Exxon Valdez Oil Spill
Restoration Project Final Report

Restoration Project 10100750

Monitoring for Evaluation of Recovery and Restoration of Injured Nearshore Resources

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Study History

The work reported here is part of several linked programs designed to monitor the nearshore ecosystem of the Gulf of Alaska (GOA) in the years since the 1989 *Exxon Valdez* oil spill (EVOS). In this section, we summarize the history of preceding efforts, as well as subsequent and ongoing monitoring programs, to provide the necessary context for discussion of work conducted under Restoration Project 10100750 from 2010-2012.

Development of a nearshore monitoring plan (2003 – 2006). In the early 2000's, the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) supported development of a restoration and ecosystem monitoring plan for nearshore marine ecosystems in the GOA affected by the EVOS. This effort was done under EVOS Restoration Projects 030687 & 040687, conducted by the U.S. Geological Survey (USGS) and reported by Dean and Bodkin (2006). Subsequently, in 2005, the EVOSTC supported the USGS to further develop the nearshore monitoring plan under EVOS Restoration Project 050750. Within this plan it was recognized that (1) restoration of resources injured by the spill would benefit from information on the status and trends of those resources on a variety of spatial scales within the Gulf, and (2) changes independent of the oil spill were certain to occur in the GOA, from a variety of potential underlying agents (e.g., natural environmental drivers, global climate change, and shoreline development and associated inputs of pollutants). Further, to evaluate constraints to recovery and implement any potential restoration of injured resources, an understanding of EVOS-related effects relative to other sources of change would be beneficial.

Implementation of the nearshore monitoring plan (2007 – 2012) and the role of this project. The EVOSTC provided funding to the USGS in 2007, to conduct a pilot year of nearshore fieldwork and data collection in western Prince William Sound (WPWS) (EVOS Restoration Project 070750; reported by Bodkin et al. 2009). The same nearshore monitoring plan (Dean and Bodkin 2006) was adopted in 2005 by the National Park Service Southwest Alaska Network (NPS SWAN) for their Inventory and Monitoring program (I&M), and implemented in Katmai National Park and Preserve (KATM) in 2006 and Kenai Fjords National Park (KEFJ) in 2007. The NPS SWAN and the USGS worked collaboratively to implement the monitoring program in these regions, and monitoring has proceeded annually in both parks (with the exception of KATM, not sampled in 2011). The three study areas (Figure 1) lie along the northern perimeter of the oiled area, where oil spilled in 1989 washed up into the nearshore. **In 2010, the EVOSTC funded Restoration Project 10100750, the subject of this report, for the USGS to implement the nearshore monitoring plan in WPWS over a three year period, 2010-2012.** The plan provided for monitoring of biological resources in the nearshore environment, with a focus on sea otters, black oystercatchers, intertidal kelps, seagrasses, and invertebrates, and included evaluation of the status of recovery of resources injured by the EVOS. Metrics sampled and data collection methods in WPWS under this project paralleled ongoing nearshore monitoring at KATM and KEFJ, and the two efforts were closely coordinated, providing an opportunity to integrate results over a broader region. Also in 2010, the EVOSTC provided funding for additional surveys to monitor the recovery of the sea otter population in WPWS, as an amendment to Project 10100750 (Restoration Project 10100750A). The findings of that work are included in this report.

In 2012, the EVOSTC funded implementation of the 20-year Gulf Watch Alaska program (GWA; Restoration Project 12120114; http://www.gulfwatchalaska.org/), a multi-dimensional monitoring and

research program directed at environmental drivers and pelagic and nearshore food webs in the Gulf of Alaska. The ongoing nearshore monitoring efforts in WPWS, KATM, and KEFJ were assembled under the Nearshore component of the new GWA program, with support for 5 more years of monitoring (2012 – 2016) from the EVOSTC, and additional funding from USGS and NPS. The years, areas, and funding sources for the series of nearshore monitoring activities are summarized in Table 1 below. Nearshore monitoring is anticipated to be continued after 2016, potentially as part of the Gulf Watch Alaska program, and at KATM and KEFJ, through NPS SWAN.

