and inherent ability of the population to recover from the initial impacts of the spill, the nature and degree of ongoing exposure to lingering EVO that could cause adverse effects and injury, and the nature and magnitude of other factors that could affect the condition of the population.

14.2.1 Initial Impact from Spill

Sea otters are considered particularly susceptible to the effects of oil spills (Davis et al. 1988; Bodkin and Ballachey 1997). Unlike seals that have blubber for insulation, sea otters rely on air trapped within their thick pelage to maintain a constant body temperature. Sea otters also have a high metabolism and spend nearly all of their time in the water foraging and resting. Many sea otters were in the path of the oil as it spread southwest from Bligh Reef into bays and around islands of western PWS. Of the 871 recovered carcasses, 493 were collected from PWS, 181 from the Kenai Peninsula, and 197 from the Kodiak Island/Alaska peninsula area (Ballachey et al. 1994).

Hundreds of sea otters became coated with oil in the days following the spill. The 871 carcasses that were recovered included some that died prior to the spill but total mortality was underestimated to the extent that not all carcasses were recovered (Ballachey et al. 1994; Bodkin et al. 2002; Garshelis 1997; DeGange et al. 1994). Initial mortalities were due to acute injury (primarily oil coating leading to hypothermia, stress, and specific pathologies as described in Section 14.2.2; Lipscomb et al. 1993, 1994). In PWS, Garrott et al. (1993) estimated 40 percent (2,650 sea otters) of the population was lost to acute mortality, and that the pre-spill sea otter population size in oiled areas of western PWS was 6,546. However, using different assumptions, Garshelis (1997) estimated that fewer than 1,000 otters died. It is likely that the true number will never be known. Due to the convoluted nature of the shorelines, some otters survived by finding refuge in bays and inlets that escaped oiling or were only lightly oiled (Garrott et al. 1993). A massive effort to rehabilitate injured sea otters took place in the weeks following the spill, although survival of rehabilitated and released otters was relatively low (Monnett et al. 1990; Bodkin and Ballachey 1997).

14.2.2 Residual Effects Following the Spill

Studies to assess damage to sea otters from long-term exposure to oil have been focused on examination of population growth rates, mortality rates and mortality age-distribution, reproductive success, and juvenile survival (see “Acute and Chronic Toxicity to Individuals,” below). Because pre-spill data are limited, many studies relied heavily on comparisons between sea otters from oiled portions of PWS and sea otters from areas not affected by the oil spill. Some pre-spill data were available on sea otter abundance and mortality, but data specific to western PWS are particularly lacking for the years immediately prior to the oil spill (1986–1989).

14.2.2.1 Impacts on Population

Two modeling efforts projected recovery rates for the sea otter population in PWS following the spill. Garrott et al. (1993) used the very simple method of applying the pre-spill annual growth rate of 9 percent, and estimated at least 3 years but more likely 5 years would be needed for the population to recover to pre-spill abundance. This simple model applied to all of PWS, which assumed that all sea otters contribute equally to growth, did not consider potential ongoing exposure and did not address chronic effects that may influence other important population parameters. Garrott et al. (1993) acknowledged that population growth following the spill was not evident based on post-spill surveys through 1991.

Udevitz et al. (1996) applied an age-specific population model to western PWS and predicted recovery times ranging from 10 to 23 years, depending on assumptions regarding survival rates. Like the Garrott et al. (1993) projection, the Udevitz et al. (1996) model did not incorporate potential chronic effects related to the spill into projected recovery times.

The sea otter population of western PWS was thought to be near equilibrium density prior to the spill (Estes et al. 1981; Garshelis et al. 1986). Garrott et al. (1993) estimated that the population of western PWS grew only 2 percent per year between 1985 and 1989. After an estimated loss of about 40 percent of the western PWS population following the spill in 1989, the population was slow to begin recovery, with no observed growth in 1990 and 1991 (Garrott et al. 1993).[62] But after 1993, the sea otter population in western PWS began to increase at a rate about one-half the estimated long-term pre-spill rate of increase (Bodkin et al. 2002). From 1993 to 2000, the population increased by about 600 otters, representing an annual growth rate of approximately 4 percent (Bodkin et al. 2002). However, within some of the most heavily oiled areas on northern Knight Island, numbers of sea otters were well below pre-spill levels, with no population growth observed (Bodkin et al. 2002). Since 2002, the population at northern Knight Island has declined significantly, in contrast to the larger western PWS area (Ballachey and Bodkin 2006).

Given the discrepancy in estimates of population loss, it is useful to look at growth rates. Garshelis and Johnson (2001) estimated an annual growth rate from 1990 to 1996 of 2.5 percent in western PWS. Bodkin et al. (2002) report an annual growth rate from 1996 to 2000 in western PWS of 5 percent. They conclude that the western PWS population growth rate is lower than expected, based both on the observed growth rate of 10 percent throughout most of the 20th century (Bodkin et al. 1999) and population modeling predictions of 9 percent growth by Garrott et al. (1993) and 10–14 percent growth by Udevitz et al. (1996). The 9 percent growth rate suggested by Garrott et al. (1993), however, is for the entire PWS and is an average of higher growth rates in the more recently colonized northeast with an estimated 1985–1989 growth rate of 2 percent in the spill area. Thus, the observed annual growth rate of 5 percent in the spill area between 1996 and 2000 is higher than the estimated pre-spill growth for that area from 1985 to 1989 and appears in keeping with expected growth rates, given that they are lower in the longer-occupied western PWS than the more recently colonized eastern PWS. The longer term rate of change in western PWS between 1993 and 2005 is about 2 percent (Ballachey and Bodkin 2006).

The subpopulation of sea otters on northern Knight Island has shown no evidence of population growth from 1993 through 2000 and has demonstrated a significant negative population trajectory during the period 1993–2005 (Bodkin et al. 2002; Ballachey and Bodkin 2006). This

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[62] Raw numbers of estimates of the pre-spill population size and the number of mortalities in western PWS spill vary greatly between researchers (e.g., Garrott et al. [1993] and Garshelis [1997]). However, it is widely agreed that the decrease in sea otter population following the spill was extensive and widespread.

area received heavy oiling and sea otter mortality after EVOS approached 90 percent (Bodkin and Udevitz 1994). From 1993 to 2000, the mean population size was 77; from 2002 to 2005, the mean population size declined to 39 individuals. A mark-resighting study from 1996 to 1999 showed retention rates of otters at Montague Island three times as high as on northern Knight Island (Bodkin et al. 2002). The Montague Island subpopulation had been stable for many years, while the Knight Island subpopulation appears to never have regained stable population structure (age and sex distribution) after being greatly reduced by the oil spill. Food limitation has been ruled out as the probable cause of lack of population growth, because food resources are at least as plentiful for the northern Knight Island subpopulation as for the Montague Island subpopulation (Dean et al. 2002; Bodkin et al. 2002). Nevertheless, Bodkin et al. (2002) suggest that it is possible that interactions between food availability and chronic exposure to oil contamination are influencing sea otter mortality and may contribute to the lack of recovery at Knight Island.

A closer look at the known population dynamics on northern Knight Island provides some insight into differences between oil-impacted and unimpacted otter populations. Data reported on population structure show that in 1996–1998, there was a lower than usual proportion of females in the population, and that 48 percent of the females were in the 0–3 age class (Bodkin et al. 2002). Also, in 1996, a bachelor group of 26 males immigrated into the area, but were no longer there in 1997. These data indicate that the northern Knight Island subpopulation has not achieved a stable structure. Many of the females were below reproductive age and in 1996, one-third of the population consisted of young non-territorial males. Given the unstable dynamics, the population would not be expected to grow at the same rate as the stable Montague Island subpopulation.

Monson et al. (2000a) looked for evidence of long-term effects of EVOS by examining the distribution of ages at death from sea otter carcasses collected in western PWS between 1989 and 1998. They compared the age distribution of post-spill mortalities to that of pre-spill mortality. Pre-spill carcasses were collected from Green Island in 1977–1985. They also compared pre-spill age distribution to three time periods of post-spill mortality, 1989 post-spill, 1990–1991, and 1992–1998, using the Kolmogorov-Smirnov two-sample test. The post-spill mortality age distribution in 1989 differed significantly from pre-spill; the post-spill mortality age distribution in 1990–1991 also differed significantly from the pre-spill distribution. The 1992–1998 data did not differ significantly from the pre-spill data, nor did it differ significantly from the 1990–1991 data, but it was significantly different from the 1989 post-spill distribution, suggesting a gradual return to the pre-spill pattern (Monson et al. 2000a).

Because of the small number of animals at northern Knight Island, a small amount of predation (or any additional source of mortality) on this population (i.e., loss of three animals annually) would also have a greater impact on the Knight Island subpopulation than on larger populations that could better absorb the loss (Bodkin et al. 2002). Given all of the unanswered questions surrounding social dynamics and other influences on the Knight Island subpopulation, the mechanism underlying its lack of growth is far from clear, but is most likely due to elevated mortality and emigration rates potentially linked to chronic exposure to lingering oil (Bodkin et al. 2002).

14.2.2.2 Acute and Chronic Toxicity to Individuals

Necropsies were performed on many of the sea otter carcasses recovered after the spill to examine the pathological response to oil. Many different agencies were involved in the rehabilitation and necropsy of sea otters, but a lack of coordination led in some cases to incomplete collection and documentation of data. Nevertheless extensive pathological examinations were conducted on a large sample of carcasses (Lipscomb et al. 1993, 1994).

A general picture of acute toxicity from the initial oil spill has been generated based on 214 carcasses of sea otters that died in the spill (carcasses recovered from the wild rather than those that died in captivity). Of these carcasses, 152 were oil-coated, and 62 were not oil-coated. Cause of death for many of the sea otters was shock. Based on necropsy data collected, Lipscomb et al. (1994) proposed that a series of events took place. Heavily oiled otters initially became hypothermic. Some otters died of hypothermia, while many did not. Those that survived the immediate effects of hypothermia by grooming themselves of the oil undoubtedly ingested large amounts of it. These otters stopped feeding to groom, and body fat stores became depleted. Oil exposure (likely through inhalation or ingestion) led to interstitial pulmonary emphysema. Of 152 oiled carcasses recovered from the wild, 100 (66 percent) had interstitial pulmonary emphysema while only 13 (21 percent) of unoiled carcasses recovered had pulmonary emphysema. The extreme stress on the otters from all of the preceding events led to gastric erosions that resulted in gut hemorrhage. Of the oiled carcasses, 83 (55 percent) had gastric erosions and hemorrhage, while only 4 (6.5 percent) of the unoiled carcasses had gastric hemorrhaging. Finally, the oiled otters went into shock, followed by death.

Chronic effects of either the initial oiling or lingering oil have not been clearly established. Some indicators of chronic effects have been measured. In 1992, wild sea otters from the spill area were compared to sea otters from an unoiled area and found to have differences in blood serum chemistry (consistent with liver damage) (Ballachey et al. 2003). This finding indicates there were some otters that survived the initial oiling, but suffered chronic effects and, possibly, premature mortality. Continuing studies (1996–2005) have found that blood values have largely returned to normal levels, but a low proportion of otters still show elevated serum enzymes indicative of liver dysfunction (Ballachey and Bodkin 2006) (see "Biomarker Measurements" in Section 14.2.3, below). From 2001 to 2005, livers of sea otters in western PWS were examined grossly and biopsied using endoscopy (Ballachey and Bodkin 2006). Generally, livers of sea otters from the oiled areas of northern Knight Island were observed to be slightly swollen and pale, and these changes were seen to a lesser extent in sea otters captured at Montague Island. However, when biopsies were examined for histopathological changes, few differences were noted between the two regions. Studies of river otters have shown that low levels of petroleum hydrocarbons in the diet were associated with anemia and increased metabolic costs (Duffy et al. 1994).

Monson et al. (2000a) used data from sea otter carcasses collected between 1989 and 1998 to develop demographic models with varying survival rates from year to year. Each model was run for 9 years, simulating the post-spill years 1990–1998. For each simulation, they compared the predicted age distribution of otters dying in each year with those actually recovered from the field, and used maximum likelihood methods to determine the most likely patterns of change.

The pattern predicted by the models and supported by the data shows that the youngest animals suffered the greatest mortality after the spill, but their survivorship increased in the years following the spill (Monson et al. 2000a). The older animals, on the other hand, showed greater and greater rates of mortality as the years went by. These long-term effects were strongest on animals that were 4–5 years old at the time of the spill. The models also showed that through the mid 1990s, there were likely reduced survival spill effects on otters born after 1989, suggesting either maternal influences or exposure to lingering oil in the environment. Analysis of age-at-death data collected in western PWS since 1998, using the models developed by Monson et al. (2000a), further indicate that the anomalous mortality patterns continue at least through 2005 (Ballachey and Bodkin 2006). Advances to the earlier Monson et al. (2000a) models describe a pattern of higher survival among a peripheral or “less spill affected” area in PWS that is contributing individuals to a “core” area, such as Knight Island, where mortality is higher (Ballachey and Bodkin 2006).

Ballachey et al. (2003) compared first-year survival of sea otter pups between oiled and unoiled parts of PWS in 1992–1993. Survival was significantly higher (0.74 vs. 0.52, p=0.05) in pups from eastern PWS than those from western PWS. An earlier study by Rotterman and Monnett (1991) also found lower post-weaning survival of sea otter pups in oiled western PWS, compared to those from unoiled areas in eastern PWS. Ballachey et al. (2003) noted that sea otters (both adults and pups) from eastern PWS were in significantly better condition (when comparing the condition variable of mass/length) than western PWS sea otters. A few aspects of the study make it difficult to draw a conclusive link between juvenile survival and oiling.

First, cause of death could not be established for most of the pups that died. The few that were subject to necropsy were found to have suffered from either malnutrition or trauma, and evidence of fighting (presumably among conspecifics) was apparent, but no link was made to pathologies that would indicate oil contamination. Second, the western PWS sample may not have been representative of the oil-spill-affected population (Ballachey et al. 2003). Because of low sea otter densities, Ballachey et al. were not able to obtain sufficient numbers of animals from the most heavily oiled portions of PWS, and thus sampled otters from areas that were not as strongly affected by oil according to the Alaska Shoreline Fall 1989 Oiling Survey Map (NOAA). Third, the two populations varied in duration of occupation. Eastern PWS was more recently colonized (1970s) than western PWS (1950s). Sea otters are known to reduce the density and mean sizes of their prey over time (Kvitek 1993), and greater foraging efficiency has been noted in areas recently occupied by sea otters than areas with longer established populations (Garshelis et al. 1986). More recently occupied areas would be expected to have greater food resources, possibly leading to better survival.

A possible link to oil contamination from this study is the finding of elevated levels of certain blood serum enzymes and other blood chemistry parameters in the western PWS population similar to those that have been linked to oil contamination in laboratory tests (Ben-David et al. 2000; Mazet et al. 2000). There was no relationship, however, between blood variables and subsequent survival of juvenile otters (Ballachey et al. 2003). Thus, the study provides evidence of lower juvenile survival in the western PWS population, but the effects of oil cannot be isolated from other potential area effects.

14.2.2.3 Effects on Reproductive and Other Population Parameters

Reproduction is not a likely limiting factor and does not vary among populations demonstrating different growth rates (Monson et al. 2000b). Garshelis and Johnson (2001) compared pre- and post-spill pup production in western PWS, using data that had been collected in 1977–1985, 1990–1991, and 1993–1996. They chose three sites in western PWS: Applegate Rock, Green Island, and Montague Island. Only Montague Island was not directly affected by EVO. At Applegate Rock, the most heavily oiled of the sites sampled, the pup ratio (number of pups to number of adults) was significantly higher in 1990 than pre-spill. Pup production was generally greater than or equal to the pre-spill values in all of the post-spill samples. There was no significant difference in pup ratios between pre-spill and 1990 at unoiled Montague Island or heavily oiled Green Island.

There was no difference in reproductive rates between otters on oiled northern Knight Island and otters on unoiled Montague Island in 1995 to 1997 (Bodkin et al. 2002). In fact, reproductive rates (as measured by pup to adult ratios) exceeded those reported from other parts of Alaska and Russia.

14.2.3 Exposure to Lingering Oil

Exposure of sea otters to lingering oil has been evaluated in terms of 1) home ranges and feeding behavior and their relations to lingering oil, and 2) biomarker measures of PAH exposure.

14.2.3.1 Feeding Behavior

Exposure to lingering oil for sea otters would occur primarily through direct contact with oil while excavating for prey in contaminated sediment, through ingestion of contaminated prey such as clams and mussels, or through exposure to oil resuspended in the water following some source of disturbance (Bodkin et al. 2002). The overlap between nearshore sea otter foraging habitats and likely locations of lingering oil in the intertidal zone supports this assumption.

Because of small home range size and strong fidelity to home ranges, sea otters inhabiting areas with lingering oil would be expected to encounter oil that remained in foraging habitats, including the intertidal zone. In the decade following the spill, many studies were conducted in western PWS to measure sea otter survival, reproduction, and mortality, but this information was never linked to any measured exposures to lingering oil at the level of the individual. In 2002, researchers began collecting data that would help quantify the frequency and duration of sea otters' use of habitats that likely still contained lingering oil (i.e., the intertidal zone of previously heavily oiled sites). Using Knight Island as a study area, U.S. Geological Survey researchers looked at foraging habits of 16 individual sea otters, including measurement of the proportion of foraging time spent in the intertidal zone where lingering oil is known to occur (Ballachey and Bodkin 2006). They found that sea otters conducted most of their foraging in the subtidal zone, with an average of 13 percent of their foraging occurring in the intertidal zone. Foraging primarily for clams, this translates to digging about seven intertidal pits per otter per day, or an average of 2,500 (range < 200 to 10,000) intertidal pits per otter per year. Preliminary analyses failed to detect significant correlations with the amount of intertidal foraging and CYP1A levels in individuals. However, the study demonstrates the propensity for individual otters to contact intertidal sediment frequently. Ballachey and Bodkin (2006) also discovered that the proportion of foraging in the intertidal was significantly less in the summer, when biomarker measures of oil exposure were obtained, than in the spring.

14.2.3.2 Biomarker Measurements

A 3-year study was conducted from 1996 to 1998 to examine the biomarker levels in blood of PWS sea otters (Ballachey et al. 2002). Levels were compared between otters from areas that were oiled by EVOS and otters from nearby unoiled locations. The study also compared the general health of the two populations through blood serum chemistries and body condition analysis. The oiled population was sampled from northern Knight Island and Naked Island; the unoiled population was sampled from Montague Island.

Measurement of activity of CYP1A has proven to be a sensitive and specific biochemical indicator of exposure to PAHs. Selected PAH compounds induce CYP1A activity, which can then be used to assess the degree of exposure to PAH.[63] RT-PCR[64] testing was conducted on sea otter blood samples in 1996, 1997, and 1998. In all three years, RT-PCR results demonstrated greater induction of CYP1A for the oiled population than the unoiled population. Analysis of variance on ranks of values showed the area effect to be significant ($p<0.001$) while age, sex, year, and capture method were not. CYP1A levels generally declined from 1996 to 1998, suggesting that CYP1A in sea otters corresponded to declining residual oil in the environment (Ballachey et al. 2002). Preliminary results demonstrating the bioavailability of lingering EVO and its ability to induce CYP1A have been recently demonstrated by Short et al. (2005), who compared the potential for CYP1A induction by PAHs collected by SPMDs deployed in different areas of PWS where different types of petroleum contamination were known to occur. Extracts were injected into trout fry (Springman et al. 2005) and EVO was demonstrated to be a potent inducer of CYP1A, unlike samples collected from human use sites or other area-wide sources.

Additional studies were conducted in 2001–2005 (Ballachey and Bodkin 2006). Data from these studies show an apparent trend of convergence of CYP1A levels in the two populations, with no difference by 2005, which would be consistent with diminishing persistence of EVO in the environment.

The 1996–1998 study also compared blood serum enzymes for indication of general health differences between the oiled and unoiled populations. Significantly higher levels of gamma glutamyl transferase (GGT), a blood serum enzyme used as an indicator of liver function, were found in sea otters from oiled areas ($p<0.001$) in all three study years, 1996, 1997, and 1998 (Ballachey et al. 2002). None of the other serum enzymes (AST, ALT, AP, and LDH) were elevated. In follow-up studies conducted in 2001–2005 the pattern continued: few to none of the sea otters from the unoiled population had high GGT, whereas about 20 percent of those

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[63] PCBs can also induce CYP1A.

[64] "RT-PCR" is a reverse-transcriptase-polymerase chain reaction that quantifies mRNA for CYP1A.

from the oiled population had relatively high (defined as >20 U/L) GGT levels (Ballachey and Bodkin 2006).

14.2.3.3 Indirect Effects of Lingering Oil

Lingering oil impacts to sea otter food supplies could occur through either contamination of prey or a decrease in prey populations. Clams (particularly the butter clam *Saxidomus giganteus*) are of particular interest, because clams make up about 70–80 percent of western PWS sea otter diets and butter clams are a preferred prey species. Mussels are also of interest, because they make up 10–20 percent of adult sea otter diets, and possibly much more for individual adults and most juveniles (Doroff and Bodkin 1994; Dean et al. 2002).

Several studies have examined hydrocarbon levels in clams and mussels from the oiled area (Carls et al. 2004; Trowbridge et al. 2002). Overall, clams sampled from the intertidal zone of oiled beaches had elevated levels of hydrocarbons after the spill, while clams sampled from subtidal locations did not. Blue mussels found in the intertidal zone of oiled beaches were also shown to have elevated levels of hydrocarbons in their tissues for at least 2 years after the spill; by 2002, these levels were no longer elevated over background.

Doroff and Bodkin (1994) found no significant difference in mean hydrocarbon concentrations in clam tissue from subtidal areas of two oiled sites compared to an unoiled site in 1991. A previous study had shown elevated levels of hydrocarbons in mussels located at the intertidal portion of one of the oiled sites (Green Island) in 1989 (Andres and Cody 1993).

Summaries of recent studies of PAH bioavailability and accumulation in bivalves are presented in Section 7 for clams and Section 8 for mussels. In general, PAH concentrations in mussels have declined to background levels in recent years and no longer represent a substantive pathway to EVO exposure to sea otters. Recent data for clams are limited and suggest that clam populations located near patches of lingering EVO may have slightly elevated TPAH concentrations in comparison with those in reference locations.

Based on these studies, there is more evidence of lingering oil in bivalves from the intertidal than the subtidal zone. Sea otters forage primarily in the subtidal zone (Bodkin et al. 2004; Ballachey and Bodkin 2006). The risk of contamination from lingering oil, then, would be highest for juveniles and certain individual adults that focus their predation in intertidal habitats (Doroff and Bodkin 1994; Bodkin et al. 2004; Ballachey and Bodkin 2006).

While some studies have shown slower growth rates and higher mortality of clams in heavily oiled areas (Fukuyama et al. 2000), a comparison of food resources between heavily oiled, northern Knight Island and unoiled Montague Island measured more (but not significantly more) prey energy available to sea otters in the oiled area (Dean et al. 2002). However, sea otters required significantly less foraging time, and juvenile female sea otters were in significantly better condition (weight/total length) at northern Knight Island than at Montague Island (Dean et al. 2002). They concluded that the greater foraging efficiency and female condition could be attributed to the effects of reduced sea otter density on their prey populations, resulting in greater prey densities and mean prey sizes (Dean et al. 2002).

14.2.4 Other Stressors

Hatfield (1998) reported that killer whales were preying on sea otters in PWS in the early 1990s. There are no data quantifying the impact of this predation on sea otters in PWS. The amount of predation, as well as removals by subsistence hunting, would be useful information to help evaluate the current circumstances of the sea otter population in western PWS. Killer whales have been implicated in sea otter population declines in the Aleutian Islands (Estes et al. 1998). A small number (as few as three or four) of otters lost to predation or harvest on Knight Island could have a significant impact because of the small size of the population (Bodkin et al. 2002). However, evidence contrary to predation or harvest as the sole cause of sea otter decline comes from beach-cast carcasses, an indication of mortality from other sources than predation (Monson et al. 2000a, Bodkin et al. 2002). In the juvenile sea otter survival study (Ballachey et al. 2003), most of the carcasses were not recovered and some could have been lost to predation.

It is possible that cascading social or cultural effects resulting from the loss of specific age or sex components to the population, or disruption to the social structure, may continue to affect recovery of sea otter populations in ways similar to those proposed for the PWS killer whale groups and that may occur with other social species of mammals (e.g., wolves). However, these avenues of injury would be difficult to assess and they have not been addressed as part of post-spill studies.

14.3 SUMMARY AND RECOMMENDATIONS

Information on sea otter population parameters, habitat, exposure to lingering oil, and behavioral/physiological indicators was weighed to assess the current condition of sea otters and their relationship to EVO. The most thorough study of sea otters was performed in the northern Knight Island Archipelago, which was heavily oiled in 1989 and provides a “worst case” evaluation of ongoing EVOS impacts to sea otters.

Sea otters suffered significant impacts from both the initial spill and from ongoing exposure to lingering oil. Sea otters are considered one of the most vulnerable of marine animals to the effects of oil spills. Many sea otters were in the path of the oil as it spread south from Bligh Reef into bays and around islands of western PWS. It was estimated that 40 percent of the population in western PWS was lost to acute mortality, and in some areas, mortality approached 90 percent. Because sea otters forage in the intertidal and subtidal zones, digging up to several thousand intertidal pits per year, they have a high potential for exposure to lingering EVO, which is concentrated in the intertidal region of the shoreline. Exposure of sea otters on northern Knight Island to lingering oil has been measured since 1996 using CYP1A, an enzyme that is induced in vertebrate species following exposure to PAHs. The most recent biomarker data on exposure collected in summer of 2004 and 2005 (Ballachey and Bodkin 2006) indicate that levels of CYP1A in sea otters from northern Knight Island have declined to levels measured in sea otters from unoiled Montague Island, suggesting that exposure to PAHs is no longer a concern in this oiled area. Most researchers agree that as the spatial extent of lingering oil diminishes over time, the potential for sea otters to be exposed to lingering oil and their degree of exposure should also diminish.

Sources of uncertainty in the assessment of sea otters include the necessarily focused nature of the study (on Northern Knight Island), the methodologies used for CYP1A measurements (different techniques were used over a 10-year span), the uncertain relationship between exposure (as measured by CYP1A) and individual or population effects, and the importance of other stressors. The subpopulation of sea otters on northern Knight Island is relatively small and is susceptible to small impacts on the total population. Predation by killer whales may be particularly important, and subsistence hunting could also be a factor. Emigration of sea otters must also be considered. Food resources apparently are not limiting on northern Knight Island and should not limit population growth.

It is likely that sea otter populations in some portions of western PWS are recovering from measurable acute and chronic effects of the spill, evidenced by a modest average annual rate of increase between 1993 and 2005. However, recovery of the subpopulation on northern Knight Island appears to be constrained by demographic lag, residual oil effects, continuing exposure, or by some other unknown stressors.

It is recommended that the Trustee Council continue to classify the sea otter population in PWS as “recovering.” It is also recommended that studies continue to monitor the condition of the western PWS and northern Knight Island sea otter populations and to better understand factors that may be causing delayed recovery.

15. HARBOR SEAL

15.1 INTRODUCTION

Harbor seals (*Phoca vitulina richardsi*) are year-round residents and one of the most common marine mammals in PWS and the Gulf of Alaska. Initial impacts of EVOS were assessed by observing and enumerating harbor seals. Numbers of seals at oiled and unoiled sites in the years following EVOS were compared to determine if there were differences in abundance, tissue chemistry, or population trends (Frost et al. 1994a,b, 1999).

15.1.1 Statement of Problem

The harbor seal was classified as "not recovering from the effects of the spill" in 2002 (EVOS Trustee Council 2002b). This conclusion is based on the current recovery objective for harbor seals of "a stable or increasing population." However, this objective does not fully address the overall goal of a *return to conditions that would have existed if the spill had not occurred.* For that reason, the overall goal was considered when evaluating the condition of the harbor seal population.

In this report, the life history of harbor seals and scientific data on the severity and nature of impacts from the spill (43 percent decline at oiled sites between 1988 and 1989 compared to an 11 percent decline at unoiled sites), as well as population trends in PWS and the region, are used to reevaluate the current recovery status of harbor seals.

15.1.2 Natural History and Ecology

Harbor seals are one of the most common marine mammals in PWS and the Gulf of Alaska. They are year-round residents, their habitat is near-coastal, and their haul-out sites in PWS are often located in estuaries and protected coves. Harbor seals spend much of their time hauled out on land during pupping and molting season; haul-out sites are selected for protection from land predators and access to deep water and food. Haul-out sites include intertidal reefs, rocky shores, mud and sand bars, floating glacial ice, and gravel and sand beaches (Frost 1997). Harbor seals show high fidelity to their haul-out sites, with individual seals averaging only two to four haul-out sites per season (Frost 1997).

Harbor seals prey primarily upon fish and invertebrates. Major food items of PWS harbor seals include pollock, capelin, Pacific cod, herring, and octopus (Frost 1997). Harbor seals are also known to eat other schooling fish, flatfish, squid, and crustaceans (Wynne 1993). Detailed studies on fatty acid composition of seal blubber show that harbor seals from different haul-outs within PWS may have very different diets (Iverson et al. 1997). This may, in part, reflect their tendency to eat whatever is locally and seasonally available. Harbor seals tend to remain within 50 km of shore, and typically feed in water less than 200 m deep (Frost et al. 2001; Lowry et al. 2001; Hastings et al. 2004; Small et al. 2005).

15.1.3 Status of Injury and Recovery Classification

The number of harbor seals in PWS and the Kodiak Archipelago began to decline in the 1970s and 1980s, before EVOS. In 1994, the EVOS Trustee Council (1994) reported that if the conditions that were causing seal populations to decline before the spill improved, normal growth might replace animals lost to the spill. However, if conditions continued to be unfavorable, the affected population would continue to decline.

The recovery objective established for harbor seals in both the 1994 restoration plan and 2002 update is a stable or increasing population (EVOS Trustee Council 1994, 2002b). In 2002, based on continued population declines, the EVOS Trustee Council (2002b, p. 11) concluded that harbor seals "are considered not recovering from the effects of the oil spill."

15.1.4 Overview of EVOS Trustee Council-Funded Restoration Efforts

The EVOS Trustee Council strategy for harbor seal restoration was four-fold: 1) to conduct research to find out why the population was not recovering; 2) to initiate, sustain, or accelerate recovery; 3) to monitor population recovery; and 4) to protect the seals and their habitats (EVOS Trustee Council 1994). Since the early 1990s, the EVOS Trustee Council has funded numerous projects toward these restoration efforts (see Appendix A).

15.2 RESOURCE ASSESSMENT

The current condition of the harbor seal population in PWS can potentially derive from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed on the basis of harbor seal life history and inherent ability of the population to recover from the initial impacts of the spill, residual effects from the original spill, the likelihood that the behavior of harbor seals could result in ongoing exposure to lingering EVO to a degree that could cause adverse effects and injury, and the nature and magnitude of other factors that could affect the condition of the population.

15.2.1 Initial Impact from Spill

In the early weeks after the spill, harbor seals swam in oiled water, surfacing in oil slicks to breathe at the air–water interface where volatile hydrocarbon vapors were present (Frost et al. 1994a). Through spring and summer, seals crawled over and rested on oiled rocks and algae at haul-outs. Harbor seals inhabiting central PWS, including Eleanor Island, the north part of Knight Island, and the west side of Knight Island Passage became heavily coated with oil. More than 80 percent of the seals observed in these areas in May 1989 had oil on them (Frost 1997).

Many seals remained oiled until their annual molt in August (Frost et al. 1994a). Some of the haul-out sites remained oiled through the May/June pupping season. Many pups became oiled shortly after birth (Frost 1997). In the Bay of Isles and Herring Bay on the north end of Knight Island, 89–100 percent of all seal pups seen were oiled (Lowry et al. 1994).

Nineteen seal carcasses were recovered from PWS and the Gulf of Alaska following the spill, 14 of which were oiled (Loughlin et al. 1996). Spraker et al. (1994) examined the seals, but because of carcass decomposition, were unable to determine exact cause of death. To assess injuries, researchers then harvested 27 additional seals, both oiled and unoiled. They documented brain and liver lesions, as well as skin irritation and conjunctivitis in oiled seals. Brain lesions may have been responsible for the abnormal behavior exhibited by many seals immediately after the spill in April and May 1989 (Loughlin et al. 1996). They were lethargic, disoriented, and unusually tame. These atypical behaviors had ceased by September 1989 and were not observed again (Frost 1997).

Using data from trend counts at major haul-out sites in PWS, Frost et al. (1994a) estimated the total mortality of harbor seals caused by EVOS to be 302. This number was based on the number of seals missing from oiled haul-out sites relative to previous counts. This estimate was called into question by Hoover-Miller et al. (2001), who suggested that invalid assumptions were used in Frost's analysis. They agreed that seals declined at oiled sites in 1989, but suggested mortality was lower than the 302 estimate, and that many seals simply relocated (i.e., moved to unoiled haul-out sites). They suggested that Frost et al. (1994a) did not sample a large enough geographic region to determine whether the missing seals had died, and that a greater portion of PWS (beyond the 25 sample sites in central and eastern PWS) should be sampled.

Frost et al. (1994b) examined tissues (brain, liver, blubber, muscle, etc.) from seals collected in heavily oiled parts of PWS and compared them with seals from moderately oiled and unoiled areas in 1989 and 1990. In 1989, concentrations of PAHs were significantly higher in blubber of seals from the oiled population. Blubber was the only tissue sampled that exhibited elevated PAH concentrations. For seals from both populations, PAH concentrations in other tissues (brain, liver, muscle, etc.) were near or below detection limits. By 1990, PAH concentrations in oiled seals were significantly lower than they had been in 1989, indicating oil impacts had decreased one year later.

Frost et al. (1994b) also examined metabolites of petroleum-related aromatic compounds in bile samples from the same two populations. Seals from the 1989 and 1990 oiled populations had significantly higher concentrations of fluorescent aromatic compounds than the control population. They concluded that the level of exposure to petroleum-related hydrocarbons for harbor seals in PWS had declined by 1990, but was still higher than exposure for seals outside the spill path.

15.2.2 Residual Effects Following the Spill

Surveys were conducted after the spill to compare counts of harbor seals at oiled and unoiled sites (Frost et al. 1994a). The study used a survey route that had been established to document harbor seal population trends in PWS in 1984. The number of seals at each of the 25 haul-out sites within the survey route was counted in 1983, 1984, and 1988. Seven of the 25 sites were oiled by EVOS, whereas the other 18 sites remained unoiled. Surveys continued annually after 1989. The number of harbor seals at oiled sites declined from an estimated 675 harbor seals in 1984 to 418 seals in 1988, and at unoiled sites declined from 1,121 in 1984 to 637 in 1988. The estimated annual rate of decrease for both unoiled and oiled sites was approximately 12 percent per year between 1984 and 1988. In 1989, the average number of seals at oiled sites declined by 43 percent compared with an 11 percent decline at unoiled sites (Frost et al. 1994a). By 1990, there was no longer any difference in the rate of decline between oiled and unoiled sites, and the authors concluded that the effects of the oil spill were evident only in population declines of 1989 (Frost et al. 1994a).

Frost et al. (1999) continued post-spill surveys at the same 25 sites from 1990 to 1997. Surveys were conducted during the annual molt (August–September) each year. The objective was to determine the overall population trend of harbor seals in PWS and included both oiled and unoiled areas. Counts were found to be substantially influenced by time of day, date, and time relative to low tide each day. Because of this, the authors chose to use a model with a standardized set of covariates to adjust the annual counts to the expected count under optimal conditions. Bootstrap methods[65] were used to address uncertainty. Counts were then analyzed with both linear and loglinear regression. Adjusted counts showed significant annual population declines of 4.6 percent per year. There was no significant trend in unadjusted counts, which fluctuated annually.

In the last decade, the number of seals in the Kodiak Archipelago has been increasing (Small et al. 2003; Blundell et al. 2005), although the abundance level is much reduced from the 1970s. ADFG continued to conduct annual surveys in PWS following 1997, and recent counts indicate the population may be stabilizing after the sustained decline over the past two decades (Figure 15-1) (Blundell et al. 2005; Small 2006, pers. comm.).

Residual effects of the original spill are unlikely. In the initial oiling, harbor seals were exposed via direct contact with EVO and possibly indirectly through consumption of contaminated food. These exposures were short-lived, however, and were probably unimportant in the years subsequent to the oil spill (Hartung 1995). Although harbor seal populations declined at a greater rate at oiled sites in comparison with unoiled sites in 1989, these differences were transient and no longer discernible by 1990.

15.2.3 Exposure to Lingering Oil

Harbor seals could potentially be exposed to lingering oil as they move about on their haul-out sites. Exposure would be limited to dermal contact because seals do not forage in intertidal sediments. Lingering oil in surface sediments occurs primarily in the form of highly weathered, solid asphalt-like material (Short et al. 2004a). Weathered oil in this form is insoluble and, therefore, unlikely to be bioavailable to seals. Although some seals may come into contact with

[65] In statistics, bootstrapping is a method for estimating the sampling distribution of an estimator by resampling with replacement from the original sample.

this oil, impacts from this type of contact would be negligible. In contrast to surface oil, subsurface lingering oil is less weathered and more soluble, and therefore potentially bioavailable. However, it is highly unlikely that seals would ever come in contact with subsurface EVO at isolated subsurface locations in the intertidal environment.

Indirect effects of lingering oil on harbor seal via exposure to nearshore food resources are also expected to be negligible. The low likelihood of contamination in prey, combined with large feeding areas relative to the extent of lingering oil, makes continued exposure to lingering EVO through food resources for harbor seals unlikely. To the extent that such exposure may occur, its influence on harbor seal populations would probably be small relative to the conditions that affected population declines prior to the spill, which may continue to exist today.

In summary, there is no evidence that harbor seals are affected by lingering EVO. Although lingering oil may remain in small amounts at some haul-out sites, the low potential for exposure suggests that its overall direct impact on harbor seals is likely to be negligible.

15.2.4 Other Stressors

The number of harbor seals in PWS and the Kodiak Archipelago began to decline in the 1970s and 1980s, before EVOS. Researchers reported a 63 percent decline in PWS during 1984–1997 (Frost et al. 1999) and an 85 percent decline on Tugidak Island during 1976–1988 (Pitcher 1990). Although those declines may have begun earlier, comparable counts are not available. In other parts of the Kodiak Archipelago, counts also likely declined substantially between the mid 1970s and the early 1990s (Small et al. 2003).

Causes of harbor seal population declines in PWS and the Gulf of Alaska prior to EVOS are not known with certainty. Many possible factors may have contributed to the declines and could continue to affect harbor seal populations. These include predation by killer whales, disease and parasitism, reduced prey biomass and quality due to either commercial fisheries or climate-driven ecosystem shifts, and human-caused mortality from illegal shooting and subsistence harvests, contaminants, and incidental takes from fishery operations. The extent to which these factors influenced population declines, either individually or cumulatively, is unknown (Frost 1997; Jemison and Kelly 2001; Small et al. 2003).

Fadely et al. (1998) did a broad study of blood chemistry, blubber parameters, and body condition of seals in PWS, southeast Alaska, and Kodiak Island to determine if there were differences between declining (PWS) and non-declining (southeast Alaska) populations. They found no differences among the populations sampled (Kodiak Island, PWS, and southeast Alaska) during 1993–1996. Based on the measured blood values, the majority of seals sampled showed no indication of poor health. Some researchers have suggested that the population declines may be due, in part, to a decrease in carrying capacity created during the oceanic regime shift of 1976. Average climate in the Gulf of Alaska shifted in 1977 from cool to warm, and over subsequent years, a reorganization of fish and shellfish communities occurred (Anderson and Piatt 1999). The impact of such reorganization of the fish community on apex predators, such as the harbor seal, is unknown.

The subsistence take of harbor seals provides some useful perspective on the magnitude of other stressors on the harbor seal population. It is important to note that subsistence harvesting of harbor seals is not considered by regulators or by experts to have an adverse impact on the harbor seal population (Fall 2006c, pers.comm.). The annual take of harbors seals in the area historically impacted by the spill[66] ranged from 495 to 695 from 1992 to 2004, with more than 7,000 individuals harvested from this area since 1992 (Wolfe et al. 2005).

15.3 SUMMARY AND RECOMMENDATIONS

The information provided in the previous sections was weighed to determine the overall recovery status of harbor seals and to assess the need for additional restoration efforts. This evaluation included assessment of the current condition of harbor seals and consideration of factors contributing to that condition. Key evidence weighed in the recovery evaluation included population survey data, the potential for oil exposure (from the initial spill and residual effects, as well as current exposure to lingering oil), and effects of other stressors.

The recovery objective for harbor seals is "a stable or increasing population." This evaluation of harbor seals also took into consideration the relative importance of EVOS and other stressors in influencing the current condition of the population.

It is recommended that the Trustee Council classify the harbor seal as "recovered" from the effects of EVOS based on the following:

- In the weeks after the initial spill, harbor seals were exposed directly to EVO in the water and on the shoreline; however, initial oil exposure was short-lived. The total mortality of harbor seals caused by EVOS was estimated to be 302 individuals.
- Although harbor seal populations declined at a greater rate at oiled sites in comparison with unoiled sites in 1989, these differences were transient and were no longer discernible by 1990.
- It is unlikely that harbor seals have significant exposure to lingering oil in intertidal sediments. Although lingering EVO may remain in small amounts at some seal haul-out sites, weathered oil on the surface is insoluble and not bioavailable to seals.
- Indirect exposure of seals to lingering EVO via food resources is also unlikely due to the low likelihood of contamination in prey and the large size of feeding areas relative to the extent of lingering oil.
- Based on the last five years of surveys, the number of harbor seals in PWS appears to have stabilized and may be increasing, although the abundance level is still reduced from the 1970s. The average decline between 1990 and 2005 is 2.4 percent.
- The effects of other stressors and natural variability are the most likely explanation for the current condition of harbor seal populations in PWS and the Kodiak Archipelago.

[66] Defined for this discussion as the harvest areas known as North Pacific Rim (PWS and lower Cook Inlet), Kodiak, Chenega Bay, Chenega Lagoon, Chenega Lake, and Perryville.

Harbor seal populations were declining in these areas prior to EVOS, indicating the effect of other stressors. The factors contributing to this decline are not known with certainty but could include predation, disease, reduced prey biomass or quality, human-caused mortality, contaminants, incidental takes from fishery operations, or some combination of these factors.

- As an example of the magnitude of another stressor, the annual subsistence take for harbor seals in this general area ranged from 495 to 695 from 1992 to 2004. Subsistence harvesting of harbor seals is not considered by regulators or by experts to have an adverse impact on the harbor seal population.

This evaluation took into consideration the level of uncertainty associated with the available data. For harbor seals, there is uncertainty associated with population estimates due to 1) natural variability, and 2) sampling (i.e., population count) variability. However, this level of uncertainty is relatively low and does not affect analysis of general harbor seal population trends over multiple years. In addition, while the mechanism causing an observed effect may be highly uncertain or unknown, the observed effect may still be highly certain. For example, the harbor seal population decline prior to EVOS is well documented even though the cause of the decline is unknown.

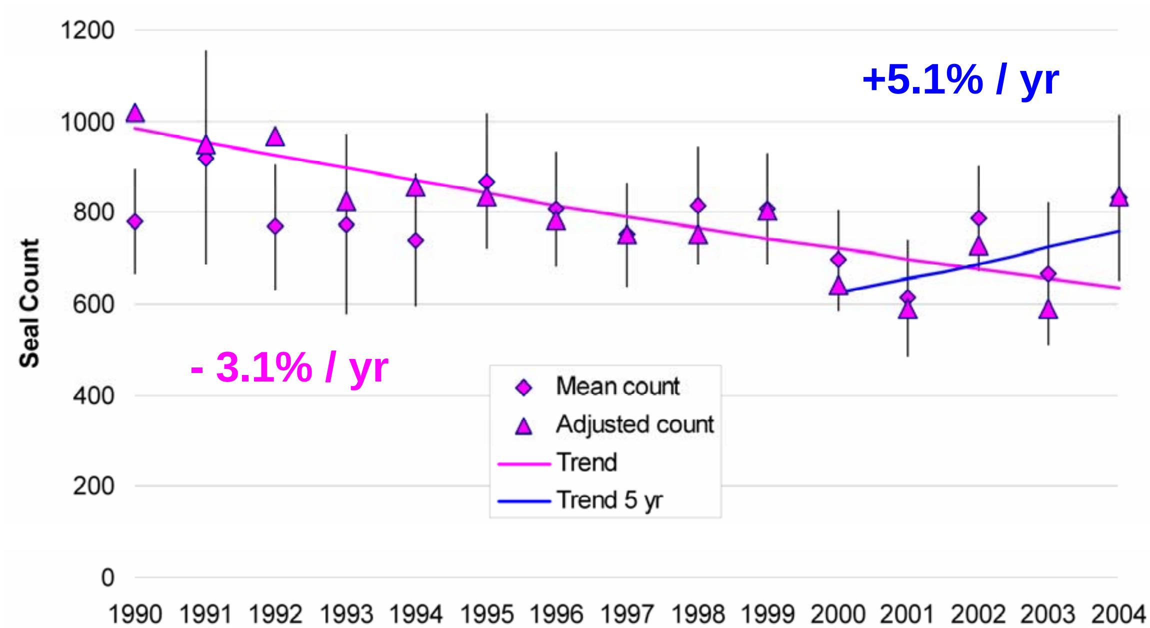

Figure 15-1. Long-Term (1990–2004) Population Trend for Harbor Seals in Prince William Sound, Alaska. (More recent data [2000–2004] may indicate that the population is stabilizing and beginning to increase, but short-term trend results should be viewed with caution because 1999–2003 results still demonstrated a negative trend.) (Source: ADFG 2005d)

16. KILLER WHALE

16.1 INTRODUCTION

As many as eight resident pods and members of the AT1 transient population of killer whales (*Orcinus orca*) are sighted regularly in the PWS/Kenai Fjords region. Initial impacts of EVOS were assessed by observing and photographing the individual whales of these pods during the spring and summer for three years (1989, 1990, and 1991) following the spill. These observations were compared with known demographics of the pods to determine if there were changes in overall population, seasonal abundance, birth rates, mortality rates, and/or habitat usage (Matkin et al. 1994; Dahlheim and Matkin 1993).

16.1.1 Statement of Problem

The AB pod of the killer whale was classified as "recovering" in the 2002 assessment of resource recovery status (EVOS Trustee Council 2002b). Information on the life history of the killer whale (i.e., long lived and slow to reproduce), severity and nature of impacts from the spill (i.e., loss of 36 percent of the population, loss of females from the AB pod), population modeling, and population trends are evaluated here to assess the current recovery status of the killer whale. The AT1 population is included in the discussion because the population trend of this resource shows a similar response to EVOS.

16.1.2 Natural History and Ecology

The killer whale, or orca, is the largest member of the dolphin family (Delphinidae), attaining sizes of 8 m in length for males and 7 m for females, and weighing as much as 4,000 kg in males and 3,000 kg in females (Wynne 1993; Matkin and Saulitis 1997). They are found worldwide, but have been studied most heavily in the northern Pacific, including waters of the western U.S., Canada, and Alaska, where researchers have identified and tracked pods and individual orcas for more than three decades (Reeves et al. 2002; Gordon and Flaherty 1990; Matkin et al. 1994).

The killer whale is a long-lived species with a relatively low rate of reproduction (Matkin and Leatherwood 1986). Males live 50 to 60 years and females up to 80 or 90 years (Reeves et al. 2002). The maximum reproductive life span of a female is about 30 years, with a calf born approximately every 5 years; thus, each female produces only four to six calves throughout her life (Gordon and Flaherty 1990).

Unique markings on individual killer whales make it possible to identify them as individual and thus conduct population studies on them using photographic techniques (Matkin and Saulitis 1997). Males and females can be distinguished by the shape and size of the dorsal fin. Males have a large (1–1.8 m), triangular dorsal fin. The dorsal fin of females is much smaller (less than 0.9 m) and is distinctly curved, or sickle-shaped. In addition, individual killer whales can be identified by the unique saddle-patch markings immediately behind the dorsal fin (Gordon and Flaherty 1990; Reeves et al. 2002).

Three genetically distinct lineages occur throughout the northern Pacific. They are known as residents, transients, and offshores. Residents and transients are found in PWS and are discussed in this report. Residents forage on fish and maintain extremely stable social groups over time. Transients feed on marine mammals and there may be some emigration/immigration from groups.

Resident pods may number up to 40–50 individuals. Pods comprise smaller, maternal groups, which include a female and her offspring of both sexes. Resident whales remain in these maternal groups for life (Matkin and Saulitis 1997). One or more maternal groups may occasionally split off and form a new pod, but there is no exchange of individuals between established resident pods (Matkin et al. 1994). Transient groups are much smaller than resident pods, averaging fewer than six individuals per pod (Gordon and Flaherty 1990), and often range over a wider area than residents (Matkin et al. 1994), although the AT1 transient group is an exception. The social dynamics of these groups are not well understood, but are more complex than that of resident pods (Dahlheim and Matkin 1994).

Resident pods of killer whales enter PWS during any time of year, but primary use is in the summer (July, August, and September), when large numbers of coho salmon pass through PWS on their way to spawning grounds. Southwestern PWS, Resurrection Bay, and Aialik Bay all appear to be important feeding areas for resident killer whales during salmon migration (Matkin and Saulitis 1997). During this time, the AB pod is one of the more commonly sighted resident pods in PWS (Matkin and Saulitis 1997).

One group of transient killer whales, the AT1 population, appears to center its range in PWS/Kenai Fjords and may be found there year-round. These whales hunt harbor seals along the shorelines of Knight and Montague islands and in the glacial fjords of Kenai Fjords. They also hunt Dall's porpoises in Knight Island Passage, Montague Strait, and Kenai Fjords (Matkin and Saulitis 1997). Unlike other groups of transients, this population has shown up repeatedly and consistently in the same area year after year, appearing to center their range on PWS (Matkin and Saulitis 1997).

Of the few behaviors that bring killer whales into direct contact with the shoreline, one that has been documented for both residents and transients of PWS is beach rubbing. Groups of whales enter shallow water for brief periods of time to rub their bodies on smooth, rounded stones. Some pods appear to do this quite regularly while others only sporadically (Matkin 2004, pers. comm.). Specific beaches in PWS and Kenai Fjords appear to be selected for this behavior, including Point Nowell, Sleepy Bay on Latouche Island, southern Perry Island, and Sunny Cove in Resurrection Bay (Matkin and Saulitis 1997; Matkin 2004, pers. comm.).

16.1.3 Status of Injury and Recovery Classification

The recovery objective established in 1994 for killer whales is a return to pre-spill numbers of 36 individuals for the AB pod. Monitored natural recovery was adopted as the restoration strategy that would be implemented to meet the recovery objective.

