

Draft
Conceptual Exposure Model

**2004 Assessment of
Lingering Oil and Resource
Injuries from the Exxon
Valdez Oil Spill**

Prepared for the
State of Alaska
Department of Law
Anchorage, Alaska

Prepared by



Seattle, Washington

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integral

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Prepared for

State of Alaska—Department of Law

1031 West Fourth Street, Suite 200

Anchorage, Alaska 99501-1994

Prepared by



7900 SE 28th Street

Suite 300

Mercer Island, WA 98040

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INTRODUCTION

This technical memorandum presents the general conceptual exposure model (CEM) developed to support the evaluation of the nature and extent of lingering oil and present-day resource injuries that can be linked to lingering oil from the Exxon Valdez oil spill. The CEM developed for this evaluation follows the general framework described for the development and implementation of conceptual site models used in risk assessment as outlined by the U.S. Environmental Protection Agency (USEPA 1997, 1998) and the Alaska Department of Environmental Conservation (ADEC 2000a,b; 2004).

The general CEM represents a series of working hypotheses developed to support the evaluation of whether, how, and to what degree lingering Exxon Valdez oil (EVO) can be linked to present-day resource injuries in Prince William Sound (PWS). Injuries cannot be prescribed in part or wholly to lingering EVO unless 1) resources come into contact with lingering EVO; 2) lingering EVO has the ability to cause adverse effects to those resources; and 3) an adverse effect to the resource has been measured or observed. The CEM seeks to establish to what extent, if any, these conditions co-exist. In its most general form, therefore, the CEM is a planning tool used to determine whether a complete environmental exposure pathway exists between lingering EVO and resources. In more complete terms, the CEM is a series of pictorial representations of past and lingering sources of EVO, chemical release and transport mechanisms, and environmental exposure pathways leading to recovering and non-recovering habitats and natural resources of concern.

The CEM serves as the foundation from which more detailed evaluations of the potential link between lingering EVO and present-day resources can ensue. These include evaluations of the weathering, toxic fraction, bioaccessibility, bioavailability, and nature and extent of lingering EVO, as well evaluations of the biological processes of exposure, uptake, and transfer of toxic EVO constituents among resources. The CEM will be used to communicate which resources are clearly associated with lingering oil based upon their degree of spatial and temporal association with lingering EVO.

There are two major components of the CEM:

1. The first component consists of the chemical and physical processes in the environment that are responsible for determining the fate and transport, and ultimately the nature and extent, of EVO in PWS. These processes include physical forcing and dispersion of EVO (including sequestering mechanisms in intertidal sediments), chemical and microbial processes of degradation and transformation of EVO, and partitioning into abiotic and biotic environmental matrices. These processes are illustrated and discussed.

2. The second component consists of an identification of the recovering and non-recovering ecological resources present in relation to lingering EVO.¹ These include resources such as intertidal invertebrates coming into direct contact with lingering EVO, as well as the higher-trophic level resources, such as sea otters and harlequin ducks, which may be indirectly exposed to EVO through the food chain. The biological processes of exposure, uptake, and food-chain transfer of lingering EVO associated with these resources are illustrated and discussed.

Each of these components is discussed and their corresponding depictions are presented in the following sections. It is important to note that the general CEM as presented below will likely be refined.² The refinement will likely entail additional focus on the critical exposure pathways based upon the degree of association between lingering EVO and the resources. This is particularly the case for select resources, for which resource-specific CEMs will likely be developed.

¹ Sediments and Designated Wilderness Areas are additional resources classified as recovering. Recovery of these resources is predominantly based on the presence and possible toxicity of lingering EVO. These resources will be addressed relative to ecological resources as part of the lingering oil evaluation.

² The future refinement of the general CEM is consistent with overall procedures outlined for development of site conceptual models by USEPA (1997, 1998) and ADEC (2000a, b, 2004). These procedures explicitly entail refinement of conceptual site models as risk assessment evaluations proceed.

CHEMICAL AND PHYSICAL PROCESSES

This section presents the chemical and physical processes of the general CEM, which have dictated the nature and extent of EVO in PWS over time. These processes are depicted in **Figure 1**. Separate discussions are presented for these processes as they occurred immediately after the spill in open water (acting as a primary source of exposure) and from the time EVO landed on the beaches of PWS and its subsequent persistence in the intertidal zone of these beaches (potentially acting as a secondary and ongoing source of exposure). Because present-day resource injuries are being evaluated relative to lingering EVO present in the intertidal zone, the overall focus of this section is on those chemical and physical processes that dictate the nature and extent of lingering EVO in this area.

