4 Biological Resources

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Chapter 4.
Biological Resources

Introduction

Determining which biological resources may be at risk in an environment threatened by an oil spill is an important part of spill response. This information will be an integral part of establishing priorities for protection efforts, and deciding on an appropriate response strategy. The following questions about biological resources are some of the first that will need to be answered during a spill event:

- What are the biological resources (including birds, plants, invertebrates, fish, mammals) that inhabit the areas potentially impacted? (Consider as well, human uses of resources, such as fisheries and recreational activities)
- What is the likelihood that these resources will be impacted by oil, and what kind of impacts can be anticipated?
- How sensitive are these resources to oil?

Answers to these questions will provide the information needed to address related issues, including establishing priorities for habitat protection, and evaluating possible response strategies.

Evaluating resources at risk

When drawing up a list of the resources at risk in a given area, seasonal migrants as well as resident populations should be included. Detailed information on the life stages present at any given season will aid in determining the sensitivity of different populations.

For advance planning, regions may wish to establish databases on biological resources and habitat locations in their region. Resource information should be updated periodically. Other available sources of information include state resource agencies, Federal agencies (such as U. S. Fish and Wildlife Service for information on birds and some mammals, NOAA for fisheries and marine mammals), experts from local academic or other institutions, Environmental Sensitivity Maps (ESI) and personal knowledge.

Factors affecting oil impacts on biota

A number of different factors will determine the degree of effects that can be expected from an oil spill. These can be grouped into degrees of severity, such as, heavy, long-lasting effects, intermediate levels of effects, and comparatively little or no effects (NAS 1985). The following factors, many of which have been discussed previously, will all be important in determining the levels of impact on biota:

- *Geographic location*

- *Oil dosage and impact area*
  Different habitat types within an area may be impacted quite differently. For example, in the intertidal zone, the lower intertidal usually contains the most diverse group of species. Frequently, however, oil impacts are heaviest in the upper intertidal zone. This was the case in many parts of Prince William Sound after the *Exxon Valdez* spill.

- *Oceanographic and meteorological conditions*
  The physical exposure and weather conditions at a site will determine not only where oil may strand on the shoreline, but will also indicate how quickly oil will weather once stranded on that shoreline. Habitats in high energy environments will likely experience much shorter residence time of oil than habitats in sheltered, low-energy environments.

- *Season*
  Population concentrations of species that may be present in the impacted area will include those that are not year round residents, but may be present seasonally in large aggregations. These will include migratory birds, and mammals, and fish spawning aggregations. Season and temperature will also determine the behavior of species present in the area that may affect their vulnerability to oil. An example is salt marsh crabs which were impacted during winter by a spill in Arthur Kill, New Jersey. Oil in sediment drove the crabs out of their burrows during extremely cold temperatures, causing increased mortality (Burger et al. 1991).

- *Oil type*
  The toxic properties of the oil and its longevity (i.e. how quickly it will evaporate) will strongly influence the impacts that can be expected in a particular habitat.

Overview

Toxicity

Toxicity is defined as, "The inherent potential or capacity of a material to cause adverse effects in a living organism" (Rand and Petrocelli 1985). Another way of saying this is that no chemical is completely safe, and no chemical is completely harmful. Concentration, duration of exposure, and sensitivity of the receptor organism will all determine the toxic effect.

Sensitivity

Sensitivity to toxic compounds varies greatly by species, by life stage within a particular species, and by individual. In general, younger stages are more sensitive than adults (for example, eggs and larvae are often more sensitive than adult fish), but some exceptions exist (See Figure 4-1; NAS 1985).

Oil impacts between species groups vary. Though individual exceptions undoubtably exist, a broad categorization can be made for the anticipated degree of impact as follows (NAS 1985):

Little to no long-term effects:	annelids, gastropods, copepods
Some effects:	macrophytes, barnacles
Long-term effects:	corals, bivalves, decapod crustacea

Within one species, individual characteristics will also determine the degree of impact, including age, sex and contamination history. A study on kelp shrimp found that animals that had been previously exposed to naphthalene (a component of oil) had less tolerance to the compound. In contrast, pink salmon exhibited the opposite effect; fish that were previously exposed to naphthalene had significantly greater tolerance when tested later with bioassays (Rice and Thomas 1989).