The recovery objectives and restoration strategy were not modified in 2002, although monitoring was expanded to include the AT1 population of killer whales. In 2002, the EVOS Trustee Council (2002b, p. 14) concluded that "since AB pod has not regained its pre-spill size of 36 individuals, killer whales are considered to be recovering, but not fully recovered from the effects of the oil spill."

16.1.4 Overview of EVOS Trustee Council-Funded Restoration Efforts

The EVOS Trustee Council strategy for killer whale restoration was to rely on natural recovery, to monitor population recovery, and to protect the whales and their habitat (EVOS Trustee Council 1994). Since the early 1990s, the EVOS Trustee Council has funded numerous projects toward these restoration efforts (see Appendix A). Most restoration efforts have focused on research to better evaluate killer whale recovery and mechanisms of injury. This has included development of photo identification techniques, biopsies of skin and blubber, genetic and contaminant analysis, and population modeling.

16.2 RESOURCE ASSESSMENT

The current condition of the killer whale population in PWS can potentially derive from one or more of the following:

- Residual effects from the spill
- Ongoing exposure to lingering oil
- Other stressors.

The relative importance of these different factors is assessed on the basis of killer whale life history and inherent ability of the population to recover from the initial impacts of the spill, the likelihood that the behavior of killer whales could result in ongoing exposure to lingering EVO to a degree that could cause adverse effects and injury, and the nature and magnitude of other factors that could affect the condition of the population.

16.2.1 Initial Impact from Spill

Within a week of EVOS in March 1989, the AB pod of killer whales was exposed to the spreading oil slick. The actual connection between individual deaths within the AB pod and exposure to the oil spill had not been formally established; however, the pod was observed surfacing in an EVO slick in the weeks following the spill and nearly all these deaths occurred at the time of the spill or the following winter. The resident AB pod suffered an unusually high rate of mortality. Prior to the spill, the pod numbered 36 individuals. One week following the grounding of the *Exxon Valdez*, seven members of this pod were unaccounted for. The following spring, six more members of the pod were missing. By the third year of the study, a total of 14 whales were missing from the AB pod. No carcass of any of these whales was ever discovered, which is not unusual because whales apparently sink when they die (Matkin and Saulitis 1997). In addition, in studies from Puget Sound to Kenai Fjords, resident whales missing from their matrilineal groups have never appeared in other pods or matrilineal groups. In studies all along the west coast, it is accepted that if an animal is missing from a resident pod for more than a year, it is considered dead (Dahlheim and Matkin 1994). While matrilineal groups may occasionally split off from the main pod and form a new pod, the demographics of the whales that went missing from the AB pod indicate that was not the case. (The missing whales included individuals from four different subpods, and two of the missing females left behind 2- and 3-year old juveniles [Dahlheim and Matkin 1994].) Therefore, although there was a lack of material evidence, researchers concluded that all 14 missing whales had died (Matkin and Saulitis 1997).

The mortality rate for the AB pod was 19 percent in 1989 and 21 percent in 1990 (Matkin et al. 1994). This rate compares to a natural mortality rate for killer whales of 2.2 percent or less (Dahlheim and Matkin 1994). Although the exact cause of mortality of these whales has not been proven, killer whales were observed swimming through and surfacing in oil slicks in the days and weeks following the spill. It is possible that petroleum or petroleum vapors were inhaled by these whales (Matkin and Saulitis 1997). Killer whales may have been exposed to petroleum hydrocarbons at the time of the spill via consumption of contaminated fish (Dahlheim and Matkin 1993). The AB pod is a resident group of killer whales that forages primarily on coho salmon during its seasonal foraging excursions into PWS and may also prey on other fishes (herring, halibut, and sablefish). However, although nearshore rockfish were affected by the spill, concentrations of petroleum hydrocarbons in rockfish or other species of fish were not identified as a causative factor in the decline of the AB pod. Similar mechanisms of exposure have been proposed for the AT1 population of transient killer whales, including nearshore predation on harbor seals, but have not resulted in determination of injury.

Spatial and temporal patterns in killer whale populations provide an important framework for judging recovery in the context of past and present exposure to EVO as well as natural variability. By 1991, the resident AB pod had been reduced from 36 to 22 whales. Since then, the population has fluctuated with additional births and mortalities, to between 22 and 26 individuals. Despite the birth of seven new calves between 1990 and 1996, the pod still numbered only 26 whales in 2001. As of 2005, the pod numbered 27 (Matkin 2005, pers. comm.). The remaining six resident pods that frequent PWS and Kenai Fjords have seen an overall increase in population from 86 in 1984 to 105 in 1992 (Matkin et al. 1994) and 134 in 2004 (Matkin 2005, pers. comm.).

The post-spill distribution of killer whales in PWS is shown in Figure 16-1. There is nothing reported in the literature to suggest that killer whales have shifted their geographic distribution following EVOS.

The AT1 transient population has not been identified by the EVOS Trustee Council as an injured resource, but it should be noted that this group also suffered losses subsequent to the oil spill. At the time of the spill, members of the AT1 population were observed in the area of the spill and adjacent to the tanker when it was leaking oil. Two stranded AT1 whales were found in 1990, but the cause of death was not determined. Nine whales from the AT1 transient population disappeared shortly after the spill (Matkin and Saulitis 1997). Because transient whales do not always remain in their natal groups, it could not be determined immediately that the missing AT1 whales were dead. However, after 5 years, these whales still had not reappeared in their original groups or in any other observations of killer whales and therefore were considered dead. It was suspected the missing whales died from the protracted effects of either inhaling oil or oil vapors or as a result of extensive feeding on heavily oiled harbor seals following the spill (Matkin and Saulitis 1997). Because of the initial difficulty in confirming deaths of the missing AT1 whales, a listing of "injured" for this population was not pursued in the years immediately following the spill. Consequently, the EVOS Trustee Council (1999, 2002b) has not recognized the sharp decline in the AT1 group following the spill and has not identified this population as an injured resource. The EVOS Trustee Council (1999, 2002b) has noted the presence of high levels of non-EVO contaminants in tissues of AT1 whales and has recommended continued monitoring of these substances as possible contributing factors in recent populations trends in the AT1 group.

16.2.2 Residual Effects Following the Spill

The killer whale is a long-lived species with a relatively low rate of reproduction (Matkin and Leatherwood 1986). Males live 50 to 60 years and females up to 80 or 90 years (Reeves et al. 2002). The maximum reproductive life span of a female is about 30 years, with a calf born approximately every 5 years; thus, each female produces only four to six calves throughout her life (Gordon and Flaherty 1990). These characteristics suggest that recovery rate of a population following a significant loss of individuals will be relatively slow.

Modeling of killer whale population dynamics in PWS was performed by Matkin et al. (2003). They also discuss the characteristics of the AB pod relative to those of other resident pods in PWS and in northern British Columbia. The modeling analysis indicates that the AB pod was impacted by EVOS primarily through the loss of young and reproductive females. These are the age/sex classes that usually demonstrate very low mortality rates. The reproductive value of the AB pod decreased as a result of EVOS because the young females offer the most potential contributions to future population growth. Based on this modeling effort, it is concluded that the AB pod has not yet recovered from the initial impacts of EVOS because of the loss of young females, but would have recovered had there been no loss of females at the time of the spill.

The analysis of birth and death rates shows that although birth rates were not affected by the spill, the death rate for the AB pod was much higher than expected during and immediately following the spill (Matkin et al. 2003). During 1989–1990, there were 14 deaths in this pod, when only 1 would have been expected. By 1996, the death rate returned to within the range of other resident pods in PWS. The resident population of killer whales in PWS excluding the AB pod grew 3.3 percent per year. This rate is somewhat higher than the 2.6 percent growth rate for the resident killer whale population in northern British Columbia in the 1970s and 1980s. Matkin et al. (2003) hypothesize that the PWS population is recovering from a previous perturbation (prior to EVOS) or that the carrying capacity of the habitat for killer whale in PWS has increased.

Matkin et al. (2003) looked at the effect that loss of females had on the potential recovery of the AB pod. Their analysis of reproductive value and birth and death rates does suggest that the AB pod would not yet have recovered to a pre-spill abundance given its age/sex structure and reproductive condition after EVOS. In addition to loss of females, AB pod recovery has suffered from higher mortality rates since the spill compared to other pods. It might be useful to analyze the potential population growth rate and projected abundance of AB pod based on age/sex structure after EVOS and fecundity/mortality rates estimated from PWS pods as a whole.

16.2.3 Exposure to Lingering Oil

At the time of the spill in 1989, contact with liquid oil on the sea surface and inhalation of oil vapor at the air–sea interface were the environmental pathways of most concern for resident killer whales, although transient AT1 killer whales may have contacted oil through ingestion of oiled harbor seals. These pathways and routes of exposure are not significant today because except for occasional sheens from beaches, lingering oil does not occur at the sea surface, but rather is predominant in the intertidal zone as highly weathered asphalt-like material in surface sediments or is largely sequestered in subsurface sediments.

Dermal contact with intertidal sediments during beach rubbing is a possible but unlikely route of exposure to lingering oil for killer whales. Three of the rubbing locations used by killer whales in PWS (Point Nowell, Perry Island, and Sleepy Bay) were within the trajectory of the oil spill, and Sleepy Bay was heavily oiled. However, there are three major factors, which when considered collectively, indicate that significant dermal exposure to lingering oil is unlikely. These factors are as follows:

- The AB pod has been observed visiting rubbing beaches only on an infrequent basis (Matkin and Saulitis 1997) and most rubbing occurs for only 10 to 20 minutes at a time (Matkin 2004, pers. comm.). Hence, the frequency and duration of exposure via dermal contact with rubbing beaches is likely to be low, if it occurs at all.
- Rubbing locations would need to coincide with the elevation and patchy distribution of lingering oil, and the depth of disturbance caused by rubbing must be sufficient to mobilize subsurface lingering oil and bring it into contact with the killer whale. Because subsurface lingering oil is patchily distributed over a relatively small fraction of the beach area of PWS, the likelihood of whales encountering lingering oil is low.
- The depth of disturbance that could be caused by rubbing is unknown, but must be sufficient to bring the oil into contact with the skin of the whale. The bioavailability of lingering oil via dermal contact with killer whales is also unknown,[67] and is likely to be mitigated by continuous washing by seawater during routine swimming following beach rubbing.

In summary, none of the exposure pathways and routes considered at the time of the spill is present today. Because lingering EVO is sequestered in subsurface sediments or occurs predominantly as a weathered solid in surface sediments of the intertidal zone, it is not bioaccessible via the inhalation route of exposure, and exposure is also unlikely via dermal contact during beach rubbing. Significant food-chain exposure is unlikely because fish metabolize PAHs rapidly (Lawrence and Weber 1984; Eisler 2000), and significant

[67] The dermal route of exposure would be difficult to quantify even for well-known mammalian wildlife species that could be studied in controlled laboratory settings and is almost never conducted in ecological risk assessments where the frequency and duration of contact is much higher than indicated here.

bioaccumulation is unlikely. Moreover, the prey fish favored by resident killer whales do not occur in the vicinity of lingering oil or, in the case of Pacific herring, are present in the intertidal zone only transiently during spawning (Matkin and Saulitis 1997; Hart 1973; Brown and Carls 1998).

Based on the low likelihood of exposure and the low bioaccessibility of oil to killer whales, chances for lingering oil impacts to killer whales are very low.

16.2.4 Other Stressors

Conflicts between killer whales and fisheries may have contributed to the AB pod mortalities. In 1985, the AB pod began removing fish from the longlines of commercial fishing boats. Fishermen attempted many methods of deterring the whales, including attempts to frighten them away by shooting at them (Dahlheim and Matkin 1994). At least 10 whales were documented with bullet wounds in 1985 and 1986. Five of these whales subsequently died (Matkin and Saulitis 1997). The shooting of killer whales apparently ceased after 1986 when it was outlawed by the Marine Mammal Protection Act, and there is no indication that it has been a problem since that time. It is possible that the wounding of some whales may have weakened them and, over time, contributed to their premature mortality (EVOS Trustee Council 2002b). However, the AB pod increased in numbers in 1987 and 1988 and it is unlikely that bullet wounds suffered 3 years previously caused the unprecedented mortalities of 1989–1990.

Transient whales prey on harbor seals, whose population in PWS has been in decline since before the oil spill (Matkin and Saulitis 1997). In addition, AT1 and other transients contain high concentrations of non-EVOS-related contaminants in their blubber (EVOS Trustee Council 2002b; Ylitalo et al. 2001). However, levels of contaminants are 10–20 times lower in resident whales and it is unlikely that exposure to non-EVOS-related chemicals is adversely affecting recovery of the AB pod.

16.3 SUMMARY AND RECOMMENDATIONS

Information was evaluated to determine the recovery status of killer whales and to assess the need for additional restoration efforts. The AB pod and the AT1 transient population both provide good examples of the challenges, data limitations, and uncertainties in assessing the condition of living resources in a dynamic environment with multiple stressors. Spatial and temporal patterns in killer whale populations provide an important framework for judging recovery in the context of past and present exposure to EVO as well as natural variability.

Within 2 years of the spill, the resident AB pod of killer whales had been reduced from 36 to 22 whales. The actual connection between individual deaths within the AB pod and exposure to the oil spill has never been formally established; however, the pod was observed surfacing in an EVO slick in the weeks following the spill. Despite the birth of seven new calves between 1990 and 1996, additional mortalities resulted in a total number of 27 whales in 2005. The linkage between the oil spill and the current condition of the population is established through consideration of population trends, life history characteristics, and population modeling. The AB population has been increasing steadily in the 17 years since the spill. Killer whales are long-lived and slow to reproduce, and a disproportionate number of females were lost at the time of the spill. Modeling of the population dynamics (Matkin et al. 2003) indicates that the AB pod was impacted by EVOS primarily through the loss of young and reproductive females, who offer the most potential contributions to future population growth. However, additional unanticipated mortalities after the spill also contributed to the very slow recovery. Deaths included young whales orphaned at the time of the spill and other whales that lost their close relatives at the time of the spill. Based on this modeling effort, it was concluded that the AB pod has not yet recovered from the initial impacts of EVOS primarily due to the loss of young females, and would have recovered had there been no loss of females at the time of the spill.

The AT1 transient population provides a good example of how a resource injury can be overlooked. At the time of the spill, members of the AT1 population were observed in the area of the spill and adjacent to the tanker when it was leaking oil. Two stranded AT1 whales were found in 1990, but the cause of death was not determined. It appears that the AT1 population centers its range in PWS/Kenai Fjords, and may be found there year-round. They had maintained stable numbers from the time studies began in 1984 until the time of the spill. A retrospective evaluation of population trends for the AT1 population indicates that shortly after the spill, it suffered a loss similar in scale to that observed for the AB pod (Figure 16-1); nine whales disappeared shortly after this spill. Because transient whales do not always remain in their natal groups, it could not be determined immediately after the spill that the missing AT1 individuals (other than the two stranded whales) were dead. However, after 5 years, these whales had not reappeared in their original group or in any other observation of killer whales, and they were considered dead. It is suspected that these whales died from the protracted effects of either inhaling oil or oil vapors, or as a result of extensive feeding on heavily oiled harbor seals immediately after the spill. The AT1 population was recently classified as threatened under the Marine Mammal Protection Act. The timing and magnitude of the loss of individuals from the AT1 population directly following the spill and the fact that the AT1 population is found in PWS year-round suggest that exposure to the spill was the likely cause of the decline immediately following the spill.

It is unlikely that killer whales could be exposed to lingering oil in intertidal sediments. Because lingering EVO is sequestered in subsurface sediments or occurs predominantly as a weathered solid in surface sediments of the intertidal zone, it is not bioaccessible via the inhalation route of exposure, and exposure is also unlikely via dermal contact during beach rubbing. Significant food-chain exposure is unlikely because fish metabolize PAHs rapidly.

Conflicts between killer whales and fisheries may have contributed to the AB pod mortalities in the past. At least 10 whales were documented with bullet wounds in 1985 and 1986, and five of these whales subsequently died (Matkin and Saulitis 1997). The shooting of killer whales was outlawed in 1986 under the Marine Mammal Protection Act, and there is no indication that it has been a problem since that time. As time passes, other stressors play an increasingly important role in determining the condition of the AB pod and the AT1 population. Transient whales prey on harbor seals, whose population in PWS has been in decline since before the oil spill (Matkin and Saulitis 1997). In addition, AT1 and other transients contain high concentrations of non-EVOS-related contaminants in their blubber (EVOS Trustee Council 2002b; Ylitalo et al. 2001).

However, levels of contaminants are 10–20 times lower in resident whales and it is unlikely that exposure to non-EVOS related chemicals is adversely affecting recovery of the AB pod.

It is recommended that the Trustee Council consider the following:

- Continue to classify the AB pod as “recovering.”
- Add the AT1 population to the list of injured resource and classify as “not recovering.”
- Revise the recovery objective for the AB pod to more directly reflect the overall goal of a *return to conditions that would have existed if the spill had not occurred*. Other ecological factors or stressors can affect population trends, and they should be considered in the assessment of recovery status.
- Recognize that the depleted AT1 transient population warrants additional study before the status and factors affecting population trends of this group can be evaluated.

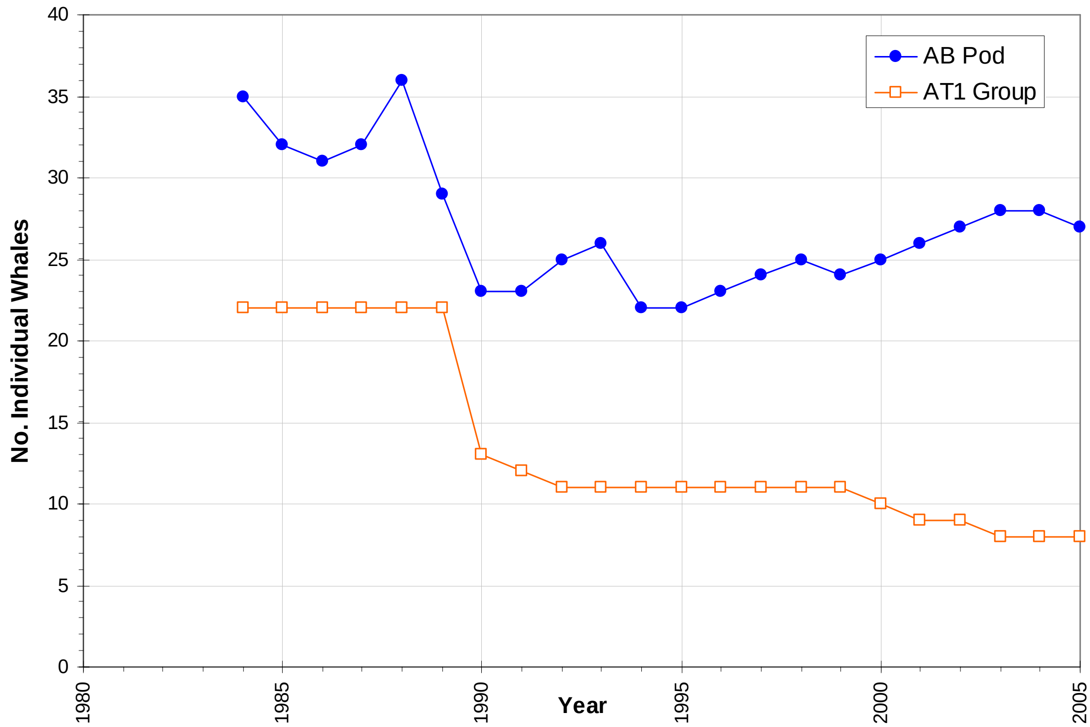

Figure 16-1. Numbers of Whales in the AT1 Group and in AB Pod, 1984–2005 (data provided by C. Matkin, North Gulf Oceanic Society)

SERVICES

17. COMMERCIAL FISHING

17.1 INTRODUCTION

EVOS resulted in the oiling of approximately 1,500 km of south-central Alaska's coastline, with heavy oiling affecting approximately 350 km of this area. The spill produced both acute and chronic impacts on many of the natural resources on which users depend. Commercial fishing depends directly on and intersects with many of the natural resources of this area, and commercial fisheries have long provided an important service in Alaska and the EVOS area. With approximately 54,000 km of shoreline, nearly 10,700 km of coastline, and more than 3,000 rivers and 3 million lakes, Alaska provides habitat for abundant quantities of harvestable fish (Frenette et al. 1997). Commercial fishing is important to Alaska's economy—approximately one-fifth of Alaska's employment is related to the seafood industry, and the commercial fishing industry is Alaska's largest private sector employer (Frenette et al. 1997).

EVOS produced acute and chronic impacts on species important to commercial fishing. Following the spill, commercial fisheries were closed and commercial fishing was listed as an injured service (EVOS Trustee Council 1994). The Pacific herring population in PWS continues to be depressed (Section 11). In the most recent assessment of service recovery status, commercial fishing was classified as recovering (EVOS Trustee Council 2003). Our objectives are to assess the current state of commercial fishing in the spill area and provide recommendations for future actions. We focus on those resources with commercial fisheries that are currently classified as injured, with some discussion of fisheries resources that have been injured in the past.

17.1.1 Background

The spill area falls within the Westward and Central ADFG management regions (Frenette et al. 1997). The Westward region includes Kodiak and the Alaska Peninsula; PWS and Cook Inlet are located in the Central region (Frenette et al. 1997). Because other waters are also within these regions, it is difficult to isolate EVOS as a factor when viewing historical data. However, these data do provide insight into overall trends in Alaska's commercial fishing industry.

As in the state of Alaska as a whole, commercial fishing is important to the spill area's economy (Goldsmith 2001). Combined, the Westward and Central regions contributed 76 percent of the total exvessel value (amount fishermen are paid for catch) for Alaska for salmon and 67 percent for herring in 1995 (Frenette et al. 1997). The 2005 commercial salmon harvest in PWS, was worth nearly $50 million after hatchery cost recovery was taken into account (Lewis and Hollowell 2005). Salmon account for about 39 percent of fishery values in the Westward region and approximately 87 percent in the Central region (Frenette et al. 1997). Herring were worth approximately 2 and 10 percent of exvessel values in the Westward and Central regions, respectively. Within the spill area, Kodiak has historically been among Alaska's top ports in volumes and values of salmon and herring landed (Frenette et al. 1997). Apart from halibut, groundfish and shellfish were not listed as significant generators of revenue in either the Westward or Central regions (Frenette et al. 1997).

Historical state data demonstrate the fluctuating nature of commercial fishery revenue and prices. These fluctuations may be caused by changes in resource abundance and catchability, market demands, and even the value of foreign currencies (Frenette et al. 1997). EVOS adds yet another factor to the dynamic economic service of commercial fishing.

17.1.2 Initial Impact from Spill

Initial impacts of EVOS on commercial fishing included damage to harvested resources and the subsequent emergency closures of commercial fisheries. Commercial fisheries for salmon, herring, crab, shrimp, rockfish, and sablefish were closed in 1989 for PWS, Cook Inlet, Kodiak, and the Alaska Peninsula (EVOS Trustee Council 1994). Shrimp and salmon commercial fisheries remained closed in parts of PWS through 1990 (EVOS Trustee Council 1994). The closure of commercial fisheries reduced potential incomes of commercial fishermen in the spill area (EVOS Trustee Council 1994).

17.1.3 Status of Injury and Recovery Classification

In 1994, the Trustee Council linked a large portion of the injury to commercial fishing to declines in pink salmon and Pacific herring populations. These species were the primary targets of Trustee Council-funded restoration and research projects (EVOS Trustee Council 1994). The recovery objective for commercial fishing was based on the recovery of “population levels and distribution of injured or replacement fish used by the commercial fishing industry” (EVOS Trustee Council 1994). The recovery objective required commercial fish population numbers and distributions to reach levels that would have existed in the absence of EVOS, or, as a substitute measure, to reach pre-spill levels. Strategies were developed to accelerate fish population recovery (e.g., determine what was hindering pink salmon growth and address it), protect and acquire fish habitat, and monitor recovery progress (EVOS Trustee Council 1994).

By 2001, both pink and sockeye salmon had been removed from the list of injured resources (EVOS Trustee Council 2002b). An assessment of commercial fishing in 2001 documented additional economic injury as a result of EVOS. The 2001 update on injured resources and services noted that high salmon prices made 1987 and 1988 years of relative prosperity for Alaskan fishermen and raised fishermen’s income expectations (EVOS Trustee Council 2002b, 2003). EVOS-related fisheries closures were claimed to be even more disruptive in the face of these high expectations (EVOS Trustee Council 2002b, 2003). In addition, the EVOS Trustee Council 2001 and 2003 updates on injured resources and services noted variable exvessel prices and reduced fishing permit utilization as potential indicators of long-term EVOS-related effects. The status of shellfish fisheries was not mentioned in status updates after 1994.

In 2001, the recovery objective was redefined as “when the commercially important fish species have recovered and opportunities to catch these species are not lost or reduced because of the effects of the spill” (EVOS Trustee Council 2002b, 2003). Restoration strategies continued to focus on restoring commercially important fish populations, developing fishery research techniques, and acquiring and protecting fish habitat (EVOS Trustee Council 2003). Because Pacific herring had not yet recovered and the herring fishery remained closed in the spill area in 2003, commercial fishing was considered recovering but not recovered (EVOS Trustee Council 2003).

17.1.4 Overview of Commercial Fishing Monitoring, Restoration, and Research Projects Conducted to Date

The EVOS Trustee Council funded nine projects to restore, monitor, or protect commercial fishing. In addition, the ADFG Commercial Fisheries Management and Development Division monitored catch and production of commercial fisheries on an annual basis.

17.1.4.1 Summary of Projects Funded by the EVOS Trustee Council

Commercial fisheries projects funded by the Trustee Council focused on research and monitoring of commercial fishing resources (summarized in Appendix A). Some projects, for example, Seitz et al.'s (2002) project *Testing Pop-up Satellite Tags as a Tool for Identifying Critical Habitat for Pacific Halibut* (Hippoglossus stenolepsis) *in the Gulf of Alaska,* produced results of immediate use to commercial fishermen, such as where resources could be located. Others facilitated communication between the scientific community and commercial fishermen (e.g., Adams and Mullins 2005). Another project evaluated the status of commercial fishing particularly with respect to herring fishery viability (Cooney 1999). One of the nine projects was listed as funded but no final report could be obtained for evaluation (Wilson 2006).

17.1.4.2 Summary of Projects Funded by Other Sources

ADFG monitors annual catch, production, and revenue of Alaskan commercial fisheries. Recent reports have shown commercial salmon harvest levels in the spill area to be at record highs (Lewis and Hollowell 2005), whereas herring fisheries have not recovered to harvestable biomass threshold levels as set by the Alaska Board of Fisheries (Ashe et al. 2005). Status updates on PWS shellfish fisheries are provided in Berceli and Trowbridge's (2006) report for ADFG.

17.1.4.3 Relationship of Projects to Recovery Objectives and Restoration Strategy

Commercial fishing has been considered in formulating management objectives for individual resources. In 1994, the Alaska Board of Fisheries increased the minimum herring biomass spawning threshold to ensure the viability of long-term herring harvest in the spill area. Projects to monitor and restore resources important to commercial fishing allow ADFG to manage resources with the goal of profitable and sustainable commercial fishing in mind.

17.2 ASSESSMENT OF RESOURCES ON WHICH COMMERCIAL FISHING DEPENDS

Commercial fishing depends on the profitable and sustainable harvest of finfish and shellfish species. These harvests rely on the health and availability of marine fish and shellfish. Commercial harvest level data are available from ADFG that provide costs and estimates of commercial fishing metrics, including harvest levels and values, across all Alaskan fisheries by region (e.g., for PWS between 1994 and 2005 [ADFG 2006b]). Statewide fisheries data for commercial finfish and shellfish are available in annual reports; these data include harvest levels and exvessel values by management region from 1986 to 1995 (Frenette et al. 1997).

17.2.1 Assessment of Individual Resources Important for Commercial Fishing

Finfish species of historical commercial importance and of concern to the Trustee Council include salmon, Pacific herring, and rockfish (EVOS Trustee Council 1994). Clams are the shellfish of historical commercial importance and of concern to the Trustee Council. Commercial harvest data from ADFG described above are included in individual resource assessments below. Overall, fishing permits in PWS had been reduced from 250 in 1981 to 130 in 2000 (EVOS Trustee Council 2002b). Citing a court case, the EVOS Trustee Council (2001) stated that declines in commercial fishing harvests other than herring and salmon could not be attributed to EVOS. By 2001, pink and sockeye salmon were considered recovered (EVOS Trustee Council 2002b, 2003). There were no oil-related fisheries closures in the spill area by 2001 (EVOS Trustee Council 2002b). Herring populations had not recovered as of 2003, and the recovery status of rockfish populations was unknown (EVOS Trustee Council 2003).

17.2.1.1 Salmon

Salmon are the most important commercial fish species in the spill area (Eggers 2005). Salmon provide approximately 87 percent of the spill area's exvessel values (Frenette et al. 1997). The Trustee Council considers salmon populations in PWS to be recovered (EVOS Trustee Council 2003). Commercial fishery data show that the 2005 PWS salmon harvest was the largest on record, and nearly twice the 1987 harvest (Figure 17-1). However, exvessel prices and overall revenue generated by salmon fisheries have not increased proportionately to harvest levels for a variety of reasons not linked to EVOS (Lewis and Hollowell 2005). Alaskan salmon prices are not currently as high as they were in the late 1980s for multiple reasons including the widespread availability of farmed fish (Frenette et al. 1997). The prices of most salmon species in PWS were comparable to or exceeded average statewide prices from 1984 to 2002 (ADFG 2002). Prices for sockeye salmon from PWS were above the state average from 1984 to 2002, and were nearly twice the statewide average from 2001 to 2002 (ADFG 2002). PWS salmon prices for all species displayed trends similar to statewide salmon prices before and after the spill (ADFG 2002). These data support the EVOS Trustee Council (2003) finding that PWS commercial salmon fishing does not continue to be affected by EVOS, and this important portion of the service may be considered recovered.

17.2.1.2 Herring

Pacific herring are of both ecological and commercial importance in PWS. Not only are they central to the marine food web but they and their spawn are harvested both commercially and for subsistence (Thomas and Thorne 2003). Pacific herring populations in PWS increased in the late-1980s before EVOS, and record numbers were reported immediately after EVOS primarily as a result of strong recruitment of the 1988 (pre-spill) year class. However, in 1993, the Pacific herring fishery was only 14 percent of the 1992 harvest and the 1989 year class was one of the smallest cohorts ever to return to spawn.

Historically, Pacific herring has been an important fishery in the spill area. In PWS, recorded pre-spill harvest levels ranged from 8.5 tons in 1974 to 1,335 tons in 1989 (Figure 17-2). Commercial herring harvests peaked in 1992 in PWS at 4,258 tons (Figure 17-2). The largest component of the herring fishery consisted of sac roe collected by seining (Ashe et al. 2005). The peak herring fishery exvessel value before EVOS exceeded $12 million (Figure 17-3). In 1994, the Alaska Board of Fisheries increased the spawning biomass threshold for herring from 8,400 tons to 22,000 tons (Ashe et al. 2005). Because estimated herring stocks were below this level, this increase effectively closed the fishery. Commercial herring fisheries were reopened in PWS from 1997 to 1999, and closed from 1999 to 2006 (Ashe et al. 2005). Herring fisheries in PWS will reopen when the biomass threshold exceeds 22,000 tons as determined by ongoing ADFG bioacoustics sampling. Herring biomass was estimated at 21,064 tons in 2005, close to the threshold (Ashe et al. 2005).

EVO exposure was suspected as a potential cause of the herring population decline in 1993. There is little evidence linking the depressed herring population to residual effects from the spill, and numerous other factors could explain the decline, including disease aggravated by high population density, food scarcity, and poor ocean conditions (EVOS Trustee Council 1999; Integral 2006). Regardless, the PWS herring population has not reached adequate biomass to be harvested, and commercial herring fishing has not recovered, though the lack of herring recovery may not be linked to EVOS (Integral 2006).

17.2.1.3 Clams

Clams are abundant and widely distributed in PWS, and they are used both by a wide variety of wildlife and humans for consumption. Clam populations have been affected by many factors including the displacement and alteration of habitat due to the 1964 earthquake and a siltation event in 1958 (Berceli and Trowbridge 2006). In the context of these events, the population-level effects of EVOS are relatively small (Integral 2006).

Clam harvest levels have decreased in the spill area for many reasons including decreased market demand for human consumption, depressed population levels, and reduced demand for bait clams in recently closed crab fisheries (Berceli and Trowbridge 2006). In addition, ADFG imposed stricter commercial clam harvest regulations in the 1980s to reduce conflicts between recreational and commercial clam diggers (Berceli and Trowbridge 2006). Commercial razor clam harvests in the spill area have declined since EVOS (Berceli and Trowbridge 2006). Butter and littleneck clam harvest takes place only in Cook Inlet, and recent commercial harvest levels have remained low (0.024 million to 0.5 million lb; ADFG 2005a). Data for pre-spill commercial harvests are inconsistent and absent for many years (ADFG 2005a).

The extent to which EVOS affected commercial clam harvests was never quantified (ADFG 2005a). A small number of commercial shellfish permits were issued in 1993, but clam harvest and exvessel data remain confidential for this year (Frenette et al. 1997; Berceli and Trowbridge 2006). With commercial clam digging occurring only in 1993, clams contributed a negligible portion to the commercial fishing economy in the spill area (Frenette et al. 1997). Commercial razor clam harvesting decreased dramatically in the 1970s and 1980s, and the 1989 fishery was closed prior to the spill due to paralytic shellfish poisoning and population level concerns (Figure 17-4). No beaches in PWS have been certified for commercial clam harvest by ADEC in recent years, so no commercial harvest has taken place (Berceli and Trowbridge 2006). Noncommercial clam digging data suggest that razor clam stocks remain depressed, and commercial digging is unlikely to occur in the near future (Berceli and Trowbridge 2006).

Although there are important data gaps in assessing commercial harvest in the context of EVOS, there is an abundance of factors external and prior to EVOS that likely influenced commercial clam harvesting declines. EVOS continues to elicit localized effects in a patchy manner throughout heavily oiled areas, but overall, clam populations are considered to be recovered (Section 7).

17.2.1.4 Rockfish

Before 1989, commercial fishing for rockfish was permitted throughout the year and not actively managed by the state; as a result, there are few harvest data available for the years before 1988 (Berceli et al 2005). Commercial rockfish harvest levels varied greatly from 1988 to 2006 in both state and federal waters of PWS, reaching a maximum of 506,468 lb in 1990 and a minimum of 47,990 lb in 2004 (Figure 17-5) (Berceli et al. 2005; ADFG 2006c). Berceli et al. (2005) cited increased market demand for rockfish as the primary factor behind the high 1990 harvest. After reaching their peak in the late 1980s and early 1990s, commercial rockfish harvest levels declined as a result of stricter management (Berceli et al. 2005). In the years following those of peak rockfish harvests, ADFG imposed an annual guideline harvest level of 150,000 lb for the directed rockfish fishery in state waters in 1992; after this limit was reached, rockfish could be retained only as bycatch from other groundfish fisheries (Berceli et al. 2005). However, a directed rockfish fishery remained open in federal waters after the state fishery imposed harvest limits, so total rockfish harvests remained high from 1994 to 1996 because of misreporting problems from vessels operating in both state and federal waters (Berceli et al. 2005). Rockfish harvest levels in PWS decreased with the close of any directed fishery in 2000, and bycatch levels fell with declining participation in Pacific cod fisheries; total rockfish harvest levels in PWS from 2001 to 2005 ranged from 47,990 lb in 2003 to 74,612 lb in 2002 (Berceli et al. 2005). Relative to earlier highly variable harvest levels, commercial rockfish harvest appears to have stabilized in recent years (Berceli et al. 2005).

Rockfish continue to be harvested only as bycatch in other groundfish fisheries, and harvest levels remain below levels deemed to be protective by fisheries managers (Ashe et al. 2005; Berceli et al. 2005). Historically, fishing pressure was the primary factor of concern for rockfish populations. It is unlikely that EVOS continues to affect rockfish in the spill area, and rockfish are considered to be recovered from its effects (Section 12).

17.2.2 Potential Confounding Factors in Evaluating the Role of EVOS in Commercial Fishing

There are several factors affecting commercial fishing that may confound any EVOS-related effects. The 1994 restoration plan included a discussion of potential confounding factors, including variable fishing returns, economic factors, fishery management restrictions, and the closure of fish processors. In addition, the management of noncommercial species in the spill area, natural resource population fluctuation, and conflicts with other service users may influence the status of commercial fishing

Since EVOS, commercial fishing market demands have altered substantially. Exvessel values are directly related to seafood market prices (Frenette et al. 1997). Farm-raised salmon and other factors caused salmon prices to decrease relative to inflation from pre-spill conditions (Frenette et al. 2005). Seafood market demands also change in reaction to outbreaks of paralytic shellfish poisoning and other diseases (Ashe et al. 2005; Berceli and Trowbridge 2006). These fluctuating demands explain most of the variability in exvessel prices, and might mask any influence of EVOS on commercial fishing. The efficiency of fish processing facilities can also affect the profitability of seafood harvests. For example, salmon harvest profits were damaged in 2005 when fish processors in Port Valdez, unable to cope with the record setting fish numbers, allowed an estimated 3.0 million fish to spoil to the point of becoming unmarketable (Lewis and Hollowell 2005).

Management practices of other species affect commercial fisheries as well. For example, groundfish fisheries in the spill area have been spatially limited for the purpose of sea lion management (Kruse et al. 2000). These practices may change harvest levels of rockfish and octopus, providing another confounding factor in measuring the recovery of commercial fishing for these species.

Cyclical fluctuations may occur naturally in resource populations (Eggers 2005). Overlap of these cycles with EVOS can make it difficult to distinguish effects of natural stressors from those of EVOS. Pacific herring populations, for example, have been known to experience “boom and bust” population cycles (Eggers 2005). Directional changes resulting from impacts such as EVOS may be masked by such natural fluctuations in abundance (Integral 2006).

Other services may conflict with commercial fishing interests, and their management may affect commercial harvest levels and values. Among these services are recreational and subsistence harvesting (Szarzi and Begich 2004; Fall et al. 2005; see Sections 18 and 19 of this document). Recreational anglers, recreational clam diggers, and subsistence harvesters of fish and shellfish all require access to many of the same resources as commercial fishermen. Seafood population levels are managed with these three groups in mind (ADFG 2006d). These three user groups often view each other as competitors for fisheries resources, as they harvest in the same waters of the spill area (ADFG 2005c; Fall et al. 2005). Subsistence harvesters in particular have lobbied for reduced commercial harvest limits for key species including herring and salmon (Alaska Board of Fisheries 2005).

17.3 SUMMARY AND RECOMMENDATIONS

The Trustee Council defines commercial fishery recovery as "when the commercially important fish species have recovered and opportunities to catch these species are not lost or reduced because of the effects of the spill" (EVOS Trustee Council 2002b, 2003). The most important fishery resources, pink and sockeye salmon, had recovered by 2001. As noted in Sections 7 and 12, respectively, clams and rockfish are considered to have recovered from the impacts of EVOS.

The historically profitable Pacific herring population has not recovered in the spill area. There are likely multiple factors that explain the lack of herring recovery, and there is little direct evidence that EVOS is among the factors still driving this decline (Section 11). According to the Trustee Council recovery objective, commercial fishing will have recovered when "commercially important fish species have recovered" (EVOS Trustee Council 1994). By this measure alone, commercial fishing cannot be considered recovered until herring are harvestable again.

It is recommended that the Trustee Council continue to classify commercial fishing as "recovering." The recommendations provided in Section 11 related to Pacific herring are also directly relevant to the commercial fishery for herring:

- Pursue the development and implementation of a herring restoration project or projects, including pilot studies.
- Consider including herring fishermen (with their considerable expertise in vessel handling, marine equipment, and herring behavior) in projects to restore Pacific herring.

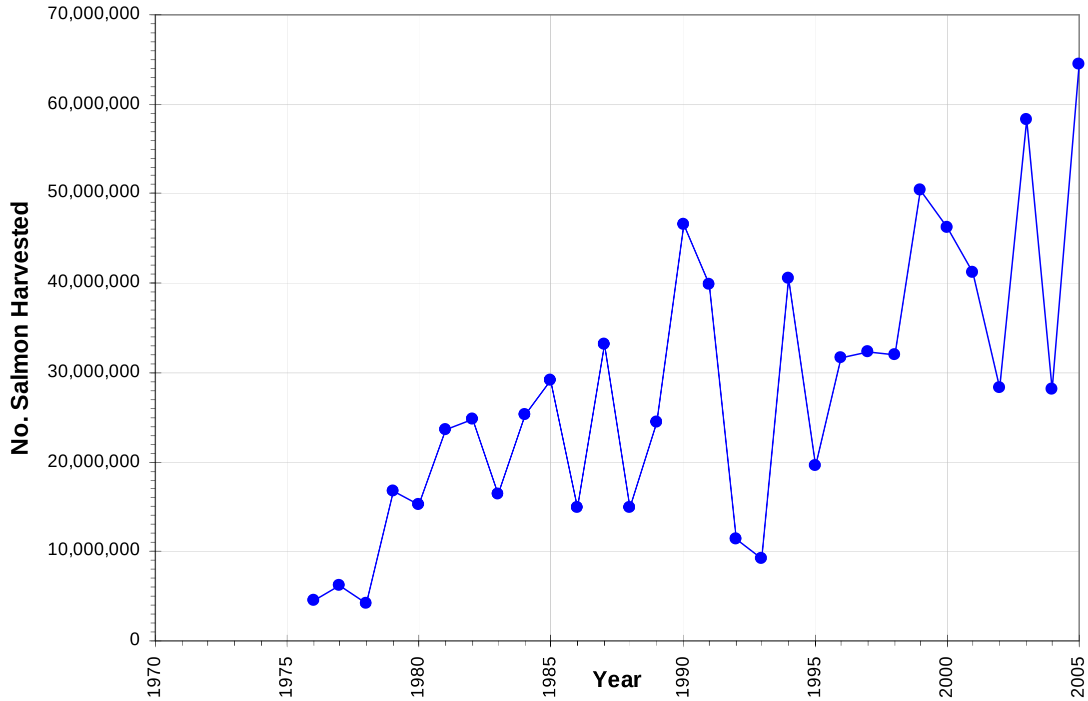

Figure 17-1. Annual Numbers of Salmon Harvested by Commercial Fishermen in Prince William Sound from 1976 to 2005 (data from Ashe et al. 2006).

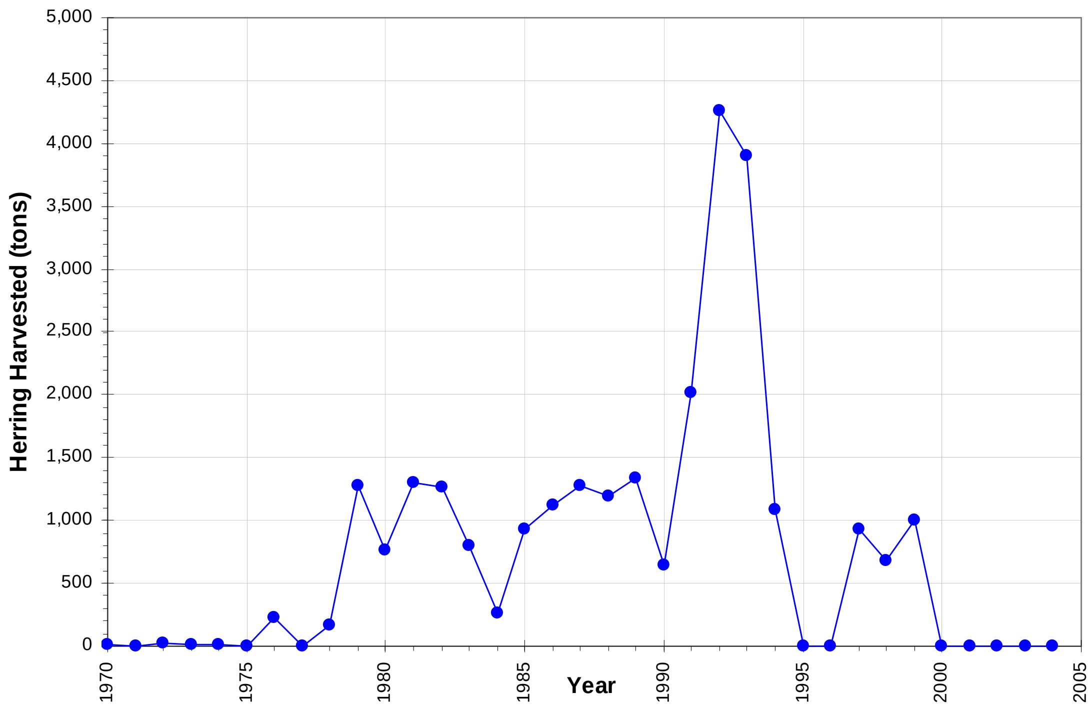

Figure 17-2. Prince William Sound Commercial Pacific Herring Fishery Harvests from 1970 to 2004 (Ashe et al. 2005)

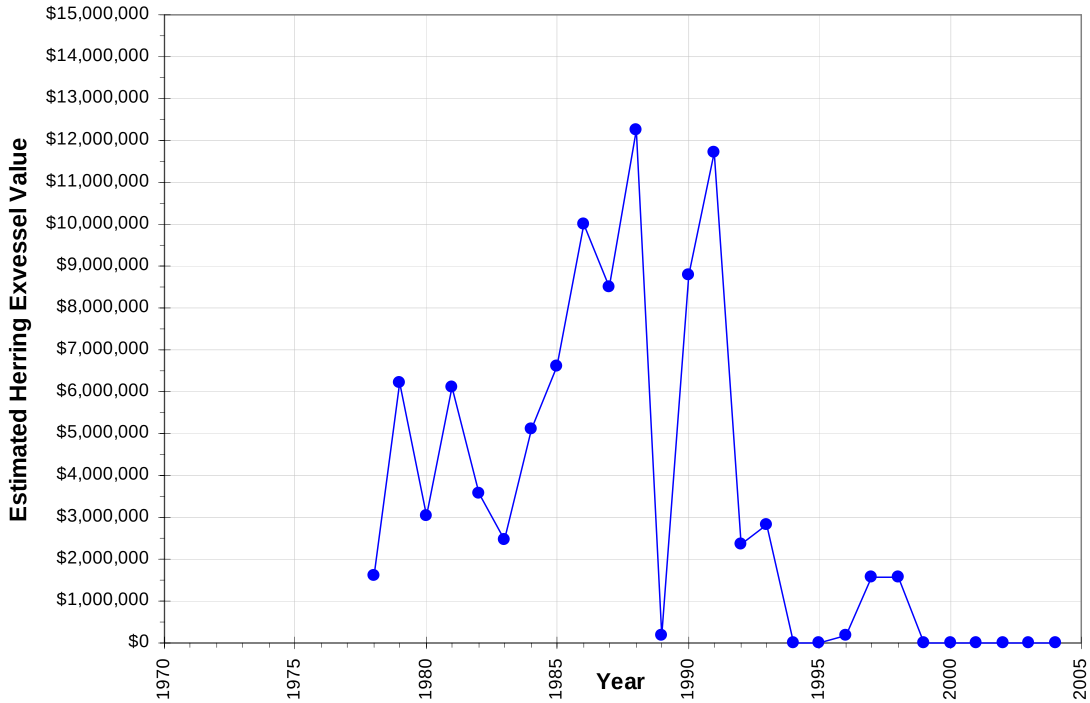

Figure 17-3. Pacific Herring Exvessel Values in Prince William Sound from 1978 to 2004 (data from Appendix G12 in Ashe et al. 2005).

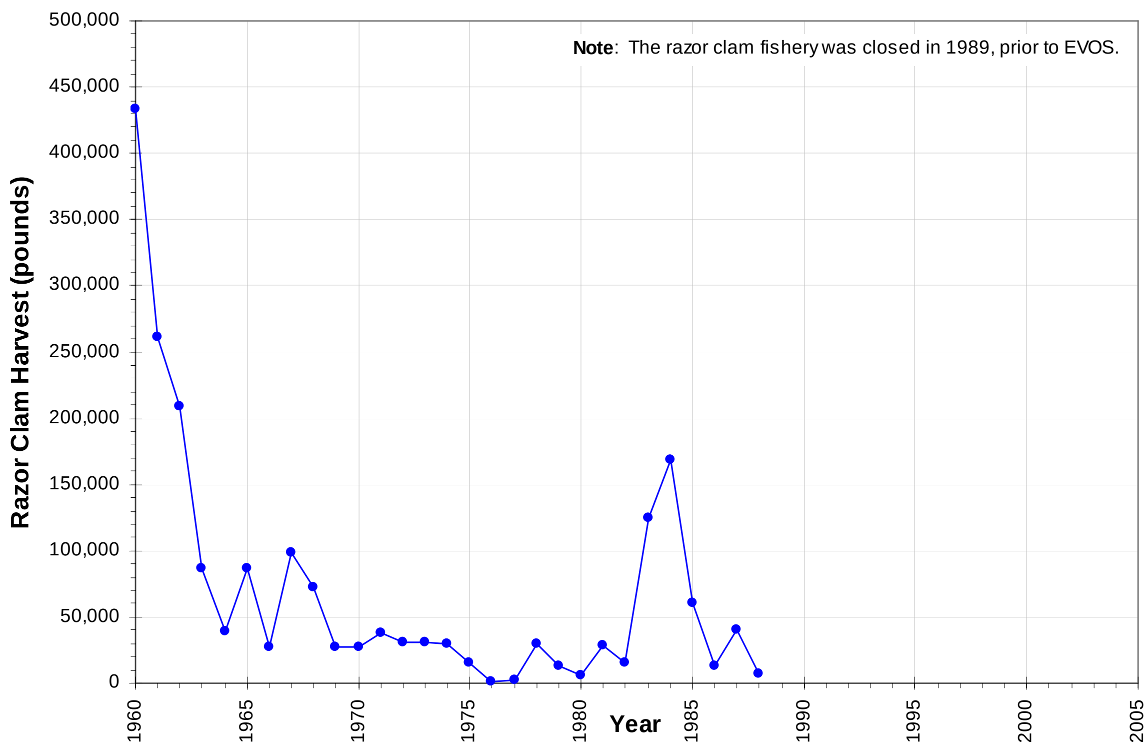

Figure 17-4. Commercial Razor Clam Harvests in Prince William Sound from 1960 to 2005 (data from Appendix A-4 in Berceli and Trowbridge 2006).