Here, we provide a final report for EVOS Restoration Project 10100750, including amendment 10100750A, recognizing that the work and data streams will be carried forward as part of GWA. Data that have been collected under this project will be integrated in GWA program syntheses, as interpretation of data collected over broader ecologic, geographic and temporal scales may be more meaningful in terms of understanding large-scale ecosystem processes and patterns. This report is submitted as a final product for Project 10100750, but we emphasize that data collection continues under the NPS SWAN I&M and GWA programs.

Abstract

In 2012, we completed three consecutive years of full field sampling in WPWS for EVOS Restoration Project 10100750. Nearshore monitoring was conducted in collaboration with the NPS SWAN I&M program and, beginning in 2012, as part of the EVOSTC GWA program. Data collection was done in accordance with standard operating procedures set forth to monitor marine water chemistry and quality, marine intertidal invertebrates, kelps and seagrasses, marine birds, black oystercatchers, and sea otters. Summer sampling in 2012 represented the fourth year of sampling in WPWS (an initial year of sampling was done in WPWS in 2007; EVOS Restoration Project 070750). Based on our monitoring of nearshore species in WPWS, and comparisons of data from WPWS and other areas within the Gulf of Alaska, we have no evidence of continued injury to biological resources at the spatial scales we are monitoring. A key finding is that recovery of the sea otter population is no longer constrained by exposure to lingering oil; this is consistent with related EVOSTC studies on harlequin ducks (Restoration Project 12120114-Q). We anticipate continued annual nearshore monitoring in WPWS and at KATM and KEFJ under GWA, with data summaries and analyses including all three areas to provide a larger spatial and temporal context to the understanding of processes and patterns in nearshore ecosystems of the GOA which were impacted by the EVOS of 1989.

Key Words

Prince William Sound, nearshore monitoring, *Exxon Valdez*, EVOS, injured resources, Katmai, Kenai Fjords, Gulf Watch Alaska

Project Data

Data collected under Restoration Project 10100750 (collected in WPWS) will be kept in digital format (csv files with metadata) at the USGS Alaska Science Center, Anchorage, Alaska. Data custodian – Daniel Esler, Research Wildlife Biologist and Project Leader, Nearshore Marine Ecosystem Research program, U.S. Geological Survey, Alaska Science Center, Anchorage, Alaska. Project data and associated metadata files also are served online on the Alaska Ocean Observing System Workspace as part of the Gulf Watch Alaska Data Management program (EVOS Restoration Project 12120114).

Citation

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Restoration Project Final Report (Restoration Project 10100750), U.S. Geological Survey, Alaska Science Center, Anchorage, Alaska.

INTRODUCTION

The 1989 EVOS spilled approximately 260,000 barrels of crude oil into the waters of Prince William Sound (PWS), Alaska (Morris and Loughlin 1994, Shigenaka 2014, Spies et al., 1996). Oil spread in a southwesterly direction, leaving a heavy layer on many shorelines within western Prince William Sound (WPWS) before exiting Montague Strait and other passages at the southwestern corner of PWS (Galt et al. 1991). Oil eventually covered more than 26,000 km^2 of water in WPWS and the GOA and contaminated more than 1,900 km of coastline (Morris and Loughlin, 1994).

Nearshore habitats in the path of the oil were severely affected by the spill. In the following weeks, the equivalent of about 150,000 barrels of oil washed ashore on beaches in PWS (Wolfe et al. 1994), with the most heavily oiled shorelines located in the islands of the central western Sound. Accordingly, most studies of biological effects of the spill focused on nearshore species and communities within PWS.