OPEN WATER

The Exxon Valdez oil spill 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 fate and transport of spilled 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 fairly rapid evaporation, dissolution, dispersion, and degradation of EVO in the open water environment.

The left side of **Figure 1** depicts the chemical and physical processes dictating the short-term nature and extent of EVO in open water. Over the course of hours and days following the spill, EVO spread on the surface of the ocean as a slick (Galt et al. 1991, Kelso and Kendziorek 1991, Maki et al. 1991, Wolfe et al. 1994, Neff and Stubblefield 1995, Patin 1999). Weathering of the oil started immediately as the more volatile and water-soluble fractions were rapidly lost to the atmosphere and water column through evaporation and dissolution, respectively (Galt et al. 1991, Neff et al. 1995, Neff and Stubblefield 1995, Wells et al. 1995, Wolfe et al. 1994). In response to wind and wave turbulence, emulsions (mixtures of tiny droplets of oil and water) formed both on the water surface (water-in-oil emulsions) and in the water column (oil-in-water emulsions) (Mackay et al. 1980, Payne et al. 1991, Wolfe et al. 1994). Emulsions on the water surface took the form of a mousse [a fairly stable form consisting of up to 70% water (Payne 1983, Patin 1999)]. Tar balls also developed at the water surface as the oil slick and/or mousse fragmented, due to continued evaporation and spreading (Payne and Philips 1985). Oil on the water surface was additionally subjected to oxidation by exposure to ultraviolet light [photo-oxidation, typically photolysis (Patin 1999)]. Within the water column, the tiny droplets of oil were also subjected to photo-oxidation to the depths to which light can penetrate. In addition, hydrocarbons may have been partially degraded or completely

metabolized by microbes or other organisms (Patin 1999). Sorption of hydrocarbons to suspended solids and subsequent sedimentation also likely occurred (Patin 1999, Payne et al. 1991, Galt 1991, ITOPF 2004).

Collectively, the persistence of EVO in open water following the spill was limited due to the rapid degradation and dispersion processes in the sea (Neff et al. 1990, Wolfe et al. 1994, Short and Harris 1996, Spies et al. 1996, Neff and Stubblefield 1995). Today, 15 years after the original spill, EVO contamination in the open water is not present in measurable quantities.³

INTERTIDAL ZONE

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

The right side of **Figure 1** depicts the chemical and physical processes dictating the long-term nature and extent of EVO in the intertidal zone of PWS. On the third day after the spill (March 26), a large storm generated and persisted for 3 days producing winds ranging from 20 to 25 knots from the northeast, with gusts up to 70 knots. Winds rapidly moved the oil to the southwest, driving it to shorelines of several islands throughout PWS. Three weeks later (April 9-10), after the leading edge of the oil passed into the Gulf of Alaska, gale force winds (40 - 70 knots) occurred again, along the Kenai coast, churning and moving the oil toward Lower Cook Inlet (Wolfe et al. 1994). EVO and associated mousse washed ashore in PWS over the course of approximately two months (Wolfe et al. 1994, Gibeaut and Piper 1995, Neff et al. 1995), oiling an estimated at 780 km (490 miles) of shoreline (Short et al. 2004, Neff et al. 1995).

EVO coated beach surfaces resulting in surficial contamination predominantly within the intertidal zone. EVO additionally penetrated the surface through cobbles, gravel, and sediments resulting in subsurface contamination in the intertidal zone. EVO at each of these depths may potentially result in exposures to resources. However, the chemical and physical processes acting on EVO in surface and subsurface environments of the intertidal

³ Similar conclusions regarding the general absence or very low concentrations of EVO in benthic sediments of PWS have also been reached (Page et al. 1995).

zone vary in type and degree, and result in distinctive nature and extent profiles within these areas.

Surface EVO

At the surface, EVO has been susceptible to a number of chemical and physical weathering processes 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 in 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, photo-oxidation, 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. 2002, Short et al. 2004).

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, Short et al. 2004). Additionally, a small percentage of surface EVO consists of oil coats and oil films in the intertidal (Gibeaut and Piper 1995, Short et al. 2004). Trustee researchers have recently estimated that approximately 4.13 hectares (10.2 acres) of surface EVO may remain in PWS, with the majority being present in the upper half of the intertidal (Short et al. 2004). The majority of surface oil present in the intertidal is believed to consist of EVO, with less than 10% considered attributable to other sources (e.g., Monterey Formation petroleum products release from tanks during the 1964 earthquake) (Short et al. 2004).