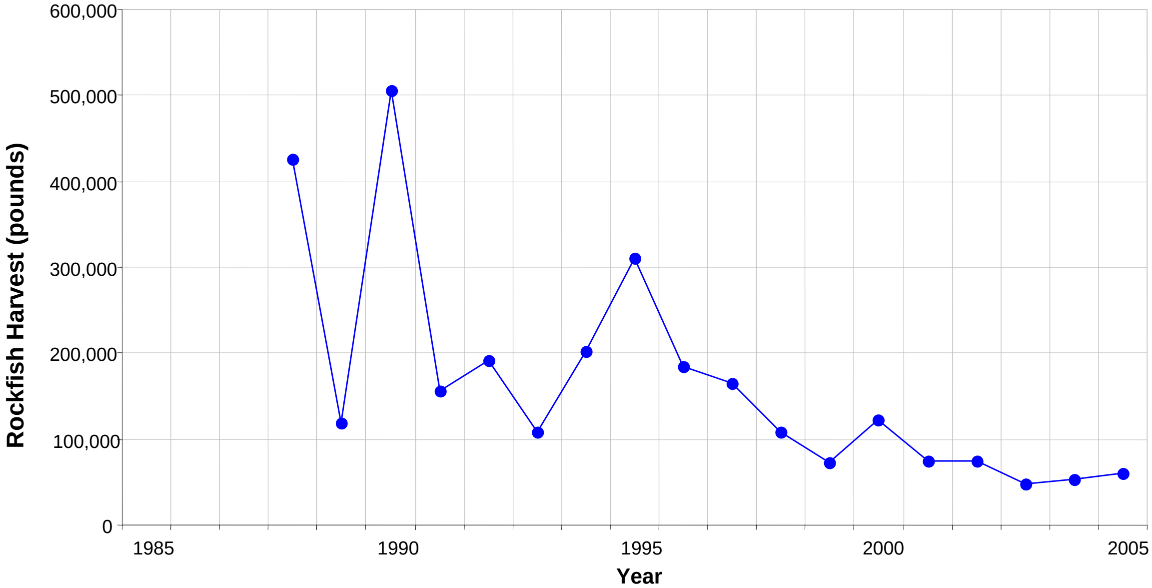

Figure 17-5. Commercial Rockfish Harvest for 1988–2005 in Prince William Sound Waters under Both State and Federal Jurisdiction

18. SUBSISTENCE USE

18.1 INTRODUCTION

EVOS resulted in the oiling of approximately 1,500 km of south-central Alaska's coastline, with heavy oiling affecting approximately 350 km of this area. The spill produced both acute and chronic impacts on many of the natural resources of the area.[68] In addition, the spill affected the lives of approximately 15,000 subsistence users, including Alaska Natives, living within the spill area. Natural resources traditionally harvested by residents were injured and killed, and traditional foods became contaminated with oil. Subsistence users' confidence in the health of the environment on which they depended was shaken. Traditional harvesting and uses of resources were disrupted by fisheries closures and influxes of spill-related money and personnel.

Over time, injured resources began to recover, and Alaska Natives and others resumed many subsistence activities. Programs were developed and funded to respond to injured subsistence uses in the restoration plan, and ADFG monitored aspects of the recovery of subsistence. Changes to and status of subsistence harvests, uses, and cultural values were evaluated through multiple surveys conducted by ADFG.

Using data from these surveys and from scientific assessments of resources both important to subsistence users and injured by EVOS, we evaluated the status of subsistence harvesting in the spill area. Our objectives were to assess the status of various components of subsistence, delineate data gaps and impediments to recovery, and provide recommendations for future actions with respect to subsistence activities.

18.1.1 Background

The area encompassing PWS, LCI, the Kodiak Island Archipelago (Kodiak), and the Alaska Peninsula was home to approximately 2,000 Alaska Native subsistence users in 15 subsistence communities at the time of EVOS (Fall 1999b). An additional 13,000 people, approximately 1,600 of which were Alaska Natives, were eligible for subsistence permits in larger communities within the spill area (Fall 1999b). The city of Cordova and the villages of Chenega Bay and Tatitlek in PWS; Nanwalek and Port Graham in LCI; Akhiok, Karluk, Larsen Bay, Old Harbor, Ouzinkie, and Port Lions on Kodiak; and Chignik, Chignik Lagoon, Chignik Lake, Ivanof Bay, and Perryville on the Alaska Peninsula fall within the general boundaries of EVOS (Figure 18-1, adapted from Fall et al. 2001, Figure V-9). These communities' survival and culture rely on subsistence resource harvesting and related activities (Fall 1999a). Disruption of subsistence activities by EVOS occurred through many mechanisms, including oiling of coastlines and

[68] The EVOS Trustee Council has historically approached EVOS as a natural disaster in addressing subsistence restoration; restoration projects funded by the 1991 Exxon civil claims settlement necessarily focus on natural resources (Fall 1995). EVOS may also be considered a technological disaster with social, cultural, and psychological implications for residents of the spill area (Fall et al. 2001). The human dimensions of EVOS are vitally important, but are outside the purview of this assessment.

harvestable resources, injury to fish stocks, which led to reduction and/or closure of some fisheries, contamination of resources, and litigation (Fall et al. 2001). Fish, shellfish, birds, and marine mammals important for subsistence were injured by EVOS, and human subsistence uses of these resources were disrupted (Fall et al. 2001). Subsistence users' perceptions of natural resources were changed, and many users were concerned about the safety of their traditional foods (Miraglia 1995). Subsistence communities experienced reduced subsistence harvest opportunities and disruption of traditional lifestyles as a result of EVOS, the ensuing cleanup, and litigation procedures (Fall et al. 2001).

18.1.2 Initial Impact from Spill

Oil from the *Exxon Valdez* polluted waters, beaches, and natural resources used by 15 predominantly Alaska Native communities in south-central Alaska (Fall 1995). Tatitlek is only 6 miles from the site of the spill (Fall et al. 2001). Most subsistence harvest areas used by Chenega Bay residents were oiled by EVOS; Tatitlek residents also harvested in these areas (Fall et al. 2001). By April 15, 1989, EVOS reached subsistence areas in LCI used by villagers from Nanwalek and Port Graham (Fall et al. 2001). By April 17, 1989, EVOS began to wash up on Kodiak beaches and subsistence areas (Fall et al. 2001). EVOS damaged important subsistence resources and disrupted subsistence use patterns in PWS and surrounding waters as evidenced by declines in participation in subsistence harvesting and in subsistence harvest quantities and variety after the spill (Fall 1995). Subsistence herring fisheries were closed in PWS in 1989 due to EVOS, and emergency salmon fisheries were opened for subsistence users in oil-free areas (Fall et al. 2001). Though there were no hunting restrictions issued, bear and deer hunters were encouraged to avoid the spill area (Fall et al. 2001).

In the year following EVOS, subsistence harvests declined between 9 and 77 percent in 10 subsistence communities within PWS, LCI, and Kodiak (Fall 1995). In PWS, the villages of Chenega Bay and Tatitlek experienced harvest declines of 57 and 56 percent, respectively (Fall et al. 2005). Harvests in the LCI settlements of Nanwalek and Port Graham declined 50 and 46 percent, respectively (Fall et al. 2005). Harvests in Akhiok, on the side of Kodiak leeward to EVOS, declined 9 percent, while those in Ouzinkie on the northern side of Kodiak decreased by 77 percent (Fall et al. 2005). Karluk, Larsen Bay, Old Harbor, and Port Lions had harvest declines of 32–58 percent. Food sharing and traditional knowledge transmission similarly declined (Fall 1995). The primary concern for subsistence users was that oil had rendered resources unfit for consumption (Miraglia 1995; Fall et al. 1999a).

18.1.3 Status of Injury and Recovery Classification

In 1994, the Trustee Council listed continuing injury to subsistence caused by injury to resources, lingering oil on subsistence beaches, and uncertainty of food safety (EVOS Trustee Council 1994). Subsistence would be recovered when "resources used for subsistence are healthy and productive and exist at pre-spill levels…" and "people are confident that the resources are safe to eat." The Trustee Council identified the reintegration of food-related cultural values such as gathering, preparing, and sharing as an indicator of subsistence recovery. The status of natural resources, food-safety perceptions, and cultural values were all considered important in evaluating subsistence.

Strategies for restoring subsistence involved restoring injured resources, removing residual oil, protecting subsistence from further degradation, and monitoring progress (EVOS Trustee Council 1994). To address the issue of subsistence resources, the Trustee Council proposed to increase availability of resources to subsistence users (e.g., allow higher fishing limits in oil-free areas if oiled areas remained closed) and facilitate food safety testing (EVOS Trustee Council 1994; Fall et al. 2001). Oil would be removed preferentially from beaches of high value to subsistence users, if the removal would be cost-effective and less harmful than allowing oil to remain (EVOS Trustee Council 1994). Plans for protecting subsistence from further injury involved acquiring and protecting resource habitat and implementing conservative management practices as needed (EVOS Trustee Council 1994).

In 2001, the Trustee Council continued to list subsistence as a recovering service contingent on the recovery of important subsistence species. The Trustee Council noted disruption of the traditional lifestyle as an additional injury to subsistence (EVOS Trustee Council 2002b). The 2001 restoration plan stated that subsistence users "continued to feel the effects of the spill," highlighting the complexity of determining subsistence recovery metrics. Subsistence harvest levels per person nearly matched or exceeded pre-spill levels by 1998, but subsistence users' assessments of the status of subsistence suggested that recovery was not complete (Fall and Field 1996; EVOS Trustee Council 2002b). Subsistence needed to reach three benchmarks to be considered recovered:

- That injured resources used for subsistence be healthy, productive, and abundant at pre-spill levels
- That people be confident in the safety of subsistence food resources (EVOS Trustee Council 2002b)
- That cultural values related to subsistence resource harvesting, preparation, and sharing be reintegrated into community life (EVOS Trustee Council 2002b).

Because clams, mussels, herring, and harbor seals had not yet recovered, and subsistence users still felt effects of the spill, subsistence was listed as recovering (EVOS Trustee Council 2002b).

There were no further amendments to the status of subsistence in the 2002–2003 updates, but the Trustee Council delineated restoration strategies (EVOS Trustee Council 2003). Among these strategies were plans to restore injured resources by creating a coho salmon run near Tatitlek and a proposal to remove oil from Chenega beaches. To address food safety perceptions, the Trustee Council planned to have subsistence foods tested. Plans to protect subsistence resources would be enacted through the Trustee Council's habitat protection program (EVOS Trustee Council 2003). Programs to increase subsistence users' participation in restoration programs were proposed as well. Monitoring of subsistence recovery would be accomplished through surveys. All of these programs aimed to restore subsistence users' assessments of the safety of subsistence foods and status of subsistence resource populations.

18.1.4 Overview of Subsistence Monitoring, Restoration, and Research Projects Conducted to Date

The Trustee Council and ADFG led projects to restore subsistence use in the spill area. Approximately 7 percent of Trustee Council restoration funds were allocated to specific subsistence restoration projects (Fall et al. 2001). Progress was made in restoring and monitoring subsistence resource populations, addressing food safety concerns, and measuring the status of subsistence harvesting.

18.1.4.1 Summary of EVOS Trustee Council-Funded Projects

Projects relevant to the restoration of subsistence were funded from 1993 onward (Fall et al. 2001). Subsistence-related projects funded by the Trustee Council are further described in Appendix A. Most of these projects directed funding towards restoration in PWS, as this was where data suggested recovery of subsistence was slowest (Fall 1995). Six projects attempted to restore subsistence resources. For example, Project No. 220 (Hodges and Schmid 1999) increased salmon stocks in PWS. Other projects helped subsistence users assess food safety issues (e.g., Jellett 2000; Shemet and Miraglia 1998). Projects led by James Fall and others (1999a, 2001, 2005) periodically surveyed subsistence users to assess harvest levels and perceptions in the spill area. These studies monitored the recovery of subsistence harvests in PWS, LCI, and Kodiak. Ten projects addressing subsistence restoration were funded by the Exxon criminal settlement (Fall 2006a, pers. comm.). One example is Project No. 428, which planned for the distribution of more than $1 million in civil settlement funds and $3 million in criminal settlement funds to subsistence restoration projects, including resource enhancement efforts, research, subsistence food testing, meetings, and a conference (Fall 1995). Criminal settlement funding addressed cultural values in five projects including outreach meetings and youth camps (e.g., Native Village of Eyak Traditional Council 2001 and Brown-Schwalenberg 2003). Many outreach, educational, and community projects were designed as stand-alone activities and did not result in final papers or quantified results.

18.1.4.2 Summary of Projects Funded by Other Sources

In addition to those projects funded by the EVOS Trustee Council, ADFG monitors subsistence harvests. The fisheries division accounts for subsistence harvests in developing overall management goals (e.g., Frenette 1997). The ADFG Division of Subsistence monitored marine mammal harvests statewide, including in the spill area (e.g., Wolfe et al. 2004).

18.1.4.3 Relationship of Projects to Recovery Objectives and Restoration Strategy

Projects funded by the EVOS Trustee Council have addressed the recovery objectives and restoration strategies outlined in 1994 and 2003, respectively. Many projects addressing injured resources have been successful. For example, salmon populations recovered with the aid of restoration and restocking efforts (EVOS Trustee Council 2002b). A substantial amount of oil was removed from Chenega beaches (Brodersen 1998). The success of those projects in terms of their effects on public perception is less certain. Efforts to restore confidence in food safety were only partly successful (Miraglia 1995). Outreach and community projects such as the establishment of subsistence camps (e.g., 286) produced no written reports that could be used to evaluate the effectiveness of these efforts.

18.1.5 Assessment Approach

The evaluation of subsistence use is structured to parallel the key elements of the recovery objective. The initial discussion of harvest levels, harvest composition, and harvest effort is designed to put the communities affected and the resources injured in context. The key elements of the subsistence service objective are discussed as follows:

- Section 18.3, Assessment of individual injured resources important to subsistence
- Section 18.4, Food safety
- Section 18.5, Cultural values.

18.2 ASSESSMENT OF SUBSISTENCE HARVESTING

Subsistence use of resources comprises not only the amount of each resource harvested (harvest level or quantity), but the variety of harvested resources (harvest diversity) and the effort required to obtain resources (harvest effort) (Fall and Field 1996; Fall et al. 2005). Surveys were used to quantify these subsistence characteristics (Fall and Field 1996; Fall et al. 1999a, 2005). These metrics were then used to evaluate the status of subsistence within the spill area.

18.2.1 Subsistence Harvest Levels

In the year after EVOS, subsistence harvests and uses in many subsistence communities declined substantially (Fall and Field 1996). Fall (1999a) recorded subsistence harvest declines of between 9 and 77 percent from pre-spill levels within EVOS boundaries. Subsistence harvests in PWS in 1989 were approximately 43 percent of pre-spill levels (Fall and Field 1996). Declines in subsistence communities' harvest levels were inversely related to their distance from EVOS (Fall and Field 1996): harvest levels decreased 31–77 percent for subsistence communities within PWS, LCI, and Kodiak, whereas those on the Alaska Peninsula stayed the same or increased (Fall and Field 1996). Because the Alaska Peninsula is located far enough away from the spill to have avoided most of the negative effects of EVOS, and subsistence harvest numbers did not suggest impacts in the aftermath of the spill, this region is not considered further in this assessment (Fall 2006b, pers. comm.).

Within 2 years of EVOS, harvest levels had recovered in several LCI and Kodiak communities, but PWS harvest levels remained depressed (Fall and Field 1996). By the third year following EVOS, harvest levels in PWS began to recover (Fall et al. 2005, but see discussion in Fall and Field [1996] on potential pre-spill harvest underestimates[69]). In 1998, harvest levels in PWS

[69] Fall and Field (1996) discuss underestimates in harvest levels for Chenega Bay due to the fact that pre-spill data are from the two years after the village of Chenega Bay was established in 1984. Subsistence hunters most likely increased harvest levels as they became more familiar with the harvest areas (Fall and Field 1996). In addition, Fall

surpassed pre-spill levels (Fall et al. 2005). Harvest levels in 2003 were higher than pre-spill levels in LCI, but were lower than pre-spill levels for communities in PWS (excluding Cordova) and Kodiak (Fall et al. 2005). Overall, however, harvest levels in the spill area were within the range of those of other Alaska rural communities in 2003 (Fall et al. 2005).

18.2.2 Subsistence Harvest Composition

Harvest diversity declined substantially from pre-spill levels in PWS, LCI, and Kodiak communities in the year following EVOS (Fall and Field 1996). Communities in PWS experienced the largest decline, from 19.0 types of resources harvested pre-spill to 9.0 resource types harvested in 1990, followed by LCI communities, which decreased from 22.9 to 12.2 resource types, and Kodiak communities, which fell from 15.4 to 11.2 resource types (Fall et al. 2005). Harvest diversity was recovering in LCI and Kodiak communities by 1990, and was recovering in all three regions by 1992 (Fall et al. 2005). In 2003, harvest diversity in PWS and Kodiak exceeded pre-spill levels (22.1 vs. 19.0 resource types and 17.2 vs. 15.4 resource types, respectively) and was near pre-spill levels in LCI (21.0 vs. 22.9 resource types; Fall et al. 2005). The average 2003 resource diversity across all three regions showed a slight increase in harvest diversity from pre-spill levels (18.7 vs. 17.2 resource types). These data demonstrate that harvest diversity was similar to or approaching pre-spill levels in all three regions by 2003.

In addition to causing changes in absolute harvest diversity, EVOS affected harvest composition in subsistence communities (Fall and Field 1996). For example, subsistence users in PWS shifted their harvests from marine mammals to salmon and other fish in the first three years following EVOS (Fall and Field 1996). The primary reasons given by survey participants for the shift in harvest composition were the reduced availability of marine mammals and the relatively low risk of oil contamination in fish compared to perceived contamination in marine mammals and shellfish (Fall and Field 1996). Marine mammal and marine invertebrate harvests continued to be lower than pre-spill levels in several communities in 2003 (Fall et al. 2005); harvest composition remains altered.

18.2.3 Subsistence Harvest Effort

Harvest effort was measured indirectly in pre-spill years as the number of resources sought during a given study year (Fall and Field 1996). For subsistence communities in PWS, LCI, and Kodiak, the average harvest effort declined from pre-spill levels in 1989 (Fall and Field 1996). In addition, the effort needed to obtain certain resources such as marine mammals increased in these same communities (Fall et al. 1999a). Harvest effort data for 1998 showed that, in general, subsistence users in PWS perceived that efforts needed to harvest resources such as salmon and marine invertebrates had increased or remained the same as in years before EVOS (Fall et al. 1999a). The data for other resources did not display a clear pattern (Fall et al. 1999a). Harvest effort data were confounded by differences in individual harvester's abilities, financial resources, and dedication to harvesting (Fall et al. 1999a).

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and Field (1996) noted that data from 1989 included harvests gathered before EVOS reached harvest area, artificially inflating harvest levels the first year after EVOS.

In 2003, respondents denoted marine mammals as requiring the most harvest effort, but the primary reason given for increased effort was interference from recreational users instead of resource scarcity (Fall et al. 2005). Harvest efforts for resources including salmon, other fish, marine invertebrates, and birds were reportedly lower than in 1998 (Fall et al. 2005). Because of uncertainty associated with harvest effort data (e.g., reported vs. direct measures, differences in harvesters' perceptions), no definitive conclusions can be drawn as to whether harvest effort is the same as before the spill (Fall et al. 1999a). However, harvest effort surveys provide insight into subsistence users' perceptions of what is affecting their harvests (Fall et al. 1999a). In 2003, interference from increased numbers of other service users instead of resource conditions was cited as the primary contributor to harvest efforts. However, 15 percent of users reporting lower subsistence uses than before EVOS cited spill-related resource scarcities as the main reason (Fall et al. 2005). Though these respondents constitute a small portion of spill area subsistence users, they demonstrate that EVOS continues to affect perceptions of natural resource harvests.

18.3 ASSESSMENT OF INDIVIDUAL RESOURCES IMPORTANT FOR SUBSISTENCE

Subsistence users in the spill region harvest a variety of foods. The most important of these are salmon, halibut, cod, rockfish, herring, Dolly Varden, clams, chitons, crabs, octopus, deer, black bear, mountain goats, moose, caribou, marine mammals, birds, and plants (Fall 1999a; Table 18-1). When EVOS occurred, many important resources were injured including salmon, rockfish, herring, Dolly Varden, clams, harbor seals, and sea otters (EVOS Trustee Council 1994). Although there are other subsistence resources such as harlequin duck that are considered injured resources, we excluded them due to their low importance in subsistence harvesting (Table 18-1).

All salmon species were listed as recovered by 2001 (EVOS Trustee Council 2002b). Currently, clams, rockfish, harbor seals, and Dolly Varden are all considered to be recovered (see Sections 7, 12, 15, and 13) and sea otters are considered to be recovering (Section 14). Pacific herring are considered to be not recovering, but the condition of the herring population is not conclusively linked to EVOS (Section 11). Octopus is another important subsistence resource that may have been injured by EVOS, but about which little is known. Subsistence users see octopus as an index species for the health of the ecosystem, and survey respondents said they did not find octopus in numbers that existed prior to EVOS (Fall 2006a, pers. comm.). The octopus survey funded by the Trustee Council in 1995–1998 produced no final report (EVOS Trustee Council Project 009). In the following sections, the status of resources listed in 2003 as not recovering, recovering, or unknown are examined within the context of EVOS.

Table 18-1. Pre- and Post-Spill Subsistence Harvest Levels and Perceptions of Harvest Level and Harvest Effort among 14[a] Villages in the Spill Area (based on Fall et al. 2005).

Resource	Rank (percentage of 2003 subsistence harvest)[b]	Recovery status	Average pre-spill harvest level (1988)	Post-spill harvest level (2003) (lb/person)	Perceived 1998 level of effort relative to pre-spill[c]			Perceived level of effort relative to 1998[c]			Perceived level of effort relative to 1998[d]	
					Increased	Stayed the same	Decreased	Increased	Stayed the same	Decreased	EVO related	Other/ non-EVO-related
Salmon	1 (49.2%)		No data	164.1	41	32	27	29	40	31	X	X
King Salmon		No data										
Sockeye		Recovered										
Pink Salmon		Recovered										
Chum Salmon		No data										
Coho Salmon		No data										
Other Fish	2 (20.7%)		No data	69.1	41	35	24	26	48		X	X
Herring		Not recovering										
Halibut		No data										
Herring Spawn		Not recovering										
Smelt		No data										
Dolly Varden		Unknown										
Pacific Cod		No data										
Rockfish		Unknown										
Cutthroat Trout		Unknown										
Land Mammals	3 (12.6%)		No data	41.9	27	48	25	22	55	23	X	X
Black Bear		Unrelated										
Deer		Unrelated										
Goat		Unrelated										
Shellfish	4 (7.1%)		No data	23.6	31	27	42	24	44	33	X	X
Chitons		Recovering										
Clams		Recovering										
Cockles		Recovering										
Shrimp		Unknown										
Crabs		Unknown										
Octopus		Unknown										
Marine Mammals	5 (6.1%)		No data	20.2	36	24	40	33	49	18	X	X
Harbor Seal		Not recovering										
Sea Lion		No data										
Sea Otter (crafts)		Recovering										
Wild Plants	6 (3.2%)	Unrelated	No data	10.5	32	56	12	25	55	20	-	X
Birds and Eggs	7 (1.2%)		No data	4.1	30	44	26	22	51	27	X	X
Seabird Eggs		Species-dependent										
Ducks (harlequin duck)		Not recovering										

[a]Data from Karluk were incomplete.
[b]Based on weight (lb) of resource harvested per person in 2003, averaged across 14 villages (Fall et al. 2005).
[c]Perceived levels of effort are listed as percentage of respondents believing effort increased/stayed the same/decreased. Data are from Fall et al. (2005) Figures XVII-20-26.
[d]Survey respondents were not asked about harvest level or effort perceptions in a way that discerns between lingering and residual oil issues.

18.3.1 Herring and Herring Spawn

The subsistence Pacific herring roe-on-kelp fishery was closed in PWS on April 3, 1989, soon after EVOS (Fall et al. 2001). This closure prevented subsistence users from accessing important resources: herring and other fish constitute approximately 21 percent of the subsistence harvest by mass harvested per person in the spill area (Table 18-1). Subsistence herring fisheries remained open in LCI, Kodiak, and the Alaska Peninsula (Fall et al. 2001). There is little evidence linking the depressed herring population to residual effects from the spill, and numerous other factors could explain the decline, including disease aggravated by initially high population density, food scarcity, and poor ocean conditions (EVOS Trustee Council 1999; Integral 2006).

Subsistence users in PWS reported a decline in herring harvest availability in both 1998 and 2003 compared to pre-spill conditions, though herring and herring spawn continue to constitute a significant portion to subsistence users' diets in the spill area (Fall et al. 2005). Due to the fact that herring populations have not recovered in PWS, subsistence harvests of this resource cannot be considered recovered. The condition of herring, however, has been linked to disease, which has not been directly linked to EVOS (Section 11).

18.3.2 Harbor Seals

The hunting of marine mammals historically has been an important subsistence and cultural activity for the Alutiiq people of the spill area (Fall 1999a). Prior to EVOS, most subsistence marine mammal harvests consisted of harbor seals and Steller sea lions (Fall 1999a). Although no hunting restrictions were imposed after EVOS, subsistence users expressed concern over the scarcity of seals and the safety of marine mammals as food resources (Fall et al. 2001).

In 2003, harbor seals constituted approximately 6 percent of subsistence users' diets in the spill area (Fall et al. 2005, Table 18-1). The majority of subsistence users in the spill area reported that harbor seal populations were lower in both 1998 and 2003 than before EVOS (Fall et al. 2005). Approximately 33 percent of respondents believed that more effort was required to harvest harbor seals than before EVOS, but interference from the increased presence of recreation and tourism users was provided as the primary reason for increased effort (Fall et al. 2005, Table 18-1). Of those spill area users harvesting seals, the vast majority believed harbor seals were safe to eat (Table 18-2). The minority believing seals unsafe to eat attributed the reason to EVOS (Table 18-2).

Harbor seal populations were declining in the spill area prior to EVOS and continued to decline afterwards (Section 15). Recent data suggest that harbor seal populations have recently stabilized, and may be considered recovered (Section 15). Though there are no data comparing resource-specific pre- and post-spill harvest levels, it is apparent that overall subsistence harvests of seals are recovering in the spill area (Table 18-1). Most subsistence harvesters of harbor seals believe them safe to eat, and EVOS is no longer indicated as the primary reason for lower resource populations and increased harvest efforts. The few food safety issues that remain, however, are still perceived as being linked to EVOS.

Table 18-2. Perceptions of Food Safety and Perceived Causes of Safety Issues among 15 Villages in the Spill Area.

	Resource	Rank (percentage of subsistence harvest)[a]	Recovery status	Food perception safety	Of those perceiving safety issues, reason given is associated with: EVO-related[b]	Other/ non-EVO-related
Salmon		1 (49.2%)				
	King Salmon		No data	No data[c]		
	Sockeye		Recovered	Majority believe safe		
	Pink Salmon		Recovered	Majority believe safe		
	Chum Salmon		No data	No data		
	Coho Salmon		No data	No data		
Other Fish		2 (20.7%)				
	Herring		Not recovering	Majority believe safe	X	X
	Halibut		No data	No data		
	Herring Spawn		Not recovering	Majority believe safe		
	Smelt		No data	No data		
	Dolly Varden		Unknown	No data		
	Pacific Cod		No data	No data		
	Rockfish		Unknown	No data		
	Cutthroat Trout		Unknown	No data		
Land Mammals		3 (12.6%)				
	Black Bear		Unrelated	N/A		
	Deer		Unrelated	N/A		
	Goat		Unrelated	N/A		
Shellfish		4 (7.1%)				
	Chitons		Recovering	Majority believe safe	X	X
	Clams		Recovering	52% believe safe	X	X
	Cockles		Recovering	No data		
	Shrimp		Unknown	No data		
	Crabs		Unknown	No data		
	Octopus		Unknown	No data		
Marine Mammals		5 (6.1%)				
	Harbor Seal		Not recovering	Majority believe safe	X	X
	Sea Lion		No data	No data		
	Sea Otter (crafts)		Recovering	No data		
Wild Plants		6 (3.2%)	Unrelated			
Birds and Eggs		7 (1.2%)				
	Seabird Eggs		Species-dependent	No data		
	Ducks (harlequin duck)		Not recovering	No data		

[a]Based on mass of resource harvested per person in 2003, averaged across 14 villages (Fall et al. 2005).
[b]Survey participants were not asked specifically about whether spill-related safety concerns were based on lingering or residual oil issues; however, it is likely that oil-related safety concerns are based on exposure to lingering oil.
[c]Survey participants were asked about their perceptions of safety in relation to only four resources: clams, chitons, herring, and seals.

18.3.3 Clams

Clams and other shellfish contribute approximately 7 percent to subsistence users' diets in the EVOS-affected area (Table 18-1). Littleneck and butter clams constitute the majority of clam species harvested by subsistence users (Fall 2006b, pers. comm.). No increases in harvest effort for clams were reported from the time of EVOS; clams are often avoided where available (Fall et al. 2005). Recent analysis of clams in the spill area suggests that clam populations have likely recovered from effects of EVOS (Section 7).

Of the subsistence resources affected by EVOS, clams were regarded by subsistence users as the least safe to eat in 2003 (Fall et al. 2005). Across the entire affected area, a slight overall majority believed clams safe to eat; however, the majority of some villages in Kodiak refused to eat clams (Table 18-3). Confidence in clam food safety declined from 1998 to 2003 throughout the spill region, and EVOS was often cited as the reason (Table 18-3). Outbreaks of paralytic shellfish poisoning were also cited as reasons for avoiding clams (Fall et al. 2005). In rural PWS, however, EVOS was not cited as a reason for safety concerns despite the presence of lingering oil in Chenega Bay (Fall et al. 2005).

Food safety studies reported that health risks from spill-area bivalves were low (Bolger et al. 1996; Brown et al. 1999). Although subsistence users in Chenega Bay avoided beaches with lingering oil, they did not report EVOS-related food safety concerns. Many subsistence harvesters, however, continue to perceive clams and other shellfish as unsafe, and many attribute their concerns to EVOS. Paralytic shellfish poisoning, which many users also associate with EVOS, is an additional detractor in food safety perceptions. Clams are available in numbers exceeding the demands of subsistence harvesters, but harvest levels remain lower than pre-spill levels due to food safety concerns. Overall, clams are available and safe to eat in the context of EVOS, but substantial food safety concerns remain. For these reasons, subsistence use of clams is considered recovering. When food safety concerns are further alleviated, the relationship between EVOS and paralytic shellfish poisoning is made clear, and harvest levels increase, subsistence use of clams will have recovered.

18.3.4 Intertidal and Subtidal Communities and Resources

Intertidal and subtidal communities are considered to be recovered (Sections 5 and 6). However, not all resources of interest to subsistence harvesters have been evaluated as part of the assessment of intertidal and subtidal resources. The resources important to subsistence include chitons, octopus, cockles, mussels, shrimp, and crabs (Fall et al. 1999a, Table 18-1). Along with clams (see section above), these resources were all categorized as shellfish by surveyors (Fall et al. 2005), and constitute approximately 7 percent of spill area subsistence users' diets by mass harvested per person (Table 18-1).

Table 18-3. Pre- and Post-Spill Subsistence Harvest Levels and Perceptions of Harvest Level and Harvest Effort by Region in the Spill Area.[a]

Region	Average pre-spill harvest level	Post-spill harvest level (2003)	Post-spill harvest as a percentage of pre-spill harvest	% of respondents believing harvest levels same or greater than pre-spill levels [b]	Perceived increased level of effort relative to 1998	Of those who perceive harvest level or effort issues, reason given is associated with: EVO related[c]	Other/ Non- EVO related	Resource	% of respondents believing unsafe	Of those who perceive safety issues, reason given is associated with: EVO related[c]	Other/ non-EVO related
Prince William Sound (except Cordova)	436.5	368.2	84%	34%	No data	X	X				
								Clams	4-25	-	X
								Chitons	0	NA	NA
								Herring	0-8	X	-
								Seals	0-4	X	-
Cordova	199.9	175.1	88%	55%	No data	X	X				
								Clams	13	X	X
								Chitons	6	X	No data
								Herring	12	X	X
								Seals	14	X	No data
Kodiak Island	392.1	289.8	74%	62%	No data	X	X				
								Clams	8-100	X	X
								Chitons	0-16	X	X
								Herring	0-4	No data	No data
								Seals	0-6	X	X
Lower Cook Inlet	254.3	422.7	166%	40%	No data	X	X				
								Clams	9-18	X	X
								Chitons	4-32	X	X
								Herring	4-5	X	No data
								Seals	2-10	X	No data
Alaska Peninsula	287.0	375.4	131%	46%	No data	-	X				
								Clams	0-17	-	X
								Chitons	0-8	-	X
								Herring	0	NA	NA
								Seals	0-8	-	X

[a] Unless otherwise indicated, data are taken from Fall et al. (2005). Update of the status of subsistence use in *Exxon Valdez* oil spill area communities.
[b] Data presented as average percent believing harvests and use to have increased or remained the same. Data are derived from Table A-52 in Fall et al. (2005).
[c] Survey respondents were not asked about safety perceptions in a way that discerns between lingering and residual oil issues; however, it is likely that concerns about oil-related food safety issues are related to lingering oil.

After EVOS, subsistence users' harvests of these resources decreased due to resource scarcity and food safety concerns (Fall et al. 2001). Bivalves in particular were perceived as being damaged and unsafe to eat (Fall et al. 2001). Aside from providing nutrition, octopus and other shellfish had cultural value for subsistence harvesters; their unavailability and injury affected more than just caloric intake (Fall et al. 2001a; Fall 2006b, pers. comm.).

In 2003, Fall et al. (2005) measured perceptions of food safety of chitons. Their findings showed that the majority (93.4 percent) of subsistence users regarded chitons as safe to eat (Fall et al. 2005). No respondents in rural PWS stated food safety concerns with chitons (Table 18-3). The small number of respondents expressing concerns about food safety indicated EVOS as a reason for their concern (Fall et al. 2005). No food safety data on other important intertidal resources such as octopus were gathered, so the status of subsistence uses of these resources remains unknown. Generally, subsistence users are still concerned with the availability and safety of some intertidal and subtidal resources.

18.4 FOOD SAFETY

In the years following EVOS, oil contamination of food resources was the primary concern for subsistence users (Fall et al. 2005). Information was provided to subsistence harvesters telling them that if they could not smell oil in their food, it was safe to eat; this communication was met with distrust (Fall 1999a). Studies of oil contamination in subsistence resources concluded that there were low health risks to subsistence users in the spill area due to EVOS (e.g., Bolger et al. 1996), and projects were funded to improve subsistence users' confidence in their food (e.g., Miraglia 1995). Despite these efforts, concerns among subsistence harvesters about marine resource food safety remained (Fall et al. 1999a).

Marine mammals and shellfish were the subsistence resources perceived as being the most likely to be contaminated with EVO directly after the spill (Fall and Field 1996). Fall et al. (2005) examined food safety perceptions of the following four resources within the spill area in 2003: clams, chitons, herring, and seals. By 2003, most subsistence users perceived resources as safe to eat (Table 18-2). Food safety concerns with shellfish, and clams in particular, were attributed primarily to EVOS, followed by paralytic shellfish poisoning (Fall et al. 2005). Fall et al. (2005) note, however, that many subsistence users believed that EVOS and paralytic shellfish poisoning were linked. Most subsistence users regarded finfish (including salmon and herring), harbor seals, and chitons as safe to eat (Table 18-2).

Regional differences in food safety perception were apparent as well, though individual responses within each region accounted for most variation. Communities within the spill-affected areas of PWS, LCI, and Kodiak expressed more concern over food safety than communities on the Alaska Peninsula (Table 18-3). There was little difference between the percentages of respondents reporting food safety issues for any resources among PWS, LCI, and Kodiak residents (Table 18-3). Most notably, in PWS, those respondents with food safety concerns about clams did not cite EVOS as the primary reason (Table 18-3). Although the available evidence does not support any claim that oil contamination from EVOS poses health risks to subsistence users, food safety perception continues to be affected by the presence of lingering oil from EVOS (Bolger et al. 1996; Fall et al. 2005).

18.5 CULTURAL VALUES

Harvest levels and uses by themselves provide an incomplete picture of the status of subsistence in the spill area. Subsistence use is central to the way of life in many spill area communities, and embodies traditional and cultural values (Fall 1999a). EVOS disrupted traditions surrounding subsistence when it interrupted access to natural resources and provided employment opportunities unrelated to subsistence (Fall et al. 1999a). The Trustee Council endeavored to restore many disrupted cultural activities through community outreach and educational projects (Fall et al. 2001). Cultural values are acknowledged to be important, but evaluating them is a difficult and uncertain process (Fall et al. 2001). The status of three aspects of cultural values in the spill area is discussed and evaluated in the context of EVOS in this section.

18.5.1 Influence of Elders

Fall et al. (1999b, 2005) reported mixed perceptions about the status of elders' influence in terms of teaching subsistence skills and values. The majority of respondents in most surveyed communities responded that elders' influence is either remaining stable or is declining in their communities. Major reasons provided by respondents included demography (there are fewer elders than there were in the past) and cultural changes in the community's way of life (these were not more specifically described).

There were a few exceptions to this stated decline, including the towns of Ouzinkie and Cordova. In Ouzinkie, 64 percent of respondents in 1998 stated that elders' influence had declined; however, in the 2004 survey, 76 percent of respondents said that elders' influence had increased relative to 1998, a distinct change in response. Fall et al. (2005) stated that most respondents did not give a reason as to why they thought elders' influence had increased, but noted that several of the survey participants were raising grandchildren or had them in the summers and stated that they were getting involved in their grandchildren's subsistence education. In Cordova, 51 percent of respondents said elders' influenced had increased. Respondents attributed this rise in influence to more activity by elders and a renewed interest in the community in learning traditional skills.

18.5.2 Youth Learning Subsistence Skills

In 1996, the Trustee Council's overview of the status of subsistence skills stated particular concern that the oil spill disrupted opportunities for young people to learn subsistence culture (EVOS Trustee Council 2002b). Following EVOS, a majority of surveyed residents in the spill area stated that youth were not learning sufficient subsistence skills, with fewer than half of respondents (39 percent) in 1992 stating that youth were learning the necessary skills (Fall et al. 2005). This number rose in subsequent years: in 1998, 48 percent of respondents stated that youth were learning the necessary skills, and in 2004, 53 percent of respondents in the 15 communities surveyed stated that youth were learning sufficient subsistence skills.

There was some variability in responses to this issue across the surveyed communities; response rates ranged from 90 percent of respondents in Ouzinkie stating they believed youth were learning subsistence skills, to only 14 percent of those surveyed in Karluk responding this way. However, the majority of the communities had a mixed response to this question; in nine out of 15 communities surveyed, 40 to 60 percent of respondents stated that youth were not learning sufficient skills. Responses on the extremes of this distribution did not appear to have a clear geographic pattern, but rather were suggested to relate to particular activities at a village level; for example, active participation in spirit camps by Ouzinkie youths was suggested by Fall et al. (2005) to account for some of the positive response from this community.

Reasons given by respondents who did not feel youth were learning sufficient subsistence skills were similar in 1998 and 2004 surveys, and included lack of interest on the part of youth (reason given by approximately 39 percent of respondents saying youth were not learning sufficient subsistence skills), lack of teachers (19 percent), and change in community way of life (13 percent).

18.5.3 Sharing Patterns

Sharing of subsistence foods shifted in the years immediately following the oil spill. During the initial years following the spill, when harvest levels were reduced, sharing was prioritized for the more vulnerable members of the community, including elders, single mothers with dependent children, and inactive single person households (Fall et al. 2005). In 1998, 28 percent of respondents across the survey communities stated that sharing had declined, while the majority stated that sharing remained the same (43 percent) or increased (24 percent) (Fall et al. 1999a). Fall et al. (2005) report that, by 2003, sharing was frequent, widespread, and engaged in by most households in the 15 communities they studied within the spill area, with 70 percent of households in 10 of the study communities reporting increased or no change in sharing.

Reported declines in sharing between the 1998 and 2003 surveys were concentrated in four communities—Karluk (Kodiak Island), Tatitlek (PWS), Port Graham, and Nanwalek (LCI), where more than 40 percent of respondents reported declines in sharing. Of those respondents reporting decreased sharing, the primary reason given (31 percent of respondents) was personal reasons, influenced predominantly by a large response with this reason from Cordova participants. Excluding Cordova, environmental reasons (not defined further) ranked first in terms of responses as to why sharing might have declined.

18.5.4 Status of Traditional Way of Life

The "traditional way of life" as discussed by Fall et al. (2005) is an amalgamation of the aspects discussed above—intergenerational knowledge transfer, subsistence harvesting, and food sharing. However, this phrase was not precisely defined for survey respondents, nor did surveyors ask participants about their understanding of this term. A majority of respondents, when asked whether EVOS had affected their traditional way of life, responded affirmatively: 83 percent said the traditional way of life had been injured by EVOS, 74 percent of respondents in 2004 stated that recovery of the traditional way of life had not occurred, and 14 percent did not know. These results suggest a widespread perception among survey respondents that 1) EVOS impacted these communities and that 2) EVOS is still in some way impacting these communities. However, responses to more specific questions regarding cultural aspects of community life described above were decidedly more mixed and a wide variety of reasons were given for perceptions; the role of EVOS in many of these reasons is difficult to discern. These findings demonstrate that even local residents struggle to separate EVOS-related factors from other factors affecting their traditional way of life (Fall et al. 2005).

18.6 POTENTIAL CONFOUNDING FACTORS IN EVALUATING THE ROLE OF EVOS IN SUBSISTENCE

A variety of factors concurrent with EVOS may influence the service of subsistence in the spill area. In the time since EVOS, demographic and societal changes in subsistence communities have occurred, participation in competing services has increased, and events affecting food safety have occurred (Bowker 2001; Fall et al. 2005). Demographic shifts in subsistence communities may account for changes in both resource-based and cultural aspects of subsistence.

Within the subsistence communities in the spill area, demographics have shifted. There are fewer elders to transfer knowledge than in the years prior to EVOS (Fall et al. 2005). With time, cultural values and norms may shift as well; these factors may obscure cultural changes caused by EVOS (Fall et al. 2005). In addition, harvest effort depends, in large part, on individual harvesters' outlooks, resources, and energy (Fall et al. 2001). As demographics shift and remaining subsistence harvesters have different distributions of attitudes and resources, harvest effort would be expected to change independent of EVOS.

Another potential confounding factor is increased participation in other human services such as recreation and tourism (Section 19). Subsistence users reported increased numbers of wildlife viewers and recreational anglers interfering with subsistence hunting in 2003 (Fall et al. 2005). Commercial fishermen compete for subsistence resources as well (Fall et al. 2001; see Section 17 of this document). Patterns in resource use and harvest efforts may be influenced by these competing uses as well as by effects of EVOS. As recreation, tourism, and commercial fishing efforts continue in the spill area, subsistence users will continue to interact and compete with them.

Subsistence users rely on natural resources for their food, and their need for this food as part of their diet may override misgivings about food safety (Fall 1999a). For economic and cultural reasons, many subsistence users returned to harvest in the spill area waters despite misgivings about food safety (Fall 1999a). Outward measures of subsistence recovery such as harvest levels and harvest diversity may not be reflective of the fact that subsistence users are still concerned about the health of underlying resources. The need to survive may confound remaining food safety effects of EVOS.

An additional factor in food safety is the recent outbreaks of paralytic shellfish poisoning. Many subsistence users associate these outbreaks with EVOS, although scientific evidence for such a connection is lacking (Fall et al. 2005). Users attributing paralytic shellfish poisoning to EVOS might therefore be responding that their concerns are EVOS-related, when they are actually worried about disease-related effects.

18.7 SUMMARY AND RECOMMENDATIONS

The Trustee Council (2001) established the following criteria for the recovery of subsistence:

- That injured resources used for subsistence be healthy, productive, and abundant at pre-spill levels
- That people be confident in the safety of subsistence food resources
- That cultural values related to subsistence resource harvesting, preparation, and sharing be reintegrated into community life.

We evaluated resource and subsistence data with these objectives and EVOS in mind. However, as discussed in other sections, the overall objective of a "return to conditions that would have existed had the spill not occurred" was considered for resources because a return to pre-spill conditions does not consider other stressors that may affect a population or resource.

18.7.1 Summary

Subsistence use of natural resources, food safety perceptions, and cultural values need to be recovered from injuries inflicted by EVOS. The recovery of the subsistence use of natural resources was examined using harvest level, harvest diversity, and harvest effort data. We evaluated previous assessments of food safety using resource contamination and perception data. Finally, information on the recovery of cultural values was evaluated.

18.7.1.1 Natural Resources Harvested by Subsistence Users

Most natural resources important for subsistence harvests are considered recovered from EVOS. The condition of Pacific herring appears to be associated with disease; scientific data have not established a link between EVOS and herring. Because most important subsistence resources have recovered or are no longer suffering from the effects of EVOS, subsistence resources are considered recovered. This judgment acknowledges that the status and relationship to EVOS of some important resources such as octopus, which subsistence users perceive as declining, remain unknown.

Several metrics of subsistence harvest, including total harvest quantities in most areas, and diversity of taxa harvested, have neared or exceeded pre-spill levels. The extent of subsistence harvest recovery varied spatially throughout the spill area. Harvest levels were higher than pre-spill levels in the PWS community of Chenega Bay and most others throughout the spill area (Fall et al. 2005). Harvest estimates for Tatitlek, Akhiok, Port Lions, and Chignik Lake remained lower than pre-spill harvest levels (Fall et al. 2005). It is doubtful that these decreases are entirely attributable to EVOS because Chignik Lake's harvest levels exceeded pre-spill levels in the year of EVOS and afterwards, and Akhiok's and Port Lion's harvest levels had nearly recovered to pre-spill levels in 1992 and 1993, respectively (Fall et al. 2005). On average, 2003 harvest levels exceeded pre-spill levels in LCI and the Alaska Peninsula, and remained below pre-spill levels for rural villages in PWS and Kodiak (Fall et al. 2005). In two PWS communities and in many Kodiak communities, harvests of shellfish remained below pre-spill levels due to perceived resource scarcity and concerns over paralytic shellfish poisoning, and marine mammal harvests were low due to resource scarcity (Fall et al. 2005). Tatitlek and Cordova both reported lower availability of herring compared to pre-spill years (Fall et al. 2005). Although subsistence harvest volumes in Chenega Bay recovered by 2003, lingering oil on subsistence beaches continued to discourage subsistence harvesters from using some resources (Miraglia 1995; Fall et al. 2005). These data show that harvest levels in the spill area have recovered in LCI, and are recovering in Kodiak and PWS.

Harvest diversity has recovered in all regions of the spill area, though, as noted above, harvest composition remains altered from pre-spill conditions in some areas (Fall et al. 2005). Some shifts in harvest composition may have resulted from the relative abundance of salmon; while marine mammals required more effort to harvest compared to pre-spill years, salmon required relatively less (Fall et al. 2005). Harvest diversity is considered recovered in respect to EVOS.

18.7.1.2 Food Safety

EVOS-related food safety concerns appear to have declined over time for several resources important to subsistence harvesters. Throughout the spill area, the majority of harvesters considered most finfish including herring and herring spawn, chitons, and seals safe to eat (Fall et al. 2005) EVOS continued to affect perceived food safety in clams and other shellfish. While communities in PWS appeared to be regaining confidence in the safety of clams, those in Kodiak appeared to be losing confidence (Fall et al. 2005). The Kodiak communities of Ouzinkie and Port Lions associated EVOS with paralytic shellfish poisoning, and cited EVOS as the primary cause of food safety uncertainty (Fall et al. 2005). Because EVOS continues to be perceived as a detriment to food safety, and much work remains to be done to restore confidence in marine invertebrate food safety, confidence in resource safety relating to EVOS is recovering, but not recovered.

18.7.1.3 Cultural Values

Subsistence users are unlikely to forget that EVOS occurred and perception appears widespread that this event has significantly changed their traditional way of life. In light of this perspective it may be more appropriate to consider recovery based on a sustainable Alaska Native subsistence culture. It is difficult to assess the extent to which EVOS continues to be responsible for changes in cultural values in the context of confounding factors. Subsistence users perceive altered resource abundance, harvest levels, harvest efforts, and uses from pre-spill levels, for both EVOS and non-EVOS related reasons (Fall et al. 2005). For these reasons, the service of subsistence in the context of EVOS has nearly, but not completely, recovered.

18.7.2 Recommendations

It is recommended that the Trustee Council classify subsistence use as recovering. The Trustee Council should also consider the following restoration actions related to subsistence use:

- Assess the status and relative importance of resources about which little is known
- Develop strategies to address remaining food safety concerns
- Continue to incorporate subsistence users in resource stewardship and restoration to benefit cultural values and reconcile conflicts between spill-area users.

These recommendations endeavor to address data gaps, delineate restoration strategies and provide subsistence users with sustainable and productive futures in the spill area.

Mussels have been the subject of many oil contamination studies (Section 8). Mussels are used by subsistence users (Fall et al. 2005), but are not as important to subsistence users as are other shellfish such as clams (Fall 2006b, pers. comm.). It may be more appropriate to prioritize clams as endpoints for testing contamination and health risks of subsistence resources.

Important concerns remain among subsistence users as to the safety of some resources, particularly clams. Continued efforts to restore subsistence users' confidence in food resources could encompass outreach, restoration, and educational programs. More outreach to help users understand and avoid diseases such as paralytic shellfish poisoning would help communities disassociate this disease from EVOS. Continued monitoring of EVO weathering and location and dissemination of this information might also build confidence in the use of previously oiled subsistence areas over time.

Subsistence users should be encouraged to participate in restoration and monitoring projects. Working relationships between resource managers and subsistence users will demonstrate the scientific community's respect for subsistence users' beliefs and needs, and increase subsistence users' confidence in subsequent scientific results. In addition, subsistence users' concerns need to continue to be publicly considered in management decisions of subsistence, recreational, and commercial resources in order to foster respectful relationships between competing user groups. Ensuring subsistence users access to culturally important natural resources will assist the recovery of cultural values.

Community involvement is essential in establishing stewardship of natural resources, and allowing subsistence users to believe in a sustainable future (Fall et al. 2001). Our assessment concludes that subsistence services in the spill area are nearly recovered, and provides recommendations to achieve complete recovery within the limitations of the settlement agreement terms. The Trustee Council and ADFG should continue to work closely with spill area subsistence users to address any remaining or additional EVOS-related concerns to ensure complete service restoration.