The initial acute effects of the spilled oil were dramatic and relatively well documented for birds and marine mammals, through carcass collections and response activities (EVOSTC: http://www.evostc.state.ak.us). Birds and sea otters (*Enhydra lutris*) were vulnerable to acute effects as the oil compromised the insulative properties of feathers or fur, leaving them subject to hypothermia as well as to toxic consequences of exposure. In addition to acute effects, long-term research indicated that population recovery was protracted for decades for some particularly vulnerable species, including sea otters and harlequin ducks (*Histrionicus histrionicus*) (Iverson and Esler 2010, Bodkin et al. 2012, 2014a, Esler 2013, Ballachey et al. 2014a, b). Research and monitoring efforts also were directed toward quantifying mortality among algae, seagrasses, invertebrates and intertidal fishes (see articles in Rice et al. 1996), which suffered from both direct oiling as well as clean-up efforts that included highly destructive high pressure washing in intertidal habitats (Lees et al. 1996, Hoff and Shigenaka 1999).

Nearshore areas are a significant EVOS-affected habitat, and a critical component of the GOA ecosystem. The nearshore provides (1) important habitat for a range of species, including feeding and nursery areas, (2) subsistence and recreational use for humans, and (3) an interface between sea and land, for transfer of water, nutrients and biota. Further, the nearshore is sensitive to natural and human disturbances on a variety of temporal and spatial scales. Nearshore systems are especially good indicators of change because organisms there generally are relatively sedentary, accessible, and manipulable, and there is a comparatively thorough understanding of mechanistic links between nearshore species and their physical environment that may facilitate understanding causes of change.

Long-term monitoring provides perspective and context for understanding effects of the spill by documenting timelines of injury and recovery, and by facilitating greater understanding of other sources of variation in the GOA. In 2006, a restoration and ecosystem monitoring plan for the nearshore marine ecosystems across the GOA was completed for the EVOSTC (Dean and Bodkin 2006). The framework for monitoring in the nearshore included sampling of a variety of specified biological and physical metrics (e.g., abundance and growth of intertidal organisms, abundance of selected birds and marine mammals). The plan was implemented on a one-year basis in WPWS in 2007 (Bodkin et al. 2009). The NPS SWAN adopted the same plan in 2005 for their I&M program, and implemented it at Katmai National Park and Preserve (KATM) in 2006 and Kenai Fjords National Park (KEFJ) in 2007.

In 2010 - 2012, the EVOSTC funded the long-term nearshore monitoring program in WPWS (Project 10100750), the subject of this report. The objectives of this project were:

1. Continue restoration monitoring in the nearshore in order to evaluate the current status of injured resources in oiled areas.

2. Identify if those injured resources being monitored may be considered recovered from EVOS effects.

3. Identify potential factors that could inhibit recovery of injured resources, and recommend potential restoration actions.

Here, we provide a summary of results from Project 10100750, and describe the synthesis of data collected under this project with data sets from the closely related NPS SWAN nearshore monitoring and the long-term nearshore monitoring program underway as part of Project 12120114, Gulf Watch Alaska, for the period from 2012-2016.

METHODS

The areas that have been monitored in each year (2006-2014) and the agencies that have supported the monitoring work are presented in Table 1. The metrics that are monitored within the nearshore component are listed in Table 2, and areas and sites within each area that are included in the monitoring program are shown in Figure 1. Standard operating procedures (SOP's) for all data collection have been developed as part of the preparation and implementation of nearshore monitoring by NPS SWAN, and are listed in Table 3. A Protocol Narrative (Dean et al. 2014) describes the overall monitoring program, with the specific SOP's providing details on data collection and analytical approaches for each metric. A discussion of how these resources or "vital signs" can be integrated to provide insight on causes of change is provided in the Protocol Narrative. SOP's are posted on the NPS SWAN website (http://science.nature.nps.gov/im/units/swan/monitor/nearshore.cfm).