Significant debate continues with respect to the nature and extent of surface EVO in the intertidal zone (e.g., Rice et al. 2001, Page et al. 2002, Page et al. 2003, Peterson et al. 2003, Rice et al. 2003, Short et al. 2004). In general, surface EVO appears to persist in limited and localized intertidal areas and is present in predominantly weathered forms. The aerial extent, weathering, chemical composition, bioaccessibility, bioavailability, toxicity, and future persistence of surface EVO in relation to non-recovering and recovering resources will be the focus of subsequent evaluations conducted by Integral.

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 and is more persistent. 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 subsurface EVO has been sequestered in beaches armored by boulders and cobbles (Hayes and Michel 1999, Michel and Hayes 1999, Page et al. 2002, Short et al. 2004), in low-angle middle intertidal areas (Short et al. 2004), 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 moderate to highly sheltered shorelines that were heavily oiled soon after the initial spill (Hayes and Michel 1999, Wolfe et al. 1994, Short et al. 2004). Trustee researchers have recently estimated that approximately 7.8 hectares (19.3 acres) of subsurface EVO, located predominantly in the lower and middle intertidal zone, may remain in PWS (Short et al. 2004).

Despite being largely sequestered, subsurface EVO is nevertheless subject to some degree of weathering and other transformation/partitioning processes. These include dissolution into pore waters and metabolization by microbial and other benthic organisms. Such processes are most likely to result in relatively slow weathering and transformation. More rapid changes to sequestered EVO may occur as a result of re-introduction to the sediment surface, where the more rapid transformation and weathering processes occur. Re-introduction 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). Re-introduction of subsurface EVO can also be caused by bioturbation by benthic invertebrates and digging activity of sea otters (Peterson et al. 2003, Rice and Peterson 2004).

As is the case with surface EVO, significant debate also continues with respect to the nature and extent of subsurface EVO in the intertidal zone (e.g., Rice et al. 2001, Page et al. 2002, Page et al. 2003, Peterson et al. 2003, Rice et al. 2003, Short et al. 2004). In general, subsurface EVO appears to persist to a greater extent than surface EVO, and it is generally less weathered. However, key issues remain, particularly the degree to which subsurface EVO is accessible and toxic to natural resources. In addition, the aerial extent, weathering, chemical composition, bioavailability, toxicity, and future persistence of subsurface EVO in relation to non-recovering and recovering resources will be the focus of subsequent evaluations conducted under Integral's Task 2 and Task 3 work.

ECOLOGICAL RESOURCES

The ecological resources component of the CEM entails a depiction of resources present in the food web of the nearshore coastal ecosystem of PWS. This depiction is presented in **Figure 2**.

The shallow nearshore coastal ecosystem in PWS is highly complex, yet conforms to well-understood and strong patterns of vertical zonation (Peterson 2001). The physical processes that have resulted in the distribution of lingering EVO in intertidal sediments also, in part, define the marine communities that are present and which could be exposed to lingering EVO. The distributions of plants and animals of rocky shorelines are strongly influenced by both physical (e.g., wave action) and biotic (predation and competition) factors. Thus, nearshore marine communities are defined by the degree of exposure to waves (e.g., sheltered vs. exposed coast) and by their height on the shoreline. These nearshore communities are also subjected to foraging and predation by consumer organisms from other upland⁴ and nearshore communities. Thus, the ecological resources of the CEM fall within the following ecological groupings:

- Intertidal and shallow, nearshore, subtidal, benthic communities
- Nearshore foragers.

The ecological resources present in the food web of the nearshore coastal ecosystem include those that are currently classified as not recovering or recovering, as indicated in the table below.⁵

Not Recovering	Recovering
Common loon	Clams
Cormorants (3 spp.)	Intertidal communities
Harbor seal	Killer whales (AB pod)
Harlequin duck	Marbled murrelet
Pacific herring	Mussels
Pigeon guillemot	Sea otter

⁴ Exposure to upland foragers is not considered here because none are currently listed as an injured resource.

⁵ Sediments and Designated Wilderness Areas are additional resources classified as recovering that will be addressed separately as part of the lingering oil evaluation.