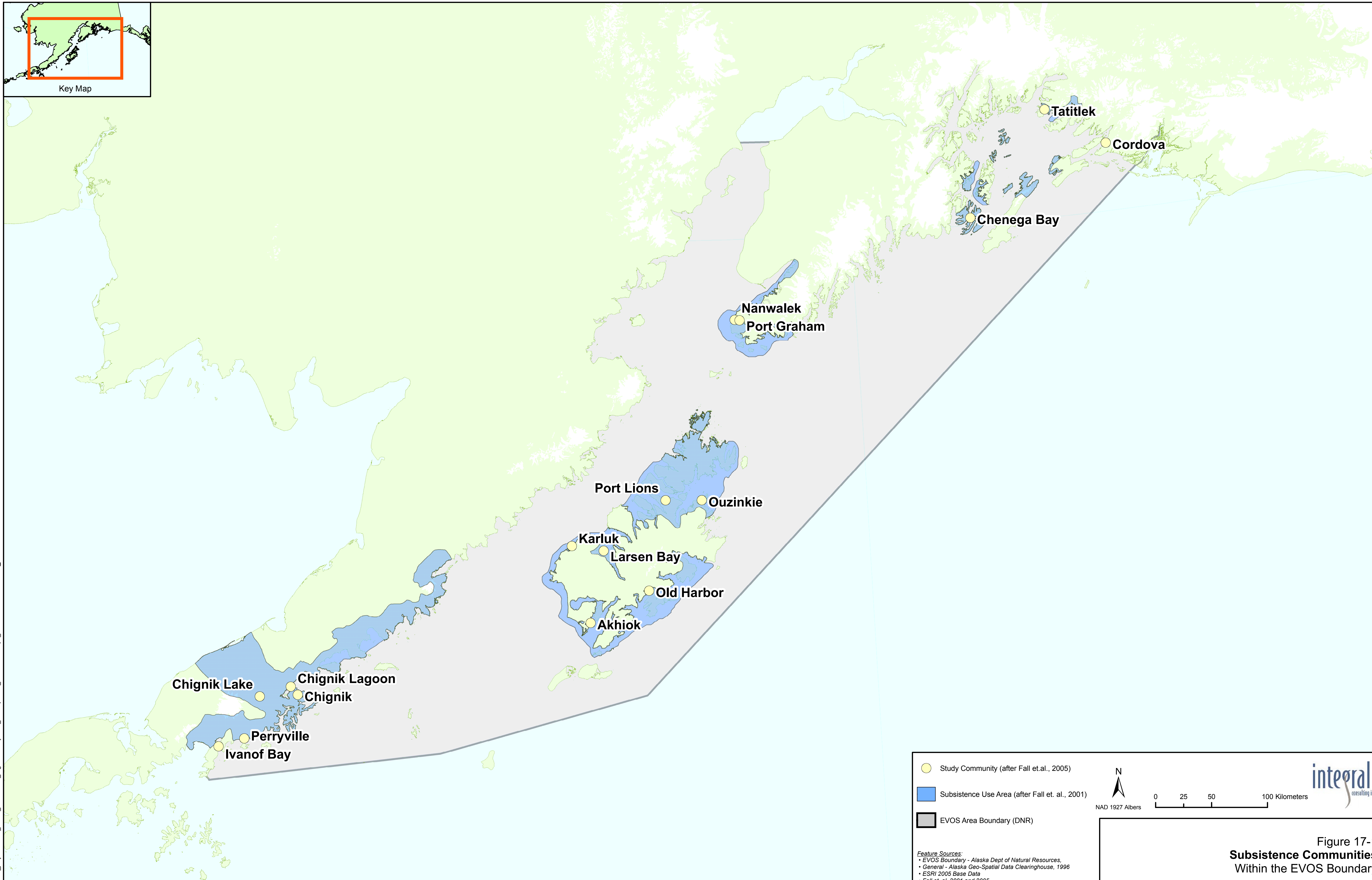

Figure 17-1
Subsistence Communities
Within the EVOS Boundary

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19. RECREATION AND TOURISM

An abundance of public land, a small resident population (<10,000), calm waters, and rich fish and wildlife resources make PWS a wilderness attraction for Alaskan residents and visitors alike (Brooks and Haynes 2001). In 2003, recreation (outdoor leisure activities of Alaska residents) and tourism (outdoor leisure activities of non-Alaska residents) accounted for 26,000 jobs, generated $2.4 billion in gross sales, and contributed $1.5 billion to Alaska's economy (Alaska Department of Commerce, Community, and Economic Development 2004).

19.1 INTRODUCTION

This section provides background on recreational use of resources in PWS, the recovery objective and 2002 recovery status of recreational services, and an overview of studies and reports relevant to recreation in PWS.

19.1.1 Background

Recreation and tourism produced sustained economic growth in Alaska from 1991 to 2001 (Parks 1999; Brooks and Haynes 2001; Goldsmith 1999). Recreation and tourism usage figures from the Chugach National Forest indicate that south-central Alaska (including PWS) supported a large recreation and tourism industry projected to grow at an approximate rate of 28 percent or more through 2020 (Bowker 2001; Brooks and Haynes 2001; Goldsmith 2001). In addition, Brooks and Haynes (2001) reported that, compared to other average U.S. residents, Alaskans spent proportionally more of their leisure time in pursuit of outdoor recreation. The authors noted, therefore, that recreation and tourism opportunities contributed not only to Alaska's economy, but to Alaskan residents' quality of life (Brooks and Haynes 2001).

19.1.2 Initial Impact from Spill (1989–1991)

EVOS resulted in the oiling of approximately 1,500 km of south-central Alaska's coastline, with heavy oiling affecting approximately 350 km of shoreline. The initial spreading of EVO in open water was exacerbated by a series of significant storm events resulting in EVO washing ashore throughout PWS over a 2-month period. The spill produced both acute and chronic impacts on many of the natural resources on which regional recreational activities were based, including clams and fish for sport fisheries and marine mammals and seabirds popular for wildlife viewing (Integral 2006). EVOS damaged access to recreation and tourism opportunities and natural resources in PWS, and left visible oil on accessible beaches.

The initial injuries to recreation and tourism by EVOS varied by location and included the following:

1. Reduced recreation and tourism participation and quality due to resource injuries. Resource managers reacted to the spill by limiting access to resources. Sport fishing and hunting areas in the path of the spill were closed, increasing pressure on nearby

recreational facilities by displaced users (EVOS Trustee Council 1994). Recreation use in the spill area, and sport fishing in particular, declined in 1989 in PWS, Cook Inlet, and the Kenai Peninsula (Mills 1992; Menefee and Hennig 1995; EVOS Trustee Council 1994).

2. Reduced recreation and tourism participation and quality due to visible residual oil (EVOS Trustee Council 1994). Residual oil was observed mostly by shoreline recreational users such as kayakers (Menefee and Hennig 1995).

3. Direct damage to Green Island cabin and Fleming Spit campsites by EVOS cleanup crews (EVOS Trustee Council 1994).

19.1.3 Status of Injury and Recovery Classification

The EVOS restoration plan (EVOS Trustee Council 1994) provides long-term guidance for restoring services injured by the 1989 spill. The 1994 recovery objective for recreation was stated as:

> Recreation and tourism will have recovered, in large part, when the fish and wildlife resources on which they depend have recovered, recreational use of oiled beaches is no longer impaired, and facilities and management capabilities can accommodate changes in human use.

By 2002 (EVOS Trustee Council 2002b), this objective had been refined to be:

> Recreation and tourism will have recovered, in large part, when the fish and wildlife resources on which they depend have recovered and recreational use of oiled beaches is no longer impaired.

In 1994, recreation and tourism were classified as injured and partially recovering in PWS, Kenai, Kodiak, and the Alaska Peninsula (EVOS Trustee Council 1994). By 2001, the EVOS Trustee Council reported increases in recreation and tourism in the spill region, and noted that $10 million had been devoted to the repair and restoration of recreation facilities. These efforts effectively ameliorated the damage to Green Island cabin and Fleming Spit campsites, and possibly accommodated changes in human use. Visitation to parks had increased in Kenai and PWS, and sport fishing efforts had grown in Kenai, Kodiak, and PWS. Despite localized cleanup efforts, subsurface oil remained on PWS beaches used for recreation (e.g., Chenega Bay), and continued to impair recreation (EVOS Trustee Council 2002b). Telephone surveys in 1999 and 2002 of key informants who used PWS and surrounding areas for recreation before and after the spill suggested that although oil remained on beaches outside PWS, it did not deter recreationists or tourists from using the Kenai coast, the Kodiak Archipelago, or the Lake Clark and Katmai National Park coastlines (EVOS Trustee Council 2002b).

Recreation and tourism participation was high in 2003 and had surpassed pre-spill levels, but some resources important to recreation and tourism had not recovered. Recreation and tourism continued to be classified as recovering (EVOS Trustee Council 2002b) because related natural resources had not yet recovered, and recreational use of beaches containing lingering oil remained impaired. Among those species considered important to recreation and tourism but not recovered in 2002 were killer whales (AB pod), harbor seals, sea otters, harlequin ducks, and seabirds, including common loons, cormorants, Kittlitz's murrelets, marbled murrelets, and pigeon guillemots. Remaining oil in areas accessible to recreational users and tourists affected aesthetic perception, linking satisfactory recreation and tourism experiences to the restoration of perceptions of the spill area as wilderness (EVOS Trustee Council 2003).

19.1.4 Overview of Recreation and Tourism Projects Conducted to Date

The EVOS Trustee Council, Alaska State agencies, and the federal government performed research important for our assessment of the recovery of recreation and tourism in PWS. Examples of projects specific to recreation and tourism are listed below.

19.1.4.1 Summary of Projects Funded by the EVOS Trustee Council

Of the projects funded by the EVOS Trustee Council, five focused on restoring damaged resources and enhancing recreational access to resources, and five assessed, researched, or monitored recreation and tourism. One project, FS6, was funded to monitor sport fishing harvest and effort, but no final report is available through the EVOS Trustee Council. A comprehensive list of projects on recreation and tourism funded by the EVOS Trustee Council is provided in Appendix A.

The 1994 restoration plan (EVOS Trustee Council 1994) formulated recovery objectives reliant on recovery of natural resources, restoration of recreation on oiled beaches, and provision for adequate recreational facilities. Projects funded by the EVOS Trustee Council and other entities successfully addressed many of the 1994 restoration plan objectives. Projects aimed to restore injured resources potentially benefited recreation and tourism as well. In addition, the EVOS Trustee Council initiated projects to increase recreational access to beaches and other areas, and improved and expanded spill-area recreational facilities (Kuwada and Weiner 1998). The overall strategy of assessing, monitoring, and restoring resources important to recreation and tourism was upheld by the funded projects.

19.1.4.2 Summary of Projects Funded by Other Sources

Several federal agencies performed research relevant to spill-area recreation and tourism. The U.S. Census Bureau (USDOI et al. 2003) examined usage numbers and patterns in fishing, hunting, and wildlife recreation on national and statewide levels. This study gathered data on participation and types of recreation prevalent in Alaska. Similarly, the U.S. Forest Service performed two studies on recreation and tourism participation in south-central Alaska and the Chugach National Forest (see Brooks and Haynes 2001 and Bowker 2001). USFWS managed hunting of migratory birds, including harlequin ducks, and, though the data were not available at the time of this writing, presumably tracked recreational harvest numbers of this species.

State agencies invested in valuable spill-area research as well. ADFG continued its monitoring of recreational fisheries harvest and effort in south-central Alaska on an annual basis (e.g., Walker et al. 2003; Miller 2001; Berceli and Trowbridge 2006). Other state agencies monitored the economic contributions of recreation and tourism within Alaska including the Alaska Department of Commerce, Community, and Economic Development (e.g., Global Insight 2004) and the Institute for Social and Economic Research (e.g., Goldsmith 1999).

19.2 ASSESSMENT OF RECREATION AND TOURISM

Successful recreation and tourism in PWS depend on access to natural resources desirable for both consumptive and nonconsumptive activities and on the ability of PWS to provide satisfactory recreation and tourism experiences.

We reviewed available literature on recreation and tourism (summarized in Section 19.1.4) to assess the role of EVOS in the statuses of consumptive recreation (hunting, fishing, and harvesting of marine resources) and nonconsumptive recreation (e.g., wildlife viewing) dependent on natural resources. Potential effects of EVOS were examined in the context of other factors influencing recreation and tourism.

19.2.1 Recovery of Sport Fishing and Marine Harvesting

Both consumptive and nonconsumptive recreation rely on access to natural resources. Natural resources must possess sufficient abundance and health to be exploited by tourists and recreationists in a sustainable manner. The resources listed by the EVOS Trustee Council as not recovering, recovering, or unknown, and of importance to hunting and fishing are harlequin duck, cutthroat trout, Dolly Varden, rockfish, and butter, littleneck, and razor clams. Additional scientific information on the biology and recovery of several these resources is available in the individual resource sections (Integral 2006).

19.2.1.1 Recreational Angling

Recreational angling in PWS has surpassed pre-spill levels: marine angler days of effort increased from 30,383 in 1988 to 173,554 in 2004 (Hoffman and Miller 2000; Ashe et al. 2005; Figure 19-1). Increased angler effort in PWS coincided with a similar regional pattern (Walker et al. 2003; Jennings et al. 2004; Bernard 2006, pers. comm.; Figure 19-2). Furthermore, in 2003, recreational harvest numbers of most game fish, including rockfish and trout, exceeded previous records, potentially indicating favorable recreational fishing conditions (Ashe et al. 2005). Recreational harvests of rockfish in southern Alaska grew from 8,157 in 1990 to 35,085 in 2004 (see Figure 19-3).

For many fish species, there were no regulatory differences between PWS and the rest of southwest and southeast Alaska. Dolly Varden bag limits in PWS and southwest and southeast Alaska were the same. Total rockfish harvest limits were identical in the spill area and elsewhere in Alaska, though the limit on non-pelagic rockfish was lower in PWS (two vs. five). Recreational access to cutthroat trout remained limited in 2006; cutthroat trout in the spill area retained the lower catch limits and spawning season fishery closure enacted in 1991 (EVOS Trustee Council 2003; ADFG 2005b). Notably, however, cutthroat trout bag limits were no different in the spill area than in southeast Alaska; the species was managed carefully statewide (EVOS Trustee Council 2003; ADFG 2005b). Although recreational use data suggest a robust and expanding fishery for these game fish, it is difficult to assess to what extent these data are a result of fishery pressure, or reflective of the health of these fish populations. There is little or no scientific information for populations of Dolly Varden, cutthroat trout, and rockfish in the spill area.

19.2.1.2 Recreational Harvesting of Intertidal Resources

Scientific information indicates that, for most of PWS and the spill area, butter and littleneck clams (collectively known as "hardshell clams") are largely recovered (see Section 7). However, no data could be found for recreational harvest of butter and littleneck clams in PWS that would enable an assessment of recreational use of these species in this area.

Hardshell clam recreational harvest limits were introduced in Cook Inlet in 1994, though they had no apparent effect on harvest levels (Szarzi and Begich 2004). Though recreational harvesters had not exceeded harvest management limits, daily and possession limits were imposed to prevent commercial hardshell clam harvest under the auspice of recreation (Szarzi and Begich 2004). An assessment of recreational hardshell clam harvests in Katchemak Bay and LCI indicated that harvest levels were stable and well below the management limits (Szarzi and Begich 2004). In this study area, recreational and personal use harvest levels exceeded commercial harvest levels of hardshell clams (Szarzi and Begich 2004). Recreation harvest levels of hardshell clams were lower than in the past, but many users requested the further lowering of harvest limits to ensure high quality clam harvesting (Szarzi and Begich 2004; see Figure 19-4). A decline in hardshell clam digger effort was reported in 1998, but was attributed to the closure of the Dungeness crab fishery; crabs and clams historically were harvested concurrently (Szarzi and Begich 2004).

Recreational razor clam harvests varied within the spill area.[70] In Cook Inlet, which contains Alaska's largest razor clam fishery, researchers considered razor clam populations and harvest levels healthy despite declines from historical harvest levels (Szarzi and Begich 2004; Figure 19-5). Bag limits for razor clams in Cook Inlet were reduced from 60 to 45 in 1994, and a possession limit was introduced; these limits remained through 2006 (Szarzi and Begich 2004; ADFG 2005c). Szarzi and Begich (2004) made no mention of EVOS as affecting razor clam harvesting, and considered the outlook for razor clam harvests to be positive.

In PWS, permits were required and size restrictions existed for recreational razor clam harvests, though there were no bag limits (ADFG 2005c). Razor clam harvests and harvest success levels (measured as mass of clams taken per digger) remained lower than in pre-spill years (Figures 19-6 and 19-7). Berceli and Trowbridge (2006) attributed low harvest levels to depressed razor clam populations in the Copper River delta, Katalla, and Controller Bay. While they implied that clam populations were affected by historical overharvesting and habitat

[70] Although razor clams are not specifically discussed as an injured resource by the EVOS Trustee Council, they are part of the overall clam community and are discussed here because of their importance in recreational harvesting in some spill-affected areas.

alteration (specifically a 1958 siltation event and the March 1964 earthquake), they did not attribute current low clam populations to any specific factors (Berceli and Trowbridge 2006). The authors noted that recreational harvests might have been influenced by perceptions of paralytic shellfish poisoning in addition to actual clam population levels (Berceli and Trowbridge 2006). Berceli and Trowbridge (2006) made no mention of EVOS as a potential factor affecting razor clam populations, though a study of subsistence users indicates that recreational clam users may erroneously link paralytic shellfish poisoning to EVOS (Fall et al. 2005). One acknowledged data gap in the Berceli and Trowbridge (2006) study was the fact that ADFG did not measure PWS razor clam abundance directly, so razor clam population status remains uncertain.

19.2.1.3 Recreational Hunting

Harlequin ducks, among other waterfowl, are hunted recreationally in the EVOS area (EVOS Trustee Council 2003). Harlequin duck harvest levels in PWS and Kenai Fjords were reduced by the Alaska Board of Game in 1991, limiting recreational access (EVOS Trustee Council 2003). Harlequin duck hunting regulations in PWS and the Kenai Fjords conformed to Alaska statewide limits of 6 per day or 12 in possession from 2000 through 2006; hunting harlequin duck was no longer regulated differently in the spill area compared to elsewhere in Alaska (ADFG 2005c; EVOS Trustee Council 2003). No data were available to analyze hunting efforts or harvest levels to assess recreational access to harlequin ducks. Examination of historical and current recreational harlequin duck harvest would assist evaluation of the status of recreational access to harlequin ducks.

Without recreational harvest data, we relied on the status of spill-area harlequin duck populations as a measure of their availability for recreational hunting. Population trends for harlequin ducks are the same in oiled and unoiled portions of PWS and most important demographic measures are the same. From a population perspective, harlequin ducks are considered to be recovered.[71] USFWS considers the western harlequin duck population “Birds of Management Concern” and designates harlequin ducks “Game Birds Below Desired Condition (GBBDC)” (USFWS 2005).

19.2.2 Recovery of Nonconsumptive Recreation and Tourism Activities

According to the EVOS Trustee Council, resources of concern that are important to nonconsumptive recreation and tourism include killer whales, harbor seals, sea otters, common loons, marbled murrelets, Kittlitz’s murrelets, pigeon guillemots, and double-crested, pelagic, and red-faced cormorants. Additional scientific information on the biology and recovery of several of these resources is available in the individual resource sections (Integral 2006).

Respondents in the key informant study reported decreased wildlife sightings in 2002 in the spill area compared to pre-spill years (EVOS Trustee Council 2003). The EVOS Trustee Council (2003) acknowledged that changes in wildlife viewing levels could have resulted from a suite of

[71] A measure of exposure, CYP1A continues to be elevated in harlequin ducks collected from oiled portions of PWS.

undetermined factors, including but not limited to EVOS. Based on the most recent evaluation of seabirds and sea mammals discussed in Sections 10, 15, 16, and 17, the weight of scientific evidence suggests that the populations of these resources are generally affected by factors other than EVOS.[72] Despite the decline in wildlife sightings, nonconsumptive recreation and tourism levels continued to increase in the spill area, though not at rates as high as during 1993–1997 (Brooks and Haynes 2001). Projections of recreation and tourism activities based on visitation numbers predicted relatively high growth in nonconsumptive activities such as wildlife viewing, scenic driving, off-road driving, and biking in the Chugach National Forest area (Bowker 2001). Based on Bowker's (2001) analysis, these activities were increasing beyond pre-spill levels at a rate slightly greater than the population growth rate. In the PWS area, Brooks and Haynes (2001) predicted that, for all recreation and tourism activities, wildlife and scenery viewing would exhibit the fastest growth in both recreation and tourism. These trends indicate a robust market for nonconsumptive recreation and tourism; no data were found, however, comparing rates in PWS to those of comparable but unoiled parts of Alaska.

19.2.3 Perceived Quality of Recreational Experience

Assessments of recreationists' and tourists' perceptions since the spill remain inconclusive. Menefee and Hennig (1995) argued that EVOS and the cleanup effort in PWS "...reduced the perceived wilderness character forever" (p. 10). Initial studies demonstrated that EVOS was of concern to recreationists and tourists, while later studies concluded that, while, users were aware of and displeased by the continued presence of oil, they did not alter their usage patterns in the spill area outside of PWS (Menefee and Hennig 1995; EVOS Trustee Council 2003). Within PWS, lingering oil on beaches remains an aesthetic detriment, and is avoided by local recreationists (EVOS Trustee Council 2003). The demonstrated persistence of lingering oil (Short et al. 2003a) suggests that this deterrent factor is still present today.

Increasing tourism usage numbers might indicate that aversion to lingering oil is outweighed by public interest in taking advantage of recreation and tourism opportunities in PWS. EVOS is not cited as a factor in the available literature (Brooks and Haynes 2001). Brooks and Haynes (2001) do note that "the quality of experience also may be a limiting factor for some uses" (p. 17), but attribute the limit in quality to overcrowding of facilities, not diminished natural resources. Brooks and Haynes (2001) discuss other factors contributing to recent decreased growth rates in recreation and tourism in Chugach National Forest including lack of infrastructure, competition with other Alaskan parks and recreation areas, and demographic and economic shifts. Usage studies note that small, specialized businesses in recreation and tourism are flourishing, especially in providing nonconsumptive recreation and tourism experiences (Brooks and Haynes 2001; Bowker 2001). No recent conclusive data has been gathered on the extent to which the public views PWS as wilderness; nevertheless, recreation and tourism continue to increase in the spill area at a rate similar to or exceeding that in Alaska as a whole (Brooks and Haynes 2001; Goldsmith 2001; Global Insight 2004).

[72] The number of individuals in the AB pod of killer whales continues to be depressed, likely due to the slow reproduction rate and loss of females at the time of the spill. A localized subpopulation of sea otters in northern Knight Island is also lower than would have been anticipated.

19.3 POTENTIAL CONFOUNDING FACTORS IN EVALUATING THE ROLE OF EVOS IN RECREATION AND TOURISM

Confounding factors in determining the connection between present conditions in recreation and tourism in PWS and EVOS include non-EVOS-related effects on important recreation resources (e.g., predator–prey relationships, climate and oceanographic effects), time elapsed since the spill, increased recreation-related visitation, and competing uses.

Any effects EVOS had on the growth of recreation of tourism could be confounded by increases in human population. From 1990 to 2004, the population of the U.S. has grown approximately 15 percent, and the population of Alaska about 16 percent (U.S. Census Bureau 2006). Accordingly, recreation and tourism grew at a similar rate (Bowker 2001). Bowker (2001) predicted that *per capita* growth rates of recreation and tourism would remain relatively flat; population growth would account for most increases in recreation and tourism in the spill area. We could not locate studies of recreation and tourism in comparable oiled vs. unoiled areas, which could have resolved potential effects of EVOS in the context of national and regional population growth.

The increase in recreation and tourism participation in recent years creates problems independent of EVOS. One negative aspect of increased numbers of recreationists is the potential for crowding, which could diminish the quality of recreationists' and tourists' experiences (Brooks and Haynes 2001). Furthermore, increased harvest pressure from recreationists may apply additional pressure on natural resources important to commercial fishing and subsistence users (Szarzi and Begich 2004; Fall et al. 2005). Increased pressure on resources could trigger more restrictive management practices that might displease consumptive recreationists. Even the presence of nonconsumptive recreation and tourism users has been cited as affecting subsistence harvesters; resource managers need to address these conflicting interests (Fall et al. 2005).

19.4 SUMMARY AND RECOMMENDATIONS

Based on available recreational and tourism data, PWS appears to provide increasingly popular and lucrative recreation and tourism experiences. Consistent increases in participation since EVOS in both consumptive and nonconsumptive activities indicate that recreational opportunities are robust and growing proportionately to the population. While lingering oil remains a perceived detriment in local areas to some users, it does not appear to deter visitors from participating in recreational activities in the spill-affected area.

For some resources, particularly sport fish species such as rockfish and Dolly Varden, assessing the effects of EVOS on recreational harvest opportunities is hindered by an absence of resource population data. Large sustained increases in recreational fisheries harvests suggest that recreational harvest opportunities for these species have been plentiful to date. However, because neither baseline nor monitoring data are available for these species in the spill-affected area, it is not possible to assess to what extent these increases might be driven by increased fishing pressure rather than sustainable species abundance.

Recreation and tourism will have recovered when "the fish and wildlife resources on which they depend have recovered…" (EVOS Trustee Council 2003). Our assessment finds that populations of virtually all recreational resources have recovered. However, recovery of recreation and tourism services also requires that recreational use of oiled beaches is no longer impaired. Despite the fact that recreational users have returned to the area in great numbers, there are still some users aware of and displeased by lingering oil on beaches. If perceived impairment to beaches by lingering oil is of concern, these perceptions could be more directly quantified by methods such as user surveys of Alaska recreationists and tourists comparing the level of satisfaction attained in the spill area and that elsewhere.

It is recommended that the Trustee Council classify recreation and tourism services as recovering.

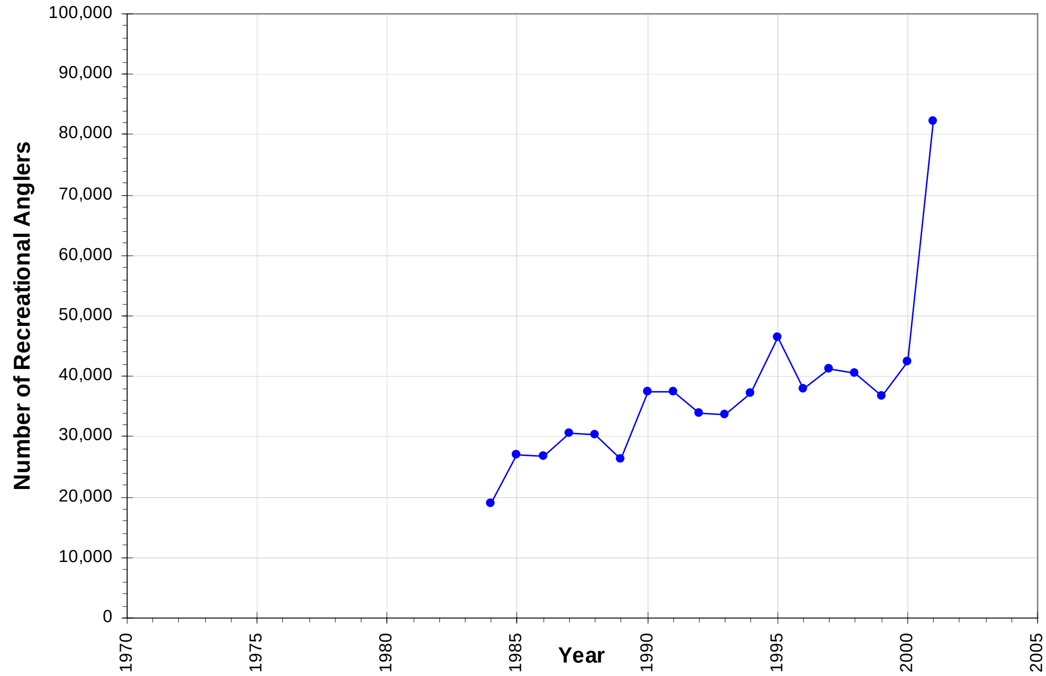

Figure 19-1. Annual Survey Estimates of Prince William Sound Recreational Anglers from 1984 to 2001 (data from Hoffman and Miller 2000 and Miller 2001).

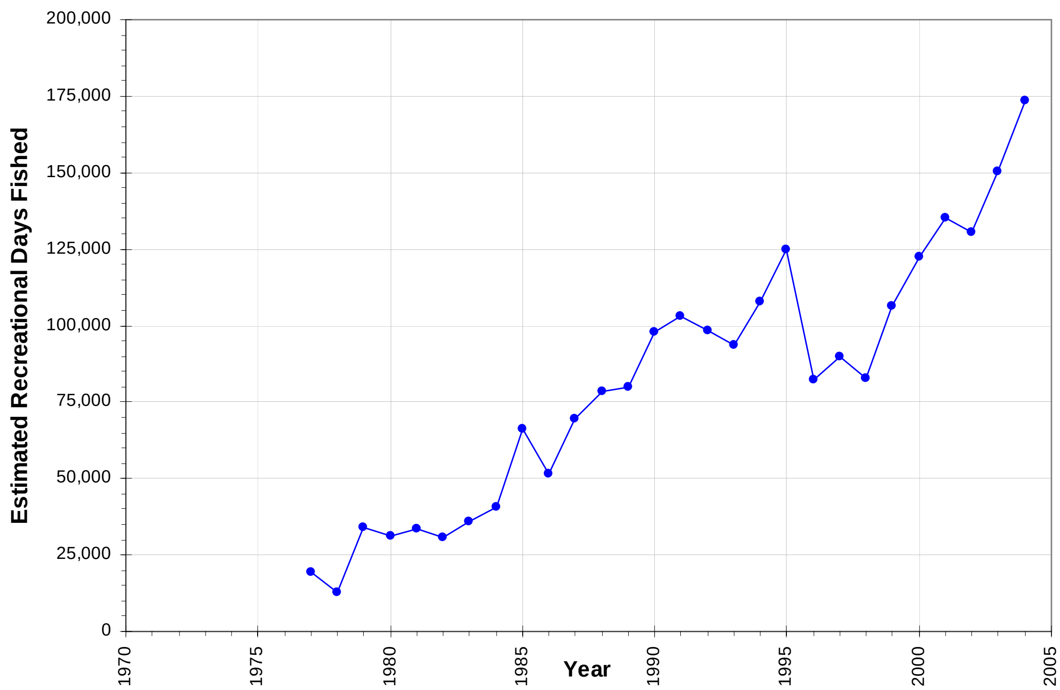

Figure 19-2. Estimated Fishing Effort for Prince William Sound Region between Cape Suckling and Cape Puget, Alaska, from 1977 to 2004 (data from Walker et al. 2003, Jennings et al. 2004, and Bernard 2006, pers. comm.).

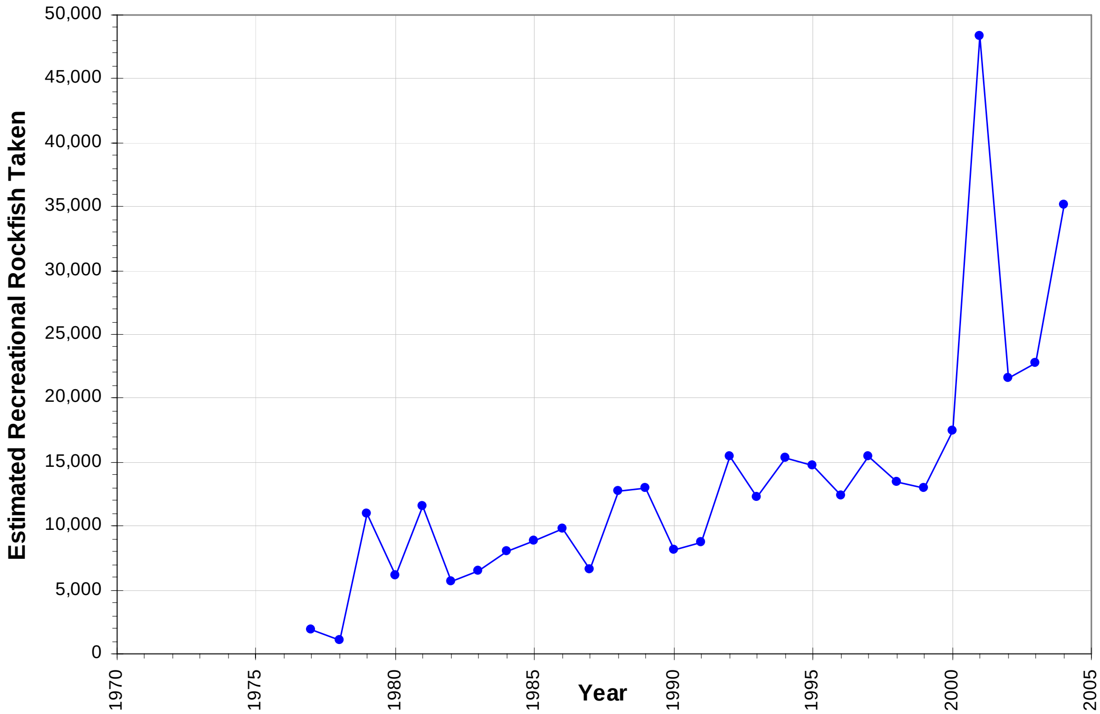

Figure 19-3. Estimated Numbers of Rockfish Caught and Kept in Prince William Sound Region between Cape Suckling and Cape Puget, Alaska, from 1977 to 2004 (data from Walker et al. 2003, Jennings et al. 2004, and Bernard 2006, pers. comm.).

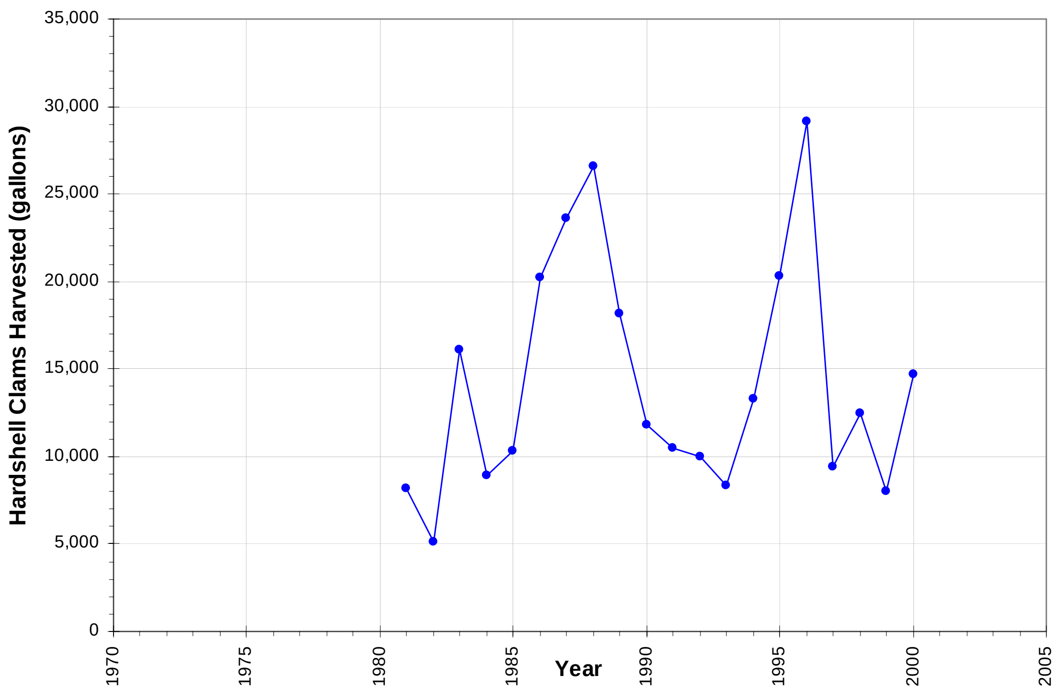

Figure 19-4. Estimated Sport and Personal Use Hardshell Clam Harvests in Kachemak Bay and Lower Cook Inlet from 1981 to 2000 (data from Szarzi and Begich 2004).

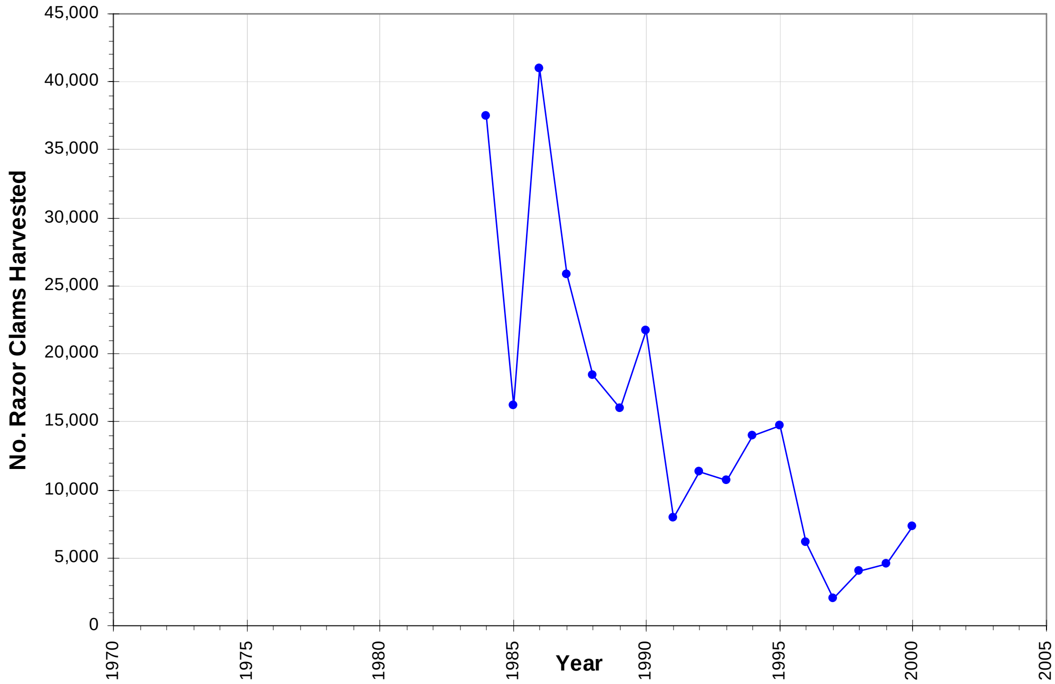

Figure 19-5. Estimated Sport and Personal Use Razor Clam Harvests in Kachemak Bay and Lower Cook Inlet from 1984 to 2000 (data from Szarzi and Begich 2004).

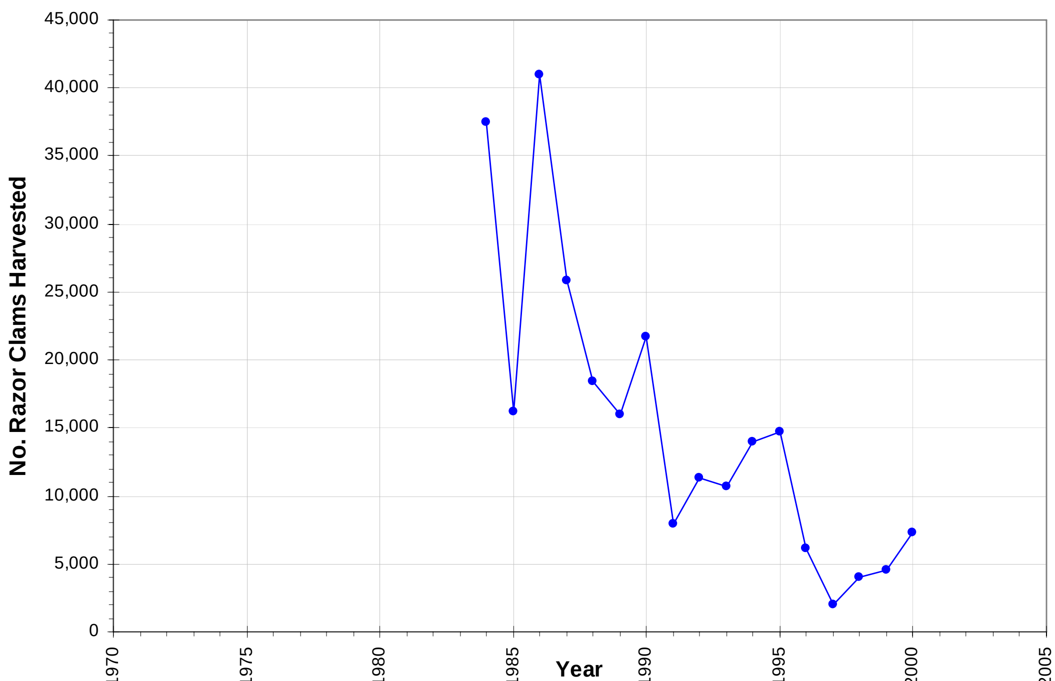

Figure 19-6. Recreational Harvest of Razor Clams in Prince William Sound from 1985 to 2005 (data from Berceli and Trowbridge 2006).

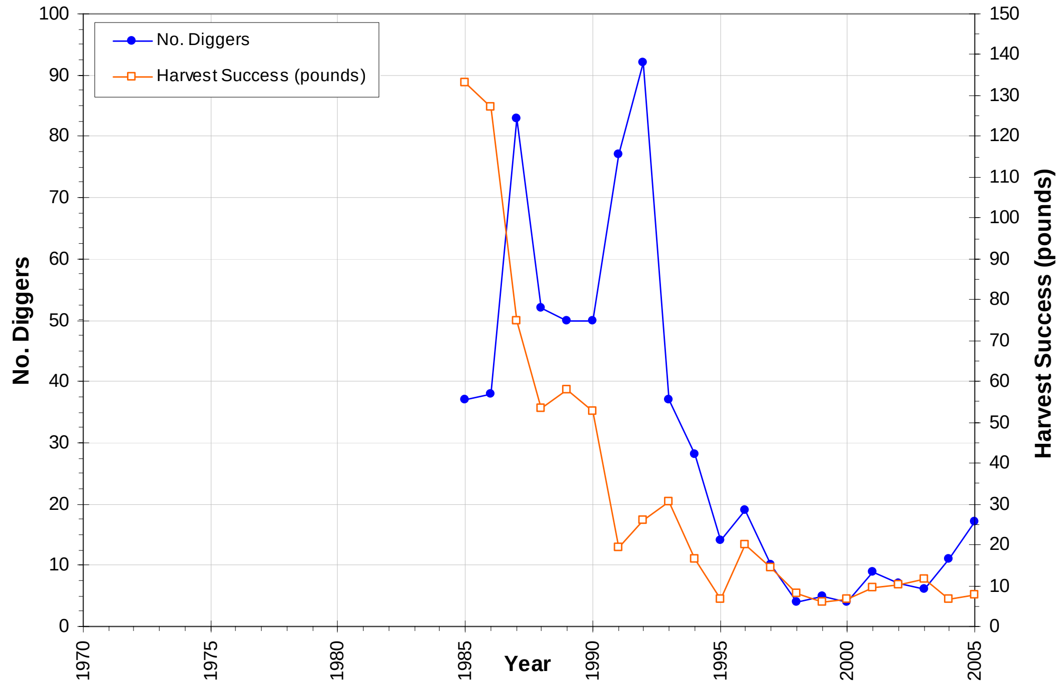

Figure 19-7. Numbers of Clam Harvesters ("Diggers") and Harvest Success (pounds of clams harvested per harvester) in Prince William Sound from 1985 to 2005 (data from Berceli and Trowbridge 2006).

20. PASSIVE USE

20.1 INTRODUCTION

The EVOS resulted in the oiling of approximately 1,500 km of south-central Alaska's coastline, with heavy oiling affecting approximately 350 km of this area. The spill produced both acute and chronic impacts on many of the natural resources on which users depend. A wide range of people actively use the natural resources of the spill-affected area, including commercial fishermen, anglers, hunters, tourists, and subsistence harvesters. In addition, the area affected by EVOS is also valued passively by those who do not live, recreate, visit, or harvest within it. The ecosystem within the area affected by EVOS was highly valued for its passive uses by the American public before the spill, and a number of them suffered passive use losses because of EVOS (EVOS Trustee Council 1994).

The EVOS Trustee Council defined passive use to be restored in the spill area when passive use values associated with the spill were no longer diminished by EVOS (EVOS Trustee Council 1994). By 2002, passive use of the spill area was considered to be recovering, but not recovered, because recovery of injured resources was still incomplete (EVOS Trustee Council 2002b). Our objectives are to critically review and synthesize information regarding the current state of passive use in the spill area in the context of EVOS and to provide recommendations for future actions with respect to passive use recovery.

20.1.1 Background

When natural resources are injured, services that depend on those resources are likewise injured. Passive uses are the services provided by natural resources to people who do not visit, contact, or otherwise use the resources (Kopp and Smith 1993a; Carson et al. 2003). Examples of passive uses injured by EVOS include the appreciation of aesthetic natural areas and wilderness and the pleasure of knowing natural resources exist (EVOS Trustee Council 1994) at a given level of quality. Passive use services are classified by economists as pure public goods. They are not exchanged in organized markets, quality is not reduced by increasing numbers of participants, access cannot be controlled, and quantity cannot be observed or inferred (Kopp and Smith 1993a). Valuation of pure public goods, including passive use services, is a complex undertaking. Many tools for estimating passive use values are available to economists, however; some of these tools are discussed below.

20.1.2 Initial Impact from Spill

The oil spill injured what many may have previously perceived as an undisturbed area. EVOS caused visible injuries to the PWS ecosystem in the form of oiled, injured, and dead fish and wildlife and oil-contaminated shorelines and intertidal and subtidal habitats (EVOS Trustee Council 1994). A contingent valuation study performed in 1991 estimated that there were a minimum of $2.8 billion in passive use losses to U.S. households from the EVOS (Carson et al. 1992, EVOS Trustee Council 1994).

20.1.3 Status Injury and Recovery Classification

The EVOS restoration plan (EVOS Trustee Council 1994) provides long-term guidance for restoring services injured by the 1989 spill. The 1994 recovery objective for passive use was stated as:

> Passive uses will have recovered when people perceive that aesthetic and intrinsic values associated with the spill area are no longer diminished by the spill.

This recovery objective was not altered in the most recent assessment of recovery status (EVOS Trustee Council 2002b).

In 1994, the EVOS Trustee Council linked injuries to passive use values because EVOS injured natural resources from which passive use services are derived, including scenic shorelines, and popular wildlife such as seabirds and marine mammals (EVOS Trustee Council 1994). The status of passive use was classified as recovering because resources were recovering, and much of the visible oil on the shoreline had been removed or had weathered (EVOS Trustee Council 1994). Realizing that passive use values relied on public perception, the Trustee Council resolved to provide the public with continually updated scientific information on injured resources (EVOS Trustee Council 1994).

By 2002, the EVOS Trustee Council had decided not to fund further contingent valuation studies to evaluate the status of passive use values (EVOS Trustee Council 2002). The Trustee Council continued to disseminate information on resource recovery to the public throughout the restoration and recovery processes (EVOS Trustee Council 2002b). EVOS Trustee Council also developed programs to foster stewardship of the spill-area ecosystem to maintain passive use values for the future (EVOS Trustee Council 2002b). Furthermore, the Trustee Council acquired land to protect ecological habitat for the benefit of both passive use values and natural resources (EVOS Trustee Council 2002b). Because not all injured resources had recovered, passive use was listed as recovering, but not recovered (EVOS Trustee Council 2002b). In addition, the recovery goal of “a return to conditions that would have existed had the spill not occurred” was added (EVOS Trustee Council 2002b).

20.1.4 Overview of Passive Use Projects Conducted to Date

The State of Alaska directed a contingent valuation study to directly evaluate EVOS-related damages to passive use. Resource restoration and monitoring studies and land acquisition, stewardship, and outreach programs all addressed passive use indirectly.

20.1.4.1 Summary of Projects Funded by the EVOS Trustee Council

Three projects related to passive use were funded by the EVOS Trustee Council and are further described in Appendix A. These projects included initiatives to assist spill-area landowners in participating in resource and habitat restoration and to include spill area residents in gathering and communicating scientific data relating to resource recovery (Kuwada 2006; Brown-

Schwalenberg 2006). A third project modeled human disturbance patterns in the spill area with the intent of determining how human activity could be regulated to maximize resource recovery rates (Murphy et al. 2004).

20.1.4.2 Summary of Projects Funded by Other Sources

Two contingent valuation studies funded by sources other than the EVOS Trustee Council addressed passive use issues in the EVOS-affected area. The first study surveyed a sample of the public to assess the lost monetary passive use value of the spill area (Carson et al 1992). The results estimated lost passive use values at $2.8 billion using the median value the survey sample was willing to pay to prevent an event similar to EVOS (Carson et al. 1992). The same data were examined in a later paper (Carson et al. 2003).

The Carson et al. 1992 contingent valuation study estimated monetary lost passive use values to U.S. households. Efforts to restore passive use have been associated with efforts to restore injured resources and inform the public of restoration progress. While it is generally thought that this approach will influence passive use, there have been no studies conducted to estimate the extent to which passive use values have recovered for the injured resources (Carson et al. 2003).

20.2 ASSESSMENT OF PASSIVE USE

The recovery of passive use values in the EVOS impact area is related to the public's perceptions of the spill area's natural resources (EVOS Trustee Council 1994). Extensive work has been done to restore and monitor natural resources in the spill area and to communicate scientific findings to the public (see Appendix A). There were no data on passive use values or perception in the spill area prior to EVOS; however, the contingent valuation study estimated damages to passive use values from EVOS (Carson et al. 1992) and provides a baseline for comparison to perceptions following the spill. The efficacy of efforts to inform the public about the status of natural resources following the spill and the effects this information had on public perception were not studied after EVOS.

Creating achievable and measurable metrics for passive use recovery could facilitate an understanding of whether recovery goals are being met. Specifying quantities to measure in passive use valuation and actually measuring them is a complex undertaking (Kopp and Smith 1993b); however, there are well-developed, published methods that, in consultation with experts in this field, are available for application. One method for valuating passive use is contingent valuation, which quantifies passive use by having survey respondents assign monetary values to natural resource damages (Carson et al. 2003). This method has been criticized for several reasons (for further discussion see Kopp and Smith 1993b, Mitchell and Carson 1989; Adamowicz et al. 1995, and Carson et al. 2003). Other methods for estimating passive use value may lie with choice experiments, also known generally as stated choice methods (Adamowicz et al. 1995; Meade 2006, pers. comm.). These methods can be time-consuming and costly to develop and implement, especially if they involve face-to-face interviews (Meade 2006, pers. comm.). The advent and continual refinement of internet survey techniques may provide a more cost-effective alternative to traditional interviews, and these techniques are becoming increasingly accepted by the economic community (Meade 2006, pers. comm.).

20.2.1 Assessment of Individual Resources Important for Passive Use

The EVOS Trustee Council defined the resources on which passive use recovery depended as the spill area and all natural resources contained within it. Individual resources were not highlighted. Among those resources listed as not recovering in 2003 were sediment, herring, harbor seals, sea otters, harlequin ducks, common loons, cormorants, Kittlitz’s murrelets, marbled murrelets, and pigeon guillemots.

20.2.2 Potential Confounding Factors in Evaluating the Role of EVOS in Passive Use

Direct uses have the potential to decrease passive use values (Kopp and Smith 1993a). For example, if overfishing by commercial and recreational fishermen led to the injury of a species, the passive value of that species may be diminished. In the spill area, many active uses of injured resources have increased since EVOS (e.g., recreational fishing for salmon; see Sections 17 and 19, “Commercial Fishing” and Recreation and Tourism”), and the population in the spill-affected area has increased (U.S. Census 2006). These increases in resource exploitation and human presence may confound the recovery of passive use in the context of EVOS.