Table 1. Years of data collection and agency support for areas included in nearshore monitoring programs. Support has been provided by NPS SWAN (SWAN), USGS Alaska Science Center (USGS), EVOS Restoration Projects 070750 (EVOS 070750) and 10100750 (EVOS 10100750) and the EVOS Gulf Watch Alaska program (GWA). The cells with bold text are the year and area combinations explicitly funded under the Restoration Project 10100750, which is the subject of this final report. See Figure 1 for location of the areas.

	YEAR*								
AREA	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
KATM	SWAN & USGS	SWAN & USGS	SWAN & USGS	SWAN & USGS	SWAN & USGS		SWAN USGS & GWA	SWAN USGS & GWA	SWAN USGS & GWA
KEFJ		SWAN & USGS	SWAN & USGS	SWAN & USGS	SWAN & USGS	SWAN & USGS	SWAN USGS & GWA	SWAN USGS & GWA	SWAN USGS & GWA
WPWS		EVOS 070750 & USGS			**EVOS 10100750 & USGS**	**EVOS 10100750 & USGS**	**EVOS 10100750 & USGS**	SWAN USGS & GWA	SWAN USGS & GWA
EPWS**							SWAN USGS & GWA		SWAN USGS & GWA
NPWS**								SWAN USGS & GWA	

* Monitoring is anticipated to continue through at least 2016 at all sites, with support from GWA and NPS SWAN, and thereafter at PWS sites depending on availability of funding. Sites at KATM and KEFJ are scheduled to be monitored for a longer term, as part of the NPS SWAN I&M program.
** EPWS = Eastern Prince William Sound, NPWS = Northern Prince William Sound

Table 2. List of metrics measured as part of the nearshore monitoring program. Metrics* are collected at 5 sites at each of 5 study areas: KATM, KEFJ, WPWS ("Intensive" sampling blocks), and EPWS and NPWS ("Extensive" sampling blocks). Intensive sites are monitored annually and extensive sites biennially.

1. Rocky intertidal shoreline:
   - % cover of various species (algae and sessile invertebrates) at tidal elevations of 0.5 and 1.5 MLLW
   - *Lottia persona* (limpets) – mean size and density, at the upper tidal elevation
   - *Nucella* spp. (sea snails) and *Katharina tunicata* (chiton) – densities, at 0.5 m and 1.5 m MLLW
   - Sea star densities along a 100 m transect at the 0 tidal elevation
   - Temperature
2. Mussel (*Mytilus trossulus*) beds:
   - Density of mussels ≥ 20 mm
   - Overall density of mussels
   - Area (m^2) of mussel beds
3. Bivalves in soft sediments:
   - Species composition
   - Density
   - Size distribution
4. Eelgrass beds:
   - Proportion of area with eelgrass present
5. Marine bird and mammals surveys:
   - Density and distribution of birds and mammals
6. Black oystercatchers:
   - Density of active nests
   - Number of eggs and chicks / active nest
   - Species composition and size distribution of prey (shell remains) at nest sites
7. Sea otter foraging observations:
   - Visual observations of foraging sea otters to quantify energy recovery rates through:
     -prey type
     -prey size
     -dive and surface times
     -proportion of successful dives
     -caloric recovery rates
8. Sea otter abundance:
   - Aerial surveys to estimate abundance of sea otters
9. Sea otter mortality patterns:
   - Annual collection of carcasses from shorelines to assess patterns of mortality, based on ages at death

*Metrics 5-9 are not collected at the extensive sites; and metric 8 is not collected annually. Bivalves in soft sediment sites in all areas are only sampled every other year to minimize effects from destructive sampling. More detailed information on these metrics is available in the Standard Operating Protocols (see Table 3).