This classification of recovery status, however, does not represent which resources have the greatest potential for exposure to EVO. Through emphasizing spatial position of each resource within the food web, the model is intended to communicate which resources are clearly associated with lingering EVO. Temporal aspects of the habits of each resource also can be used to communicate associations with lingering EVO. The collective degree of spatial and temporal association between lingering EVO and ecological resources is used to discriminate low-risk from high-risk resources.

An overview of the ecological resources in the context of their respective intertidal, nearshore subtidal, and nearshore communities, and the possible association of these resources with lingering EVO, is provided in the following sections. As discussed above, more detailed evaluations of the potential associations between ecological receptors and lingering EVO will be performed as the general CEM is refined and as receptor-specific CEMs are developed.

INTERTIDAL AND NEARSHORE SUBTIDAL COMMUNITIES

Sheltered rocky shoreline and gravel and mixed sand beaches are the two major habitats (58%) of the PWS coast (Bodkin and Dean 2003). As described above, sheltered shoreline habitats, especially those that are armored by boulders and cobbles, are areas where residual EVO may be found. Other major coastal habitats, including exposed rocky shores and exposed wave cut platforms (Bodkin and Dean 2003), are areas less likely to have residual EVO. Therefore, the food web model in **Figure 2** provides a depiction of ecological resources residing in a generalized sheltered and rocky/gravel/sand shoreline habitat where exposure to lingering EVO might occur. This shoreline habitat consists of intertidal and nearshore, subtidal, benthic communities.

The intertidal community consists of upper, middle, and lower intertidal zones that have characteristic assemblages of organisms that can exploit rocky surfaces and withstand the rigors of tides and waves. Dominant attached organisms in these intertidal assemblages are:

- **Upper Intertidal Zone.** Algal cover in the high intertidal zone is provided principally by several green algae species, *Ulvaria* and sea lettuce (*Ulva*), and by common rockweed (*Fucus gardneri*), which is a brown alga. Invertebrate species attached to rock surfaces beneath this algal cover include several species of snails (mask limpets and periwinkles) and shield barnacles.
- **Middle Intertidal Zone.** Algal cover in the mid-intertidal zone is provided by rockweed and sea sac, which is a species of red alga. Invertebrate species include several types of acorn barnacles, bay mussels, and snails that graze on rock

surfaces (shield limpets) or scavenge and prey on other invertebrates (spindle whelks).

- **Lower Intertidal Zone.** The algal canopy in the low intertidal zone is a complex array of numerous species of red algae, including dulce (*Palmaria* spp.), false Irish moss (*Mastocarpus* sp.), and black pine (*Neorhodomela* spp.). Predominant invertebrates include predatory snails (purple whelk) and starfish (sunflower star, leather star, mottled star, and ochre star).

Sheltered rocky shorelines also provide habitat for intertidal and shallow subtidal forage fishes, such as pricklebacks, gunnels, sand lance, capelin, eulachon, sandfish, and juvenile rockfish. Pacific herring (*Clupea pallasii*) spawn on algae (rockweed) in shallow vegetated areas in the intertidal and subtidal zones. Pacific herring are a group of small schooling fish that are the preferred prey of many seabirds and marine mammals. They are most likely to encounter lingering EVO through exposure at the egg stage.

The ecology of gravel and mixed sand and gravel beaches is less complex. Algae species are not supported, and invertebrates are dominated by mid-intertidal clams such as native littleneck/steamer (*Protothaca staminea*) and macoma clams (*Macoma* spp.), and clams such as the butter clam (*Saxidomus gigantea*) (Bodkin and Dean 2003). Where beaches extend subtidally, eel grass (*Zostera marina*) beds can be found, which provide a variety of important ecological functions as nursery areas for juvenile salmon and Dungeness crab (*Cancer magister*) and as a substrate for spawning by Pacific herring (*Clupea pallasii*).

Lingering oil persists in both surface and subsurface sediments in the intertidal zone. Exposure to surface EVO is possible to surface-dwelling and surface-foraging organisms by a number of mechanisms, including direct contact and incidental ingestion. In subsurface sediments, exposure to lingering EVO is possible in areas where it either co-occurs with deeper burrowing organisms or where it is exposed via a number of disturbance mechanisms. Disturbance mechanisms include erosion during winter storms, bioturbation by burrowing invertebrates, and excavation of sediments by foraging organisms such as sea otters. As indicated above, surface EVO occurs primarily in a weathered form (e.g., asphalt pavement) and subsurface EVO is sequestered in a less weathered state. However, for both surface and subsurface environments, the extent to which lingering EVO is bioaccessible or bioavailable to intertidal resources is the subject of current research and will be a key focal point for the injury re-evaluation.