20.3 SUMMARY AND RECOMMENDATIONS

Efforts directed towards restoration and public outreach most likely have had positive effects on passive use values, but the extent of their success remains unknown. It is likely that the continuing presence of lingering oil in intertidal sediments, the failure of the herring fishery, and publicity related to the reopener will contribute to public perceptions that PWS resources continue to be injured.

Passive uses will have recovered when people perceive that aesthetic and intrinsic values associated with the spill area are no longer diminished by the spill (EVOS Trustee Council 1994).

It is recommended that the Trustee Council classify passive uses as “recovering.” Until the public perceives that lingering oil has diminished to levels that no longer adversely affect aesthetics, this service cannot be consider recovered, even if most of the resources upon which it depends have recovered. It is also recommended that the Trustee Council continue to communicate the progress being made toward recovery of resources and services important to public perception.

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Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary			Project information						
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
MAMMALS										
Harbor Seals	Harbor seals will have recovered from the effects of the oil spill when their population is stable or increasing.	Not recovering	Conduct research to find out why these resources are not recovering.	2003	30689	Population Monitoring of Fjord-inhabiting Harbor Seals of the Kenai Peninsula	Anne Hoover-Miller	CLICK TO ACCESS		Monitoring & Research
			Initiate, sustain, or accelerate recovery.	2005	50749	Harbor Seal Monitoring in Southern Kenai Peninsula Fjords	Anne Hoover-Miller	CLICK TO ACCESS	$305,300	Monitoring & Research
			Monitor recovery.	1997	97170	Isotope Ratio Studies of Marine Mammals in Prince William Sound	Donald Schell	CLICK TO ACCESS	$371,300	Monitoring & Research
			Protect injured resources and their habitats.	1998	98170	Isotope Ratio Studies of Marine Mammals in Prince William Sound	Donald Schell	CLICK TO ACCESS		Monitoring & Research
				1999	99371	Effects of Harbor Seal Metabolism on Stable Isotope Ratio Tracers	Donald Schell	CLICK TO ACCESS	$375,500	Monitoring & Research
				2000	371	Effects of Harbor Seal Metabolism on Stable Isotope Ratio Tracers	Donald Schell	CLICK TO ACCESS		Monitoring & Research
				2001	1371	Effects of Harbor Seal Metabolism on Stable Isotope Ratio Tracers	Donald Schell	CLICK TO ACCESS		Monitoring & Research
				1994	94244	Community-based harbor seal management and biological sampling	James Fall	CLICK TO ACCESS	$628,900	Info/Mgmt/Admin
				1996	96244	Community-Based Harbor Seal Management and Biological Sampling	Monica Riedel	CLICK TO ACCESS		Info/Mgmt/Admin
				1997	97244	Community-Based Harbor Seal Management and Biological Sampling	Monica Riedel	CLICK TO ACCESS		Info/Mgmt/Admin
				1998	98244	Community-Based Harbor Seal Management and Biological Sampling	Monica Riedel	CLICK TO ACCESS		Info/Mgmt/Admin
				1999	99245	Community-Based Harbor Seal Management and Biological Sampling	James Fall	CLICK TO ACCESS		Info/Mgmt/Admin
				2000	245	Community-Based Harbor Seal Management and Biological Sampling	Vicki Vanek	CLICK TO ACCESS		Info/Mgmt/Admin
				2001	1245	Community-Based Harbor Seal Management and Biological Sampling	Vicki Vanek	CLICK TO ACCESS		Info/Mgmt/Admin
				2002	2245	Community-Based Harbor Seal Management and Biological Sampling	Vicki Vanek	CLICK TO ACCESS		Info/Mgmt/Admin
				1992	MM5	Assessment of injury to harbor seals in Prince William Sound, Alaska, and adjacent areas following EVOS	Kathryn Frost	CLICK TO ACCESS		Monitoring & Research
				1992	R73	Assessment of injury to harbor seals in PWS and adjacent areas following EVOS	Kathryn Frost	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Summary: Recovery Status (2002)	Recovery Summary: Restoration Strategy	FY	Project Number	Title	Project information: Principal Investigator	Project information: Link	Cost[2]	Action Category (1994)
				1993	93046	Habitat Use, Behavior, and Monitoring of Harbor Seals in PWS	Kathryn Frost	CLICK TO ACCESS		Monitoring & Research
				1994	94320F	SEA_Trophic Interactions of Harbor Seals in PWS	Kathryn Frost	CLICK TO ACCESS	(b)	Monitoring & Research
				1994	94064	Monitoring, Habitat Use, and Trophic Interactions of Harbor Seals in Prince William Sound	Kathryn Frost	CLICK TO ACCESS	$2,166,500	Monitoring & Research
				1995	95064	Monitoring, Habitat Use, and Trophic Interactions of Harbor Seals in PWS	Kathryn Frost	CLICK TO ACCESS		Monitoring & Research
				1996	96064	Monitoring, Habitat Use, and Trophic Interactions of Harbor Seals in Prince William Sound	Kathryn Frost	CLICK TO ACCESS		Monitoring & Research
				1997	97064	Monitoring, Habitat Use, and Trophic Interactions of Harbor Seals in PWS	Kathryn Frost	CLICK TO ACCESS		Monitoring & Research
				1998	98064	Monitoring, Habitat Use, and Trophic Interactions of Harbor Seals in Prince William Sound	Kathryn Frost	CLICK TO ACCESS		Monitoring & Research
				1999	99064	Monitoring, Habitat Use, and Trophic Interactions of Harbor Seals in Prince William Sound	Kathryn Frost	CLICK TO ACCESS		Monitoring & Research
				2000	64	Monitoring, Habitat Use, and Trophic Interactions of Harbor Seals in Prince William Sound	Kathryn Frost	CLICK TO ACCESS		Monitoring & Research
				2001	1064	Monitoring, Habitat Use, and Trophic Interactions of Harbor Seals in Prince William Sound	Kathryn Frost	CLICK TO ACCESS		Monitoring & Research
				1995	95001	Recovery of harbor seals from the EVOS: condition and health status	Michael Castellini	CLICK TO ACCESS	$575,700	Monitoring & Research
				1996	96001	Recovery of Harbor Seals From EVOS: Condition and Health Status	Michael Castellini	CLICK TO ACCESS		Monitoring & Research
				1997	97001	Recovery of Harbor Seals From EVOS: Condition and Health Status	Michael Castellini	CLICK TO ACCESS		Monitoring & Research
				1998	98001	Recovery of Harbor Seals From EVOS: Condition and Health Status	Michael Castellini	CLICK TO ACCESS		Monitoring & Research
				1995	95117	Harbor Seals and EVOS: Blubber and Lipids as Indices of Food Limitation	Michael Castellini	CLICK TO ACCESS		Monitoring & Research
				1998	98341	Harbor Seal Recovery: Effects of Diet on Lipid Metabolism and Health	Michael Castellini	CLICK TO ACCESS	$798,300	Monitoring & Research
				1999	99341	Harbor Seal Recovery: Effects of Diet on Lipid Metabolism and Health	Michael Castellini	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	Project information: FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2000	341	Harbor Seal Recovery: Effects of Diet on Lipid Metabolism and Health	Michael Castellini	CLICK TO ACCESS		Monitoring & Research
				2001	1341	Harbor Seal Recovery: Effects of Diet on Lipid Metabolism and Health	Michael Castellini	CLICK TO ACCESS		Monitoring & Research
				2002	2546	Assessing Harbor Seals: Methods to Identify Metabolic Responses to Environmental Change	Michael Castellini	CLICK TO ACCESS		Monitoring & Research
				1999	99441	Harbor Seal Recovery: Effects of Diet on Lipid Metabolism and Health	Randall Davis	CLICK TO ACCESS	$463,600	Monitoring & Research
				2000	441	Harbor Seal Recovery: Effects of Diet on Lipid Metabolism and Health	Randall Davis	CLICK TO ACCESS		Monitoring & Research
				2001	1441	Harbor Seal Recovery: Effects of Diet on Lipid Metabolism and Health	Randall Davis	CLICK TO ACCESS		Monitoring & Research
				2002	2441	Harbor Seal Recovery: Effects of Diet on Lipid Metabolism and Health	Randall Davis	CLICK TO ACCESS		Monitoring & Research
				2000	509	Long-Term Monitoring of Harbor Seal Populations: Development of an Experimental Design	Robert Small	CLICK TO ACCESS	$51,400	Monitoring & Research
				2001	1558	Harbor Seal Recovery: Application of New Technologies for Monitoring Health	Shannon Atkinson	CLICK TO ACCESS	$572,500	Monitoring & Research
				2002	2558	Harbor Seal Recovery: Application of New Technologies for Monitoring Health	Shannon Atkinson	CLICK TO ACCESS		Monitoring & Research
				2003	30558	Harbor Seal Recovery: Application of New Technologies for Monitoring Health	Shannon Atkinson	CLICK TO ACCESS		Monitoring & Research
Killer Whales	The original recovery objective for killer whales was a return to prespill numbers for the AB pod. The objective was changed in 1999, but upon further reflection and public comment, the recovery objective is once again a return to prespill numbers for the AB pod - 36 individuals.	Recovering	Rely on natural recovery.	1992	MM2	Assessment of injuries to killer whales in PWS	Byron Morris	CLICK TO ACCESS		Monitoring & Research
			Monitor recovery.	1995	95012	Comprehensive Killer Whale Investigation in Prince William Sound	Craig Matkin	CLICK TO ACCESS	$1,127,000	Monitoring & Research
			Protect injured resources and their habitats.	1996	96012A	Comprehensive Killer Whale Investigation in Prince William Sound	Craig Matkin	CLICK TO ACCESS		Monitoring & Research
				1997	97012	Comprehensive Killer Whale Investigation in Prince William Sound	Craig Matkin	CLICK TO ACCESS		Monitoring & Research
				1998	98012A	Comprehensive Killer Whale Investigation in Prince William Sound	Craig Matkin	CLICK TO ACCESS		Monitoring & Research
				1999	99012A	Comprehensive Killer Whale Investigation in Prince William Sound	Craig Matkin	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Project information: Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2000	00012A	Photographic and Acoustic Monitoring of Killer Whales in Prince William Sound and Kenai Fjords	Craig Matkin	CLICK TO ACCESS		Monitoring & Research
				2001	1012	Photographic and Acoustic Monitoring of Killer Whales in Prince William Sound and Kenai Fjords	Craig Matkin	CLICK TO ACCESS		Monitoring & Research
				2002	2012	Photographic and Acoustic Monitoring of Killer Whales in Prince William Sound and Kenai Fjords	Craig Matkin	CLICK TO ACCESS		Monitoring & Research
				2003	30012	Photographic Monitoring of Resident Killer Whales	Craig Matkin	CLICK TO ACCESS		Monitoring & Research
				2004	40012	Monitoring of Killer Whales in Prince William Sound/Kenai Fjords in 2004	Craig Matkin	CLICK TO ACCESS	$19,500	Monitoring & Research
				2005	50742	Monitoring of Killer Whales in Prince William Sound/Kenai Fjords in 2005-2007	Craig Matkin	CLICK TO ACCESS	$66,600	Monitoring & Research
				1993	93042	Assessment of injuries and recovery monitoring of PWS killer whales using photo-identification techniques	Marilyn Dalheim	CLICK TO ACCESS		Monitoring & Research
				1994	94092	Assessment of injuries and recovery monitoring of PWS killer whales using photo-identification techniques	Marilyn Dalheim	CLICK TO ACCESS		Monitoring & Research
Sea Otters	Sea otters will have recovered when the population in oiled areas returns to its prespill levels and distribution, and when biochemical indicators of hydrocarbon exposure in otters in the oiled areas are similar to those in otters in unoiled areas. An increasing population trend and normal reproduction and age structure in western Prince William Sound will indicate that recovery is underway.	Recovering	Rely on natural recovery.	1992	MM63	Hydrocarbons in hair, livers and intestines of sea otters found dead along the path of EVOS	not available	CLICK TO ACCESS		Monitoring & Research
			Monitor recovery.	1994	94246	Sea Otter Recovery Monitoring	Brenda Ballachey	CLICK TO ACCESS		Monitoring & Research
			Protect injured resources and their habitats.	1992	MM617	Hematology and clinical chemistry of sea otters captured in PWS, AK following EVOS	Alan Rebar	CLICK TO ACCESS		Monitoring & Research
				1992	MM68	Sea otter foraging behavior and hydrocarbon concentrations in prey following EVOS in PWS, Alaska	Angela Doroff	CLICK TO ACCESS		Monitoring & Research
				1992	MM69	Experiments to determine drift patterns and rates of recovery of sea otter carcasses following EVOS	Angela Doroff	CLICK TO ACCESS		Monitoring & Research
				1992	MM67	Surveys of sea otters in the Gulf of Alaska in response to EVOS	Anthony DeGange	CLICK TO ACCESS		Monitoring & Research
				1992	MM616	Hydrocarbon residues in tissues of sea otters (Enhydra lutris) collected following EVOS	Brenda Ballachey	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project information: Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2001	1534	Comparison of Cytochrome P4501A Induction in Blood and Liver Cells of Sea Otters	Brenda Ballachey	CLICK TO ACCESS	$20,100	Monitoring & Research
				2004	40774	Oil Exposure Biomarkers and Population Trends of Prince William Sound Marine Vertebrates	Brenda Ballachey	CLICK TO ACCESS	$328,500	Monitoring & Research
				2004	40775	Lingering Oil and Sea Otters: Pathways of Exposure and Recovery Status	Brenda Ballachey	CLICK TO ACCESS	$147,400	Monitoring & Research
				1992	MM61	Biomarkers of damage to sea otters in PWS following potential exposure to oil spilled from the Exxon Valdez	Catherine Berg	CLICK TO ACCESS		Monitoring & Research
				1992	MM612	Movements of weaning and adult female sea otters in Prince William Sound, AK, after EVOS	Charles Monnett	CLICK TO ACCESS		Monitoring & Research
				1992	MM613	Mortality and reproduction of female sea otters in PWS during the winter of 1990-91	Charles Monnett	CLICK TO ACCESS		Monitoring & Research
				1992	MM614	Mortality and reproduction of sea otters oiled and treated as a result of EVOS	Charles Monnett	CLICK TO ACCESS		Monitoring & Research
				1992	MM615	Age distributions of sea otters found dead in PWS, AK, following EVOS	Danial Monson	CLICK TO ACCESS		Monitoring & Research
				1992	MM66	Boat-based population surveys of sea otters (Enhydra hutris) in Prince William Sound, AK, following EVOS	Douglas Burn	CLICK TO ACCESS		Monitoring & Research
				2002	2657	Analysis of Genomic Stress Response in Sea Otters	F. Charles Mohr	CLICK TO ACCESS		Monitoring & Research
				1992	MM64	Age-specific reproduction in female sea otters (Enhydra lutris) from southcentral Alaska: analysis of reproductive tracts	James Bodkin	CLICK TO ACCESS		Monitoring & Research
				1992	MM65	An intersection model for estimating sea otter mortality from EVOS along the Kenai Peninsula, Alaska	James Bodkin	CLICK TO ACCESS		Monitoring & Research
				1999	99423	Pattern and Processes of Population Change in Sea Otters	James Bodkin	CLICK TO ACCESS	$1,238,800	Monitoring & Research
				2004	040620-2	Lingering Oil and Sea Otters: Pathways of Exposure and Recovery Status	James Bodkin	CLICK TO ACCESS	$167,000	Monitoring & Research
				1992	MM62	Hydrocarbon residues in tissues of sea otters collected from southeast Alaska	Kim Kloecker	CLICK TO ACCESS		Monitoring & Research
				1992	MM618	Mortality of sea otters weanlings in eastern and western PWS, AK, during the winter of 1990-91	Lisa Mignon-Rotterman	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	Project information: FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				1997	97223BAA	Analysis, Integration and Publication of Pre- and Post-Spill Data on Sea Otter Reproduction, Survival, Development, and Health	Lisa Rotterman	CLICK TO ACCESS		Monitoring & Research
				1992	MM619	Detection of sea otters in boat-based surveys of PWS, AK	Mark Udevitz	CLICK TO ACCESS		Monitoring & Research
				1993	93043	A population model for sea otters in western PwS	Mark Udevitz	CLICK TO ACCESS	$256,400	Monitoring & Research
				2002	2333	Sea Otter Monitoring	Robert Henrichs	CLICK TO ACCESS		Monitoring & Research
				1992	MM610	Histopathologic lesions associated with crude oil exposure in sea otters	T. Lipscomb	CLICK TO ACCESS		Monitoring & Research
				1992	MM611	Pathological studies of sea otters	T. Lipscomb	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Project information: Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
FISH										
Pacific Herring	Pacific herring will have recovered when the next highly successful year class is recruited into the population and when other indicators of population health (such as biomass, size-at-age, and disease expression) are within normal bounds in Prince William Sound.	Not recovering	Conduct research to find out why these resources are not recovering.	1994	94165	Herring Genetic Stock Identification in Prince William Sound	Lisa Seeb	CLICK TO ACCESS	$292,700	Monitoring & Research
			Initiate, sustain, or accelerate	1996	96302U	SEA_Energetics of Herring and Pollock	A.J. Paul	CLICK TO ACCESS	(b)	Monitoring & Research
			Monitor recovery.	1995	95320T	SEA_Juvenile Herring Growth and Habitat Partitioning	Brenda Norcross	CLICK TO ACCESS	(b)	Monitoring & Research
			Protect injured resources and their habitats.	1996	96320T	SEA_Juvenile Herring Growth and Habitat Partitioning	Brenda Norcross	CLICK TO ACCESS	(b)	Monitoring & Research
				2000	374	Coordination and Planning for Herring Research	Brenda Norcross	CLICK TO ACCESS	$35,500	Info/Mgmt/Admin
				1992	FS11	Injury to Prince William Sound herring following the Exxon Valdez oil spill	Evelyn Brown	CLICK TO ACCESS		Monitoring & Research
				1999	99375	Effect of Herring Egg Distribution and Ecology on Year-Class Strength and Adult Distribution	Evelyn Brown	CLICK TO ACCESS	$124,500	Monitoring & Research
				2000	375	Effect of Herring Egg Distribution and Ecology on Year-Class Strength and Adult Distribution	Evelyn Brown	CLICK TO ACCESS		Monitoring & Research
				1998	98274	Documentary Film on Subsistence Use of Herring, Herring Spawn, and Resources in the Nearshore Ecosystem in Prince William Sound	Gary Kompkoff	CLICK TO ACCESS	$87,800	Info/Mgmt/Admin
				1994	94320S	SEA_Disease Impacts on Prince William Sound Herring Populations	Gary Marty	CLICK TO ACCESS	(b)	Monitoring & Research
				1997	97162	Investigations of Disease Factors Affecting Declines of Pacific Herring Populations in Prince William Sound	Gary Marty	CLICK TO ACCESS		Monitoring & Research
				1998	98162	Investigations of Disease Factors Affecting Declines of Pacific Herring Populations in Prince William Sound	Gary Marty	CLICK TO ACCESS		Monitoring & Research
				1999	99162B	Investigations of Disease Factors Affecting Declines of Pacific Herring Populations: Manuscripts/Conference Attendance (Part B)	Christopher Kennedy	CLICK TO ACCESS		Monitoring & Research
				1999	99462	Effect of Disease on Pacific Herring Population Recovery in Prince William Sound	Gary Marty	CLICK TO ACCESS	$296,800	Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project information: Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2000	462	Effect of Disease on Pacific Herring Population Recovery in Prince William Sound	Gary Marty	CLICK TO ACCESS		Monitoring & Research
				2001	1462	Effect of Disease on Pacific Herring Population Recovery in Prince William Sound	Gary Marty	CLICK TO ACCESS		Monitoring & Research
				2002	2462	Effects of Disease on Pacific Herring Population Recovery in Prince William Sound	Gary Marty	CLICK TO ACCESS		Monitoring & Research
				2003	30462	Effect of Disease on Pacific Herring Population Recovery in Prince William Sound	Gary Marty	CLICK TO ACCESS		Monitoring & Research
				1994	94166	Herring Spawn Deposition and Reproductive Impairment (ADFG component)	John Wilcock	CLICK TO ACCESS	$1,580,100	Monitoring & Research
				1994	94166	The impact of exposure on adult pre-spawn herring on subsequent progeny (NOAA component)	Mark Carls	CLICK TO ACCESS		Monitoring & Research
				1995	95166	Herring Natal Habitats	Greg Carpenter	CLICK TO ACCESS		Monitoring & Research
				1996	96166	Herring Natal Habitats	Greg Carpenter	CLICK TO ACCESS		Monitoring & Research
				1997	97166	Herring Natal Habitats	Mark Willette	CLICK TO ACCESS		Monitoring & Research
				1998	98166	Herring Natal Habitats	Mark Willette	CLICK TO ACCESS		Monitoring & Research
				1995	95165	PWS Herring Genetic Stock Identification	James Seeb	CLICK TO ACCESS		Monitoring & Research
				1996	96165	Genetic Discrimination of Prince William Sound Herring Populations	James Seeb	CLICK TO ACCESS		Monitoring & Research
				1997	97165	Genetic Discrimination of Prince William Sound Herring Populations	James Seeb	CLICK TO ACCESS		Monitoring & Research
				1998	98165	Genetic Discrimination of Prince William Sound Herring Populations	James Seeb	CLICK TO ACCESS		Monitoring & Research
				1997	97320T	SEA_Juvenile Herring: Documentation of Herring and Other Forage Fish Natural History through Local and Traditional Ecological Knowledge	Jody Seitz	CLICK TO ACCESS	(b)	Monitoring & Research
				1991	FS12	Hydrocarbon injury assessment: Kodiak and Alaska Peninsula herring	Kevin Brennan	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project information: Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				1995	389	Herring Reproductive Impairment	Mark Carls	CLICK TO ACCESS	$565,500	Monitoring & Research
				1995	95074	Health and reproductive implications of exposure of Pacific herring (Clupea pallasi) adults and eggs to weathered crude oil	Mark Carls	CLICK TO ACCESS		Monitoring & Research
				1996	96074	Health and reproductive implications of exposure of Pacific herring (Clupea pallasi) adults and eggs to weathered crude oil	Mark Carls	CLICK TO ACCESS		Monitoring & Research
				1999	99328	Synthesis of the Toxicological and Epidemiological Impacts of the Oil Spill on Pacific Herring	Mark Carls	CLICK TO ACCESS	$41,400	Monitoring & Research
				1994	94320Q	SEA_Avian Predation on Herring Spawn	Mary Anne Bishop	CLICK TO ACCESS	(b)	Monitoring & Research
				1994	94320Q	SEA_Avian Predation on Herring Spawn	Mary Anne Bishop	CLICK TO ACCESS	(b)	Monitoring & Research
				1995	95320Q	SEA_Avian Predation on Herring Spawn	Mary Anne Bishop	CLICK TO ACCESS	(b)	Monitoring & Research
				2006	60782	Using otolith chemical analysis to determine larval drift of Prince William Sound Pacific herring (Clupea pallasii)	Nate Bickford	CLICK TO ACCESS		Monitoring & Research
				1996	96162	Investigations of Disease Factors Affecting Declines of Pacific Herring Populations in Prince William Sound	Richard Kocan	CLICK TO ACCESS	$2,195,400	Monitoring & Research
				1999	99162A	Investigation of Disease Factors Affecting Declines of Pacific Herring Populations: Manuscripts/Conference Attendance (Part A)	Richard Kocan	CLICK TO ACCESS		Monitoring & Research
				2002	2457	Monitoring the Fall-Winter Herring Biomass to Track the Recovery of the Prince William Sound Herring Stock	Richard Thorne	CLICK TO ACCESS		Monitoring & Research
				1998	98297	Oceanography of Prince William Sound Bays and Fjords	Shari Vaughan	CLICK TO ACCESS	$92,900	Monitoring & Research
				2005	50794	PWS Herring populations: updated synthesis on the causes and lack of recovery	Stanley Rice	CLICK TO ACCESS		Monitoring & Research
				2001	1538	Evaluation of Two Methods to Discriminate Pacific Herring Stocks along the Northern Gulf of Alaska	Ted Otis	CLICK TO ACCESS	$58,900	Monitoring & Research
				2002	2538	Evaluation of Two Methods to Discriminate Pacific Herring Stocks along the Northern Gulf of Alaska	Ted Otis	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary			Project information						
Resource	**Recovery Objective (2002)**	**Recovery Status (2002)**	**Restoration Strategy**	**FY**	**Project Number**	**Title**	**Principal Investigator**	**Link**	**Cost[2]**	**Action Category (1994)**
				2005	50769	Temporal Stability of Fatty Acids used to Discriminate Pacific Herring in Alaska	Ted Otis	CLICK TO ACCESS	$182,200	Monitoring & Research
				1998	98311	Pacific Herring Productivity Dependencies in the Prince William Sound Ecosystem Determined With Natural Stable Isotope Tracers	Thomas Kline	CLICK TO ACCESS	$209,200	Monitoring & Research
				1999	99311	Pacific Herring Productivity Dependencies in the Prince William Sound Ecosystem Determined with Natural Stable Isotope Tracers	Thomas Kline	CLICK TO ACCESS		Monitoring & Research
				1995	95320S	SEA_Disease Impacts on Prince William Sound Herring Populations	William Hauser	CLICK TO ACCESS	(b)	Monitoring & Research
Rockfish	No recovery objective can be identified.	Recovery Unknown	Rely on natural recovery.	2003	30676	Species Composition of Young-of-Year Rockfish Collected on GOA Surveys 1998-2002	Anthony Gharrett	CLICK TO ACCESS		Monitoring & Research
			Monitor recovery.	1992	ST6	Injury to demersal rockfish and shallow reef habitats in PWS	Andrew Hoffman	CLICK TO ACCESS		Monitoring & Research
			Protect injured resources and their habitats.							
Cutthroat Trout, Dolly Varden	Cutthroat trout will have recovered when growth rates within oiled areas are similar to those for unoiled areas, after taking into account geographic differences.	Recovery Unknown	Rely on natural recovery.	1994	94043B	Monitoring of Cutthroat Trout and Dolly Varden Habitat Improvement Structures	Dan Gillikin	CLICK TO ACCESS		Monitoring & Research
			Monitor recovery.	1996	96043B	Monitoring of Cutthroat Trout and Dolly Varden Habitat Improvement Structures	Dan Gillikin	CLICK TO ACCESS		Monitoring & Research
	Dolly Varden will have recovered when growth rates within oiled streams are comparable to those in unoiled streams, after taking into account geographic differences.		Protect injured resources and their habitats.	1997	97043B	Monitoring of Cutthroat Trout and Dolly Varden Habitat Improvement Structures	Dan Gillikin	CLICK TO ACCESS		Monitoring & Research
				1998	98043B	Monitoring of Cutthroat Trout and Dolly Varden Habitat Improvement Structures	Dan Gillikin	CLICK TO ACCESS		Monitoring & Research
				1997	97302	Prince William Sound Cutthroat Trout, Dolly Varden Char Inventory	Dana Schmidt	CLICK TO ACCESS		Monitoring & Research
				1996	96145	Cutthroat Trout and Dolly Varden: Relation Among and Within Populations of Anadromous and Resident Forms	Gordon Reeves	CLICK TO ACCESS		Monitoring & Research
				1997	97145	Cutthroat Trout and Dolly Varden: Relation Among and Within Populations of Anadromous and Resident Forms	Gordon Reeves	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary						Project information			
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				1998	98145	Cutthroat Trout and Dolly Varden: Relation Among and Within Populations of Anadromous and Resident Forms	Gordon Reeves	CLICK TO ACCESS		Monitoring & Research
				1999	99145	Cutthroat Trout and Dolly Varden: Relation Among and Within Populations of Anadromous and Resident Forms	Gordon Reeves	CLICK TO ACCESS		Monitoring & Research
				1992	FS5	Impact of oil spilled from the Exxon Valdez on survival and growth of Dolly Varden and cutthroat trout in PWS	K.R. Hepler	CLICK TO ACCESS		Monitoring & Research
				1992	R90	Impact of oil spilled from the Exxon Valdez on survival and growth of Dolly Varden and cutthroat trout in PWS	K.R. Hepler	CLICK TO ACCESS		Monitoring & Research
				1994	94043	Cutthroat Trout & Dolly Varden Rehabilitation in Western PWS	Ken Hodges	CLICK TO ACCESS		Restoration
				1998	98302	Prince William Sound Cutthroat Trout, Dolly Varden Char Inventory	Merlyn Schelske	CLICK TO ACCESS		Monitoring & Research
				2004	40706	The Influence of Adult Salmon Carcasses on Energy Allocation in Juvenile Salmonids	Ronald Heintz	CLICK TO ACCESS	$104,700	Monitoring & Research
				1992	R106	Technical support study for the restoration of Dolly Varden and cutthroat trout populations in PWS	Susie McCarron	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Project information: Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
BIRDS										
Harlequin Ducks	Harlequin ducks will have recovered when breeding- and nonbreeding-season demographics return to prespill levels and when biochemical indicators of hydrocarbon exposure in Harlequins in oiled areas of Prince William Sound are similar to those in Harlequins in unoiled areas.	Not recovering	Conduct research to find out why these resources are not recovering.	1996	96161	Differentiation and Interchange of Harlequin Duck Populations Within the North Pacific	Buddy Goatcher	CLICK TO ACCESS	$177,400	Monitoring & Research
			Initiate, sustain, or accelerate recovery.	1997	97161	Differentiation and Interchange of Harlequin Duck Populations Within the North Pacific	Buddy Goatcher	CLICK TO ACCESS		Monitoring & Research
			Monitor recovery.	1998	98161	Differentiation and Interchange of Harlequin Duck Populations Within the North Pacific	Buddy Goatcher	CLICK TO ACCESS		Monitoring & Research
			Protect injured resources and their habitats.	2005	50777	Quantifying Temporal Variation in Harlequin Duck Exposure to Exxon Valdez	Dan Esler	CLICK TO ACCESS		Monitoring & Research
				1994	94427	Experimental Harlequin Duck Breeding Survey	Dan Rosenberg	CLICK TO ACCESS		Monitoring & Research
				1995	95427	Harlequin Duck Recovery Monitoring	Dan Rosenberg	CLICK TO ACCESS	$1,589,600	Monitoring & Research
				1996	96427	Harlequin Duck Recovery Monitoring	Dan Rosenberg	CLICK TO ACCESS		Monitoring & Research
				1997	97427	Harlequin Duck Recovery Monitoring	Dan Rosenberg	CLICK TO ACCESS		Monitoring & Research
				1998	98427	Harlequin Duck Recovery Monitoring	Dan Rosenberg	CLICK TO ACCESS		Monitoring & Research
				2000	407	Harlequin Duck Population Dynamics	Dan Rosenberg	CLICK TO ACCESS	$197,200	Monitoring & Research
				2001	1407	Harlequin Duck Population Dynamics	Dan Rosenberg	CLICK TO ACCESS		Monitoring & Research
				2002	2407	Harlequin Duck Population Dynamics	Dan Rosenberg	CLICK TO ACCESS		Monitoring & Research
				2004	40407	Harlequin Duck Population Dynamics	Dan Rosenberg	CLICK TO ACCESS	$37,100	Monitoring & Research
				2005	50759	Harlequin Duck Populations Dynamics in Prince William Sound: Measuring Recovery	Dan Rosenberg	CLICK TO ACCESS		Monitoring & Research
				1992	R71	Breeding ecology of harlequin ducks in PWS	David Crowley	CLICK TO ACCESS		Monitoring & Research
				1993	93033	Restoration Monitoring of Harlequin Ducks	Samuel Patten	CLICK TO ACCESS		Monitoring & Research
				1994	94066	Restoration monitoring of harlequin ducks in PWS and Afognak Island	Samuel Patten	CLICK TO ACCESS		Monitoring & Research
				2002	02423am	Patterns and Processes of Population Change in Selected Nearshore Vertebrate Predators	Shannon Atkinson	CLICK TO ACCESS	$1,238,800	Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary			Project information						
Resource	**Recovery Objective (2002)**	**Recovery Status (2002)**	**Restoration Strategy**	**FY**	**Project Number**	**Title**	**Principal Investigator**	**Link**	**Cost[2]**	**Action Category (1994)**
Kittlitz's Murrelets	No recovery objective can be identified for Kittlitz's murrelet at this time.	Recovery Unknown	Rely on natural recovery.	1996	96031	Development of a Productivity Index to Monitor the Reproductive Success of Marbled and Kittlitz's Murrelets in Prince William Sound, Alaska	Katherine Kuletz	CLICK TO ACCESS		
			Monitor recovery.	1996	96142	Status and Ecology of Kittlitz's Murrelet in Prince William Sound	ABR, Inc.	CLICK TO ACCESS	$601,700	Monitoring & Research
			Protect injured resources and their habitats.	1998	98142	Status and Ecology of Kittlitz's Murrelets in Prince William Sound	Robert Day	CLICK TO ACCESS		Monitoring & Research
				1997	97142BAA	Status and Ecology of Kittlitz's Murrelets in Prince William Sound	Robert Day	CLICK TO ACCESS		Monitoring & Research
				2000	516	Publication: Comparative Habitat Use by Kittlitz's and Marbled Murrelets	Robert Day	CLICK TO ACCESS		Info/Mgmt/Admin
Marbled Murrelets	Marbled murrelets will have recovered when their populations are stable or increasing. Sustained or increasing productivity within normal bounds (based on adults and juveniles on the water) will be an indication that recovery is underway.	Recovering	Rely on natural recovery.	1992	R15	At-sea abundance and distribution of marbled murrelets in the Naked Island area of PWS	Catherine Berg	CLICK TO ACCESS		Monitoring & Research
			Monitor recovery.	1992	B06	Marbled murrelet abundance and breeding activity at Naked Island, PWS, and Kachemak Bay before and after EVOS	Katherine Kuletz	CLICK TO ACCESS		Monitoring & Research
			Protect injured resources and their habitats.	1993	93051B	Information needs for habitat protection: marbled murrelet habitat identification	Katherine Kuletz	CLICK TO ACCESS	$1,519,900	Monitoring & Research
				1994	94102	Marbled murrelet foraging patterns in PWS	Katherine Kuletz	CLICK TO ACCESS	$690,800	Monitoring & Research
				1995	95102	Murrelet Prey and Foraging Habitat in Prince William Sound	Katherine Kuletz	CLICK TO ACCESS		Monitoring & Research
				1995	95031	Relative abundance of adult and juvenile marbled murrelets in PWS, AK: developing a productivity index	Katherine Kuletz	CLICK TO ACCESS	$322,800	Monitoring & Research
				1997	97231	Marbled Murrelet Productivity Relative to Forage Fish Availability and Environmental Parameters	Katherine Kuletz	CLICK TO ACCESS	$118,400	Monitoring & Research
Common Loon	Common loons will have recovered when their population returns to prespill levels in the oil spill area. An increasing population trend in Prince William Sound will indicate that recovery is underway.	Not recovering	Conduct research to find out why these resources are not recovering.							
Red-faced Cormorant	Pelagic, red-faced, and double-crested cormorants will have recovered when their populations return to prespill levels in oiled areas. An increasing population	Not recovering	Initiate, sustain, or accelerate recovery.							

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Project information: Principal Investigator	Link	Cost[2]	Action Category (1994)
Pelagic Cormorant	in oiled areas. An increasing population trend in Prince William Sound will indicate that recovery is underway.	Not recovering	Monitor recovery.							
Double-crested Cormorant		Not recovering	Protect injured resources and their habitats.							
Pigeon Guillemots	Pigeon guillemots will have recovered when their population is stable or increasing. Sustained or increasing productivity within normal bounds will be an indication that recovery is underway.	Not recovering	Conduct research to find out why these resources are not recovering.	1994	94506	Pigeon Guillemot Recovery	Mary Cody	CLICK TO ACCESS		Monitoring & Research
			Initiate, sustain, or accelerate recovery.	1998	98327	Pigeon Guillemot Restoration Research at the Alaska SeaLife Center	Daniel Roby	CLICK TO ACCESS	$580,500	Monitoring & Research
			Monitor recovery.	1999	99327	Pigeon Guillemot Restoration Research at the Alaska SeaLife Center	Daniel Roby	CLICK TO ACCESS		Monitoring & Research
			Protect injured resources and their habitats.	2000	327	Pigeon Guillemot Restoration Research at the Alaska SeaLife Center	Daniel Roby	CLICK TO ACCESS		Monitoring & Research
				2001	1327	Pigeon Guillemot Restoration Research at the Alaska SeaLife Center	Daniel Roby	CLICK TO ACCESS		Monitoring & Research
				2002	2673	Continuing Decline of Pigeon Guillemots in the Oiled Portion of Prince William Sound	David Irons	CLICK TO ACCESS		Monitoring & Research
				1994	94173	Pigeon Guillemot Recovery Monitoring	Dennis Marks	CLICK TO ACCESS		Monitoring & Research
				1993	93034	Survey of pigeon guillemot colonies in PWS	Gerald Sanger	CLICK TO ACCESS	$174,600	Monitoring & Research
				2002	2674	Assessing Pigeon Guillemot Restoration Techniques	John French	CLICK TO ACCESS		Monitoring & Research
				1995	95163F	APEX_ Factors Affecting Recovery of Pigeon Guillemot Populations	Lindsay Hayes	CLICK TO ACCESS	(a)	Monitoring & Research
				1995	95163F1	APEX_ Reproduction of Pigeon Guillemots Populations in Prince William Sound in Relation to Food	Lindsay Hayes	CLICK TO ACCESS	(a)	Monitoring & Research
				1996	96163F	APEX_Factors Affecting Recovery of Pigeon Guillemot Populations	Lindsay Hayes	CLICK TO ACCESS	(a)	Monitoring & Research
				1992	B09	Population, reproduction and foraging of pigeon guillemots at Naked Island, Alaska, before and after EVOS	Sandy Rabinowich	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	Project information: FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
BENTHIC COMMUNITIES										
Clams	Clams will have recovered when population and productivity measures (such as size and distribution) at oiled sites are comparable to populations and productivity measures at unoiled sites, taking into account geographic differences.	Recovering	Rely on natural recovery.	1992	FS13	Effects of Hydrocarbons on Bivalves following EVOS	Charles Trowbridge	CLICK TO ACCESS		Monitoring & Research
			Monitor recovery.	1995	95131	Clam Restoration (Nanwalek, Port Graham, Tatitlek)	Patty Brown-Schwalenberg	CLICK TO ACCESS	$1,450,300	Restoration
			Protect injured resources and their habitats.	1996	96131	Chugach Native Region Clam Restoration	Patty Brown-Schwalenberg	CLICK TO ACCESS		Restoration
				1997	97131	Chugach Native Region Clam Restoration	David Daisy	CLICK TO ACCESS		Restoration
				1998	98131	Chugach Native Region Clam Restoration	Patty Brown-Schwalenberg	CLICK TO ACCESS		Restoration
				1999	99131	Chugach Native Region Clam Restoration	Patty Brown-Schwalenberg	CLICK TO ACCESS		Restoration
				2001	1131	Chugach Native Region Clam Restoration	David Daisy	CLICK TO ACCESS		Restoration
				2002	2574	Assessment of Bivalve Recovery on Treated Mixed-Soft Beaches in Prince	Dennis Lees	CLICK TO ACCESS		Monitoring & Research
				2003	30574	Assessment of Bivalve Recovery on Treated Mixed-Soft Beaches in Prince	Dennis Lees	CLICK TO ACCESS		Monitoring & Research
				2004	40574	Assessment of Bivalve Recovery on Treated Mixed-Soft Beaches in Prince	Dennis Lees	CLICK TO ACCESS	$36,200	Monitoring & Research
				2003	30632	Investigations into the Decline of Razor Clams in the Cordova Area	K. Brooks	CLICK TO ACCESS		Monitoring & Research
Intertidal Communities	Intertidal communities will have recovered when such important species as *Fucus* have been reestablished at sheltered rocky sites, the differences in community composition and organism abundance on oiled and unoiled shorelines are no longer apparent after taking into account geographic differences, and the intertidal and nearshore habitats provide adequate, uncontaminated food supplies for top	Recovering	Rely on natural recovery.	2002	2681	Nearshore/Intertidal Monitoring (placeholder)	not available	CLICK TO ACCESS		Monitoring & Research
			Monitor recovery.	2003	30587	Understanding the Cellular Processes of Recovery and Its Utility in Oil-Spill Restoration Efforts	Craig Downs	CLICK TO ACCESS		Monitoring & Research
			Protect injured resources and their habitats.	1995	95009D	Survey of Octopus and Gumboot Chiton in Intertidal Habitats	David Scheel	CLICK TO ACCESS		Monitoring & Research
				1996	96009D	Surveys of intertidal octopuses in the intertidal in PWS	David Scheel	CLICK TO ACCESS		Monitoring & Research
				1997	97009DCLO	Survey of Octopus and Chiton in Intertidal Habitats	David Scheel	CLICK TO ACCESS		Monitoring & Research
				2003	30656	Retrospective Analysis of Nearshore Marine Communities Based on Analysis of Archaeological Material and Isotopes	Gail Irvine	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary			Project information						
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2003	30690	Developing a Probability-based Design for Long-term Monitoring of the Nearshore: A Test Case for the Kenai Peninsula	Gail Irvine	CLICK TO ACCESS		Monitoring & Research
				2004	40708	Monitoring Lingering Oil on Boulder-Armored Beaches in the Gulf of Alaska	Gail Irvine	CLICK TO ACCESS	$88,900	Monitoring & Research
				2002	2639	Field Experiments for Testing Spill-Impacts Hypotheses from Long-Term Monitoring	Gary Shigenaka	CLICK TO ACCESS		Monitoring & Research
				2003	30661	Integrated Biodiversity and Natural History of Green Island: A Monitoring Update	Glenn Juday	CLICK TO ACCESS		Monitoring & Research
				2003	30556	High Resolution Mapping of the Intertidal and Shallow Subtidal Shores in Kachemak Bay	G. Carl Schoch	CLICK TO ACCESS		Monitoring & Research
				2004	40556	High Resolution Mapping of Intertidal and Shallow Subtital Shores in Kachemak Bay	W. Scott Pegau	CLICK TO ACCESS	$15,000	Monitoring & Research
				2001	1543	Evaluation of Oil Remaining in the Intertidal from the Exxon Valdez Oil Spill	Jeffrey Short	CLICK TO ACCESS	$614,900	Monitoring & Research
				2002	2543	Evaluation of Oil Remaining in the Intertidal from the Exxon Valdez Oil Spill	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				2003	30647	Investigating the Relative Roles of Natural and Shoreline Harvest in Altering the Kenai Peninsula's Rocky Intertidal	Jennifer Ruesink	CLICK TO ACCESS		Monitoring & Research
				2003	30635	Trophic Dynamics of Intertidal Soft-sediment Communities: Interaction Between Bottom-up and Top-down Processes	Mary Anne Bishop	CLICK TO ACCESS		Monitoring & Research
				2004	40635	Trophic Dynamics of Intertidal Soft-Sediment Communities: Interaction between Top-down and Bottom-up Processes (Renewal, Submitted under the BAA)	Mary Anne Bishop	CLICK TO ACCESS	$464,949	Monitoring & Research
				2002	2608	Permanent Archiving of Specimens Collected in Nearshore Habitats	Nora Foster	CLICK TO ACCESS	$61,600	Info/Mgmt/Admin
				1992	CH1A	Comprehensive assessment of coastal habitat	Raymond Highsmith	CLICK TO ACCESS		Monitoring & Research
				1992	R102	Herring Bay Experimental and Monitoring Studies	Raymond Highsmith	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Project information: Principal Investigator	Link	Cost[2]	Action Category (1994)
				1996	96086	Herring Bay Experimental and Monitoring Studies	Raymond Highsmith	CLICK TO ACCESS		Monitoring & Research
				2003	30594	Development of an Alaska Standard Species for Marine Toxicity Testing - The Alaska Green Urchin	Robert Perkins	CLICK TO ACCESS		Monitoring & Research
				2002	2585	Lingering Oil: Bioavailability and Effects to Prey and Predators	Stanley Rice	CLICK TO ACCESS		Monitoring & Research
				2003	30585	Lingering Oil: Bioavailability and Effects to Prey and Predators	Stanley Rice	CLICK TO ACCESS		Monitoring & Research
				2000	510	Recovery of Intertidal Communities and Recommendations for Future Monitoring	Thomas Dean	CLICK TO ACCESS	$49,000	Monitoring & Research
				1998	98325	Assessment of Injury to Intertidal and Nearshore Subtidal Communities: Preparation of Manuscripts	Thomas Dean	CLICK TO ACCESS		Info/Mgmt/Admin
				1999	99325	Assessment of Injury to Intertidal and Nearshore Subtidal Communities: Preparation of Manuscripts	Thomas Dean	CLICK TO ACCESS		Info/Mgmt/Admin
				2002	2395	Workshop on Nearshore/Intertidal Monitoring	Thomas Dean	CLICK TO ACCESS	$63,300	Monitoring & Research
Mussels	Mussels will have recovered when concentrations of oil in the mussels reach background concentrations and mussels do not contaminate their predators.	Recovering	Rely on natural recovery.	1992	ST3A	Caged Mussels Damage Assessment	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
			Monitor recovery.	2002	2644	Molecular Biomarkers as a New Technique for Assessing Physiological Contaminant Stress	Gary Shigenaka	CLICK TO ACCESS		Monitoring & Research
			Protect injured resources and their habitats.	1993	93036	Geographical extent and recovery monitoring of intertidal oiled mussel beds in the Gulf of Alaska	Stanley Rice	CLICK TO ACCESS		Monitoring & Research
				1992	R1032A	Geographical extent and recovery monitoring of intertidal oiled mussel beds in GOA affected by EVOS	Joel Cusick	CLICK TO ACCESS		Monitoring & Research
				1997	97195	Pristane Monitoring in Mussels	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				1998	98195	Pristane Monitoring in Mussels	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				1999	99195	Pristane Monitoring in Mussels	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				2000	195	Pristane Monitoring in Mussels	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				2001	1195	Pristane Monitoring in Mussels	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				2002	2195	Pristane Monitoring in Mussels	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				1992	ST8	Mussel tissue and sediment hydrocarbon data synthesis 1989-1995	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary			Project information						
Resource	**Recovery Objective (2002)**	**Recovery Status (2002)**	**Restoration Strategy**	**FY**	**Project Number**	**Title**	**Principal Investigator**	**Link**	**Cost[2]**	**Action Category (1994)**
				1992	TS1	Mussel tissue and sediment hydrocarbon data synthesis 1989-1995	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				1994	94090	Mussel Bed Restoration and Monitoring	Mark Carls	CLICK TO ACCESS	$2,193,900	Monitoring & Research
				1996	96090	Mussel Bed Restoration and Monitoring	Malin Babcock	CLICK TO ACCESS		Monitoring & Research
				1995	95090	Mussel Bed Restoration and Monitoring in Prince William Sound and Gulf of Alaska	Malin Babcock	CLICK TO ACCESS		Monitoring & Research
				1997	97090CLO	Mussel Bed Restoration and Monitoring	Stanley Rice	CLICK TO ACCESS		Monitoring & Research
				1999	99090	Monitoring of Oiled Mussel Beds in Prince William Sound	Mark Carls	CLICK TO ACCESS	$209,200	Monitoring & Research
				2002	2486	Links Between Persistent Oil in Mussel Beds and Predators	Stanley Rice	CLICK TO ACCESS		Monitoring & Research
Subtidal Communities	Subtidal communities will have recovered when community composition in oiled areas, especially in association with eelgrass beds, is similar to that in unoiled areas or consistent with natural differences between sites such as proportions of mud and sand.	Recovery Unknown	Rely on natural recovery.	2003	30638	Mapping Subtidal Habitats in Prince William Sound	Randall Davis	CLICK TO ACCESS		Monitoring and Research
			Monitor recovery.	1992	ST2A	Effects of EVOS on shallow subtidal communities in PWS	Stephen Jewett	CLICK TO ACCESS		Monitoring and Research
			Protect injured resources and their habitats.	1995	95106	Subtidal Monitoring: Eelgrass Communities	Stephen Jewett	CLICK TO ACCESS	$428,200	Monitoring and Research
				1995	95106	Subtidal Monitoring: Eelgrass communities in PWS, AK 1990-95	Stephen Jewett	CLICK TO ACCESS		Monitoring and Research
				1995	95285	Effects of EVOS on shallow subtidal communities	Stephen Jewett	CLICK TO ACCESS	$1,576,800	Monitoring and Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project information: Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
MEDIA										
Designated Wilderness Areas	Designated wilderness areas will have recovered when oil is no longer encountered in them and the public perceives them to be recovered from the spill.	Recovering	Rely on natural recovery, Monitor recovery, Protect resources	1999	99459	Residual Oiling of Armored Beaches and Mussel Beds in the Gulf of Alaska	Gail Irvine	CLICK TO ACCESS		Monitoring & Research
				2000	459	Residual Oiling of Armored Beaches and Mussel Beds in the Gulf of Alaska	Gail Irvine	CLICK TO ACCESS		Monitoring & Research
Sediments	Sediments will have recovered when there are no longer significant residues of Exxon Valdez oil on shorelines (both intertidal and subtidal) in the oil spill area. Declining oil residues and diminishing toxicity are indications that recovery is underway.	Recovering	Rely on natural recovery.	2000	599	Evaluation of Yakataga Oil Seeps as Regional Background Hydrocarbon Sources in Benthic Sediments of the Spill Area	Jeffrey Short	CLICK TO ACCESS	$83,600	Monitoring & Research
			Monitor recovery.	2001	1599	Evaluation of Yakataga Oil Seeps as Regional Background Hydrocarbon Sources in Benthic Sediments of the Spill Area	Jeffrey Short	CLICK TO ACCESS		Monitoring and Research
			Protect injured resources and their habitats.	1991	ST3	Nearshore transport of hydrocarbons and sediments following EVOS	David Sale	CLICK TO ACCESS		Monitoring and Research
				1991	ST2B	Injury to Deep Benthos	Howard Feder	CLICK TO ACCESS		Monitoring and Research
				1992	OS02	Idenfitication of EVO in sediments and tissues from PWS and the NW GOA based on PAH weathering	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				2000	598	Publication: Resolution of Mixtures Containing Exxon Valdez Oil and Regional Background Hydrocarbons in Subtidal Sediments	Jeffrey Short	CLICK TO ACCESS		Info/Mgmt/Admin
				2002	2662	Natural Life Restoration by Manipulation	Jerry Rusher	CLICK TO ACCESS		Monitoring and Research
				1995	95026	Hydrocarbon Monitoring: Integration of Microbial and Chemical Sediment Data	Joan Braddock	CLICK TO ACCESS	$131,600	Monitoring and Research
				1997	97026CLO	Report Writing: Integration of Microbial and Chemical Sediment Data	Joan Braddock	CLICK TO ACCESS		Info/Mgmt/Admin
				2002	2628	Resurrection Bay Contaminant Survey	P. Homan	CLICK TO ACCESS		Monitoring & Research
				1993	93047	Recovery of sediments in the lower intertidal and subtidal environment	Stephen Jewett	CLICK TO ACCESS		Monitoring and Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary						Project information			
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2004	40772	Sediment Quality Survey of Heavily-Oiled Beaches in PWS	Betsy Day	CLICK TO ACCESS	$208,200	Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project information: Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
SERVICES										
Commercial Fishing	Commercial fishing will have recovered when the commercially important fish species have recovered and opportunities to catch these species are not lost or reduced because of the effects of the oil spill.	Recovering	Rely on natural recovery.	2000	320	SEA_ Sound Ecosystem Assessment: Publishing the Integrated Final Report and a Program Synthesis	David Allan	CLICK TO ACCESS	(b)	Monitoring and Research
			Monitor recovery.	2000	478	Testing Satellite Tags as a Tool for Identifying Critical Habitat	Jennifer Nielsen	CLICK TO ACCESS		Monitoring and Research
			Protect injured resources and their habitats.	2002	2636	Management Applications: Commercial Fishing	Kenneth Adams	CLICK TO ACCESS		Monitoring and Research
				2003	30636	Management Applications: Commercial Fishing	Kenneth Adams	CLICK TO ACCESS		Monitoring and Research
				2002	2669	Hooligan Research	Robert Henrichs	CLICK TO ACCESS		Monitoring and Research
				1999	99366	Improved Salmon Escapement Enumeration Using Remote Video and Time-Lapse Recording Technology	Ted Otis	CLICK TO ACCESS	$106,800	Monitoring and Research
				2000	366	Improved Salmon Escapement Enumeration Using Remote Video and Time-Lapse Recording Technology	Ted Otis	CLICK TO ACCESS		Monitoring and Research
				2001	1366	Improved Salmon Escapement Enumeration Using Remote Video and Time-Lapse Recording Technology	Ted Otis	CLICK TO ACCESS		Monitoring and Research
				2002	2678	Identifying Community-Based Ways to Use Commercial Fisheries Bycatch for Scientific Gain	William Wilson	CLICK TO ACCESS		Monitoring and Research
Passive Use	Passive uses will have recovered when people perceive that aesthetic and intrinsic values associated with the spill area are no longer diminished by the oil spill.	Recovering	Rely on natural recovery.	1995	95052	Community Interaction/Use of Traditional Knowledge	Rita Miraglia	CLICK TO ACCESS	$1,797,200	Monitoring and Research
			Monitor recovery.	1995	95058	Landowner Assistance Program	Mark Kuwada	CLICK TO ACCESS	$90,700	Monitoring and Research
			Protect injured resources and their habitats.	1998	98339	Prince William Sound Human Use and Wildlife Disturbance Model	Karen Murphy	CLICK TO ACCESS	$201,000	Monitoring and Research
Recreation and Tourism	Recreation and tourism will have recovered, in large part, when the fish and wildlife resources on which they depend have recovered and recreation use of oiled beaches is no longer impaired.	Recovering	Rely on natural recovery.	1999	99180	Kenai Habitat Restoration and Recreation Enhancement	Art Weiner	CLICK TO ACCESS	$1,796,600	Restoration
				1997	97180	Kenai Habitat Restoration & Recreation Enhancement	Marty Rutherford	CLICK TO ACCESS		Restoration
			Monitor recovery.	1999	99314	Homer Mariner Park Habitat Assessment and Restoration Design	Jack Cushing	CLICK TO ACCESS		Restoration