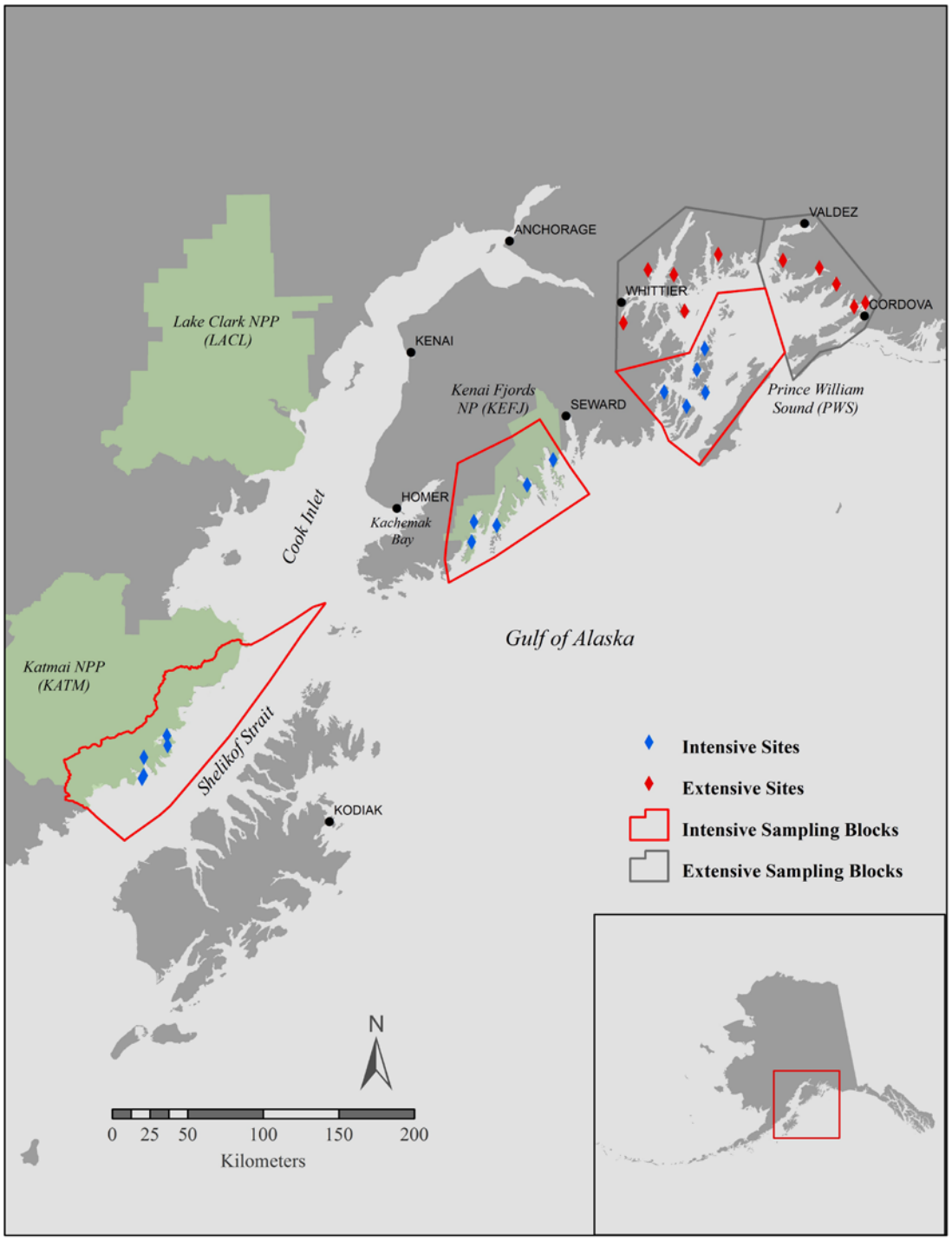

Figure 1. Map of the Gulf of Alaska showing study areas (Sampling Blocks) and sites within each of the study areas. See Table 1 for a schedule of sampling at areas from 2006-2014, and Table 2 for a list of metrics collected at intensive and extensive sites. Intensive study sites lie within the area affected by the 1989 *Exxon Valdez* oil spill.