NEARSHORE FORAGERS

Numerous feeding guilds of higher trophic-level fish, piscivorous birds (i.e., seabirds and seaducks), and marine mammals exploit the nearshore environment. The degree to which they are potentially exposed to lingering EVO depends on spatial and temporal aspects of their location, foraging preferences, and foraging ranges. An overview of each of these feeding guilds is provided below.

Fish – Pacific Herring

Pacific herring (*Clupea pallasii*) are an ecologically and economically important fish in coastal waters of the Pacific coast of North America. Adult herring congregate in schools where they are prey to many species of piscivorous fish, birds, and mammals. Adult herring migrate into estuaries and shallow nearshore areas in late winter or spring to spawn. Pacific herring spawn in shallow subtidal or intertidal areas where they deposit their egg masses on kelp, seaweed, or seagrass. Thus, Pacific herring eggs and larvae are transient members of the intertidal and subtidal epibenthic communities as described above. Upon hatching, the larval fish migrate to the surface where they feed on small plankton. Juvenile and adult Pacific herring continue to feed on plankton and also forage for small fish, marine worms, and larval clams (Hart 1973). As indicated above, Pacific herring are most likely to encounter lingering oil in the egg stage. Because Pacific herring migrate away from the intertidal and nearshore subtidal benthic habitats after hatching, it is unlikely that they would encounter lingering oil either by direct contact or by foraging activities in their later life history stages.

Seabirds

Seabirds are a collective group of birds that spend at least 80% of their lives at sea, but have a variety of feeding and nesting preferences (Meehan et al. 1998). Seabirds generally encompass piscivorous diving species that have a preference for small fish. Although common loons require freshwater habitat for nesting, their feeding mechanism (saltwater diving) and prey preferences (small fish) allow them to be grouped with the other true seabirds (pigeon guillemot, double-crested cormorant, pelagic cormorant, red-faced cormorant, and marbled murrelet). The common mechanism by which these birds may potentially be exposed to lingering EVO is indirectly through prey consumption. The foraging strategy of some of these birds may also result in direct contact with lingering EVO.

- **Common Loon (*Gavia immer*).** They are excellent divers and have been found in fish nets in water depths of 73 m (240 feet) (ADFG 2004). They generally eat small

fish up to 25 cm (10 inches) long, but also consume crustaceans, mollusks, aquatic insects, leeches, frogs, and occasionally aquatic plants.

- **Double-crested Cormorant (*Phalacrocorax auritus*).** They forage primarily on slow-moving or schooling species of fish by diving in shallow coastal waters, but they are also opportunistic feeders that may occasionally consume insects, crustaceans, and amphibians.
- **Pelagic Cormorant (*Phalacrocorax pelagicus*).** They forage primarily for fish by diving close to rocks in coastal waters. Small fish make up most of their diet, but they also consume crustaceans and other marine animals.
- **Red-faced Cormorant (*Phalacrocorax urile*).** They mainly eat fish (mostly sculpins, pollock, and sandlance) as well as invertebrates.
- **Pigeon Guillemot (*Cephus columba*).** They forage primarily for small fish by diving than 20 m (66 feet) and may capture fish from under rocks. Fish species consumed include sandlance, scuplin, blennies, and gadids. They will also take a variety of other aquatic invertebrates, including crustaceans and mollusks.
- **Marbled Murrelet (*Brachyramphus marmoratus*).** They forage typically in water less than 30 m (98 ft) deep close to shore for small, schooling fish, typically sandlance, capelin, juvenile herring, and pollock. Their diet also includes a variety of invertebrates.

Seaducks

Harlequin duck (*Histrionicus histrionicus*) breed and forage in freshwater habitats for a few months of the year and migrate to nearshore marine environments during the non-breeding portion of their annual life cycle (Esler et al. 2000). Harlequin duck inhabit more rugged areas than most other ducks and forage underwater in strong current. They are likely to encounter lingering EVO through consumption of intertidal invertebrates throughout the year, which include mollusks (snails, periwinkles, blue mussels, small clams), crustaceans (hermit crabs, shrimps, amphipods), limpits, and chitons.