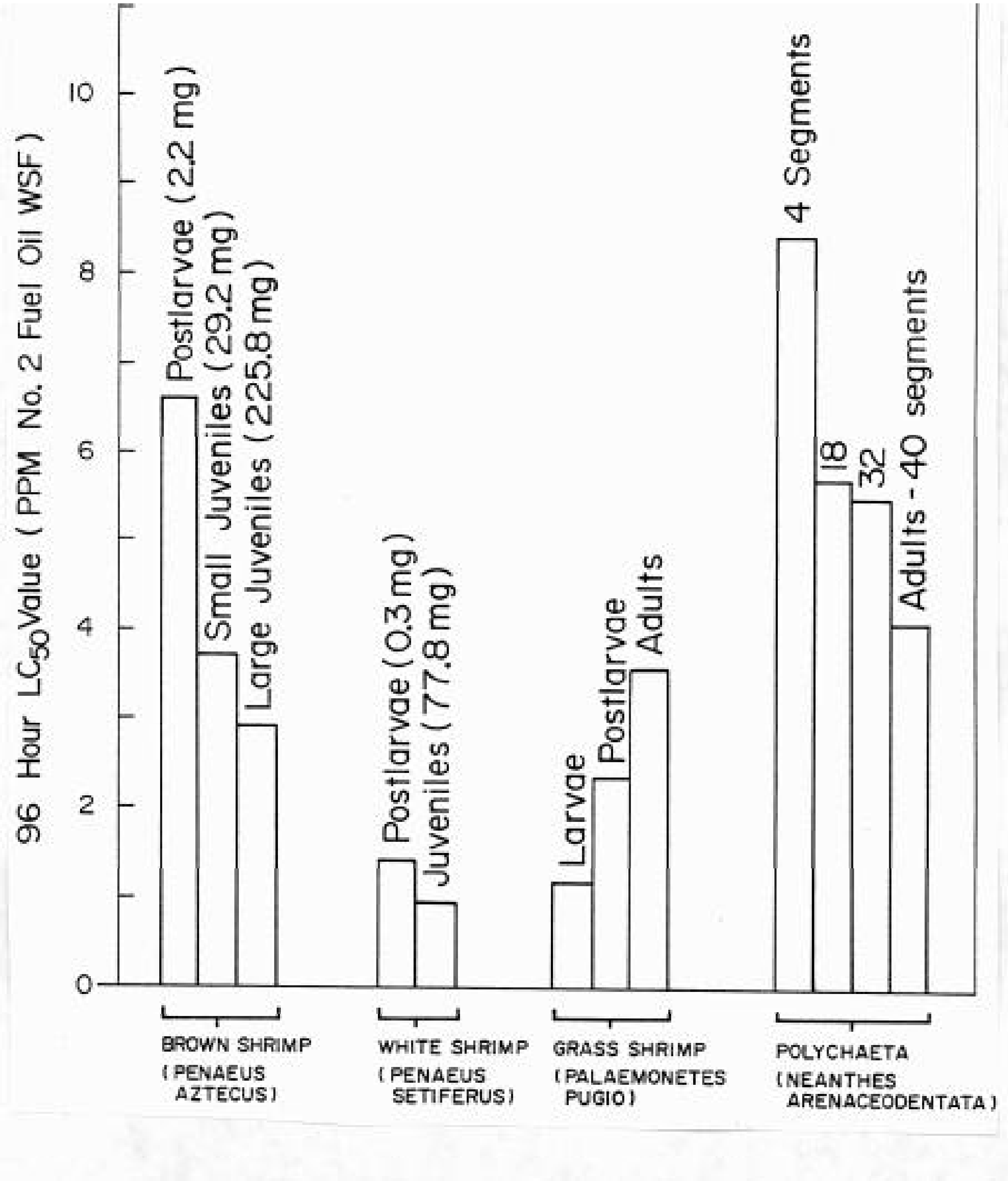


Figure 4-1. Toxicity of No. 2 fuel oil to life-cycle stages of selected marine shrimp and polychaetes. Life-cycle stages are indicated by size or segment number (NAS 1985).

Acute effects

Acute toxicity refers to immediate impacts that result in death of the organism. One acute effect of oil on shoreline organisms is the physical process of smothering (NAS 1985). Intertidal invertebrates and some plants may be especially sensitive to smothering. Acute effects can also result from the toxic components of the oil. Acute toxicity will be dependent on the toxic properties of the oil (a combination of the oil type and weathering), and the concentration and dose that the organism receives (See Figure 4-2).

Studies conducted at the *Amoco Cadiz* spill in France documented acute effects to subtidal amphipods. A reduction in biomass of approximately 40% was measured for certain amphipod populations immediately after the spill (Dauvin and Gentil 1990).

A single dose of a toxic substance at a high concentration can have the same effect as repeated doses at lower concentrations. The salt marsh plant *Juncus roemerianus* showed the same acute response to one exposure of crude oil at a concentration of 1,500 ml/m2, as to 6-10 successive spills of a concentration of 600 ml/m2 (de la Cruz et al. 1981).

Chronic effects

Some toxic effects may not be evident immediately, or may not cause the death of the organism. These are called chronic, or sublethal effects, and they can impact an organisms' physiology, behavior, or reproductive capability. Chronic effects may ultimately impact the survival rates of species affected. Chronic effects are harder to detect than acute effects and may require more intensive studies conducted over a longer period of time.

Many chronic effects result from stress responses in the physiology of an organism, such as increased metabolism, increased consumption of oxygen, and reduced respiration rate. These can be short term responses, but over extended periods of time, may cause other impacts to the organism. A common chronic response is reduced growth rates, for example in benthic organisms that live in chronically oiled sediments.