Table 3. Standard operating protocols (SOPs) established for monitoring of nearshore resources.*

METRIC	TITLE	AUTHORS AND YEAR
Protocol Narrative: (Overview of Nearshore Monitoring Program)	*Protocol Narrative for Nearshore Marine Ecosystem Monitoring in the Gulf of Alaska – Version 1.1*	Dean et al. (2014)
Intertidal invertebrates and algae	*SOP for Sampling of Intertidal Invertebrates and Algae on Sheltered Rocky Shores – Version 4.7*	Dean and Bodkin (2011a)
Eelgrass	*SOP for Sampling of Eelgrass (Zostera marina) – Version 1.1*	Dean and Bodkin (2012)
Mussels	*SOP for Sampling of Mussel Beds ─ Version 1.2*	Bodkin et al. (2014b)
Black Oystercatchers	*SOP for Monitoring Black Oystercatchers ─ Version 1.1*	Bodkin (2011a)
Marine birds and mammals (Nearshore)	*SOP for Conducting Marine Bird and Mammal Surveys ─ Version 4.1*	Bodkin (2011b)
Sea otter abundance	*SOP for Conducting Sea Otter Aerial Surveys ─ Version 1.2*	Bodkin (2011c)
Sea otter foraging	*SOP for Collecting Sea Otter Forage Data ─ Version 3.2*	Bodkin (2011d)
Sea otter mortality	*SOP for Conducting Coastline Surveys of Birds and Mammals, Animal Carcasses, Debris and Other Resources – Version 1.1*	Dean and Bodkin (2011b)

* SOPs were written for the NPS SWAN I&M program, utilized for Nearshore monitoring in Project 10100750 and now for continued monitoring under the Gulf Watch Alaska project. Protocols have been peer-reviewed and finalized over the past 5 years; periodic updates are done as needed to clarify any modifications to the protocol. A record of date and reason for updates is presented at the beginning of each SOP. SOPs are publicly available on the NPS website at: http://science.nature.nps.gov/im/units/swan/monitor/nearshore.cfm

RESULTS

Objective 1. Continue restoration monitoring in the nearshore in order to evaluate the current status of injured resources in oiled areas.

The nearshore monitoring program was successfully implemented in WPWS, with data collected over a three year period (2010-2012) that are relevant for documenting status of a number of injured resources (see below). No problems or concerns were encountered with implementation of the program during this period. Data processing was coordinated with corresponding data sets from KATM and KEFJ collected over the same period, and an annual report with descriptive data summaries on all metrics from all locations has been completed (Coletti et al. 2013, 2014). Additional summarization of selected data sets from WPWS was presented in annual reports on GWA Nearshore monitoring for 2013 and 2014, provided to the EVOSTC (Project 12120014R). Data collected in 2007, the initial year of WPWS nearshore monitoring (Project 070750), are presented in Bodkin et al. (2009).

Further synthesis of selected nearshore data sets, including considerations of recovery status of some injured resources, is underway as part of GWA; reports on that synthesis effort are scheduled for completion in spring 2015. Metrics monitored under this project continue as part of the GWA program, with associated opportunities for understanding the status and variation in resources affected by the EVOS.

Objective 2. Identify if those injured resources being monitored may be considered recovered from EVOS effects.

Two nearshore vertebrate species, the sea otter and the harlequin duck, were documented to have protracted population recovery following the EVOS. Sea otters were the primary biological resource that received consideration under this project, in terms of evaluating progress toward recovery in WPWS. With the continuing support of the EVOSTC, the USGS has studied sea otters in oiled areas of WPWS since 1989, and has developed several long-term data sets. Findings have been presented in a number of publications, including Bodkin et al. (2002, 2012, 2014a), Miles et al. (2012), Monson et al. (2000, 2011), and Ballachey et al. (2014b). In 2014, the USGS released a report summarizing findings on sea otter recovery in WPWS through 2013 (Ballachey et al. 2014b), which included data collected under this project. Based on abundance of sea otters in oiled areas (determined from aerial surveys) and patterns of mortality (determined from age-at-death, from carcass collections) through 2013, Ballachey et al. (2014b) concluded that the status of sea otters in WPWS as of 2013 was consistent with recovery, as defined by the EVOSTC (EVOS 2010).