Marine Mammals

Three marine mammals have been identified as injured resources in PWS: sea otter, harbor seal, and killer whales. These marine mammals have diverse foraging habits and ranges that affect the likelihood of exposure to lingering EVO.

Sea otters (*Enhydra lutris*) feed in nearshore coastal waters diving for one to five minutes to depths between between 1.5 and 75 m (5 to 250 feet) foraging for food such as clams and mussels. Some sea otters forage at high tide in the intertidal zone where they excavate holes to depths of several feet searching for clams. Sea otters may also inadvertently consume sediment or directly contact EVO as they forage. Thus, they have a high potential for direct exposure to lingering EVO during excavation and could also be exposed via consumption of intertidal mollusks.

Harbor seals (*Phoca vitulina*) mostly live in coastal waters venturing as far as 240 km (150 miles) from their birthplace; occasionally they travel up to 80 km (50 miles) offshore. When diving for food, they can stay underwater for approximately 20 minutes and go to depths of 180 m (600 feet). While most of their diet is fish, they also eat squid, octopus, eulachon, and capelin. The primary mechanism for exposure to lingering EVO is indirectly through food-chain transfer. However, their wide foraging range suggests that exposure to lingering EVO via this pathway would be rare.

Killer whales (*Orcinus orca*) of the resident AB pod in PWS were historically the most commonly occurring whales. They hunt for fish in groups and prefer to eat salmon, herring, halibut, and cod. Their primary exposure pathway to lingering EVO is through food-chain transfer of EVO constituents that are not metabolized in the prey consumed. However, the AB pod of killer whales has little or no potential for exposure to lingering EVO. Of the eight resident pods of killer whales that live in PWS (approximately 155 individuals), the AB pod (approximately 36 individuals prior to the spill) is the pod that was most frequently sighted prior to the spill (Matkin and Saulitis 1997, EVOTC 2002). This pod of killer whales mostly consumes fish (salmon, herring, halibut, cod), and food-chain transfer is the only likely mechanism by which these whales may be exposed (indirectly) to lingering EVO. The pod is primarily in the PWS area during the salmon migration during the summer. Resident killer whales generally travel offshore throughout the sound. On occasion they will approach specific beaches in the sound to rub their bodies on the rounded stones in shallow waters, but these beaches have not been identified as sources of lingering EVO (Matkin and Saulitis 1997).

CONCLUSIONS

A general CEM was developed to support the evaluation of the nature and extent of lingering oil and present-day resource injuries that can be linked to lingering oil from the Exxon Valdez oil spill. The CEM consists of two major components, namely the chemical and physical processes that determine the nature and extent of lingering EVO in PWS, and the ecological resources present in PWS. The CEM represents a series of working hypotheses regarding the potential link that exists between lingering EVO and current resource injuries.

The chemical and physical process which determine the fate and transport of EVO, and ultimately its nature and extent, were defined in the CEM as they occurred immediately after the spill in open water and from the time EVO landed on the beaches of PWS and its subsequent persistence in the intertidal zone. Fifteen years after the original spill, EVO contamination in the open water is not present in measurable quantities. EVO on the surface of beaches persists in limited and localized intertidal areas and is present in predominantly weathered forms. EVO sequestered beneath the beach surface appears to persist to a greater extent than surface EVO, and it is generally less weathered. Subsurface EVO may also be re-introduced to the surface by storm events, bioturbation by benthic organisms, and by sea otters.

Given the absence of EVO in open water, resources cannot reasonably be expected to come into contact with EVO in this environment. Therefore, no exposure pathway exists under current conditions to connect resources to EVO in open water. However, a complete exposure pathway may exist to link surface and subsurface EVO in the intertidal and possibly the nearshore subtidal zones with ecological resources. Resources with the greatest potential for exposure to lingering EVO are those directly associated with the benthic intertidal and nearshore subtidal habitats: sediments, intertidal communities, clams, mussels, Pacific herring, Harlequin duck, and sea otter. Potential exposure to lingering EVO diminishes for those resources that are residents of nearshore communities and forage in open water at depths and distances beyond direct influence of lingering EVO. Seabirds and harbor seals can forage in nearshore areas, but usually at depths that prohibit direct exposure to intertidal resources. Killer whales of the AB pod are unlikely to have significant exposure to lingering EVO because they range widely in distant offshore areas and forage on higher trophic-level organisms with low potential for food-chain accumulation of EVO constituents.