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Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project information: Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
			Protect injured resources and their habitats.	1991	FS6	Prince William Sound/Gulf of Alaska sport fishery harvest and effort	K. Roth	CLICK TO ACCESS		Info/Mgmt/Admin
Subsistence	Subsistence will have recovered when injured resources used for subsistence are healthy and productive and exist at prespill levels. In addition, there is recognition that people must be confident that the resources are safe to eat and that the cultural values provided by gathering, preparing, and sharing food need to be reintegrated into community life.	Recovering	Rely on natural recovery.	2000	482	Optimization of Rapid Diagnostic Test Kits for Paralytic Shellfish Poisoning and Amnesic Shellfish Poisoning	Joanne Jellett	CLICK TO ACCESS	$56,000	Monitoring & Research
			Monitor recovery.	1997	97220	Eastern Prince William Sound Wildstock Salmon Habitat Restoration	Dana Schmidt	CLICK TO ACCESS		Restoration
			Protect injured resources and their habitats.	1996	96291	Chenega-area Shoreline Residual Oiling Reduction	Dianne Munson	CLICK TO ACCESS		Restoration
				1999	99471	Update of the Status of Subsistence Uses in Exxon Valdez Oil Spill Area Communities	EVOS Administration	CLICK TO ACCESS		Info/Mgmt/Admin
				1996	96220	Eastern Prince William Sound Wildstock Salmon Habitat Restoration	Eyak Native Village	CLICK TO ACCESS		Restoration
				1994	94428	Subsistence Restoration Planning and Implementation	James Fall	CLICK TO ACCESS	$151,400	Info/Mgmt/Admin
				1995	95428	Subsistence Planning Project	James Fall	CLICK TO ACCESS		Restoration
				1998	98471	Update of the Status of Subsistence Uses in Exxon Valdez Oil Spill Area Communities	James Fall	CLICK TO ACCESS	$197,400	Info/Mgmt/Admin
				2004	40471	Update of the Status of Subsistence Uses in Exxon Valdez Oil Spill Area Communities	James Fall	CLICK TO ACCESS		Info/Mgmt/Admin
				2000	247	Kametolook River Coho Salmon Subsistence Project	Jim McCullough	CLICK TO ACCESS	$106,700	Restoration
				1994	94279	Subsistence Restoration Project: Food Safety Testing	Karen Shemet	CLICK TO ACCESS	$676,800	Monitoring & Research
				1995	95279	Subsistence Food Safety Survey and Testing	Rita Miraglia	CLICK TO ACCESS		Monitoring & Research
				2002	2052	Natural Resource Management and Stewardship Capacity Building	Patty Brown-Schwalenberg	CLICK TO ACCESS		Info/Mgmt/Admin
				2003	30052	Tribal Natural Resource Stewardship and Meaningful Tribal Involvement in GEM	Patty Brown-Schwalenberg	CLICK TO ACCESS		Info/Mgmt/Admin
				1993	93017	Subsistence Restoration	Rita Miraglia	CLICK TO ACCESS		Restoration
				1995	95138	Elders/Youth Conference on Subsistence and the Oil Spill	William Simeone	CLICK TO ACCESS	$75,100	Info/Mgmt/Admin
				1997	97286	Elders/Youth Conference on Subsistence and the Oil Spill	Robert Henrichs	CLICK TO ACCESS		Info/Mgmt/Admin

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Resource	Recovery Summary Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	Project information FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				1998	98286	Elders/Youth Conference on Subsistence and the Oil Spill	Robert Henrichs	CLICK TO ACCESS		Info/Mgmt/Admin
				2002	2503	Orca Inlet Restoration	Robert Henrichs	CLICK TO ACCESS		Restoration
				2002	2610	Kodiak Archipelago Youth Area Watch	Teri Schneider	CLICK TO ACCESS		Info/Mgmt/Admin
				2003	30610	Kodiak Archipelago Youth Area Watch	Teri Schneider	CLICK TO ACCESS		Info/Mgmt/Admin
				2002	2507	Nuchek Subsistence Camp	Robert Henrichs	CLICK TO ACCESS		Restoration

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	Recovery Summary						Project information			
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
ECOSYSTEM CONNECTIVITY										
Multiple Resource Categories										
Black Oyster-Catchers, Pigeon Guillemots	See individual resource	See individual resource	See individual resource	1994	94041	Restoration of seabirds, particularly black oystercatchers and pigeon guillemots, by removing introduced predators	Edgar Bailey	CLICK TO ACCESS		Restoration
				1995	95041	Closeout: Introduced Predator Removal from Islands	G. Vernon Byrd	CLICK TO ACCESS		Monitoring & Research
Black Oyster-Catchers, Pigeon Guillemots, Common Murres	See individual resource	See individual resource	See individual resource	1996	96101	Removal of Introduced Foxes From Islands	Steven Ebbert	CLICK TO ACCESS		Restoration
Birds, Sea Otters	See individual resource	See individual resource	See individual resource	1993	93045	Marine bird and sea otter population abundance of PWS: trends following EVOS	Beverly Agler	CLICK TO ACCESS		Monitoring & Research
				1994	94159	Winter marine bird and sea otter population abundance of PWS: trends following EVOS	Beverly Agler	CLICK TO ACCESS	$1,330,400	Monitoring & Research
				1996	96159	Surveys to Monitor Marine Bird Abundance In Prince William Sound During Winter and Summer 1996	Beverly Agler	CLICK TO ACCESS		Monitoring & Research
				1998	98159	Surveys to Monitor Marine Bird Abundance in Prince William Sound during Winter and Summer 1998	Brian Lance	CLICK TO ACCESS		Monitoring & Research
				2000	159	Surveys to Monitor Marine Bird Abundance in Prince William Sound During Winter and Summer 2000	Brian Lance	CLICK TO ACCESS		Monitoring & Research
				2002	2159	Surveys to Monitor Marine Bird Abundance in Prince William Sound 2002	David Irons	CLICK TO ACCESS		Monitoring & Research
				2004	40159	Surveys to Monitor Marine Bird Abundance in Prince William Sound during Winter and Summer 2004	David Irons	CLICK TO ACCESS	$175,518	Monitoring & Research
Common Murres, Black-legged Kittiwakes	See individual resource	See individual resource	See individual resource	2000	338	Survival of Adult Murres and Kittiwakes in Relation to Forage Fish Abundance	John Piatt	CLICK TO ACCESS		Monitoring & Research
				2001	1338	Survival of Adult Murres and Kittiwakes in Relation to Forage Fish Abundance	John Piatt	CLICK TO ACCESS		Monitoring & Research
				1998	98338	Survival of Adult Murres and Kittiwakes in Relation to Forage Fish Abundance	John Piatt	CLICK TO ACCESS		Monitoring & Research

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	Recovery Summary					Project information				
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				1999	99338	Survival of Adult Murres and Kittiwakes in Relation to Forage Fish Abundance	John Piatt	CLICK TO ACCESS		Monitoring & Research
Common Murres, Marbled Murrelets, Kittlitz's Murrelets, Pigeon Guillemots	See individual resource	See individual resource	See individual resource	1999	99169	A Genetic Study to Aid in Restoration of Murres, Guillemots, and Murrelets in the Gulf of Alaska	Vicki Friesen	CLICK TO ACCESS		Monitoring & Research
				2000	169	A Genetic Study to Aid in Restoration of Murres, Guillemots, and Murrelets in the Gulf of Alaska	Vicki Friesen	CLICK TO ACCESS		Monitoring & Research
Dolly Varden, Herring, Pink Salmon (Wild), Rockfish	See individual resource	See individual resource	See individual resource	1991	TS2	Fish histopathology damage assessment after EVOS	Gary Marty	CLICK TO ACCESS		Monitoring & Research
Dolly Varden, Other Fish	See individual resource	See individual resource	See individual resource	1992	ST7	Assessment of oil spill impacts on fishery resources: measurements of hydrocarbons and their metabolites, and their effects, in important species	Tracy Collier	CLICK TO ACCESS		Monitoring & Research
Harbor Seals, Sea Otters, Subsistence	See individual resource	See individual resource	See individual resource	1995	95244	Seal and Sea Otter Cooperative Subsistence Harvest Assistance	James Fall	CLICK TO ACCESS		Info/Mgmt/Admin
Herring, Rockfish	See individual resource	See individual resource	See individual resource	1991	FS19	Injury to larval fish in Prince William Sound	Brenda Norcross	CLICK TO ACCESS		Monitoring & Research
Humpback Whales, Killer Whales	See individual resource	See individual resource	See individual resource	1991	MM3	Cetacean necropsies to determine injury from the Exxon Valdez Oil Spill	Thomas Loughlin	CLICK TO ACCESS		Monitoring & Research
Intertidal Communities, Subtidal Communities	See individual resource	See individual resource	See individual resource	2003	30666	Alaska Natural Geography in Shore Areas: An Initial Field Project for the Census of Marine Life	Brenda Konar	CLICK TO ACCESS		Monitoring & Research
				2004	40666	Alaska Natural Geography in Shore Areas: Year 2 of a Census of Marine Life Initial Field Project	Brenda Konar	CLICK TO ACCESS	$248,729	Monitoring & Research
				2004	40687	Monitoring in the Nearshore: A Process for Making Reasoned Decisions	James Bodkin	CLICK TO ACCESS	$10,000	Monitoring & Research
				2005	50764	ShoreZone Mapping for Kodiak Island	Susan Saupe	CLICK TO ACCESS	$403,200	Info/Mgmt/Admin
				1995	95086C	Herring Bay Experimental and Monitoring Studies	Raymond Highsmith	CLICK TO ACCESS		Monitoring & Research
Intertidal Communities, Subtidal Communities, Pink Salmon (Wild), Sockeye Salmon	See individual resource	See individual resource	See individual resource	2003	30626	Monitoring Strategies for GEM: Habitat Biogeochemical Connections	Thomas Kline	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary			Project information						
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
Intertidal Communities, Subtidal Communities, Zooplankton, Pink Salmon (Wild), Stockeye Salmon	See individual resource	See individual resource	See individual resource	2004	40654	Surface Nutrients Over the Shelf and Basin in Summer - Bottom up Control of Ecosystem Diversity	Phyllis Stabeno	CLICK TO ACCESS	$49,500	Monitoring & Research
Killer Whales, Harbor Seals	See individual resource	See individual resource	See individual resource	1996	96012A	Impact of killer whale predation on harbor seals in PWS: a preliminary assessment of diet using stable isotope and fatty acid signature analysis	Graham Worthy	CLICK TO ACCESS		Monitoring & Research
Marbled Murrelets, Kittlitz's Murrelets, Common Murres, Pigeon Guillemots	See individual resource	See individual resource	See individual resource	1997	97169	A Genetic Study to Aid in Restoration of Murres, Guillemots, and Murrelets to the Gulf of Alaska	Vicki Friesen	CLICK TO ACCESS		Monitoring & Research
				1998	98169	A Genetic Study to Aid in Restoration of Murres, Guillemots, and Murrelets in the Gulf of Alaska	Vicki Friesen	CLICK TO ACCESS		Monitoring & Research
Mussels, Recreation and Tourism, Archaeological Sites/Artifacts, Harlequin Ducks, Common Murres, Pink Salmon (Wild), Sea Otters	See individual resource	See individual resource	See individual resource	2000	530	Lessons Learned: Evaluating Scientific Sampling of Oil Spill Effects	Marianne See	CLICK TO ACCESS		Info/Mgmt/Admin
Mussels, Subtidal Communities, Sediments	See individual resource	See individual resource	See individual resource	2003	30623	PWSRCAC - EVOS Long Term Environmental Monitoring Program	John Devens	CLICK TO ACCESS		Monitoring & Research
Other Fish, Mussels, Sediments	See individual resource	See individual resource	See individual resource	2000	379	Assessment of Risk Caused by Residual Oil in Prince William Sound Using P450 Activity in Fishes	Stephen Jewett	CLICK TO ACCESS		Monitoring & Research
Other Fish, Subtidal Communities	See individual resource	See individual resource	See individual resource	2000	493	Statistically-Based Sampling Strategies for Gulf of Alaska Ecosystem Trawl Survey Monitoring	Paul Anderson	CLICK TO ACCESS		Monitoring & Research
				2001	1478	Testing Satellite Tags as a Tool for Identifying Critical Habitat	Jennifer Nielsen	CLICK TO ACCESS		Monitoring & Research
Other Seabids, General Food Webs	See individual resource	See individual resource	See individual resource	2002	2163	APEX_Alaska Predator Ecosystem Experiment in Prince William Sound and the Gulf of Alaska	David Duffy	CLICK TO ACCESS	(a)	Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	Project information: FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2002	02163M	APEX_Numerical and Functional Response of Seabirds to Fluctuations in Forage Fish Density	John Piatt	CLICK TO ACCESS	(a)	Monitoring & Research
Pacific Herring, Fish Food Webs	See individual resource	See individual resource	See individual resource	1995	95320U	SEA_Somatic and Spawning Energetics of Herring/Pollock	A.J. Paul	CLICK TO ACCESS	(b)	Monitoring & Research
Pacific Herring, Mussels, Intertidal Communities, Other Birds	See individual resource	See individual resource	See individual resource	2002	2659	Preparation and Publication of Results from SEA and NVP Avian Predation Studies	Mary Anne Bishop	CLICK TO ACCESS	(b)	Info/Mgmt/Admin
Pacific Herring, Other Fish	See individual resource	See individual resource	See individual resource	2001	1468	FEATS: Fundamental Estimations of Acoustic Target Strength	Gary Thomas	CLICK TO ACCESS		Monitoring & Research
				1998	98468	FEATS: Fundamental Estimations of Acoustic Target Strength	Jay Kirsch	CLICK TO ACCESS		Monitoring & Research
				1999	99468	FEATS: Fundamental Estimations of Acoustic Target Strength	Jay Kirsch	CLICK TO ACCESS		Monitoring & Research
				1998	98347	Fatty Acid Profile and Lipid Class Analysis for Estimating Diet Composition and Quality at Different Trophic Levels	Ronald Heintz	CLICK TO ACCESS		Monitoring & Research
				2000	347	Fatty Acid Profile and Lipid Class Analysis for Estimating Diet Composition and Quality at Different Trophic Levels	Ronald Heintz	CLICK TO ACCESS		Monitoring & Research
Pacific Herring, Pink Salmon (Wild)	See individual resource	See individual resource	See individual resource	1999	99320N	SEA_ Acoustic Assessment of Pink Salmon Predators, Macrozooplankton Prey and Juvenile Herring in Prince William Sound	Gary Thomas	CLICK TO ACCESS	(b)	Monitoring & Research
				1996	96195	Pristane Monitoring in Mussels and Predators of Juvenile Pink Salmon & Herring	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				1996	96320E	SEA_Salmon and Herring Predation	Mark Willette	CLICK TO ACCESS	(b)	Monitoring & Research
				1996	96320	SEA_ Sound Ecosystem Assessment	R. Ted Cooney	CLICK TO ACCESS	(b)	Monitoring & Research
				1996	96320Z1	SEA_Synthesis and Integration	R. Ted Cooney	CLICK TO ACCESS	(b)	Monitoring & Research
				1997	97320	SEA_ Sound Ecosystem Assessment	R. Ted Cooney	CLICK TO ACCESS	(b)	Monitoring & Research
				1998	98320	SEA_ Sound Ecosystem Assessment	R. Ted Cooney	CLICK TO ACCESS	(b)	Monitoring & Research
				1999	99320	SEA_ Sound Ecosystem Assessment	R. Ted Cooney	CLICK TO ACCESS	(b)	Monitoring & Research
				2002	2320	SEA_ Sound Ecosystem Assessment: Printing the Final Report	William Hauser	CLICK TO ACCESS	(b)	Info/Mgmt/Admin
Pacific Herring, Pink Salmon (Wild), Sockeye Salmon, Commercial Fishing	See individual resource	See individual resource	See individual resource	2002	2627	A Symbiotic Acoustic Signal Processor to Increase Stock Assessment Effort	Jim Dawson	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Project information: Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
Passive Use, Subsistence	See individual resource	See individual resource	See individual resource	2000	339	Western Prince William Sound Human Use and Wildlife Disturbance Model	Lowell Suring	CLICK TO ACCESS		Monitoring & Research
				1999	99339	Western Prince William Sound Human Use and Wildlife Disturbance Model	Lowell Suring	CLICK TO ACCESS		Monitoring & Research
Pink Salmon (Wild), Other Fish	See individual resource	See individual resource	See individual resource	1999	99405	Port Graham Salmon Hatchery Reconstruction	Eleanor McMullen	CLICK TO ACCESS		Restoration
Pink Salmon (Wild), Pacific Herring, Fish Food Webs	See individual resource	See individual resource	See individual resource	1995	95320E	SEA_Juvenile Salmon and Herring Integration	Mark Willette	CLICK TO ACCESS	(b)	Monitoring & Research
Pink Salmon (Wild), Sockeye Salmon	See individual resource	See individual resource	See individual resource	1994	94137	Stock identification of chum, sockeye, chinook and coho salmon in PWS	Samuel Sharr	CLICK TO ACCESS		Monitoring & Research
				1992	R59	Assessment of genetic stock structure of salmonids	Lisa Seeb	CLICK TO ACCESS		Monitoring & Research
Pink Salmon (Wild), Sockeye Salmon, Dolly Varden	See individual resource	See individual resource	See individual resource	1996	96180	Kenai Habitat Restoration and Recreation Enhancement	Carol Fries	CLICK TO ACCESS		Restoration
Pink Salmon (Wild), Subsistence	See individual resource	See individual resource	See individual resource	1999	99225	Port Graham Pink Salmon Subsistence Project	Ephim Anahonak	CLICK TO ACCESS		Monitoring & Research
Recreation and Tourism, Subsistence	See individual resource	See individual resource	See individual resource	2002	2514	Lower Cook Inlet Waste Management Plan	Thomas Turner	CLICK TO ACCESS		Info/Mgmt/Admin
				2004	40725	Impacts of Seafood Waste Discharge in Orca Inlet, Prince William Sound	Richard Thorne	CLICK TO ACCESS	$293,315	Monitoring & Research
Sea Lions, Other Fish	See individual resource	See individual resource	See individual resource	2003	30660	Reconstructing Marine Ecosystems: Insight into Climate and Productivity Changes	Bruce Finney	CLICK TO ACCESS		Monitoring & Research
Sea Otters, Harlequin Ducks	See individual resource	See individual resource	See individual resource	2000	423	Patterns and Processes of Population Change in Selected Nearshore Vertebrate Predators	James Bodkin	CLICK TO ACCESS		Monitoring & Research
				2001	1423	Patterns and Processes of Population Change in Selected Nearshore Vertebrate Predators	James Bodkin	CLICK TO ACCESS		Monitoring & Research
				2002	2423	Patterns and Processes of Population Change in Selected Nearshore Vertebrate Predators	James Bodkin	CLICK TO ACCESS		Monitoring & Research
				2003	30423	Patterns and Processes of Population Change in Selected Nearshore Vertebrate Predators	James Bodkin	CLICK TO ACCESS		Monitoring & Research
				2003	30620	Lingering Oil and Predators: Pathways of Exposure and Population Status	Stanley Rice	CLICK TO ACCESS		Monitoring & Research
				2004	040620-1	Lingering Oil: Pathways of Exposure and Population Status (ABL)	Stanley Rice	CLICK TO ACCESS	$150,100	Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary			Project information						
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2004	40740	Lingering Oil: Contaminant Inputs to Prince William Sound and CYPIA Induction in Fish - Midterm Lingering Oil Project DOL Grant	Stanley Rice	CLICK TO ACCESS	$307,400	Monitoring & Research
Sea Otters, Harlequin Ducks, River Otters, Pigeon Guillemots	See individual resource	See individual resource	See individual resource	1999	99025	Mechanisms of Impact and Potential Recovery of Nearshore Vertebrate Predators (NVP)	Leslie Holland-Bartels	CLICK TO ACCESS		Monitoring & Research
Sediments, Intertidal Communities, Subtidal Communities	See individual resource	See individual resource	See individual resource	1992	ST4	Fate and toxicity of spilled oil from the Exxon Valdez	Douglas Wolfe	CLICK TO ACCESS		Monitoring & Research
Sediments, Mussels, Intertidal Communities	See individual resource	See individual resource	See individual resource	1992	CH1B	Pre-spill and post-spill concentrations of hydrocarbons in sediments and mussels at intertidal sites in PWS and GOA	Malin Babcock	CLICK TO ACCESS		Monitoring & Research
Sediments, Subtidal Communities	See individual resource	See individual resource	See individual resource	1992	ST1A	Petroleum hydrocarbon-induced injury to subtidal sediment resources	Byron Morris	CLICK TO ACCESS		Monitoring & Research
				1992	ST1B	Hydrocarbon mineralization potentials and microbial populations in marine sediments following EVOS	Joan Braddock	CLICK TO ACCESS		Monitoring & Research
				1992	ST3B	Nearshore transport of hydrocarbons and sediments following EVOS	David Sale	CLICK TO ACCESS		Monitoring & Research
				1994	94285	Subtidal monitoring: recovery of sediments in the NW Gulf of Alaska	Stephen Jewett	CLICK TO ACCESS		Monitoring & Research
Sediments, Subtidal Communities, Mussels	See individual resource	See individual resource	See individual resource	2002	2589	PWSRCAC - EVOS Long Term Environmental Monitoring Program	John Devens	CLICK TO ACCESS		Monitoring & Research
Sediments, Water	See individual resource	See individual resource	See individual resource	2002	2629	Development of a Paradigm for Ecosystem Monitoring	Richard Thorne	CLICK TO ACCESS		Monitoring & Research
Sediments, Water, Intertidal Communities, Subtidal Communities	See individual resource	See individual resource	See individual resource	2006	60783	Information Synthesis and Recovery Recommendations for Resources and Services Injured by the Exxon Valdez Oil Spill	Lucinda Jacobs	CLICK TO ACCESS		Info/Mgmt/Admin
Sockeye Salmon, Commercial Fishing, Subsistence, Recreation and Tourism	See individual resource	See individual resource	See individual resource	2002	2612	Detecting and Understanding Marine-Terrestrial Linkages in the Kenai River Watershed	William Hauser	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Summary: Recovery Status (2002)	Recovery Summary: Restoration Strategy	Project information: FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
Sockeye Salmon, Primary Production, Zooplankton	See individual resource	See individual resource	See individual resource	2004	40703	Marine-terrestrial Linkages in northern GOA Watersheds: Towards Monitoring the effects of Anadromous Marine-derived Nutrients on Biological Production	Bruce Finney	CLICK TO ACCESS	$240,468	Monitoring & Research
Stream Habitat, Pink Salmon (Wild)	See individual resource	See individual resource	See individual resource	1994	94139C1	Montague Island Chum restoration	Ray Thompson	CLICK TO ACCESS		Restoration
				1995	95139A2	Port Dick Creek Spawning Channel	Nick Dudiak	CLICK TO ACCESS		Restoration
Stream Habitat, Pink Salmon (Wild), Other Fish	See individual resource	See individual resource	See individual resource	2000	00139A2	Port Dick Creek Tributary Restoration and Development	Andrew Dickson	CLICK TO ACCESS		Restoration
Stream Habitat, Pink Salmon (Wild), Sockeye Salmon, Dolly Varden, Cutthroat Trout, Other Fish, Subsistence	See individual resource	See individual resource	See individual resource	2002	2416	O'Brian Creek Enhancement	Chenega Bay IRA Council	CLICK TO ACCESS		Restoration
Stream Habitat, Sediments, Pink Salmon (Wild), Sockeye Salmon	See individual resource	See individual resource	See individual resource	2003	30672	Downstream Effects of Sedimentation on Lower Kenai Peninsula Salmon Streams	Sue Mauger	CLICK TO ACCESS		Monitoring & Research
Subsistence, Commercial Fishing	See individual resource	See individual resource	See individual resource	2004	40636	Fisheries Management Applications	Kenneth Adams	CLICK TO ACCESS	$46,700	Info/Mgmt/Admin
Subsistence, Harbor Seals	See individual resource	See individual resource	See individual resource	1996	96214	Documentary on Subsistence Harbor Seal Hunting in PWS	Gary Kompkoff	CLICK TO ACCESS		Info/Mgmt/Admin
				1997	97214CLO	Documentary on Subsistence Harbor Seal Hunting in PWS	William Simeone	CLICK TO ACCESS		Info/Mgmt/Admin
Subsistence, Intertidal Communities	See individual resource	See individual resource	See individual resource	2000	481	Documentary Film on the Oil Spill Impacts on Subsistence Use of Intertidal Resources	Gail Evanoff	CLICK TO ACCESS		Info/Mgmt/Admin
Subsistence, Sediments	See individual resource	See individual resource	See individual resource	1994	94266	Workshop report: residual shoreline oiling	Robert Loeffler	CLICK TO ACCESS		Info/Mgmt/Admin
Subtidal Communities, Intertidal Communities, Sediment, Mussels, Clams, Archaeological Sites/Artifacts	See individual resource	See individual resource	See individual resource	2002	2556	Mapping Marine Habitats: Kachemak Bay	G. Carl Schoch	CLICK TO ACCESS		Info/Mgmt/Admin
				2002	2565	Bottom-Up vs. Top Down: What Forces Control Variability in Kachemak Bay?	G. Carl Schoch	CLICK TO ACCESS		Monitoring & Research
				2002	2569	Linked Monitoring Network for the Gulf of Alaska: A Workshop	G. Carl Schoch	CLICK TO ACCESS		Info/Mgmt/Admin

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Project information Principal Investigator	Link	Cost[2]	Action Category (1994)
Subtidal Communities, Intertidal Communities, Subsistence, Passive Use	See individual resource	See individual resource	See individual resource	2003	30210	Youth Area Watch	Bob Crumley	CLICK TO ACCESS		Info/Mgmt/Admin
Subtidal Communities, Pacific Herring	See individual resource	See individual resource	See individual resource	1995	95320N	SEA_Nearshore Fish	Gary Thomas	CLICK TO ACCESS	(b)	Monitoring & Research
Water, Abiotic Dynamics	See individual resource	See individual resource	See individual resource	2002	2671	Coordinating Volunteer Vessels of Opportunity to Collect Oceanographic Data in Kachemak Bay and Lower Cook Inlet	Diana Stram	CLICK TO ACCESS		Info/Mgmt/Admin
Water, Commercial Fishing	See individual resource	See individual resource	See individual resource	1992	FS18	Impacts of the Exxon Valdez oil spill on bottomfish and shellfish in Prince William Sound	Evan Haynes	CLICK TO ACCESS		Monitoring & Research
Water, Commercial Fishing, Subsistence	See individual resource	See individual resource	See individual resource	2003	30686	Instrumenting Vessels of Opportunity to Collect Coastal Oceanographic Data	W. Scott Pegau	CLICK TO ACCESS		Info/Mgmt/Admin
Water, Mussels	See individual resource	See individual resource	See individual resource	1991	AW3	Petroleum hydrocarbons in near-surface seawater of Prince William Sound, Alaska, following EVOS II: analysis of caged mussels	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
Water, Other Fish	See individual resource	See individual resource	See individual resource	2003	30670	Monitoring Dynamics of the Alaska Coastal Current and Development of Applications for Management of Cook Inlet Salmon	Mark Willette	CLICK TO ACCESS		Monitoring & Research
Water, Pink Salmon (Wild), Pacific Herring	See individual resource	See individual resource	See individual resource	2002	2552	Exchange Between Prince William Sound and the Gulf of Alaska	Shari Vaughan	CLICK TO ACCESS		Monitoring & Research
Water, Subsistence, Recreation and Tourism, Primary Production	See individual resource	See individual resource	See individual resource	2004	40699	Biophysical Observation Aboard Alaska Marine Highway Systems Ferries	Edward Cokelet	CLICK TO ACCESS	$503,300	Monitoring & Research
General										
Abiotic Dynamics, General Ecology	NA	NA	NA	2000	389	3-D Ocean State Simulations for Ecosystem Applications from 1995-98 in Prince William Sound	Jia Wang	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	Project information FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2001	1389	3-D Ocean State Simulations for Ecosystem Applications from 1995-98 in Prince William Sound	Jia Wang	CLICK TO ACCESS		Monitoring & Research
				2002	2614	Monitoring Program for Near-Surface Temperature, Salinity, and Fluorescence in the Northern Pacific Ocean	Stephen Okkonen	CLICK TO ACCESS		Monitoring & Research
				2002	2618	Measurements of Tide Rip Front Variability in Cook Inlet	Susan Saupe	CLICK TO ACCESS		Monitoring & Research
				1998	98340	Toward Long-Term Oceanographic Monitoring of the Gulf of Alaska Ecosystem	Thomas Weingartner	CLICK TO ACCESS		Monitoring & Research
				1999	99340	Toward Long-Term Oceanographic Monitoring of the Gulf of Alaska Ecosystem	Thomas Weingartner	CLICK TO ACCESS		Monitoring & Research
				2000	340	Toward Long-Term Oceanographic Monitoring of the Gulf of Alaska Ecosystem	Thomas Weingartner	CLICK TO ACCESS		Monitoring & Research
				2001	1340	Toward Long-Term Oceanographic Monitoring of the Gulf of Alaska Ecosystem	Thomas Weingartner	CLICK TO ACCESS		Monitoring & Research
				2002	2340	Toward Long-Term Oceanographic Monitoring of the Gulf of Alaska Ecosystem	Thomas Weingartner	CLICK TO ACCESS		Monitoring & Research
				2002	2609	Long-Term Temperature/Salinity Monitoring Within the Alaska Coastal Current	Thomas Weingartner	CLICK TO ACCESS		Monitoring & Research
				2003	30340	Toward Long-Term Oceanographic Monitoring of the Gulf of Alaska Ecosystem	Thomas Weingartner	CLICK TO ACCESS		Monitoring & Research
				1993	93041	Comprehensive Monitoring	not available	CLICK TO ACCESS		Monitoring & Research
				1996	96320M	SEA_Physical Oceanography in PWS	not available	CLICK TO ACCESS	(b)	Monitoring & Research
				2003	30684	Toward Sustainable Management in the Kenai River Watershed: Linking Human & Resource Development with Nutrient & Engergy Pathways	Asit Mazumder	CLICK TO ACCESS		Monitoring & Research
				1996	96290	Hydrocarbon Data Analysis, Interpretation, and Database Maintenance	Bonita Nelson	CLICK TO ACCESS		Monitoring & Research
				1997	97290	Hydrocarbon Data Analysis, Interpretation, and Database Maintenance	Bonita Nelson	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	Project information: FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				1998	98290	Hydrocarbon Data Analysis, Interpretation, and Database Maintenance	Bonita Nelson	CLICK TO ACCESS		Monitoring & Research
				1994	94163	APEX_Forage Fish Influence on Recovery of Injured Species	Bruce Wright	CLICK TO ACCESS	(a)	Monitoring & Research
				1998	98330	Mass-Balance Model of Trophic Fluxes in Prince William Sound	Daniel Pauly	CLICK TO ACCESS		Monitoring & Research
				1994	94320M	SEA_Physical Oceanography in Prince William Sound and Gulf of Alaska	Donald Schell	CLICK TO ACCESS	(b)	Monitoring & Research
				1995	95266	Experimental Shoreline Oil Removal	Ernest Piper	CLICK TO ACCESS		Monitoring & Research
				1996	96027	Kodiak Archipelago Shoreline Assessment: Monitoring Surface and Subsurface Oil	Ernest Piper	CLICK TO ACCESS		Monitoring & Research
				2003	30653	Remote Sensing for GEM Watersheds and the Nearshore Region	Evelyn Brown	CLICK TO ACCESS		Info/Mgmt/Admin
				2001	1385	Partnering with NOAA to Quantify and Monitor Environmental Attributes of Kachemak Bay	G. Carl Schoch	CLICK TO ACCESS		Monitoring & Research
				2002	2532	Coupling of Oceanic and Nearshore: The Search for Indicator Species	Gail Irvine	CLICK TO ACCESS		Monitoring & Research
				2004	40702	A Synthesis of Natural Variability in the Nearshore: Can We Detect Change?	Ginny Eckert	CLICK TO ACCESS		Info/Mgmt/Admin
				1999	99278	Development of an Ecological Characterization and Site Profile for Kachemak Bay/Lower Cook Inlet	Glenn Seaman	CLICK TO ACCESS		Monitoring & Research
				2000	278	Development of an Ecological Characterization and Site Profile for Kachemak Bay/Lower Cook Inlet	Glenn Seaman	CLICK TO ACCESS		Monitoring & Research
				2005	50778	Identify and Evaluate Oil Remediation Technologies Applicable to Lingering Oil in Prince William Sound, Alaska	Jacqueline Michel	CLICK TO ACCESS		Monitoring & Research
				2003	30687	Monitoring in the Nearshore: A Process for Making Reasoned Decisions	James Bodkin	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project information Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2005	50750	Implementation of the GEM Nearshore Monitoring Plan: Site selection, standard operating procedures, and data management	James Bodkin	CLICK TO ACCESS		Monitoring & Research
				1993	93038	Shoreline oiling assessment of EVOS	James Gibeaut	CLICK TO ACCESS		Monitoring & Research
				1995	95027	1995 Kodiak Archipelago Shoreline Assessment Monitoring Surface and Subsurface Oil of EVOS	James Gibeaut	CLICK TO ACCESS		Monitoring & Research
				1995	95290	Hydrocarbon Data Analysis, Interpretation, and Database Maintenance for Restoration and NRDA Environmental Samples Associated with the Exxon Valdez Oil	Jeffrey Short	CLICK TO ACCESS		Info/Mgmt/Admin
				1999	99290	Hydrocarbon Data Analysis, Interpretation, and Database Maintenance	Jeffrey Short	CLICK TO ACCESS		Info/Mgmt/Admin
				2000	290	Hydrocarbon Data Analysis, Interpretation, and Database Maintenance	Jeffrey Short	CLICK TO ACCESS		Info/Mgmt/Admin
				2001	1290	Hydrocarbon Database and Interpretation Service	Jeffrey Short	CLICK TO ACCESS		Info/Mgmt/Admin
				2003	30290	Hydrocarbon Database and Interpretation Service	Jeffrey Short	CLICK TO ACCESS		Info/Mgmt/Admin
				2004	40724	Development of a Strategy for Monitoring Exxon Valdez Oil and other Contamination in PWS	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				2005	50763	Long-term Monitoring of Anthropogenic Hydrocarbons in the Exxon Valdez Oil Spill Region	Jeffrey Short	CLICK TO ACCESS		Monitoring & Research
				2003	30580	Creating a GIS Map of Impervious Cover in the Cook Inlet Basin	Joel Cooper	CLICK TO ACCESS		Info/Mgmt/Admin
				2002	2613	Mapping Marine Habitats: Prince William Sound to McCarty Fjord	John Harper	CLICK TO ACCESS		Info/Mgmt/Admin
				1995	95163L	APEX_ Historic Review of Ecosystem Structure in PWS/Gulf of Alaska and Abundance/ Distribution of Forage Fish in Barren Islands (APEX)	John Piatt	CLICK TO ACCESS	(a)	Monitoring & Research
				1996	96159	Lower Cook Inlet Study	John Piatt	CLICK TO ACCESS		Monitoring & Research
				1996	96163L	APEX_Historical Review of Ecosystem Structure in the PWS/GOA Complex	John Piatt	CLICK TO ACCESS	(a)	Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary			Project information						
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2002	2622	Digital Maps from Existing Seasonal Environmental Sensitive Area Maps: Cook Inlet/ Kenai Peninsula	John Whitney	CLICK TO ACCESS		Info/Mgmt/Admin
				2004	40639	Monitoring Ecosystem Parameters in the Northern Gulf of Alaska	Kenneth Goldman	CLICK TO ACCESS		Monitoring & Research
				1995	95025	Mechanism of Impact and Potential Recovery of Nearshore Vertebrate Predators	Leslie Holland-Bartels	CLICK TO ACCESS		Monitoring & Research
				1995	95025A	Nearshore Package: Project Planning and Development	Leslie Holland-Bartels	CLICK TO ACCESS		Info/Mgmt/Admin
				1997	97025	Mechanisms of Impact and Potential Recovery of Nearshore Vertebrate Predators (NVP)	Leslie Holland-Bartels	CLICK TO ACCESS		Monitoring & Research
				1998	98025	Mechanisms of Impact and Potential Recovery of Nearshore Vertebrate Predators (NVP)	Leslie Holland-Bartels	CLICK TO ACCESS		Monitoring & Research
				2000	25	Mechanisms of Impact and Potential Recovery of Nearshore Vertebrate Predators (NVP)	Leslie Holland-Bartels	CLICK TO ACCESS		Monitoring & Research
				1995	95163A1	APEX_ Abundance and Distribution of Forage Fish and their Influence on Recovery of Injured Species	Lewis Haldorson	CLICK TO ACCESS	(a)	Monitoring & Research
				2004	40776	Applied Research Related to Lingering Oil, Resource Recovery, and Management and Monitoring of Impaired Water Bodies	Lucinda Jacobs	CLICK TO ACCESS		Monitoring & Research
				1996	96163O	APEX_Statistical Review	Lyman McDonald	CLICK TO ACCESS	(a)	Monitoring & Research
				1998	98291	Chenega-Area Shoreline Residual Oiling Reduction	Marianne See	CLICK TO ACCESS		Restoration?
				1999	99291	Chenega-Area Shoreline Residual Oiling Reduction	Marianne See	CLICK TO ACCESS		Restoration?
				2000	567	Monitoring Environmental Contaminants in the Northern Gulf of Alaska	Marianne See	CLICK TO ACCESS		Monitoring & Research
				1995	95163C	APEX_ Fish Stomach Contents Analysis	Molly Sturdevant	CLICK TO ACCESS	(a)	Monitoring & Research
				2002	2578	The Marine Macrofauna of Prince William Sound: An Annotated List	Nora Foster	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary			Project information						
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2003	30642	Database on the Marine Invertebrate Macrofauna of Prince William Sound: An Addition to the University of Alaska Museum's ARCTOS Network	Nora Foster	CLICK TO ACCESS		Info/Mgmt/Admin
				2002	2643	Design of the Environmental Specimen Bank Program for GEM	Paul Becker	CLICK TO ACCESS		Info/Mgmt/Admin
				1993	93039	Herring Bay monitoring and restoration studies	Raymond Highsmith	CLICK TO ACCESS		Monitoring & Research
				1994	94086	Herring Bay Monitoring and Restoration Studies	Raymond Highsmith	CLICK TO ACCESS		Monitoring & Research
				2002	2619	Mapping Marine Habitats: Kodiak	Robert Foy	CLICK TO ACCESS		Info/Mgmt/Admin
				1998	98300	Synthesis of the Scientific Findings from the Exxon Valdez Oil Spill Restoration Program	Robert Spies	CLICK TO ACCESS		Info/Mgmt/Admin
				1999	99300	Synthesis of the Scientific Findings from the Exxon Valdez Oil Spill Restoration Program	Robert Spies	CLICK TO ACCESS		Info/Mgmt/Admin
				2002	2600	Synthesis of the Ecological Findings from the EVOS Damage Assessment and Restoration Programs, 1989-2001	Robert Spies	CLICK TO ACCESS		Info/Mgmt/Admin
				2003	30600	Synthesis of the Ecological Findings from the EVOS Damage Assessment and Restoration Programs, 1989-2001	Robert Spies	CLICK TO ACCESS		Info/Mgmt/Admin
				2004	40600	A synthesis of the ecological findings from the EVOS Damage Assessment and Restoration Programs, 1989-2001	Robert Spies	CLICK TO ACCESS		Info/Mgmt/Admin
				1995	95320M	SEA_Observational Physical Oceanography in Prince William Sound and the Gulf of Alaska	Shari Vaughan	CLICK TO ACCESS	(b)	Monitoring & Research
				1999	99320M	SEA_ Observational Oceanography in Prince William Sound and the Gulf of Alaska	Shari Vaughan	CLICK TO ACCESS	(b)	Monitoring & Research
				1993	93053	Hydrocarbon data analysis, interpretation and database management for restoration and NRDA samples associated with EVOS	Sid Korn	CLICK TO ACCESS		Monitoring & Research
				1994	94290	Hydrocarbon Data Analysis, Interpretation and database maintenance for restoration and NRDA environmental samples associated with EVOS	Sid Korn	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Project information: Principal Investigator	Link	Cost[2]	Action Category (1994)
				2003	30614	Monitoring Program for Near-Surface Temperature, Salinity, and Fluorescence in the Northern Pacific Ocean	Stephen Okkonen	CLICK TO ACCESS		Monitoring & Research
				2003	30614	Monitoring Program for Near-Surface Temperature, Salinity, and Fluorescence in the Northern Pacific Ocean	Stephen Okkonen	CLICK TO ACCESS		Monitoring & Research
				2004	40614	A Monitoring Program for Near-Surface Temp, Salinity, and Fluorescence Fields in the northeast Pacific Ocean: Transition to an Operational Program	Stephen Okkonen	CLICK TO ACCESS		Monitoring & Research
				2003	30691	Evaluating the relative roles of environment and fisheries in Gulf of Alaska and adjacent ecosystems	Villy Christensen	CLICK TO ACCESS		Monitoring & Research
Fish Food Webs	NA	NA	NA	1994	94320I	SEA_Confirming Food Web Dependencies with Stable Isotope Tracers: Food Webs of Fishes	Donald Schell	CLICK TO ACCESS	(b)	Monitoring & Research
				1995	95163K	APEX_ Using Predatory Fish to Sample Forage Fish	David Roseneau	CLICK TO ACCESS	(a)	Monitoring & Research
				1996	96163J	APEX_ Using Predatory Fish to Sample Forage Fish	David Roseneau	CLICK TO ACCESS	(a)	Monitoring & Research
				1995	95320I2	SEA_Isotope Tracers - Food Webs of Fish	Thomas Kline	CLICK TO ACCESS	(b)	Monitoring & Research
				1996	96163C	APEX_ Fish Diet Overlap Using Fish Stomach Content Analysis	Molly Sturdevant	CLICK TO ACCESS	(a)	Monitoring & Research
				1996	96320I	SEA_Isotope Tracers - Food Webs of Fish	PWS Science Center	CLICK TO ACCESS	(b)	Monitoring & Research
				1997	97163C	APEX_Diet Overlap, Prey Selection, Diet Feeding Periodicity and Potential Food Competition Among Forage Fish Species	Molly Sturdevant	CLICK TO ACCESS	(a)	Monitoring & Research
				2004	40726	Presence and Effects of Marine Derived Nutrients (MDN) in Stream, Riparian and Nearshore Ecosystems on Southern Kenai Peninsula, Alaska	Coowe Walker	CLICK TO ACCESS		Monitoring & Research
General Food Webs	NA	NA	NA	1995	95121	Proximate Composition and Fatty Acid Signatures of Selected Forage Fish Species in PWS	Graham Worthy	CLICK TO ACCESS		Monitoring & Research
				1995	95163A	APEX_ Abundance and Distribution of Forage Fish and their Influence on Recovery of Injured Species	David Duffy	CLICK TO ACCESS	(a)	Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	Project information: FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				1995	95320I	SEA_Isotope Tracers - Food Web Dependencies in Prince William Sound (Fish, Marine Mammals, and Birds)	Donald Schell	CLICK TO ACCESS	(b)	Monitoring & Research
				1995	95320Y	SEA_Variation in Local Predation Rates on Hatchery-Released Fry	David Scheel	CLICK TO ACCESS	(b)	Monitoring & Research
				1996	96025	Mechanism of Impact and Potential Recovery of Nearshore Vertebrate Predators	Leslie Holland-Bartels	CLICK TO ACCESS		Monitoring & Research
				1996	96163	APEX_ Alaska Predator Ecosystem Experiment in Prince William Sound and the Gulf of Alaska	not available	CLICK TO ACCESS	(a)	Monitoring & Research
				1996	96170	Isotope Ratio Studies of Marine Mammals in Prince William Sound	Donald Schell	CLICK TO ACCESS		Monitoring & Research
				1996	96163J	APEX_Distribution of Forage Fish as Indicated by Puffin Diet Sampling	John Piatt	CLICK TO ACCESS	(a)	Monitoring & Research
				1996	96320R	SEA_Trophodynamic Modeling and Validation Through Remote Sensing	David Eslinger	CLICK TO ACCESS	(b)	Monitoring & Research
				1996	96320Y	SEA_Variation in Local Predation Rates on Hatchery-Released Fry	PWS Science Center	CLICK TO ACCESS	(b)	Monitoring & Research
				1997	97163	APEX_Alaska Predator Ecosystem Experiment in Prince William Sound and the Gulf of Alaska	Stanley Rice	CLICK TO ACCESS	(a)	Monitoring & Research
				1998	98163	APEX_Alaska Predator Ecosystem Experiment in Prince William Sound and the Gulf of Alaska	David Duffy	CLICK TO ACCESS	(a)	Monitoring & Research
				1999	99393	Prince William Sound Food Webs: Structure and Change	Thomas Kline	CLICK TO ACCESS		Monitoring & Research
				1999	99330	Mass-Balance Models of Trophic Fluxes in EVOS-Impacted Areas	Daniel Pauly	CLICK TO ACCESS		Monitoring & Research
				2000	330	Mass-Balance Model of Trophic Fluxes in Prince William Sound	Daniel Pauly	CLICK TO ACCESS		Monitoring & Research
				2000	393	Prince William Sound Food Webs: Structure and Change	Thomas Kline	CLICK TO ACCESS		Monitoring & Research
				2001	1393	Prince William Sound Food Webs: Structure and Change	Thomas Kline	CLICK TO ACCESS		Monitoring & Research
				2003	30625	Prince William Sound Isotope Ecology Synthesis	Thomas Kline	CLICK TO ACCESS		
				2004	40647	Investigating the Relative Roles of Natural Factors & Shoreline Harvest in Altering the Community Structure, Dynamics & Diversity of the Kenai Peninsula	Jennifer Ruesink	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