Although not directly addressed by this project, further support for recovery of injured nearshore resources comes from studies of harlequin ducks. Iverson and Esler (2010) predicted, based on population models, that harlequin ducks would be recovered by 2013. Most recent data on continuing exposure of harlequin ducks to residual oil (using the cytochrome P450 biomarker; Esler 2013) support this conclusion, as by 2013 there were no differences in the biomarker between harlequin ducks sampled in oiled vs. unoiled areas of WPWS.

The sea otter and harlequin duck studies indicate that it may take two decades or more for vulnerable species to recover from the effects of an oil spill in the nearshore environment.

Objective 3. Identify potential factors that could inhibit recovery of injured resources, and recommend potential restoration actions.

At this time, based on our monitoring of nearshore species in WPWS, and comparisons of data sets from WPWS and other areas within the GOA, we have no evidence of continued injury to biological resources at the spatial scales we are monitoring, and have not identified any factors that are thought to be inhibiting recovery. We recognize that in some areas affected by the EVOS, oil persists in intertidal sediments (Boufadel et al. 2010, Li and Boufadel 2010). However, through 2013, our data do not indicate continued population level injury to sea otters and harlequin ducks from lingering oil on shorelines, suggesting that oil remaining in sediments is no longer a significant impediment to recovery of nearshore vertebrates.

DISCUSSION and CONCLUSIONS

We collected three years of data on nearshore resources in WPWS under this project (10100750, Table 1), implementing a nearshore monitoring program initially developed in the early 2000s (Dean and Bodkin 2006, Dean et al. 2014), and implemented in WPWS for a single year in 2007 (Bodkin et al. 2009). Data collection was coordinated with comparable monitoring at KATM and KEFJ initiated under the NPS SWAN I&M program in 2006, with ongoing efforts as of 2012 supplemented by the EVOSTC through the GWA project (Table 1). Data collected under this project are archived at both the USGS and NPS (Anchorage) and on the GWA project internal workspace (data publicly available at portal.aoos.org/gulf-of-alaska.php). Detailed summaries of the 2010-2012 data have been presented elsewhere (Coletti et al. 2013, 2014: http://science.nature.nps.gov/im/units/swan/publications.cfm?tab=2, and GWA reports: http://www.gulfwatchalaska.org/resources/reports-and-documents/).

Going forward, as part of the GWA program, data collected under this project are being utilized in larger, comprehensive analyses synthesizing nearshore data sets collected across the GOA; initial products from this synthesis are scheduled for completion in spring 2015. The value of nearshore monitoring in WPWS conducted under this project is enhanced when data sets from the larger GOA area are combined, providing greater geographical and temporal scale and increasing our ability to detect and assign cause to differences in and among areas and over time.

An important aspect of our nearshore monitoring efforts has been evaluation of the recovery of nearshore resources. To this end, sea otters have been a major component of the monitoring, building on over two decades of post-spill studies to understand the extent of population injury and the status of recovery. As of 2013, several lines of evidence suggest that the status of the sea otter population in WPWS is consistent with recovery (Ballachey et al. 2014b), as defined by the EVOSTC (EVOS 2010). Recent studies on harlequin ducks (Iverson and Esler 2010, Esler 2013), and intertidal communities (Fukuyama et al. 2014) support this conclusion. Although oil is known to persist on shorelines of WPWS, and not all species are recognized to have recovered (EVOS 2010), based on studies of nearshore species including sea otters and harlequin ducks, by 2013 there is no evidence of continuing population level injury from lingering oil.

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