The CEM serves as the foundation from which more detailed evaluations can ensue. These include evaluations of the weathering, toxic fraction, bioaccessibility, bioavailability and nature and extent of lingering EVO, as well evaluations of the biological processes of exposure, uptake, and transfer of toxic EVO constituents among ecological resources. The

CEM, in conjunction with these detailed evaluations, will be used to identify the possible presence and extent of potential links between lingering EVO and current resource injuries by defining their spatial and temporal associations.

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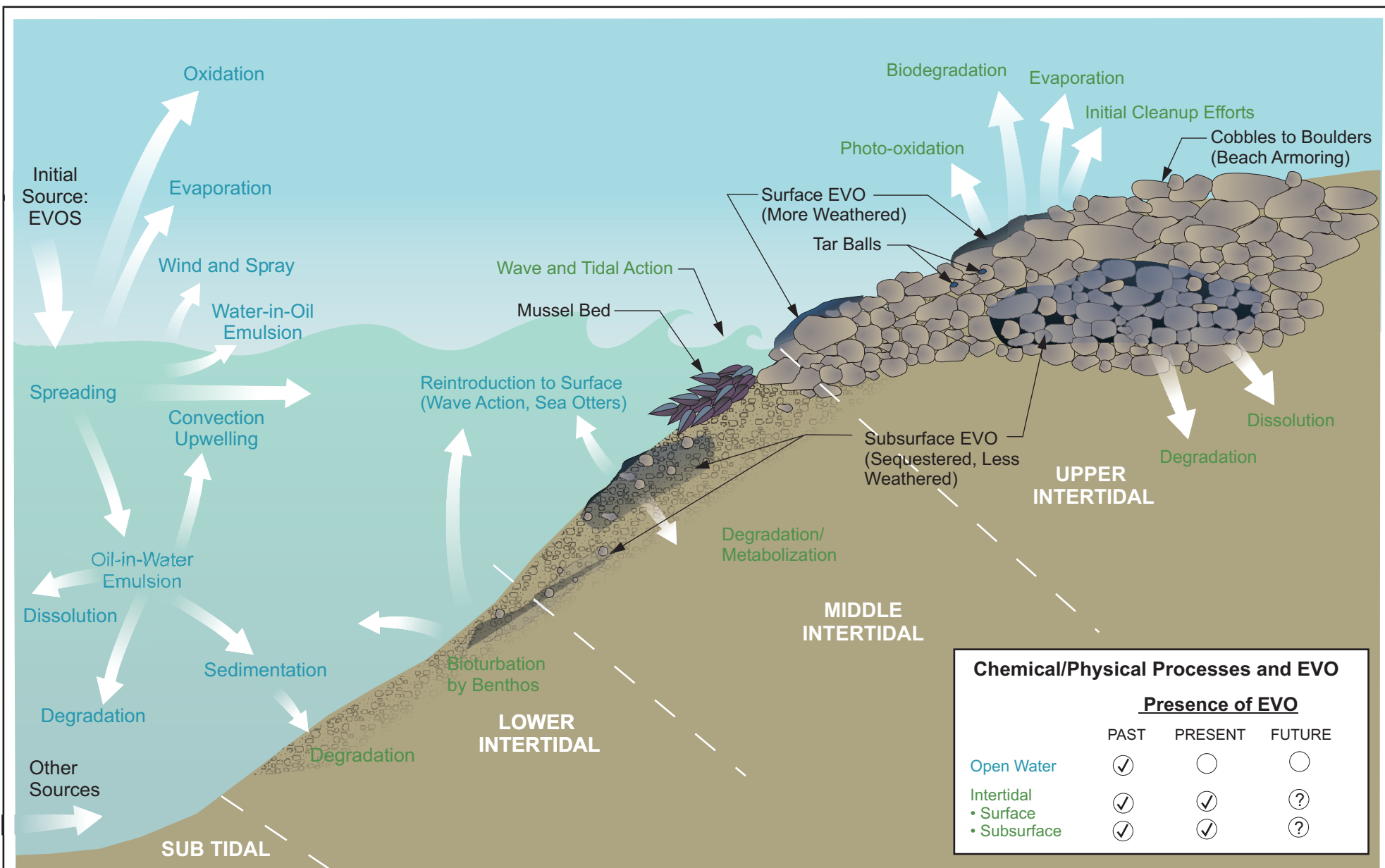
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Chemical/Physical Processes and EVO

	Presence of EVO		
	PAST	PRESENT	FUTURE
Open Water	✓	○	○
Intertidal	✓	✓	?
• Surface	✓	✓	?
• Subsurface	✓	✓	?