Resource	Recovery Summary: Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	Project information: FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2004	40712	Research for Nutrient-Based Resource Management in Watersheds and Estuaries	Carol Ann Woody	CLICK TO ACCESS		Monitoring & Research
Other Fish, Fish Food Webs	NA	NA	NA	2002	2561	Evaluating the Feasibility of Developing a Community- Based Forage Fish Sampling Project for GEM	David Roseneau	CLICK TO ACCESS		Info/Mgmt/Admin
Other Fish, Zooplankton	NA	NA	NA	1999	99347	Fatty Acid Profile and Lipid Class Analysis for Estimating Diet Composition and Quality at Different Trophic Levels	Ronald Heintz	CLICK TO ACCESS		Monitoring & Research
Primary Production	NA	NA	NA	1994	94320G	SEA_Plankton Dynamics: Phytoplankton and Nutrients	C. Peter McRoy	CLICK TO ACCESS	(b)	Monitoring & Research
				1995	95320G	SEA_Phytoplankton and Nutrients	C. Peter McRoy	CLICK TO ACCESS	(b)	Monitoring & Research
				1996	96320G	SEA_Phytoplankton and Nutrients	C. Peter McRoy	CLICK TO ACCESS	(b)	Monitoring & Research
				2001	1551	Checklist and Distributional Analysis of Marine Algal Species Collected as Vouchers Under Project CH1A	Gayle Hansen	CLICK TO ACCESS		Monitoring & Research
				2002	2597	Ocean Color Time Series of Prince William Sound	W. Scott Pegau	CLICK TO ACCESS		Monitoring & Research
				2002	2624	A CPR-Based Plankton Survey Using Ships of Opportunity to Monitor the Gulf of Alaska	Sonia Batten	CLICK TO ACCESS		Monitoring & Research
				2002	2646	Information Dissemination through the Web: Developing an Interactive Database on Southcentral Alaskan Seaweeds	Gayle Hansen	CLICK TO ACCESS		Info/Mgmt/Admin
				2003	30624	A CPR-Based Survey to Monitor the Gulf of Alaska and Detect Ecosystem Change	Sonia Batten	CLICK TO ACCESS		Monitoring & Research
				2003	30683	Seaweeds of Southcentral Alaska: Thumbnail Guide, Images, and Distribution Maps	Gayle Hansen	CLICK TO ACCESS		Monitoring & Research
				2003	30685	Visible Remote Sensing of the Gulf of Alaska	W. Scott Pegau	CLICK TO ACCESS		Monitoring & Research
Primary Production, Zooplankton	NA	NA	NA	2003	30606	Development of a Voluntary Observing Ship "Ferry Box" for the North Pacific	David Welch	CLICK TO ACCESS		Info/Mgmt/Admin
Primary Production, Zooplankton, General Food Webs	NA	NA	NA	2003	30654	Surface Nutrients Over the Shelf and Basin in Summer - Bottom up Control of Ecosystem Diversity	Phyllis Stabeno	CLICK TO ACCESS		Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary			Project information						
Resource	**Recovery Objective (2002)**	**Recovery Status (2002)**	**Restoration Strategy**	**FY**	**Project Number**	**Title**	**Principal Investigator**	**Link**	**Cost[2]**	**Action Category (1994)**
				2004	40624	Acquisition and Application of CPR data in the Gulf of Alaska	Sonia Batten	CLICK TO ACCESS		Monitoring & Research
River Habitat	NA	NA	NA	1994	94043A1	Eshamy River Restoration (W. PWS)	Eric Meyers	CLICK TO ACCESS		Restoration
				1994	94139C2	Lowe River restoration	Kathleen Wedemeyer	CLICK TO ACCESS		Restoration
				1998	98180	Kenai Habitat Restoration and Recreation Enhancement	Mark Kuwada	CLICK TO ACCESS		Restoration
				2000	180	Kenai Habitat Restoration and Recreation Enhancement	Marty Rutherford	CLICK TO ACCESS		Restoration
				2002	2621	Kenai River Flats Conservation Easement and Public Education	Mark Kuwada	CLICK TO ACCESS		Info/Mgmt/Admin
Spruce Forest Habitat	NA	NA	NA	1995	95060	Spruce bark beetle infestation impacts on injured fish and wildlife species	Betsy Parry	CLICK TO ACCESS		Monitoring & Research
Stream Habitat	NA	NA	NA	1992	R47	Stream habitat assessment project: Afognak Island	Mark Kuwada	CLICK TO ACCESS		Monitoring & Research
				1993	93051A	Stream habitat assessment project: PWS and lower Kenai Peninsula	Kathrin Sundet	CLICK TO ACCESS		Monitoring & Research
				1994	94043A2	Gumboot Creek Restoration (W. PWS)	Eric Meyers	CLICK TO ACCESS		Restoration
				1994	94043A3	Stream No. 508 Restoration	Eric Meyers	CLICK TO ACCESS		Restoration
				1994	94043A4	Stream No. 509 Restoration	Eric Meyers	CLICK TO ACCESS		Restoration
				1994	94043A5	Otter Creek/Lake Restoration (Knight I.)	Eric Meyers	CLICK TO ACCESS		Restoration
				1994	94043A6	Miners Creek/Lake Restoration (N. PWS)	Eric Meyers	CLICK TO ACCESS		Restoration
				1994	94043A7	Shrode Creek/Lake Instream Restoration	Eric Meyers	CLICK TO ACCESS		Restoration
				1994	94043A7	Shrode Creek Bypass Instream Restoration	Eric Meyers	CLICK TO ACCESS		Restoration
				1994	94043B1	Sockeye Creek/Lake Restoration (Knight I.)	Eric Meyers	CLICK TO ACCESS		Restoration
				1994	94043B2	Rocky Creek/Bay Restoration (Montague)	Ken Hodges	CLICK TO ACCESS		Restoration
				1994	94139A1	Little Waterfall Creek Restoration (Afognak)	Steven Honnold	CLICK TO ACCESS		Restoration
				1994	9413B1	Otter Creek Bypass Instream Restoration	not available	CLICK TO ACCESS		Restoration
				1995	94139B2	Otter Creek/Shrode Creek Instream Restoration	Robert Olson	CLICK TO ACCESS		Restoration

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary			Project information						
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				1995	95139A1	Salmon Instream Habitat and Stock Restoration - Little Waterfall Barrier Bypass Improvement	Steven Honnold	CLICK TO ACCESS		Restoration
				1995	95139C1	Montague Island Riparian Rehabilitation	Ken Hodges	CLICK TO ACCESS		Restoration
				1995	95139C2	Lowe River Salmon Instream Habitat and Stock Restoration	not available	CLICK TO ACCESS		Restoration
				1995	95505B	Use of aerial photograph, channel-type interpretations to predict habitat availability in small streams	Robert Olson	CLICK TO ACCESS		Monitoring & Research
				1996	96139A2	Spawning Channel Construction Project Port Dick Creek, Lower Cook Inlet	Nick Dudiak	CLICK TO ACCESS		Restoration
				1996	96139C1	Montague Island Riparian Rehabilitation	Ken Hodges	CLICK TO ACCESS		Restoration
				1997	97263	Assessment, Protection and Enhancement of Salmon Streams on Port Graham Corporation Lands	Walter Meganack	CLICK TO ACCESS		Restoration
				1997	95139C1	Wild Salmon Stock Supplementation Workshop	Ken Hodges	CLICK TO ACCESS		Info/Mgmt/Admin
				1998	98263	Assessment, Protection and Enhancement of Salmon Streams in Lower Cook Inlet	Walter Meganack	CLICK TO ACCESS		Restoration
				1998	98139A2	Port Dick Creek Tributary Restoration and Development	Wes Bucher	CLICK TO ACCESS		Restoration
				1999	99263	Assessment, Protection and Enhancement of Salmon Streams in Lower Cook Inlet	John Hall	CLICK TO ACCESS		Restoration
				2000	263	Assessment, Protection and Enhancement of Salmon Streams in Lower Cook Inlet	Walter Meganack	CLICK TO ACCESS		Restoration
				2003	30596	Securing Flow Data for a Lower Kenai Peninsula Salmon Stream	Joel Cooper	CLICK TO ACCESS		Monitoring & Research
Zooplankton	NA	NA	NA	1994	94320H	SEA_Role of Zooplankton in the Prince William Sound Ecosystem	R. Ted Cooney	CLICK TO ACCESS	(b)	Monitoring & Research
				1994	94320N	SEA_Nekton and Plankton Acoustics	Gary Thomas	CLICK TO ACCESS	(b)	Monitoring & Research
				1995	95320H	SEA_Role of Zooplankton in the Prince William Sound Ecosystem	R. Ted Cooney	CLICK TO ACCESS	(b)	Monitoring & Research
				1996	96320H	SEA_Zooplankton in the Prince William Sound Ecosystem	R. Ted Cooney	CLICK TO ACCESS	(b)	Monitoring & Research
				1996	96320N	SEA_Nekton/Plankton Acoustics	PWS Science Center	CLICK TO ACCESS	(b)	Monitoring & Research

Table A-1. Summary of EVOSTC projects for Recovering, Unknown Recovery, and Not Recovered Resources and Services.[1]

	Recovery Summary						Project information			
Resource	Recovery Objective (2002)	Recovery Status (2002)	Restoration Strategy	FY	Project Number	Title	Principal Investigator	Link	Cost[2]	Action Category (1994)
				2002	2617	Standing Stock and Secondary Production of Zooplankton in Prince William Sound	Russell Hopcroft	CLICK TO ACCESS		Monitoring & Research

[1]Project number, title, investigator, and link obtained from EVOSTC database, queried November 1, 2005. See "Introduction" for additional information.
[2]Project cost data compiled from EVOS 2003, *Summary of Restoration Strategies and Projects*, and EVOSTC workplans for FY2003, FY2004, FY2005-2007. Costs are not provided for projects not included in these reports. Some project costs are totals for

(a) APEX project total (1992 - 2002) = $10,841,200
(b) SEA project total (1992 - 2002) = $22,011,100

APPENDIX B

RESOURCE EVALUATION FRAMEWORK

APPENDIX B
RESOURCE EVALUATION FRAMEWORK

The recovery objectives established in the restoration plans and subsequent updates of 1994, 1999, and 2002 are most often expressed as assessment goals based on higher-level scientific principles of population and community ecology and environmental health. Restoration strategies are intended to generate the actual measurements that can be used to directly support progress toward these higher-level goals and facilitate judgments concerning recovery from injury caused by *Exxon Valdez* oil (EVO). However, such judgments have proved difficult or inconclusive in many cases because the relationship between the injury of a resource and its recovery is often obscured or overwhelmed by inherent ecological variability.

Five recovery categories were developed, each with quantitative measures or metrics that can provide additional perspective in describing the status of resource injury and framing progress towards higher level recovery objectives or milestones. The supplemental recovery metric categories are as follows:

- **Population characteristics—**The functional and structural characteristics of injured populations or communities consist of those characteristics that can be used to understand their growth, natural variability, and expected role in the Prince William Sound (PWS) ecosystem. Important functional components include birth and survivorship rates, which determine growth rates of populations. For example, whales are a long-lived and slowly reproducing species that will respond slowly to population disturbance over several decades. Structural population characteristics concern the extent and form of populations, whether they are continuous or divided, how they are connected through migrations, and their age structures.

- **Physical and chemical factors**—The physical nature and extent of EVO and lingering oil in relation to affected populations and important life history traits will be important in evaluating continuing injury and recovery. Evaluation of physical and chemical factors will focus on the exposure pathways and habitat conditions that are important to resource populations and communities and which can be practically used to determine whether they remain altered as a direct or indirect consequence of EVO or lingering oil.

- **Temporal factors—**Approximately 17 years have passed since the original spill. At the time of the 1994 restoration plan, it was expected that some resources would take several decades to recover. This expectation is within the time frame established for other major spills over the past 40 years. Consequently, the time frame for population growth or community succession following disturbance by EVO is important in scaling expectations for recovery.

- **Spatial factors—**The area over which lingering oil continues to affect injured resources will be expressed in relation to the distribution of resource populations in PWS and affected areas outside of the sound. For lingering oil, this will likely entail a determination of its predicted extent in relation to the presence of important habitat and corresponding injured populations. For sediments, an assessment of both the physical habitat provided and the extent to which injured resource populations are dependent on this habitat will be required. Where possible, the potentially patchy distribution of both lingering oil and injured populations will be identified and expressed using probabilities to provide perspective on co-occurrence of widely dispersed but discrete patches of EVO and exposed populations.

- **Physiological/behavioral metrics—**Physiological or behavioral metrics may be altered in response to an oil spill or other stressor, and be reflected in alterations in the general condition of the resource (e.g., changes in enzyme activity, or changes to activity-time budgets), which may be related to population-level effects.

Metrics within these five supplemental recovery categories were used to assess injury status and recovery. These metrics will principally focus on population or habitat viability and will provide a practical foundation for developing refined recovery objectives and strategies and a structured decision framework to evaluate recovery status.

RESOURCE EVALUATION FRAMEWORK

A key challenge and a chief objective of this work effort is the critical evaluation of the recovery status of recovering and unrecovered resources. The evaluation of current recovery status is complicated because the relationship between injury and recovery is often obscured or overwhelmed by inherent ecological variability. Drawing upon supplemental recovery categories discussed above, a structured framework for assessing the recovery status of resource populations within the construct of recommended recovery objective alternatives was developed.[1]

The recovery status of a resource population is determined by the magnitude of the initial impact of the spill, the population’s intrinsic recovery potential, time since the spill, the magnitude of any continuing effects, and effects of other natural and anthropogenic stresses. Because the status of a population at any given time depends on a variety of life history traits, a simple measure of population abundance at any one time may not be a reliable indicator of future population viability. Population viability is a key measure of recovery status because it indicates the ability of the population to persist within a range of acceptable abundance levels in the future. Therefore, the evaluation of recovery status should be based on those life history traits, spatial–temporal factors, physical–chemical characteristics, and other outside stresses that most heavily influence population viability.

Recovery Metrics

The evaluation of the recovery status of resource populations draws upon qualitative and quantitative information about intrinsic population variables (e.g., abundance and

[1] The framework addresses biological resources and the population-level characteristics that may be integrated into the critical evaluation of recovery status. The evaluation of recovery for sediments and designated wilderness areas is addressed in part on the basis of habitat considerations for resource populations. Evaluation of services is based upon the recovery status evaluations for biological resources.

reproductive measures) as well as extrinsic factors (e.g., habitat, harvesting) that determine population viability and attendant recovery status (Figure B-1). Collectively, these variables are referred to herein as *recovery metrics*.

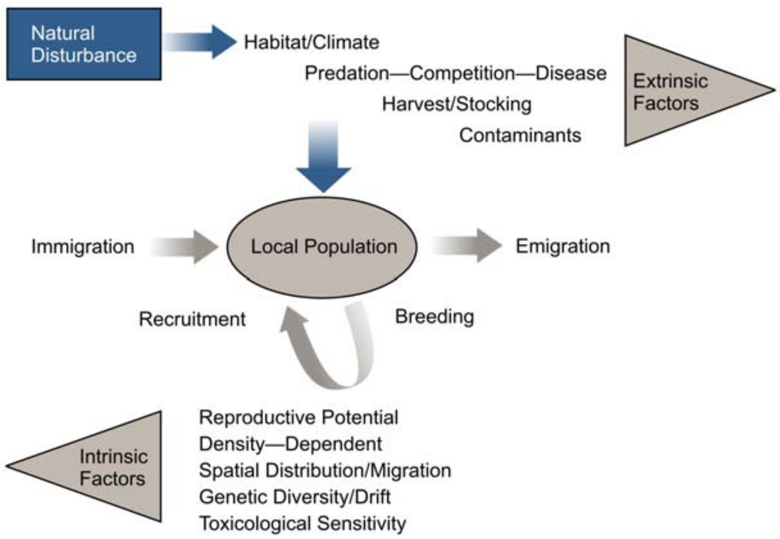

Figure B-1. Factors Affecting Resource Populations

Decision Framework

A decision framework was constructed to provide a consistent and systematic evaluation process that can be applied to all resources. The decision framework integrates both qualitative and quantitative information on multiple recovery metrics that pertain to population status.

The decision framework was applied to biological resources, and incorporates recovery metrics from the following categories:

- **Abundance and population growth—**The viability of a population, or conversely its risk of decline to undesirably low levels, depends on its abundance and productivity. Life history characteristics and food web interactions combine to determine the potential viability of a population in a given habitat.
- **Genetic and phenotypic diversity—**Small populations may be at risk for loss of genetic diversity (Nelson and Soule1987). High genetic diversity maximizes population persistence and productivity by allowing the population to use a wide range of habitats and environmental conditions (NRC 1996; McElhany et al. 2000). Genetic diversity also protects populations against climatic disturbances.
- **Spatial–temporal structure of populations—**The evaluation of population spatial structure includes consideration of the amount of habitat available, the spatial

organization and connectivity of habitat patches, and the overlap of the original spill and lingering oil with the population distribution. Temporal issues mainly relate to the amount of time since the spill in relation to generation time of a population, as well as seasonal migration behavior relative to the potential for release of lingering oil.

- **Habitat: Physical–chemical factors—**Habitat quality and extent clearly affect the recovery status of populations. In addition to spatial-temporal issues considered earlier from the standpoint of basic population ecology, the potential effects of lingering oil must be considered.
- **Confounding environmental factors—**Non-EVO-related stressors or natural disturbances may affect population recovery status.

The decision framework was developed in consultation with technical experts. The overview of the evaluation framework illustrates how population and exposure data are integrated with community and habitat data to arrive at a resource classification (Figure B-2). The population analysis (Figure B-3) integrates information on population characteristics, physiological/behavioral metrics, and habitat metrics and compares the resource condition to baseline, considering reference location data and the potential impacts of other stressors, to determine if there are significant effects expressed in the condition of the populations that can be attributed to the spill. The exposure analysis (Figure B-4) considers spatial–temporal data and bioaccessibility to determine if there is a complete exposure pathway. Biomarker measures and bioaccumulation data are factored into the analysis as measures of exposure. The causal analysis for nonrecovered populations (Figure B-5) attempts to assess the inherent ability of the population to recovery (e.g., through consideration of life history characteristics, exposure, and population modeling) to determine if sufficient time has passed for the population to recover, and if the effects of other stressors had a role in population trends.

RESOURCE EVALUATION MATRICES

In practice, information on a given resource is often limited. Resource evaluation matrices were developed for the different resources using the recovery metrics described above. Resource-specific evaluation matrices were modified, refined, and populated by experts in a series of meetings in 2005 and 2006. These resource-specific matrices, which are based on information from existing scientific studies as well as best professional judgment, are provided as Appendix C.

The experts participating in these evaluations and the topic or category they addressed are as follows:

Topic	Expert and Affiliation
Lingering Oil	Dr. Jeffrey Short , NOAA Dr. Stanley Rice, NOAA Damian Preziosi, Integral
Seabirds and Sea Ducks	Dr. Dan Rosenberg, ADFG Dr. Dan Esler, Simon Fraser University Dr. David Irons, USFWS Kathy Kuletz, USFWS
Fish	Dr. Stanley Rice, NOAA Dr. David Bernard, ADFG
Sea Mammals	James Bodkin, USGS Dr. Brenda Ballachey, USGS Craig Matkin, North Gulf Oceanic Society Robert Small, ADFG
Intertidal and Subtidal Communities	Dr. Thomas Dean, Coastal Resources Associates, Inc. Dr. Robert Spies, Applied Marine Science Dr. Al Springer, University of Alaska
Ecosystems	Dr. Al Springer, University of Alaska Dr. Robert Pastorok, Integral Dr Robert Spies, Applied Marine Sciences
Biomarkers	Dr. Brenda Ballachey, USGS Dr. Dan Esler, Simon Fraser University James Bodkin, USGS
Services	Dr. Jim Fall, ADFG Dr. Dave Bernard, ADFG Norman Meade, NOAA

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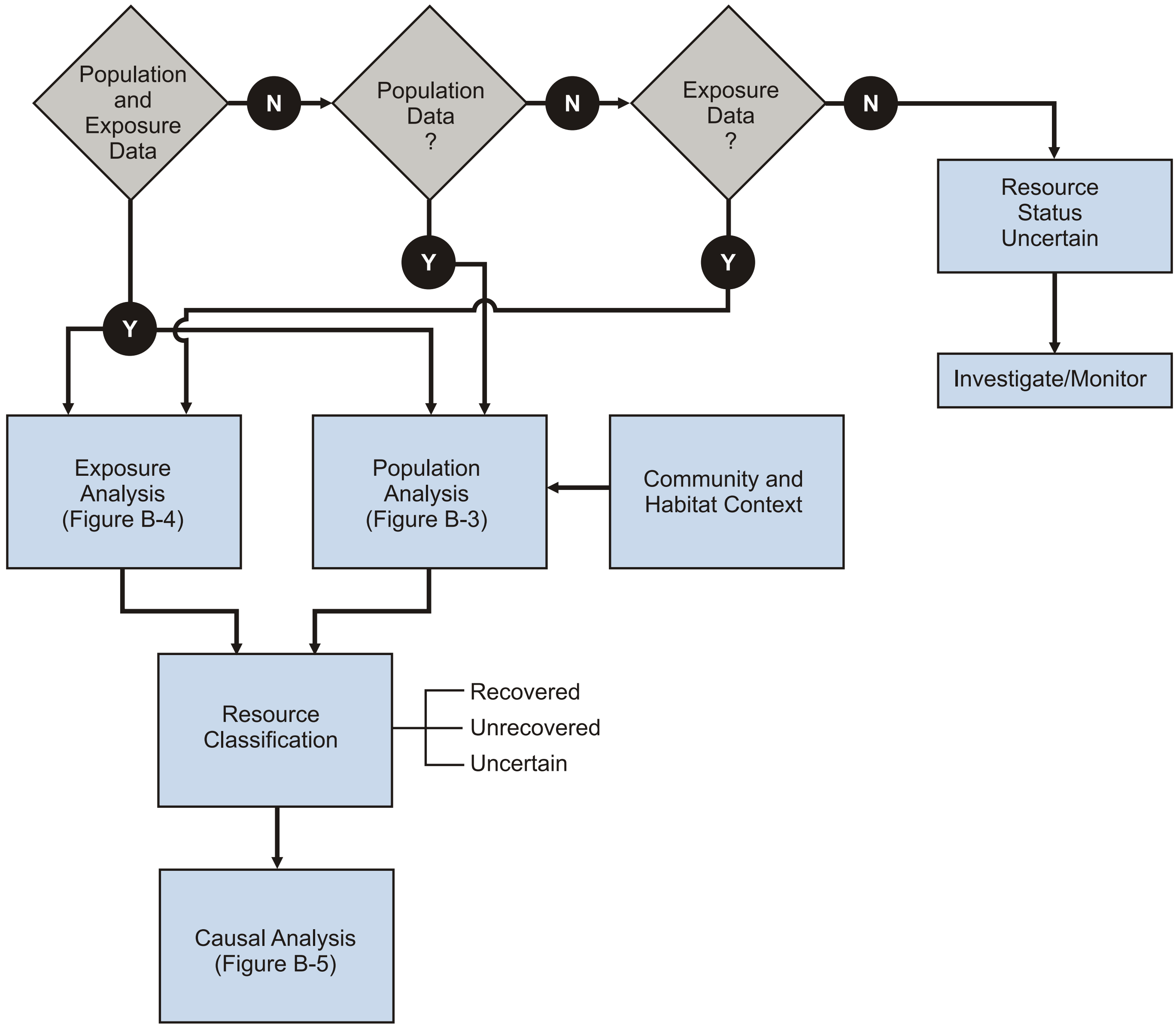


Figure B-2. Overview of Evaluation of Resource Recovery Status for Population-Level Analysis

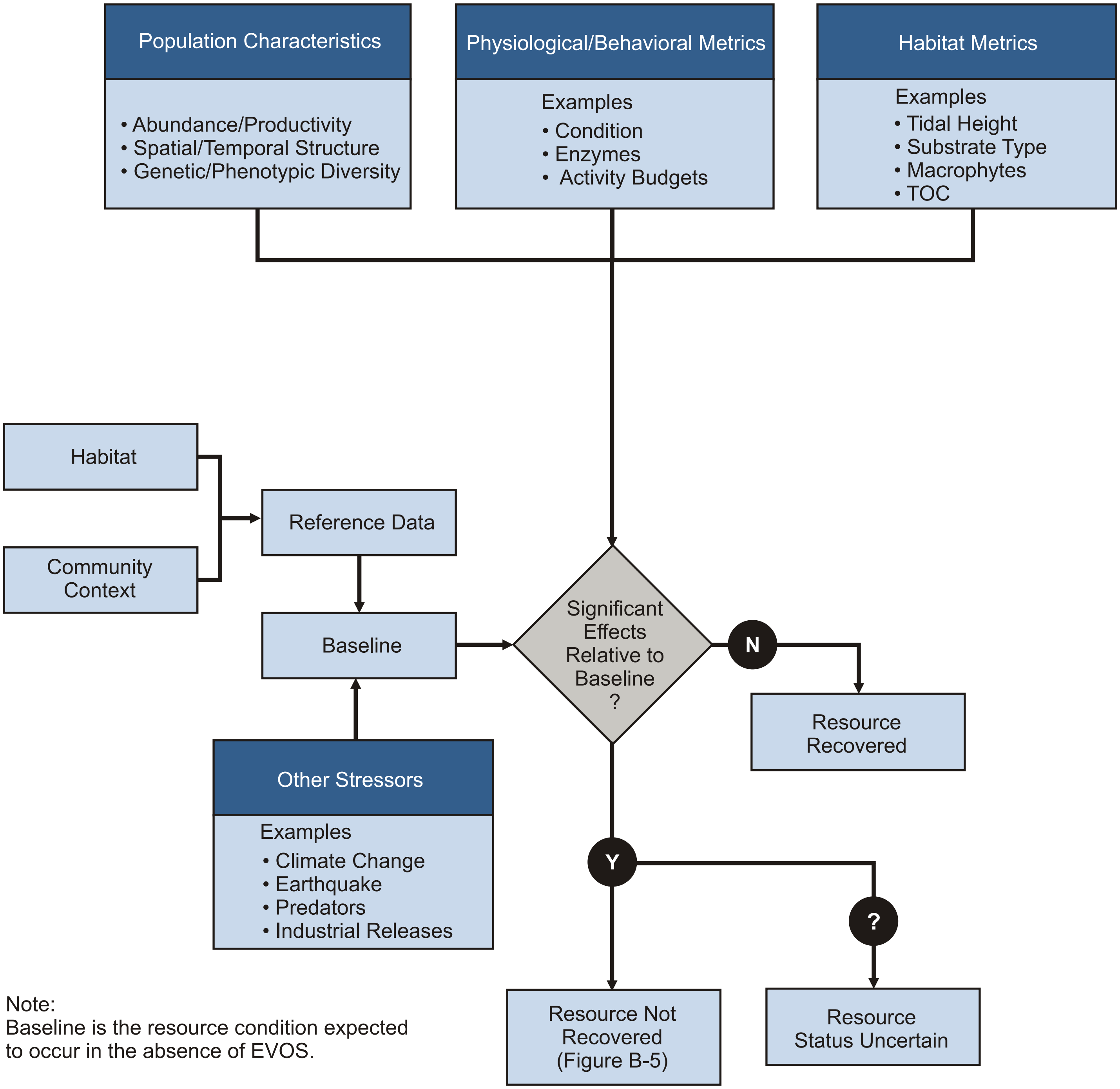
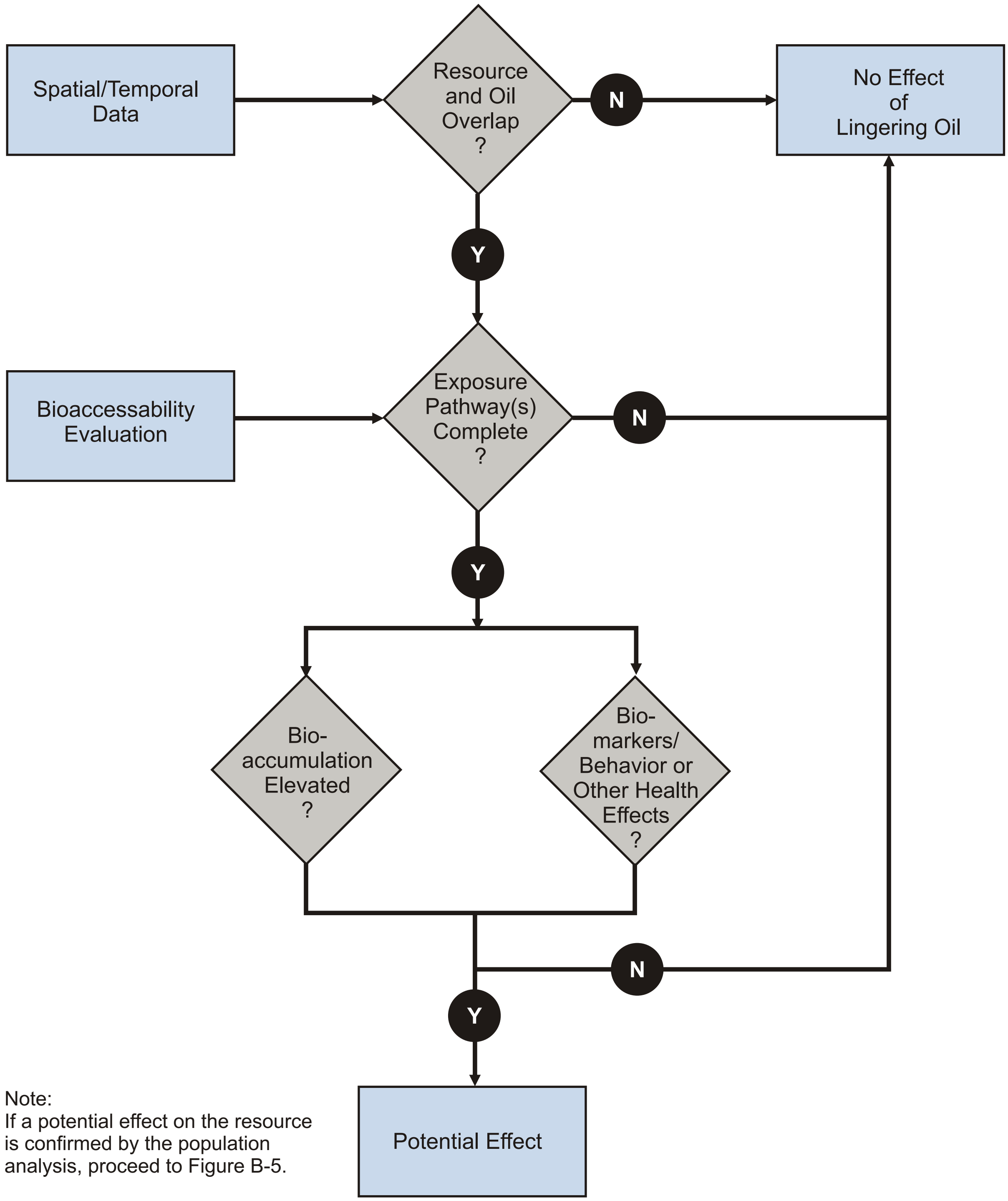


Figure B-3. Population Analysis



Note:
If a potential effect on the resource is confirmed by the population analysis, proceed to Figure B-5.

Figure B-4. Exposure Analysis

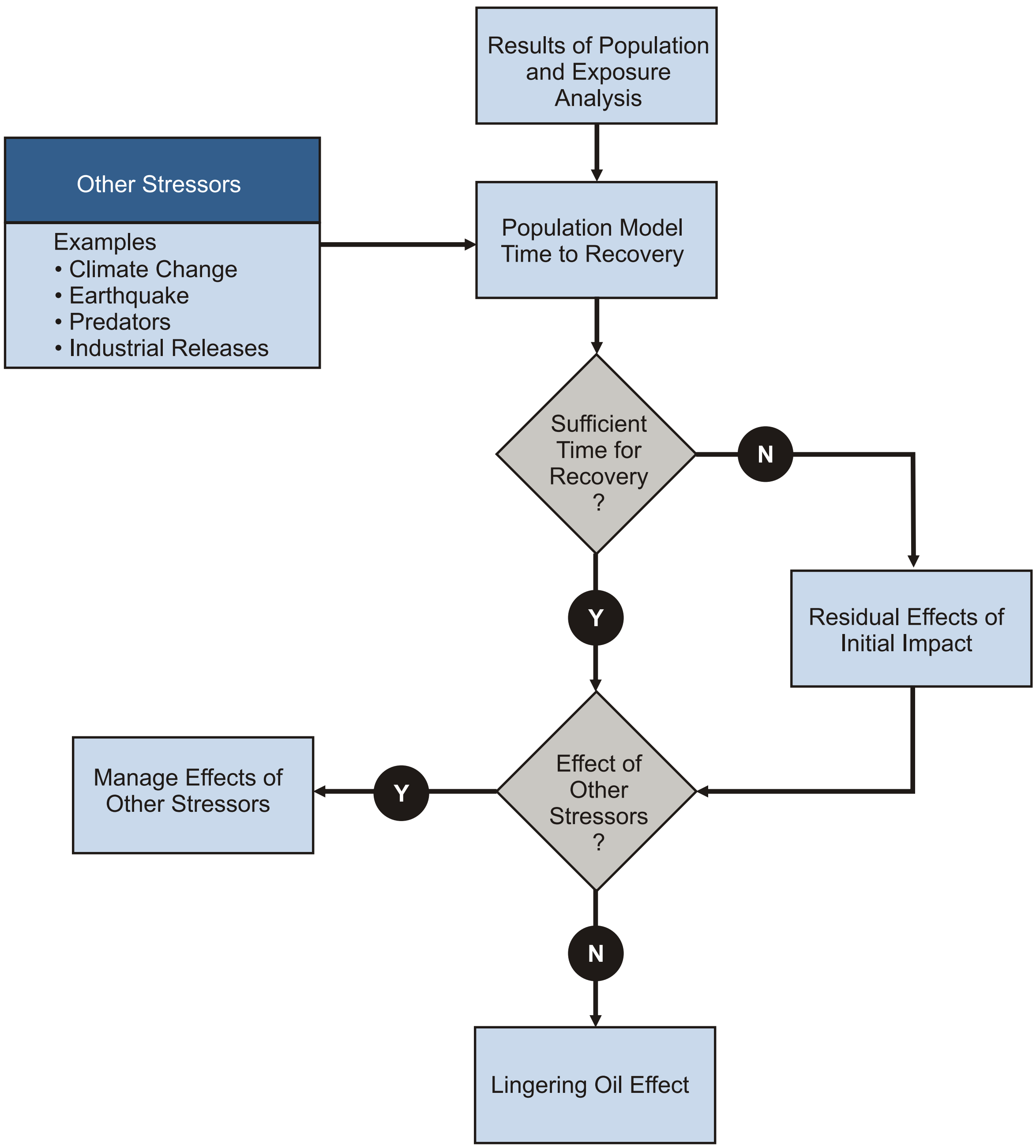


Figure B-5. Causal Analysis for Nonrecovered Populations

APPENDIX C

RESOURCE EVALUATION MATRICES

—INTERTIDAL COMMUNITY
—CLAMS
—MUSSELS
—HARLEQUIN DUCK
—PIGEON GUILLEMOT
—MARBLED MURRELET
—KITTLITZ'S MURRELET
—CORMORANTS
—COMMON LOON
—PACIFIC HERRING
—ROCKFISH
—CUTTHROAT TROUT
—SEA OTTER
—HARBOR SEAL
—KILLER WHALE AB POD
—KILLER WHALE AT1 POD

Intertidal Community (Section 5)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypothesis, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual Effetcs	Lingering Oil Effects	Other (Non EVO)	
Benthic Habitat	How much habitat is available in PWS?	S, T	1,600 km shoreline (1)	NA	NA	NA	Varied and extensive rocky and mixed substrate exist throughout the spill area.
	Is the intertidal habitat and community patchy?	B, S	Yes (1)	NA	NA	NA	
	Are the quantity and quality of the intertidal habitat different between areas disturbed by EVO or its treatment and non-oiled or reference areas now?	S	Yes (3)	Residual oiling and treatment effects (4)	Lingering oil present (2)	Other habitat quality factors (1)	
	Are the quantity and quality of the intertidal habitat in oiled areas different now in comparison with conditions that existed before disturbance created by EVO or its treatment?	S, T	Yes (3)	Residual oiling and treatment effects (4)	Lingering oil effects (4)	Changing habitat quality factors (1)	
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	<1% (1)	Residual oiling and treatment effects (4)	Lingering oil present (2)	NA	
Benthic Community Abundance, Richness, and Diversity	What percentage of the community was eliminated in the original EVOS?	B, S	<1% (4)	NA	NA	NA	
	Is abundance, richness, or diversity significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	No (2)	None (2)	None (2)	None (2)	
	Are any reduced community parameters limited to a geographic area that is a subset of the initial EVOS area?	B, S	No (2)	None (2)	None (2)	None (2)	
	Are community parameters in oiled areas different from those expected in a natural population?	B, S	No (2)	None (2)	None (2)	None (2)	
	Is inter-annual variability of community parameters different from the expected range of variation for natural populations?	B, T	No (2)	None (2)	None (2)	None (2)	
	Is the trend in community structure (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	No (2)	None (2)	None (2)	None (2)	
Indicator Species and Populations	Are current abundances and distributions of important keystone or foundation species (e.g., *Fucus*) significantly reduced in oiled areas in comparison with reference areas or pre-spill levels?	B, S	No (2)	None (2)	None (2)	None (2)	
	Are differences in keystone or foundation species limited to a geographic area that is a subset of the initial spill area?	B, S	No (2)	None (2)	None (2)	None (2)	
	Are abundances and distributions of keystone or foundational species in oiled areas different from those expected in a natural population?	B, S	No (2)	None (2)	None (2)	None (2)	

Intertidal Community (Section 5)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypothesis, and relevant assessment scales.

				Stressors and Effects[c]			
Recovery Metrics	**Injury Questions/Hypotheses**	**Assessment Scales[a]**	**Assessment Result[b]**	**Residual Effetcs**	**Lingering Oil Effects**	**Other (Non EVO)**	**Comments**
	Is inter-annual variability in keystone or foundational species different from the expected range of variation for natural populations?	B, S, T	No (2)	None (2)	None (2)	None (2)	
	Is the trend (increasing, decreasing, or stable) in affected keystone or foundation species in oiled areas different from that in unoiled areas?	B, S, T	No (2)	None (2)	None (2)	None (2)	
Community Succession	Is the time needed for recovery large relative to time since EVOS?	B, T	No (2)	None (2)	None (2)	None (2)	
Exposure	What percentage of the community's habitat has lingering oil?	S, T	<1% (1)	NA	<1%	None (1)	
	Is lingering oil bioaccessible?	C, S	Yes (1)	NA	Lingering oil in benthos (1)	Unknown	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	Yes (1)	NA	Lingering oil in benthos (1)	Unknown	
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	Yes (1)	NA	Lingering oil in benthos (1)	Unknown	
Other Structural/Functional Indicators	Are there other structural or functional indices that currently show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Yes (3)	Residual oiling and treatment effects (3)	None (3)	Other factors affecting indices (3)	
	Can observed effects on other structural or functional indices be interpreted in the context of community-level effects?	B, S	No (4)	Unknown	Unknown	Unknown	

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:

Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:

(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Clams (Section 7)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	1,600 km shoreline (2)	NA	NA	NA	Extensive coarse mixed sand gravel beaches throughout he spill area.
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S	Yes (1)	None (1)	Lingering oil present (1)	Unknown	Quality of the habitat is compromised in a small percentage of the range based on presence of lingering oil.
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S, T	Quantity: no (3). Quality: yes (3).	Residual cleanup effects (3)	None (3)	Unknown	Differences in quality as measured by grain size possible (Lees and Driskell 2005: confidence pending critical review).
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	Residual cleanup: unknown. Lingering oil: <1% (1).	Residual cleanup effects (3)	Lingering oil in some habitat (1)	NA	Residual cleanup effects possible as oiled-and-treated beaches may have altered grain sizes (pending review).
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	No (4)	Unknown	Unknown	Unknown	No direct studies of plankton. Effects unlikely to be measurable and probably unlikely today.
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	Yes (3)	Residual cleanup effects (3)	None (3)	NA	Increased size and abundance at Knight Island suggests trophic interaction.
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	Yes (3)	Residual cleanup effects (3)	None (3)	Variable hydrodynamic settings (3)	Spatial extent unknown because data cannot be extrapolated beyond study area. Effects may be related to hydrodynamic settings.
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	Yes (4)	Residual cleanup effects (4)	Lingering oil in some habitat (4)	Unknown	Reduced populations are on oiled-and-treated beaches. Study only sampled from known oiled beaches.
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S	Unknown	Unknown	Unknown	Unknown	Growth, reproduction, and mortality were not studied.
	Is inter-annual variability of each key population measure (e.g., average abundance; average fecundity) different from the expected range of variation for natural populations?	B, T	Unknown	Unknown	Unknown	Unknown	
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	Yes(2)	Residual cleanup effects (2)	None (2)	Non-EVOS population factors	Populations are increasing in oiled areas.
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	90% (2)	NA	NA	NA	90% of clams were killed on treated beaches.
	Did the population reach a critical small size that could lead to decreased phenotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	Clam populations recruit from plankton.
	Did the population reach a critical small size that could lead to decreased genotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	Clam populations recruit from plankton.
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (2)	None (2)	None (2)	None (2)	Clam populations recruit from plankton.

Clams (Section 7)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Population Structure	Is the population and habitat patchy or continuous?	B, S	Patchy (1)	NA	NA	NA	Populations are dependant on habitat availability and quality.
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	Yes (1)	Residual cleanup effects (1)	None (1)	None (1)	Clams may live 15 (littleneck) to 20 (butter clams) years.
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	No (1)	NA	None (1)	None (1)	Clams are relatively sedentary.
Exposure	What percentage of the population's habitat has lingering oil?	S, T	< 1% (1)	NA	Lingering oil in < 1% of habitat (1)	None (1)	
	Is lingering oil bioaccessible?	C, S	Yes (1)	NA	Lingering oil in < 1% of habitat (1)	NA	Clams are burrowers (SPMD).
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	Yes (1)	NA	Lingering oil in < 1% of habitat (1)	NA	Known from transplant studies and SPMD. No known physical effects.
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	Yes (2)	Unknown	Lingering oil leading to bioaccumulation (2)	Unknown	Bioaccumulation and SPMDS results are forthcoming (Rice pers. comm., Springman in press).
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Yes (2)	Unknown	Evidence of lingering oil in Comet assays (2)	Unknown	From Rice pers. comm.
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	Not studied.
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, S	Unknown	Unknown	Unknown	Unknown	Not studied.

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:
Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:
(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Mussels (Section 8)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	1,600 km shoreline (1)	NA	NA	NA	Extensive rocky and mixed substrate throughout the spill area.
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S	No (1)	None (1)	None (1)	None (1)	Mussel habitat is clean and essentially the same in oiled and unoiled areas.
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S,T	No (1)	None (1)	None (1)	None (1)	
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S,T	0% (1)	None (1)	None (1)	NA	
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S,T	Unknown	Unknown	Unknown	Unknown	No direct studies of plankton. Effects unlikely to be measurable and probably unlikely today.
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	Unknown	Unknown	Unknown	Unknown	Not studied.
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	Unknown	Unknown	Unknown	Unknown	Not studied.
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	Unknown.	Unknown	Unknown	Unknown	Not studied.
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S	Unknown	Unknown	Unknown	Unknown	Growth, reproduction, mortality were not studied.
	Is inter-annual variability of each key population measure (e.g., average abundance; average fecundity) different from the expected range of variation for natural populations?	B, T	Unknown	Unknown	Unknown	Unknown	Not studied.
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	Unknown	Unknown	Unknown	Unknown	Not studied.
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	Unknown	Unknown	Unknown	Unknown	Not studied.
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	Unknown	Unknown	Unknown	Unknown	Not studied.
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	Unknown	Unknown	Unknown	Unknown	Not studied.
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	Unknown	Unknown	Unknown	Unknown	Not studied.
Population Structure	Are the population and habitat patchy or continuous?	B, S	Patchy (1)	NA	NA	NA	Populations are dependant on habitat availability and quality.

Mussels (Section 8)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	Yes (2)	Residual population effects (2)	None (2)	Inherent reproductive potential (2)	Recovery time is long if one considers age and size structure. Mussels may live 9 years in PWS.
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	No (1)	None (1)	None (1)	None (1)	Mussels are sedentary.
Exposure	What percentage of the population's habitat has lingering oil?	S, T	0% (1)	NA	None (1)	None (1)	Lingering oil is not on the surface substrate that can be occupied by mussels.
	Is lingering oil bioaccessible?	C, S	No (1)	NA	None (1)	None (1)	Mussels are surface dwellers on primarily hard substrate.
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	No (1)	NA	None (1)	None (1)	Exposure in 2005 is not sufficient to result in measurable amounts.
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	No (2)	None (2)	None (2)	None (2)	Comet assays in 2002 (Rice pers. comm.) near lower detection limits and presumably not detectable in 2005.
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	No (2)	NA	No (2)	NA	Comet assays in 2002 (Rice pers. comm.) at limit of detection and presumably not detectable in 2005.
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	Not studied.
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, S	Unknown	Unknown	Unknown	Unknown	Not studied.

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:

Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:

(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Harlequin Duck (Section 9)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]: Residual EVO	Stressors and Effects[c]: Lingering Oil Effects	Stressors and Effects[c]: Other (Non EVO)	Comments
Habitat	How much habitat is available in PWS?	S	~3,500 km shoreline (2)	NA	NA	NA	
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S (PWS)	Yes (2)	Sediment alteration (3)	Lingering oil contamination (1)	Natural geographic differences (1)	Decrease in habitat quality primarily from contamination; some natural geographic differences exist (Esler pers. comm.).
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S (PWS)	Yes (2)	Sediment alteration (3)	Contamination of food and presence of lingering oil (1)	Human disturbances (3)	Lingering oil is issue (Short pers. comm.). Evidence of food contamination as measured by P450 found in Trust et al. (2000).
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	<1% (3)	Unknown	Lingering oil in <1% of habitat (3)	NA	Unknown extent of habitat affected by cleanup. Best estimate of lingering oil was based on Short et al. (inferences limited to heavily oiled beaches), but is inconsistent with 2005 P450 data showing widespread exposure.
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	Yes (1)	Acute residual effects (1)	Lingering oil contaminates food (2)	Other factors affect food (3)	Acute residual effects had recovered by mid-1990's.
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	Yes (1)	Acute residual effects (1)	None (2)	None (3)	Acute residual effects had recovered by mid-1990's. See early intertidal studies.
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?**	B, S, T	Yes (4)	Unknown	Unknown	Unknown	Population reduction is unknown, but likely given acute and chronic mortality in concert with demonstrated characteristics of harlequin duck. No pre-spill data exist, especially for winter populations. We need population modeling to address relative effects of acute vs. chronic mortality on populations.
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	Unknown	Unknown	Unknown	Unknown	Data not analyzed at relevant scales.
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S, T	Yes (1)	Residual population effects (1)	Lingering oil population effects (1)	Intrinsic habitat differences (4)	Age ratios (recruitment), sex ratios, female survival, and dispersal were affected in oiled areas. Initial acute mortality has residual impacts. Female survival was reduced through 2000. Correlation was found between increased levels of P450 and lower survival rates from 2000-2002 (Esler pers. comm.).
	Is inter-annual variability of each key population measure (e.g., average abundance; average fecundity) different from the expected range of variation for natural populations?	B, S, T	No (1)	Unknown	None (1)	None (2)	Measured variability in female survival, abundance, sex ratios, recruitment all seem to be within normal ranges.
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	Yes (1)	Residual decreases in oiled vs. stable unoiled areas (1)	None (1)	None (3)	Through 1997 decreased populations in oiled areas, stable in unoiled areas. No difference since 1997 but no increase in oiled area populations (i.e., no evidence of recovery). Population depressed by EVOS and maintained by lingering oil (FWS marine bird surveys and Rosenberg surveys). There is no evidence of long term changes in PWS in general.
Genetic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	7% (3)	NA	NA	NA	We have low confidence in the mortality estimate but no doubt on mortality. A much higher percentage was killed in oiled area. Of 14,000 in PWS and oiled area, approximately 25-28% of birds in oiled area were killed.
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	PWS population not genetically distinct (Lanctot et al.)
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	PWS population not genetically distinct (Lanctot et al.)
	Are there genetic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (2)	None (2)	None (2)	None (2)	PWS population not genetically distinct (Lanctot et al.)
Population Structure	Is the population and habitat patchy or continuous?	S (PWS)	Patchy (2)	NA	NA	NA	Natural variation in habitat attributes and suitability
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	Yes (2)	Residual population effects (2)	Lingering oil population effects (2)	Low inherent reproductive potential (3)	Recovery time from initial effects is expected to be slow due to life history and dispersal characteristics. Lingering oil effects are additive to initial spill mortality. Intrinsic life history and dispersal attributes suggest low rates of demographic rescue. We need population modeling to address relative effects of acute vs. chronic mortality on populations.
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	Yes (1)	Residual effects on movement (3)	Increased exposure to lingering oil due to movement to PWS (3)	Natural migration patterns (1)	Seasonal dispersal within PWS and immigration occurs. Natural movement patterns (seasonal, episodic) could lead to some birds moving to and from areas of exposure, but overall exchange rate is low.

Harlequin Duck (Section 9)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Exposure	What percentage of the population's habitat has lingering oil?	S, T	<1% (3)	NA	Lingering oil in <1 % of habitat (3)	Unknown	See caveats above.
	Is lingering oil bioaccessible?	C, S	Yes (1)	NA	Lingering oil is bioavailable (1)	Unknown	See Short et al.
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	Yes (1)	NA	Lingering oil is capable of causing physical effects (1)	Unknown	See Trust et al.
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	Yes (1)	Unknown	Lingering oil exposure is evident through P450 biomarkers (1)	Other anthropogenic P450 induces (4)	See Trust 2000 and Ballachey NVP Report and pers. comm.
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	No field data were collected. ASLC studies performed lab experiments indicating potential mechanistic reactions to external oiling primarily (not ingested oil). Inference to wild populations is uncertain. See Rizzolo thesis, NVP report.
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	No field data were collected. ASLC studies performed lab experiments indicating potential mechanistic reactions to external oiling primarily (not ingested oil). Inference to wild populations is uncertain. See Rizzolo thesis, NVP report.
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, T	Unknown	Unknown	Unknown	Unknown	No field data were collected. ASLC studies performed lab experiments indicating potential mechanistic reactions to external oiling primarily (not ingested oil). Inference to wild populations is uncertain. See Rizzolo thesis, NVP report.