Figure 1. Exxon Valdez Oil General Conceptual Exposure Model - Chemical/Physical Processes

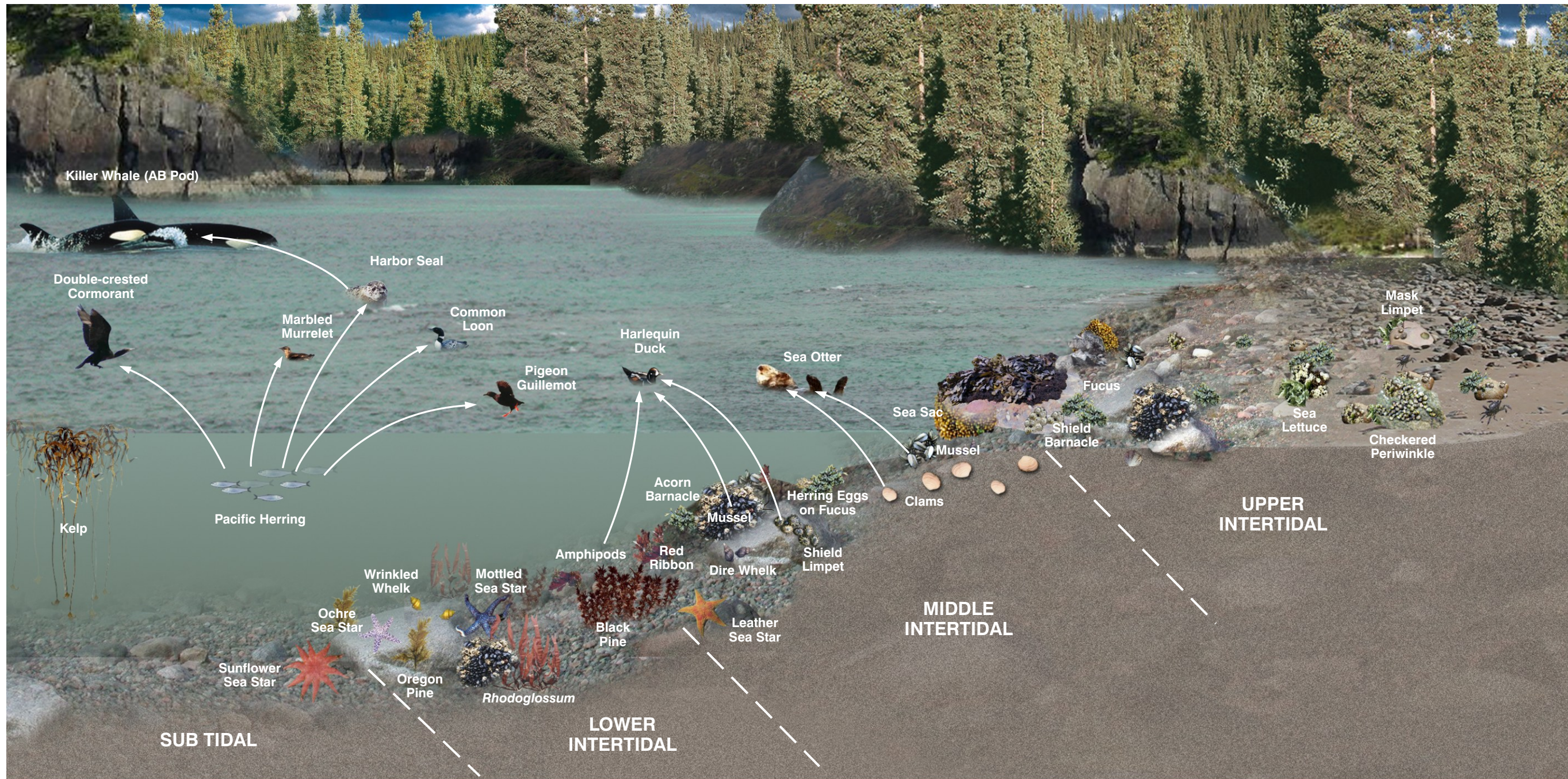


Figure 2. Exxon Valdez Oil General Conceptual Model - Food Web Relationships for Injured Resources