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors than may affect them. Examples include:
Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:
(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Pigeon Guillemot (Section 9)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	~4,000 km shoreline	NA	NA	NA	
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S	Some	Residual prey effects at some sites (3)	Lingering oil in some habitats (1)	Inherent differences between western and eastern PWS (2)	Western side of PWS more oiled than eastern side. Naturalifferences exist in forests and shorelines between oiled and unoiled sites.
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S	Yes, at small scales (2)	Residual prey effects (3)	Lingering oil on subtidal sandy beaches (1)	Increased boat traffic in oiled areas (1)	Residual effects may exist from loss of sand lance and juvenile herring. See Murphy et al. 2004 for information about increased boat traffic in western PWS.
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	~1 percent (2)	Residual EVOS/cleanup activities (2)	Lingering oil in some habitats (1)	NA	
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	Yes (2)	Residual effects from initial prey losses (1) and herring crash (3)	Lingering oil prey effects (3)	Non-EVOS factors contributing to herring crash (3.5)	EVOS immediately negatively affected herring and probably sand lance. In 1993, the herring population crashed and has not recovered; the cause of this crash is unknown. If EVOS contributed to it, then important pigeon guillemot prey could have been negatively affected for several years and may still be experiencing both residual and lingering oil effects.
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	Unknown	Residual food chain effects (4)	Lingering oil food chain effects (4)	Climate change (3)	How EVOS affected structural and trophic relationships for pigeon guillemots is largely unknown.
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?**	B, S, T	Yes relative to prespill and control site (1); no for oiled vs. unoiled post-spill (1)	Residual prey effects (2)	Unknown	Climate change (2)	Irons et al. 2000 found differences in populations compared to prespill and control sites. Sullivan et al. 2005 found that there were no differences in population trends between oiled and unoiled sites post-spill. Guillemot populations were likely declining before the spill, possibly due to climate change (Oakley and Kuletz 1996).
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	Unknown	Unknown	Unknown	Unknown	Data were not analyzed at the subset scale.
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S, T	Population and productivity lower in oiled vs. unoiled areas through mid 1990s (1). Current parameters are unknown	Residual effects for several years after the spill (2)	Lingering oil for several years after the spill (2)	Higher predation rates following spill (4)	See Irons et al. 2000 and Golet et al. 2002 for population parameters. Higher predation rates following spill may or may not be related to EVOS.
	Is inter-annual variability of each key population measure (e.g., average abundance; average fecundity) different from the expected range of variation for natural populations?	S, B, T	No (2)	Unknown	Unknown	Unknown	Variability wasot calculated, but differences are unlikely.
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	Yes relative to prespill and control site (1); No for oiled vs. unoiled post-spill (1)	Residual effects for several years after the spill (2)	Lingering oil for several years after the spill (2)	Climate change and other stressors (3)	Irons et al. 2000 found differences in populations compared to prespill and control sites. Sullivan et al. 2005 found that there were no differences in population trends between oiled and unoiled sites post-spill. These similar trends may have been caused by non EVO effects.
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	< 10 % of the PWS population	NA	NA	NA	Estimate: need to confirm.
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (2)	None (2)	None (2)	None (2)	
Population Structure	Is the population and habitat patchy or continuous?	B, S	Population is continuous, habitat is patchy (2)	NA	NA	NA	
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	Yes (2)	Unknown	Unknown	Low inherent reproductive potential (2)	Pigeon guillemots live 20 years or more and have delayed maturation and low reproductive potential.
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	Yes (2)	NA	Lingering oil in some summer breeding and foraging habitat (2)	Variable conditions in wintering areas (3)	Pigeon guillemots migrate to PWS in the spring to breed and forage nearshore (2). Conditions in wintering areas might affect length of time spent foraging in near-shore areas during the summer.
Exposure	What percentage of the population's habitat has lingering oil?	S, T	<1 %in PWS (2)	NA	Lingering EVO in <1% habitat (2)	Unknown	
	Is lingering oil bioaccessible?	C, S	Yes (2)	NA	Lingering oil in benthos (2)	Unknown	

Pigeon Guillemot (Section 9)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	Yes (2)	NA	Exposure to lingering oil through bethic invertebrate prey (2)	Unknown	
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	Yes (1)	Elevated CYP1A levels in 1999 (1)	None in 2004 in some areas (1)	None (1)	Elevated CYP1A levels were present in birds in oiled areas in 1999. In 2004, there was no evidence of exposure in light-moderately oiled areas (i.e., Naked Island), but no data exist from heavily oiled areas. Studies have shown that oil injested by birds likely came from EVO.
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	No (4)	None (4)	None (4)	None(4)	None identified
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, T	Unknown	Unknown	Unknown	Unknown	No field data collected.

Note: Assessment addresses summer breeding populations of pigeon guillemost in PWS only.

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:
Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:
(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Marbled Murrelet (Section 10)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	~4,000 km shoreline	NA	NA	NA	Marbled murrelets mainly use waters up to ~60 m in depth, though ~25 percent may be in deeper offshore waters.
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S	Yes (1)	Residual prey effects (3)	Lingering oil in some habitats (2)	Inherent spatial differences between oiled and unoiled habitats (1)	Western PWS is more oiled than eastern PWS. There are pre-existing differences in oiled and unoiled habitats
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S	Yes, at small scales (2)	Loss of sand lance and juvenile herring (3)	Oiled subtidal sandy beaches (1)	Increased boat traffic in west (oiled) side of PWS (1)	
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	Standard is ~ 1% in heavily oiled sites (2)	Residual effects from EVOS/cleanup at some sites (2)	Lingering oil in some habitats (1)	NA	
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	Yes (1)	Residual prey effects (2)	Lingering oil effects on juvenile fish (3)	Climate change (2)	EVOS affected herring and other forage fish, and may have stressed adults (see Kuletz 2005). Climate change may affect fish recruitment.
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	Unknown (4)	Residual food chain effects (4)	Lingering oil food chain effects (4)	Unknown	Largely unknown
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	Yes, relative to pre-spill (1). No, for oiled vs. unoiled (1).	Residual population loss compared to pre-spill (1)	Lingering oil effects compared to pre-spill (1)	Populations down throughout PWS (1) and elsewhere (2).	Forage range and nest distribution of marbled murrelet make this question irrelevant. PWS populations may have greater rate of decline than elsewhere (Kuletz 2005 appendix)
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	Yes (2)	Unknown	Unknown	Populations down throughout PWS (1) and elsewhere (2).	Fewer data exist for areas outside PWS. Declines may be higher in PWS than elsewhere.
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S	No, for reproduction (2); mortality etc. unknown	Residual effects due to initial loss of adults (4)	Unknown	Regime shifts, climate change (3), and gill net mortality (2)	Indicators for productivity only are available (see Kuletz and Kendall 1998, Kuletz 2005). No differences in reproduction exist between oiled and unoiled areas. Marbled murrelet populations are declining everywhere, so reproductive parameters for healthy populations are unknown. For discussion of potential residual effects, see Kuletz 2005. Regime shifts, climate change, and gill net mortality may affect overall productivity and survival (Carter et al. 1995; Manly et al. 2004; Wynne et al. 1991, 1992).
	Is inter-annual variability of each key population measure (e.g., average abundance; average fecundity) different from the expected range of variation for natural populations?	B, T	No (2)	Unknown	Unknown	Unknown	Probably no differences in fecundity between populations, but little known about natural fecundity (see above)
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	No, within PWS (1)	No (4)	No (4)	Climate change (3), changes in prey (3), and gill net mortality (2)	
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	~ 7% (3)	NA	NA	NA	Losses may have been greater in PWS
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	Original population size was very large and currently exceeds 35,000 in PWS alone (1). There is no genetic evidence of differences in south-central Alaskan populations (1).
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	Original population size was very large and currently exceeds 35,000 in PWS alone (1). There is no genetic evidence of differences in south-central Alaskan populations (1).
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (4)	Unknown	Unknown	Unknown	Genotypic or phenotypic differences are unknown but unlikely.
Population Structure	Are the population and habitat patchy or continuous?	B, S	Generally, population and habitat are continuous (2)	NA	NA	NA	Depending on scale many inter-related factors, both marine and terrestrial, affect habitat characteristics
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	Yes (2)	None (4)	None (4)	Inherent low reproductive potential (4)	Marbled murrelet are mobile, so it is unlikely their recovery continues to be affected by residual EVOS effects or lingering oil.
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	Yes (2)	NA	Summer breeding and foraging habitat contains more oil than winter habitats (2)	Variable annual foraging and breeding patterns (3)	Summer breeding and foraging habitat is more oiled than wintering (offshore) areas (3). More marbled murrelet may enter PWS from the Gulf of Alaska in warm-water years than others (unpubl. MS, Kuletz, noted in Kuletz 2005 appendix)

Marbled Murrelet (Section 10)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

				Stressors and Effects[c]			
Recovery Metrics	**Injury Questions/Hypotheses**	**Assessment Scales[a]**	**Assessment Result[b]**	**Residual EVO**	**Lingering Oil Effects**	**Other (Non EVO)**	**Comments**
Exposure	What percentage of the population's habitat has lingering oil?	S, T	~ 1% (4)	NA	Lingering EVO in ~ 1% of habitat (4)	Topography, exposure to waves, etc. (1)	Could be more if sandy beaches within oiled zone are affected, with impacts to sand lance or juvenile herring etc., and thus impacts to Kittlitz's murrelet foraging.
	Is lingering oil bioaccessible?	C, S	Yes (3)	NA	Lingering oil in benthos	Water temperature may affect oil bioavailability (4)	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	No (2)	NA	Exposure to lingering oil through benthic invertebrate prey (4)	None (4)	
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	Unknown	Unknown	Unknown	Unknown	No data available. Check with Karen Oakley (USFS). In 1989 marbled murrelets in oiled areas had petroleum hydrocarbons, but those in unoiled areas did not. Report was not followed up.
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	No data available.
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	No (4)	None (4)	None (4)	None (4)	No data available for oiled vs. unoiled.
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, S	Yes, body weights (1)	Residual prey effects (4)	Unknown	Decreasing adult body weights throughout PWS (1)	No data available for oiled vs. unoiled populations. The large foraging ranges of marbled murrelet prevent distinguishing between oiled and unoiled birds for comparison.

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:

Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:

(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Kittlitz's Murrelet (Section 10)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Example Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	~4,000 km shoreline	NA	NA	NA	Kittlitz's murrelet mainly inhabit fjords with glacial input. Within fjords, most birds forage < 200 m from shore (1). See Kuletz et al. 2003 for specific fjords and current population distribution and size. See Day et al. 2000 for general habitat use.
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S	Yes (1)	Residual prey effects (3)	Lingering oil in some habitats (2)	Inherent spatial differences betweeon oiled and unoiled sites (1)	Most Kittlitz's murrelets were in unoiled areas.
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S	Yes (2)	Residual prey effects (3)	Lingering oil on subtidal sandy beaches (1)	Increased boat traffic in oiled areas (1)	Assesment is at small scales.
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	~ 1 % in heavily oiled sites (2)	Residual EVOS/cleanup activities (2)	Lingering oil in some habitats (2)	NA	Residual effects are less than for Marbled Murrelet. In some years, Kittlitz's murrelet are scattered throughout central pelagic waters affected by EVOS activities (2; FWS unpublished data, and Kuletz 2005, appendix).
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	Yes (1)	Residual prey effects (3)	Lingering oil prey effects (3)	Climate change and resulting altered fish recruitment and increased glacial retreat (2-3)	Forage fish such as herring are particularly important in summer for raising chicks. Information on stressors in Kuletz et al. 2003, Kuletz 2005, appendix.
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	Yes(4)	Residual food chain effects (4)	Lingering oil food chain effects (4)	Trophic changes caused by glaciers' recession (3)	Possible residual and lingering oil effects through food chain, but overall unknown. No Alaskan data on trophic effects of glacier recession. Citations on glacier work in N. Atlantic in Kuletz et al. 2003.
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	Yes, relative to pre-spill (1). No for oiled vs. unoiled(1).	Residual population losses compared to pre-spill (1)	Lingering oil effects compared to pre-spill levels (1)	Populations declining throughout PWS (1) and other areas (2)	Populations are down from pre-spill levels throughout PWS (1) and other areas (2); but PWS may have greater rate of decline (Kuletz 2005-appendix). There are no differences between oiled and unoiled populations.
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	Yes (2)	Unknown	Unknown	Populations declining throughout PWS (1) and other areas (2)	Areas of reduction include PWS, Kenai Fjords, and lower Cook Inlet. Declines outside EVOS area in Glacier Bay, and Malaspina area. There may be greater declines in PWS(FWS and USGS reports, symposium presentations [e.g., Kuletz & Piatt 2006])
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S	Yes (3)	Residual effects from initial deaths (4)	Unknown	Climate change (3), gill net mortality (2), small spills (3), and watercraft disturbance (3).	No good data exist for these parameters. Limited data suggest that Kittlitz's murrelet in Kachemak Bay may be reproducing, but there is much lower juvenile abundance in PWS (3; Kuletz et al. 2003b) and Glacier Bay (report & thesis coming out). Day and Nigro 2004 report no juveniles in PWS, but FWS crews observed & caught them in 2003-05. Gill net mortality hypothesis supported by Wynne et al. 1991, 1992, unpubl. data, and NOAA study in Kodiak, 2005). The role of small spills is discussed in Kuletz 2001.
	Is inter-annual variability of each key population measure (e.g., average abundance; average fecundity) different from the expected range of variation for natural populations?	B, T	Unknown	Unknown	Unknown	Unknown	Little known about average or expected range of fecundity etc.
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	No, within PWS (1)	None (4)	None (4)	Climate change (3), gill net mortality (2), small spills (3), and watercraft disturbance (3).	
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	3%-10% (2)	NA	NA	NA	Among birds, Kittlitz's murrelets may have suffered highest losses relative to population size. Estimates range from 3% (Van Vliet 1993) to 5-10% (Van Vliet and McAllister 1994)
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	Immediately after spill, no (2). In PWS since ~ 2001, yes(2)	None (2)	None (2)	Large population declines throughout PWS since 2001 (2)	Predicted quasi-extirpation (< 100 birds) in PWS by 2006, or within 10 years. Evidence of genetic differences between western Aleutian and PWS populations equal to at least sub-species or new species (Friesen et al.).
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	Immediately after spill, no (2). In PWS since ~ 2001, yes(2)	None (2)	None (2)	Large population declines throughout PWS since 2001 (2)	
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (4)	Unknown	Unknown	Unknown	
Population Structure	Is the population and habitat patchy or continuous?	B, S	Generally patchy (2)	NA	NA	NA	Depends on scale; likely many interrelated marine and terrestrial factors
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	Yes (2)	None (4)	None (4)	Kittlitz's murrelet have low reproductive potential (2).	Not likely that slow recovery is due to EVOS effects, as Kittlitz's murrelets are located in upper fjords during breeding season
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	Yes (2)	NA	Lingering oil in some summer breeding and foraging habitat (2)	Naturally variable annual dispersal of murrelets throughout PWS (3)	Movement into PWS and other fjords for summer breeding may subject them to more oil than offshore Gulf of Alaska areas. Summer breeding and foraging habitat is more oiled, if central PWS waters are included. Variable dispersal throughout central PWS by year (in Kuletz 2005 appendix).

Kittlitz's Murrelet (Section 10)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

				Stressors and Effects[c]			
Recovery Metrics	**Example Injury Questions/Hypotheses**	**Assessment Scales[a]**	**Assessment Result[b]**	**Residual EVO**	**Lingering Oil Effects**	**Other (Non EVO)**	**Comments**
Exposure	What percentage of the population's habitat has lingering oil?	S, T	~ 1% (4)	NA	Lingering EVO in ~1 % of habitat (1)	Topography, exposure to waves, etc. (1)	Could be more if sandy beaches within oiled zone are affected, with impacts to sand lance or juvenile herring etc., and thus impacts to Kittlitz's murrelet foraging.
	Is lingering oil bioaccessible?	C, S	Yes (3)	NA	Lingering oil in benthos (3)	Water temperature may affect oil bioavailability (4)	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	No (2)	NA	Exposure to lingering oil through benthic invertebrate prey (4)	None (4)	Unknown for bioavailability in benthic crustacea and macrozooplankton, which Kittlitz's murrelet also feed on. More benthic feeding on crustacea may mean more exposure than for marbled murrelet (3). See Day et al. 1999 and Day and Nigro 2000, Day et al. 2000 for feeding and habitat use of Kittlitz's murrelet. Bioaccessibility only possible through prey.
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	Unknown	Unknown	Unknown	Unknown	No data available. Check with Karen Oakley (USFS). In 1989 marbled murrelets in oiled areas had petroleum hydrocarbons, but those in unoiled areas did not. Report was not followed up.
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	No data available
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	No (4)	None (4)	None (4)	None (4)	No behavioral data available for oiled vs. unoiled areas.
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, S	Unknown	Unknown	Unknown	Unknown	A few weakened birds picked up appeared to be starving, though no toxicological tests were done.

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:
Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:
(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Cormorants (Section 10)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	~4,000 km shoreline (2)	NA	NA	NA	
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S	Yes (2)	Unknown	Lingering oil in some habitats (1)	Natural variation between areas (2)	Habitat quality was not measured. There is lingering oil present, and natural variation between oiled and unoiled areas.
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S	Yes (1)	None (4)	Lingering oil in some habitats (1)	Increased boat traffic (1)	Lingering oil is present where it was not before the spill.
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	~1% (2)	Residual EVOS effects	Lingering oil in some habitats (1)	NA	
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	Yes (2)	Residual effects from initial prey losses (1) and herring crash (3.5)	Lingering oil prey effects (3.5)	Non-EVOS factors contributing to herring crash (3.5)	EVOS immediately negatively affected herring and probably sand lance. In 1993, the herring population crashed and has not recovered; the cause of this crash is unknown. If EVOS contributed to it, then important cormorant prey could have been negatively affected for several years and may still be experiencing both residual and lingering oil effects.
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	Unknown	Unknown	Unknown	Unknown	
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	Yes, relative to pre-spill (1); no for oiled vs. unoiled post-spill (1)	Residual prey effects (2)	Lingering oil prey effects (3)	Climate change affecting prey (3)	Residual and lingering effects remained for several years after spill. (Irons et al. 2000; Sullivan et al. 2005). Cormorant populations may have been declining before the spill, possibly due to climate shifts; these effects could have continued after the spill.
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	Unknown	Unknown	Unknown	Unknown	Data were not analyzed at relevant scale.
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S, T	Unknown	Residual population effects (2)	Lingering oil effects (2)	Unknown	Population was reduced in oiled area through mid 1990s, but parameters are currently unknown (Irons et al. 2000, Lance et al. 2001).
	Is inter-annual variability of each key population measure (e.g., average abundance; average fecundity) different from the expected range of variation for natural populations?	S, B, T	No (2)	Unknown	Unknown	Unknown	Variability was not measured, but differences are unlikely.
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	No (1)	None (2)	None (2)	Other stressors in both areas (2)	Population trends in both areas were affected (Sullivan et al. 2005).
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	< 10% of PWS population (3)	NA	NA	NA	
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	

Cormorants (Section 10)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c] Residual EVO	Stressors and Effects[c] Lingering Oil Effects	Stressors and Effects[c] Other (Non EVO)	Comments
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (2)	None (2)	None (2)	None (2)	
Population Structure	Is the population and habitat patchy or continuous?	B, S	Population is continuous; habitat is patchy	NA	NA	NA	
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	Yes (2)	None (2)	None (2)	Inherent low reproductive potential (2)	Cormorants are long lived (20+ years) and have delayed maturation and low reproductive potential.
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	Yes (2)	NA	Lingering oil in some breeding habitat (2)	None (2)	Migrate to PWS seasonally to breed and forage.
Exposure	What percentage of the population's habitat has lingering oil?	S, T	<1 % in PWS (2)	NA	Lingering oil in <1% of habitat	None (2)	
	Is lingering oil bioaccessible?	C, S	Yes (2)	NA	Lingering oil is bioaccessible (2)	None (2)	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	Yes (2)	NA	Lingering oil is bioavailable (2)	None (2)	
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	No (2)	None (2)	None (2)	None (2)	No evidence of exposure is evident in light-moderately oiled areas (i.e., Naked Island). Exposure was not measured in heavily oiled areas.
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	No (4)	None (4)	None (4)	None (4)	No behavioral measurements have been identified.
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, T	Unknown	Unknown	Unknown	Unknown	No field data were collected.

Note: Pelagic ~90%, Double Crested ~10%, Red Faced ~ <0.1%) in PWS only. Summer, immature populations. Winter adult populations.

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:
Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:
(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Common Loon (Section 10)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]: Residual EVO	Stressors and Effects[c]: Lingering Oil Effects	Stressors and Effects[c]: Other (Non EVO)	Comments
Habitat	How much habitat is available in PWS?	S	~10,000 km^2	NA	NA	NA	
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?		Yes (2)	NA	Lingering oil in some habitats (1)	Natural variation (2)	Likely effects, but not measured. Oiled areas have lingering oil effects. Natural variation may account for some differences.
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S	Yes (1)	None (4)	Lingering oil in some habitats (1)	Increased boat traffic in oiled areas (1)	Habitat quality is lower in oiled areas.
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	~1% (2)	None (2)	Lingering oil in ~1% of habitat (2)	NA	
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	Yes (2)	Residual effects from initial prey losses (1) and herring crash (3)	Lingering oil prey effects (3)	Non-EVOS factors contributing to herring crash (3.5)	EVOS immediately negatively affected herring and probably sand lance. In 1993, the herring population crashed and has not recovered; the cause of this crash is unknown. If EVOS contributed to it, then important loon prey could have been negatively affected for several years and may still be experiencing both residual and lingering oil effects.
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	Unknown	Unknown	Unknown	Unknown	
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	Yes, relative to pre-spill (1); no for oiled vs. unoiled post-spill (1)	Residual prey effects (2)	Lingering oil prey effects (3)	Climate change affecting prey (3)	There were reductions in summer loon populations compared to prespill and control site (Irons et al. 2000). Recent surveys show no postspill differences in population trends in winter or summer betweeon oiled and unoiled areas (Sullivan et al. 2005).
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	Unknown	Unknown	Unknown	Unknown	Data not analyzed at that scale
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S, T	Unknown	Residual effects (2)	Unknown	Unknown	Irons et al. 2000 found that populations were reduced through the 1990s.
	Is inter-annual variability of each key population measure (e.g., average abundance; average fecundity) different than the expected range of variation for natural populations?	S, B, T	No (2)	Unknown	Unknown	Unknown	Not measured, but unlikely
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	No (1)	None (2)	None (2)	Other stressors exist in both oiled and unoiled areas (2)	Currently, trends are not different in oiled and unoiled areas (Sullivan et al. 2005).
Genetic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	<10% in PWS (3)	NA	NA	NA	
	Did the population reach a critical small size that could lead to decreased phenotypic diversity?	B	No (2)	NA	NA	NA	
	Did the population reach a critical small size that could lead to decreased genotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	
	Are there genetic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (2)	None (2)	None (2)	None (2)	

Common Loon (Section 10)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Population Structure	Is the population and habitat patchy or continuous?	B, S	Population is continuous; habitat is patchy (2)	NA	NA	NA	
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	Yes (2)	None (2)	None (2)	Loons have low reproductive potential (2)	This species lives 20 years or more and has delayed maturation. Loons have low reproductive potential.
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	Yes (2)	NA	Lingering oil in some habitats (1)	Unknown	Loons migrate into PWS in the spring to breed and forage nearshore.
Exposure	What percentage of the population's habitat has lingering oil?	S, T	<1% in PWS (2)	NA	Lingering oil in ~1% of habitat (2)	Unknown	
	Is lingering oil bioaccessible?	C, S	Yes (2)	NA	Lingering oil in benthos (3)	Unknown	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	Yes (2)	NA	Exposure to lingering oil through benthic invertebrate prey	Unknown	
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	No (2)	Unknown	Unknown	Unknown	No evidence in light to moderately oiled areas (i.e., Naked Island). Did not measure in heavily oiled areas.
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	No data available
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	No (4)	None (4)	None (4)	None (4)	None identified
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, T	Unknown	Unknown	Unknown	Unknown	No field data collected

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:

Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:

(1): Highly likely; strongly supported by data

(2): Likely; moderately supported by data

(3): Possible, based on judgment and limited data

(4): Speculative; little or no data

Pacific Herring (Section 11)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	Extensive nearshore	NA	NA	NA	
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now? Refocus question to disturbance created by EVO.	S	No (1)	None (1)	None (1)	Disease (1)	Disease and other stressors are present.
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill? Focus question on disturbance created by treatment.	S, T	Unknown	Unknown	Unknown	Unknown	
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	0%	None (1)	None (1)	NA	
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	No (2)	None (2)	None (2)	None (4)	No data, but probably other stressors were present in 1989.
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	Yes (4)	Residual trophic effects (4)	None (1)	Unknown	
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	Yes (1)	Residual population effects (3-4)	None (1)	Disease (1)	Populations are lower than pre-spill levels. Disease is apparent, but mechanisms are unknown.
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	No (2)	None (2)	None (2)	None (2)	
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S	Yes (1)	Residual population effects (3)	None (1)	Disease (1)	
	Is inter-annual variability of each key population measure (e.g., average abundance, average fecundity) different from the expected range of variation for natural populations?	B, T	Unknown	Unknown	Unknown	Unknown	
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	Unknown	Unknown	Unknown	Unknown	
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	30%-90%	NA	NA	NA	30% estimated mortality occurred in 1989 at time of spill. 90% of the 1989 year class was missing in 1992-1993.
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	No (1)	None (1)	None (1)	None (1)	
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	No (1)	None (1)	None (1)	None (1)	
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (2)	None (1)	None (1)	Lack of disease resistance (4)	It is hypothesized that disease resistance as a phenotypic trait is missing from PWS population.
Population Structure	Are the population and habitat patchy or continuous?	B, S	Patchy (1)	None (1)	None (1)	None (4)	
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	No (1)	None (1)	None (1)	None (1)	
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	No (1)	None (1)	None (1)	None (1)	
Exposure	What percentage of the population's habitat has lingering oil?	S, T	0%	NA	No lingering oil in habitat (1)	None (1)	
	Is lingering oil bioaccessible?	C, S	No (1)	NA	None (1)	None (1)	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	Yes (1)	Yes (1)	Lingering oil is bioavailable (1)	None (1)	Oil is bioavailable, but this is moot.

Pacific Herring (Section 11)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
	Is there evidence of ongoing exposure (e.g., visual observations, bioaccumulation, biomarkers)?	B, S	No (1)	None (1)	None (1)	None (1)	Exposure assessment is based on exposure pathway analysis.
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	No (1)	None (1)	None (1)	Disease (1)	Disease mechanism unknown.
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, S	Yes (2)	Residual effects (4)	None (1)	Disease (1)	Speculative residual spill effects may be considered among disease effects. The disease mechanism unknown.

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:

Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:

(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Rockfish (Section 12)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	100% of subtidal habitat (1)	NA	NA	NA	
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S	No (1)	None (1)	None (1)	None (1)	
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill? Focus question on disturbance created by treatment.	S, T	No (1)	None (1)	None (1)	None (1)	
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	0-3% (1)	None (1)	None (1)	None (1)	
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	Unknown	Unknown	Unknown	Unknown	
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	No (2)	None (2)	None (2)	None (2)	
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	No (3)	None(3)	None(3)	None(3)	
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	No (3)	None(3)	None(3)	None(3)	
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S	No (3)	None(3)	None(3)	None(3)	Conclusions based on fisheries catch statistics prior to 1989 and immediately following the spill.
	Is inter-annual variability of each key population measure (e.g., average abundance, average fecundity) different from the expected range of variation for natural populations?	B, T	No (3)	None(3)	None(3)	None(3)	Rockfish have very stable populations with low inter-annual variability.
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	No (3)	None(3)	None(3)	None(3)	Populations are very stable with no obvious trends either up or down.
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	<3% (4)	NA	NA	NA	
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	No (3)	None(3)	None(3)	None(3)	
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	No (3)	None(3)	None(3)	None(3)	
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (3)	None(3)	None(3)	None(3)	
Population Structure	Are the population and habitat patchy or continuous?	B, S	Continuous	NA	NA	NA	
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	Yes (1)	No (1)	No (1)	No (1)	
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	No (1)	NA	None(1)	NA	
Exposure	What percentage of the population's habitat has lingering oil?	S, T	0 percent (1)	NA	None (1)	NA	
	Is lingering oil bioaccessible?	C, S	No (1)	NA	None (1)	NA	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	Yes(1)	NA	Lingering oil is bioavailable (1)	NA	Oil is bioavailable, but this is moot.
	Is there evidence of ongoing exposure (e.g., visual observations, bioaccumulation, biomarkers)?	B, S	No (3)	NA	None (3)	None (3)	

Rockfish (Section 12)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	No (3)	None (1)	None (3)	Background petroleum sources (3)	
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	Unknown, but unlikely
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, S	Unknown	Unknown	Unknown	Unknown	Unknown, but unlikely

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:
Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:
(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Cutthroat Trout (Section 13)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	12 watersheds	NA	NA	NA	
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now? Refocus question to disturbance created by EVO.	S	No (1)	None (1)	None (1)	None (1)	
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill? Focus question on disturbance created by treatment.	S, T	No (1)	None (1)	None (1)	None (1)	
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	0%-3% (1)	None (1)	None (1)	NA	
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	No (1)	None (1)	None (1)	None (1)	
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	Unknown	Unknown	Unknown	Unknown	
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	No (2)	None (2)	None (1)	Recreational fishery (2), gillnet bycatch (2)	No studies, but result is based on life history and recovery potential. Recreational fishery and gill netting likely have little effect.
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	No (3)	None (3)	None (3)	None (3)	
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S	No (3)	None (3)	None (2)	None (2)	
	Is inter-annual variability of each key population measure (e.g., average abundance, average fecundity) different from the expected range of variation for natural populations?	B, T	No (3)	None (3)	None (3)	None (3)	
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	Unknown	Unknown	Unknown	Unknown	
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	0% (1)	NA	NA	NA	
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	No (2)	None (2)	None (2)	None (2)	
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (2)	None (2)	None (2)	Unknown	
Population Structure	Are the population and habitat patchy or continuous?	B, S	Patchy	NA	NA	NA	
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	No (1)	None (1)	None (1)	None (1)	
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	No (1)	NA	None (1)	NA	
Exposure	What percentage of the population's habitat has lingering oil?	S, T	0% (1)	NA	None (1)	None (1)	
	Is lingering oil bioaccessible?	C, S	No (1)	NA	None (1)	None (1)	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	Yes (1)	NA	Lingering oil is bioavailable (1)	None (1)	Oil is bioavailable, but this is moot
	Is there evidence of ongoing exposure (e.g., visual observations, bioaccumulation, biomarkers)?	B, S	Unknown	NA	Unknown	Unknown	

Cutthroat Trout (Section 13)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

				Stressors and Effects[c]			
Recovery Metrics	**Injury Questions/Hypotheses**	**Assessment Scales[a]**	**Assessment Result[b]**	**Residual EVO**	**Lingering Oil Effects**	**Other (Non EVO)**	**Comments**
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Unknown	Unknown	Unknown	Unknown	
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, S	Unknown	Unknown	Unknown	Unknown	

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:

Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:

(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Sea Otter (Section 14)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scale[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	Unknown	NA	NA	NA	
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S	Yes (1)	Improved prey (1)	Lingering oil in habitats (1)	Inherent spatial variability (1)	Possible positive residual effect of improved prey. Habitat is defined as western PWS
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S	Yes (1)	Sediment removal (2)	Lingering oil in habitats (1)	Temporal variation and geological processes (3)	
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	< 1% (2)	Residual EVOS/cleanup activities (2)	Lingering oil in habitats (2)	NA	
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	Yes (1)	Reduced habitat but increased prey (1)	Contaminated prey (2)	NA	Positive and negative residual effects. Lingering oil contaminates current prey.
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	Unknown	Unknown	Unknown	Unknown	
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	Yes (1) for Knight Island, no for PWS (1)	Residual population losses on Knight Island (3)	Continued lingering oil effects on Knight Island (2)	Unknown	Non-EVOS factors are unknown, but are expected to be similar among areas.
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	Yes (1)	Knight Island population reduced to <50% (2)	Continued lingering oil effects at Knight Island (2)	Unknown	Non-EVOS factors are unknown, but are expected to be similar among areas.
	Are population parameters (condition, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S, T	Condition and mortality: yes (2) Reproduction: no (1)	Residual effects on condition and mortality (1)	Lingering oil effects on condition and mortality (4)	Unknown	Assessment applies to Knight Island population data from 1992 and 1999. Non-EVOS factors are unknown, but are expected to be similar among areas.
	Is inter-annual variability of each key population measure (e.g., average abundance, fecundity, survival) different from the expected range of variation for natural populations?	B, S, T	No, for abundance or fecundity (1) Unknown for survival	None for abundance or fecundity (1). Unknown for survival	None for abundance or fecundity (1). Unknown for survival	Unknown	Neither Knight Island nor PWS show differences in expected variation in abundance or fecundity. Differences in survival remain unknown. Non-EVOS factors are unknown, but are expected to be similar among areas.
	Is the trend in population abundance stable in oiled areas of Knight Island and WPWS?	B, T	Yes (1)	Residual oil effects (1)	Lingering oil effects (1)	Unknown	The trend is increasing or stable in WPWS. The trend is stable and declining at Knight Island. Non-EVOS factors are unknown, but are expected to be similar among areas.
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	25–50% in WPWS	NA	NA	NA	
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	No (2)	Unknown	Unknown	Historical population bottlenecks (2)	
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	No (2)	Unknown	Unknown	Historical population bottlenecks (2)	
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (2)	Unknown	Unknown	Historical population bottlenecks (2)	
Population Structure	Is the population and habitat patchy or continuous?	B, S	Patchy (1)	NA	NA	NA	
	Is the time needed for recovery large relative to time since EVOS?	B, T	No at PWS scale, yes at Knight Island (1)	Residual EVOS effects (1)	Lingering oil effects (1)	Unknown	Non-EVOS factors are unknown, but should be similar among areas

Sea Otter (Section 14)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scale[a]	Assessment Result[b]	Stressors and Effects[c] Residual EVO	Stressors and Effects[c] Lingering Oil Effects	Stressors and Effects[c] Other (Non EVO)	Comments
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	No (2)	NA	Dispersal-related exposure (4)	None (2)	Dispersal-related exposure is possible, but speculative.
Exposure	What percentage of the population's habitat has lingering oil in PWS?	S, T	< 1% (2)	NA	Lingering oil in < 1% of habitat (2)	Non-EVO oil sources (2)	
	Is lingering oil bioaccessible?	C, S	Yes (1)	NA	Lingering oil in benthos (1)	Non-EVO oil sources (2)	Diminishing lingering oil over time
	Is the oil in a form that is bioavailable or capable of causing physical effects?	B, C	Yes (1)	NA	Exposure through prey (1)	Non-EVO oil sources (2)	
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	Yes (1)	NA	Cytochrome P4501a histopathology evidence (1)	Non-EVO oil sources (2)	Exposure evident through 2003
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GGT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Yes (1)	NA	Diminishinf lingering oil effects (1)	Non-EVO oil sources (2)	Greater than normal GGT levels since 2000, but no current differences
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Yes (2)	Increases in prey (2)	Lingering oil contributes to lack of recovery (2)	Inherent greater prey productivity at Knight Island (4)	A positive residual effect was that density dependent increases in prey led to increased otter weight/length ratio. TDR estimates will be forthcoming.
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, S	Yes (2)	Positive prey effects (3)	Negative effects through 2003 (3)	Confidence-limiting factors confounding EVOS effects/stressors (3)	The diminishing EVOS effects over time are inconsistent with a lack of recovery at Knight Island, so other factors are probably present.

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:
Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?
Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:
(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Harbor Seal (Section 15)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	All of PWS	NA	NA	NA	
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S	No (2)	None (2)	None (2)	None (2)	
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S	No (2)	None (2)	None (2)	None (2)	
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	0% (2)	None (2)	None (2)	NA	
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	No (4)	None (4)	None (4)	None (4)	Herring could have been affected. There is no evidence of effects in other prey species.
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, T	No (2)	None (2)	None (2)	None (2)	Possible that predation by killer whales on seals was influenced by decrease in sea otters, assuming sea otters are significant prey for killer whales.
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	No, relative to reference (2)	None (2)	None (2)	None (2)	
	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	Yes (1)	No (2)	No (2)	Yes (2)	Compared to pre-spill levels
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	Unknown	Unknown	Unknown	Unknown	Reliable trend information is not available within the EVOS area, other than the subset where the population decline has been seen
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S	Growth: no (1); reproduction and mortality: unknown	None (1)	None (1)	None (1)	Reproduction and mortality unknown, yet "No" is assumed due to similar growth rates between populations.
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S, T	Yes (1)	None (2)	None (2)	Differences in population's reproduction or mortality (1)	Assuming no net immigration, reproduction or mortality must be higher than in a natural stable population
	Is inter-annual variability of each key population measure (e.g., average abundance) different than the expected range of variation for natural populations?	B,S, T	No (1)	None (1)	None (1)	None (1)	
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	No (2)	None (2)	None (2)	None (2)	Trends include oiled and un-oiled areas; for remaining areas, no reliable trend data are available
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	1%-3%	NA	NA	NA	Seals in the spill area are the population of concern
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	No (1)	None (1)	None (1)	None (1)	
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	No (1)	None (1)	None (1)	None (1)	
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (1)	None (1)	None (1)	None (1)	
Population Structure	Is the population and habitat patchy or continuous?	B, S	Continuous (1)	NA	NA	NA	
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	No (1)	None (1)	None (1)	None (1)	

Harbor Seal (Section 15)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	No (1)	NA	None (1)	None (1)	
Exposure	What percentage of the population's habitat has lingering oil?	S, T	0% (1)	NA	No habitat contains lingering oil (1)	None (1)	
	Is lingering oil bioaccessible?	B, C, S	No (1)	NA	None (1)	None (1)	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	B, C	No (1)	NA	None (1)	None (1)	
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	No (1)	None (1)	None (1)	None (1)	
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	No (1)	None (1)	None (1)	None (1)	
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	No (1)	None (1)	None (1)	None (1)	
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, T	No (1)	None (1)	None (1)	None (1)	

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:

Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:

(1): Highly likely; strongly supported by data

(2): Likely; moderately supported by data

(3): Possible, based on judgment and limited data

(4): Speculative; little or no data

Killer Whale AB Pod (Section 16)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scale[a]	Assessment Results[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
Habitat	How much habitat is available in PWS?	S	All PWS	NA	NA	NA	
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S	No (2)	None (2)	None (2)	None (2)	
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S	No (2)	None (2)	None (2)	None (2)	
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S, T	None (2)	None (2)	None (2)	None (2)	
	Did EVOS affect critical food resources (i.e., coho salmon) and are there residual or lingering oil effects on the quantity or quality of food resources?	S, T	No (4)	None (4)	None (4)	None (4)	
	Did EVOS affect critical food resources and are there residual or lingering oil effects on the quantity or quality of food resources today?	B, T	No (3)	None (3)	None (3)	None (3)	
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	B, S, T	No (2)	None (2)	None (2)	None (2)	
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S	Yes (1)	Residual population loss (1)	None (1)	None (2)	Population is increasing slightly.
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S, T	Yes (3)	Unknown	Unknown	Non-EVOS effects (2)	
	Are population parameters (e.g., growth, reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S, T	Yes (1)	Residual population loss (2)	None (2)	None (3)	Population is increasing slightly.
	Is inter-annual variability of each key population measure (e.g., average abundance; average fecundity) different from the expected range of variation for natural populations?	B, T	Unknown	Unknown	Unknown	Unknown	
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, T	Yes (1)	Residual population loss (2)	None (2)	Non-EVOS effects (4)	
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	36% (1)	NA	NA	NA	
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	No (1)	None (1)	None (1)	None (1)	
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	No (1)	None (1)	None (1)	None (1)	
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those before the spill or from those in the non-spill area?	B	No (1)	None (1)	None (1)	None (1)	
Population Structure	Are the population and habitat patchy?	B, S	No (1)	NA	NA	NA	
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	Yes (1)	None (1)	None (1)	Inherent slow recovery time (1)	

Killer Whale AB Pod (Section 16)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scale[a]	Assessment Results[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	No (1)	NA	None (1)	None (1)	
Exposure	What percentage of the population's habitat has lingering oil?	S, T	0% (1)	NA	No lingering oil in habitat (1)	None (1)	
	Is lingering oil bioaccessible?	C, S	No (1)	NA	None (1)	None (1)	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	B, C	No (1)	NA	None (1)	None (1)	
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	No (1)	None (1)	None (1)	None (1)	
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	No (1)	None (1)	None (1)	None (1)	
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Yes (4)	Residual effects (4)	None (4)	None (4)	
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, S	No (1)	None (1)	None (1)	None (1)	

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S)

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:

Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:

(1): Highly likely; strongly supported by data
(2): Likely; moderately supported by data
(3): Possible, based on judgment and limited data
(4): Speculative; little or no data

Killer Whale AT1 Pod (Section 16)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]: Residual EVO	Stressors and Effects[c]: Lingering Oil Effects	Stressors and Effects[c]: Other (Non EVO)	Comments
Habitat	How much habitat is available in PWS?	S	All PWS	NA	NA	NA	
	Are the quantity and quality of the habitat for this resource different between oiled and non-oiled areas now?	S	No (2)	None (2)	None (2)	None (2)	
	Are the quantity and quality of the habitat for this resource in oiled areas different now in comparison with conditions that existed before the spill?	S	No (2)	None (2)	None (2)	None (2)	
	What proportion of the habitat continues to be affected residually by the EVOS, by cleanup activities, or by lingering oil?	S,T	None (2)	None (2)	None (2)	None (2)	
	Did EVOS affect critical food resources (i.e., seals and otters) and are there residual or lingering oil effects on the quantity or quality of food resources today?	S, T	Yes (3)	Residual prey effects(3)	None (2)	Non-EVOS factors (2)	
	Did EVOS affect other structural or trophic relationships important to this resource and do these effects persist today?	S, T	No (2)	None (2)	None (2)	None (2)	
Abundance and Population Growth	Is the population significantly reduced in oiled areas relative to reference areas or relative to pre-spill levels?	B, S, T	Yes (1)	Residual prey effects(3)	None (1)	Non-EVOS factors (1)	
	Is the reduced population limited to a geographic area that is a subset of the initial EVOS area?	B, S	Yes (1)	None (1)	None (1)	Non-EVOS factors (2)	
	Are population parameters (e.g., reproduction, mortality) in oiled areas different from those expected in a natural population?	B, S	Yes (1)	Residual population effects (2)	None (1)	Non-EVOS factors (1)	
	Is inter-annual variability of average fecundity different from the expected range of variation for natural populations?	B, T	Yes (1)	Residual population effects (2)	None (1)	Non-EVOS factors (2)	
	Is the trend in population abundance (increasing, decreasing, or stable) in oiled areas different from that in unoiled areas?	B, S	Yes (1)	Residual population effects (2)	None (1)	Non-EVOS factors (2)	
Genotypic/Phenotypic Diversity	What percentage of the population was killed in the original EVOS?	B, S	41% (1)	NA	NA	NA	
	Did the population reach a critically small size that could lead to decreased phenotypic diversity?	B	Yes (1)	Residual population effects (1)	NA	Yes (2)	
	Did the population reach a critically small size that could lead to decreased genotypic diversity?	B	Yes (1)	Residual population effects (1)	NA	Yes (2)	
	Are there genotypic or phenotypic characteristics of the surviving population that are different from those in the non-spill area?	B	Yes (1)	Residual population effects (1)	NA	Yes (2)	
Population Structure	Are the population and habitat patchy as a consequence of EVOS?	B, S	No (2)	None (2)	None (2)	None (2)	
	Is the generation time needed for recovery large relative to time since EVOS?	B, T	Yes (1)	None (1)	None (1)	Inherent long recovery time (1)	
	Are there migratory patterns that could result in seasonal or episodic exposure to lingering EVO?	B, S, T	No (2)	NA	None (2)	None (2)	
Exposure	What percentage of the population’s habitat has lingering oil?	S, T	0% (1)	NA	No lingering oil in habitat	None (1)	
	Is lingering oil bioaccessible?	C, S	No (2)	NA	None (2)	None (2)	
	Is the oil in a form that is bioavailable or capable of causing physical effects?	C, B	No (2)	NA	None (2)	None (2)	

Killer Whale AT1 Pod (Section 16)—Lines of evidence for injury based on supplemental population recovery metrics, associated injury questions or hypotheses, and relevant assessment scales.

Recovery Metrics	Injury Questions/Hypotheses	Assessment Scales[a]	Assessment Result[b]	Stressors and Effects[c]			Comments
				Residual EVO	Lingering Oil Effects	Other (Non EVO)	
	Is there evidence of ongoing exposure (e.g., visual observations; bioaccumulation; biomarkers)?	B, S	No (2)	None (2)	None (2)	None (2)	
Behavioral/Physiological Indicators	Are there physiological measurements (e.g., GCT enzyme, energetic requirements) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B. T	Unknown	Residual oiling effects (4)	Unknown	Unknown	
	Are there behavioral measurements (e.g., activity-time budgets) that show residual effects of EVOS or of lingering oil and are these effects different from those observed in control or reference areas?	B, T	Yes (4)	Residual oiling effects (4)	Unknown	Unknown	
	Can observed physiological or behavioral effects be interpreted in the context of population-level effects?	B, S	Yes (4)	Residual oiling effects (4)	Unknown	Unknown	

[a]Relevant assessment scales are biological (B), chemical-physical (C), temporal (T), and spatial (S).

[b]Results of the various injury questions or hypotheses can be expressed in the context of the different stressors that may affect them. Examples include:

Are there natural disturbances (e.g., tectonic uplift or subsidence, climatic factors) that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are there human disturbances other than EVOS that affect the recovery metric for the resource (e.g., quality and quantity of habitat)?

Are natural and human disturbances distinguishable from those associated with EVO or lingering oil?

[c]Confidence in results is indicated in parentheses, as follows:

(1): Highly likely; strongly supported by data

(2): Likely; moderately supported by data

(3): Possible, based on judgment and limited data

(4): Speculative; little or no data

APPENDIX D

ENZYME INDUCTION AS A MEASUREMENT OF EXPOSURE

APPENDIX D
ENZYME INDUCTION AS A MEASUREMENT OF EXPOSURE

Mammals, birds, and some fish respond to small amounts of oil exposure by the induction of an enzyme, cytochrome P450 1A.[1] This enzyme has played a key role in assessing the possible effects from remaining oil because it provides a link between the residual deposits of oil in the beaches of Prince William Sound and the mobile animals that forage in the nearshore and may be experiencing negative effects from the oil. It is therefore important to understand what this enzyme is, how it is induced, and its role in these animals. This understanding provides a foundation for determining if there is a linkage between the induction of this enzyme and apparent lack of recovery of some animal populations 17 years after the spill.

WHAT ARE P450 ENZYMES?

The P450 enzymes are a diverse group of proteins responsible for the metabolism in vertebrates of a large variety of fatty acids, steroids, drugs, contaminants, and other exogenous compounds. They belong to a variety of families; the contaminant-inducible family in vertebrates is P450 1A. There are at least two forms of P450 inducible by contaminants in fish, P450 1A1 and P450 1A3 (Nelson et al. 1996). There are additional forms in higher vertebrates. These inducible enzymes were first used to detect oil exposure in aquatic animals (fish) following an oil spill in Canada (Payne 1976). Since 1976, this chemical exposure indicator has been used in more than 180 field studies and 100 laboratory experiments, utilizing more than 150 species of fish (Whyte et al. 2000). Although modulated by temperature, pH, some naturally occurring non-hydrocarbons, the reproductive cycle, and genetic adaptation in some chronically contaminated environments, they are, when properly applied and interpreted, reliable indicators of organic chemical exposure in aquatic vertebrates.

HOW ARE P450 1A ENZYMES INDUCED AND HOW ARE THEY MEASURED?

Petroleum hydrocarbons, polychlorinated biphenyls (PCBs), polybrominated biphenyls (PBBs), some pesticides, dioxins, and dibenzofurans are known inducers of P450 1A (Elcombe and Lech 1978; Stegeman and Hahn 1994; Whyte et al. 2000).

The mechanism of induction involves binding of a planar molecule (e.g., a PAH) to a receptor, the Ah receptor, which then sets in motion the cellular machinery to produce a battery of proteins, including P450 1A and other Phase II enzymes (those that bind the metabolic products from P450 1A-catalyzed reactions).

[1] Also known as CYP1A.

The presence of the inducible enzymes can be quantified either by the rate of catalytic activity in assays where a known P450 1A substrate (e.g., ethoxyresorufin), is added to the microsomal fraction of tissues (where the P450 1A enzymes are located) and the breakdown product (e.g., ethoxyresorufin-*O*-deethylase [EROD]) is measured. Alternatively, the P450 1A protein can be detected directly with an antibody either with microsomes or in thin sections (Stegeman and Hahn 1994). Assay by EROD is probably the most common measurement and may be somewhat more sensitive and precise than use of the antibody (see the review by Whyte et al. 2000). However the antibodies detect the enzyme in formalin preserved tissues, a distinct advantage. Analysis of CYP1A mRNA can also be analyzed using molecular methods, such as Northern blot (Roy et al. 1995).

The P450 1A induction response follows within hours of exposure to inducing compounds, with mRNA for the protein appearing within 6–12 hours after exposure in fish (Kloepper-Sams and Stegeman 1989). Without the stimulation of inducing compounds, the protein eventually decays from cellular machinery and will generally return to constituent levels in 10 days to 2 weeks. In rainbow trout liver cell cultures, the P450 1A protein had a half-life of 27 h once the inducing compounds were removed (Sadar and Andersson 2001). The decay of the induction response probably depends on the pharmacokinetics of the inducing compounds. In areas of chronic exposure to organic contaminants, such as in San Francisco Bay or near natural submarine oil seeps, fish will maintain elevated levels of P450 1A with some modulation of activity evident in females during gametogenesis (Spies et al. 1982, 1988).

The induction of the P450 1A enzyme in aquatic animals in the area of a large oil spill is a reliable marker of ongoing exposure to the oil. If exposure to other inducing contaminants is minimal and the effects of factors, such modulation by reproductive activity, are taken into account, it is a very sensitive indicator of exposure.

WHERE IS THE P450 1A ENZYME LOCATED?

In cells, the enzyme is located on the smooth endoplasmic reticulum and in the mitochondria within the cytoplasm. It is active in cells derived from the endodermal layers of the embryo. In fish, for example, it is found in the liver, kidney, heart, gills, and brain and in the lining of the blood vessels, the endothelium (Stegeman and Hahn 1994). It is most frequently measured in liver, where its activity is generally the highest of any tissue in exposed animals.

WHAT IS THE ROLE OF P450 1A IN ANIMALS?

Apart from playing an active role in electron transport, the P450 1A enzyme is undoubtedly part of the biochemical machinery that regulates physiological processes in animals. That is, the Ah receptor binds drugs and contaminants that have the right molecular configuration, but the receptor almost certainly binds a natural ligand. However, we do not yet know its identity. Mice that do not have Ah receptors (i.e., they have been experimentally blocked) are deficient in aromotase, the enzyme that converts testosterone to estrogen (Baba et al. 2005). Also, the P450 1A enzyme is suppressed during oogenesis in female fish, which suggests that it might be linked to reproduction in some way. So, the overall role of this enzyme in animals is not fully understood, but it appears to interact directly with reproduction in some way.

IS THERE AN INCREASED RISK TO ANIMALS FROM P450 1A INDUCTION?

It has often been thought that the induction of this enzyme in animals was an indicator of exposure to foreign compounds only. If this were true, then any effects from oil exposure would only be correlative with enzyme induction. The relationship is not, however, that simple. There is a more causal link between induction and damage arising from two separate mechanisms. First, from extensive studies of chemical carcinogenesis, it is known that this enzyme activates some petroleum hydrocarbons (e.g., benzo[a]pyrene) to highly reactive intermediate compounds capable of binding to nucleic acids and proteins, the first step in tumor initiation (Nebert et al. 1993). Thus, there are potential consequences from the action of this enzyme on petroleum hydrocarbons. Second, the binding of the inducing compound to the Ah receptor could interfere with the normal functioning of this receptor and disrupt some biochemical pathways and receptor-mediated physiological coordination. This could either take the form of blockage of a normal activity or inappropriate initiation of events out of normal sequence.

So, P450 1A induction can be an indicator of increased risk to the population in which it occurs due to the effects of intermediate oil contaminant metabolites and possible alterations of physiological homeostasis by Ah-mediated controls.

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