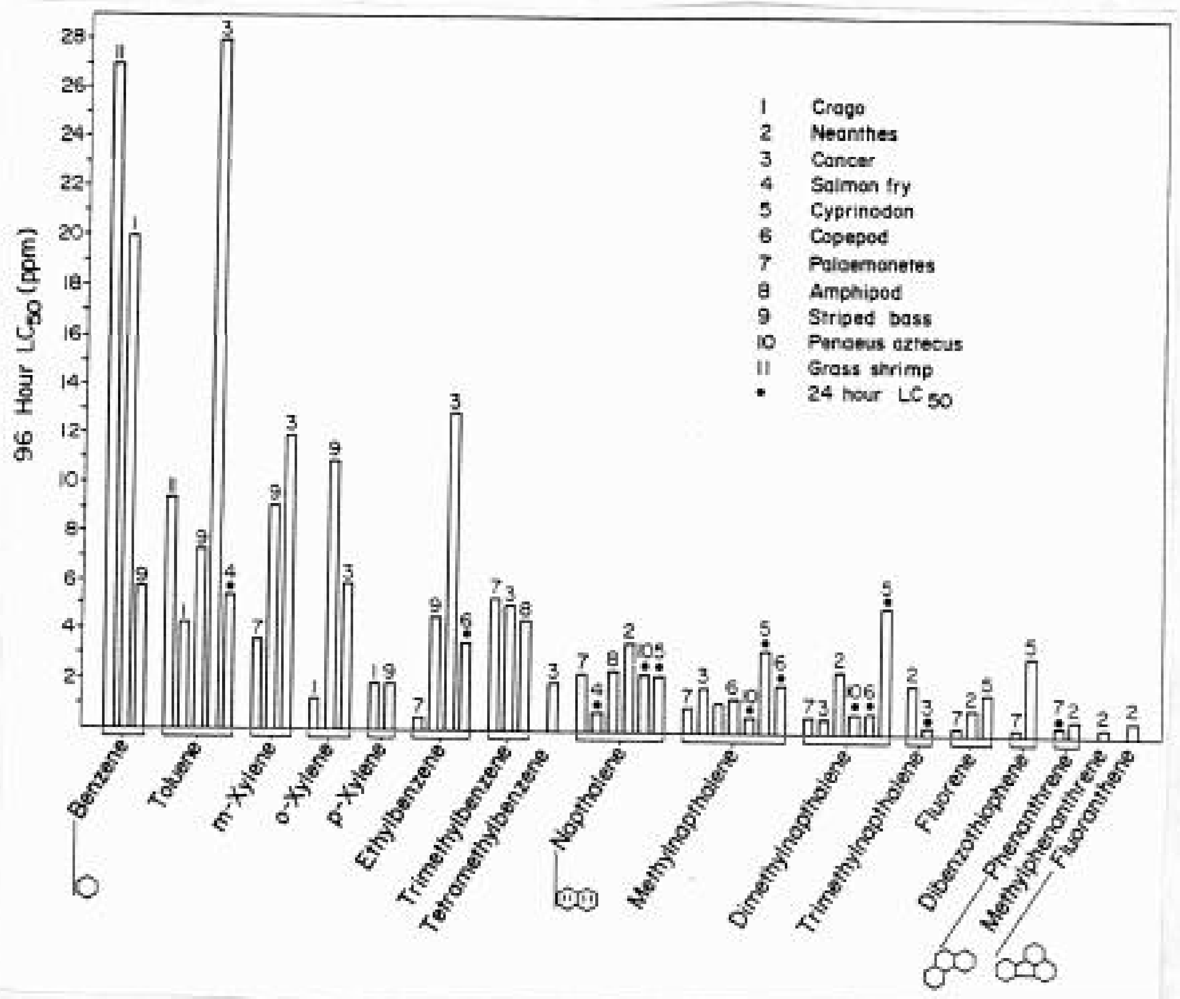


Figure 4-2. Acute toxicity (24- and 96- hour LC_{50} static tests) of some aromatic hydrocarbons for selected marine macroinvertebrates and fish (NAS 1985).

For plants, primary productivity or photosynthesis may be affected. Low concentrations of crude oil (250 ml/m2 and 600 ml/m2) affected primary productivity of *Juncus* salt marsh plants (de la Cruz et al. 1981).

Effects on reproduction from chronic exposure to oil in sediments has been documented for benthic fish species. Effects have been found for those species that spend most of their life cycle in intimate contact with contaminated sediments, for instance, flatfish such as English sole or Winter flounder (Kuhnhold et al. 1978).

Changes in behavior have also been noted for several species of fish and invertebrates when exposed to oil. Littleneck clams (*protothaca staminea*) buried themselves in sediments more slowly and at shallower depths in oiled sediments, compared with unoiled sediments. This behavior increased the clams vulnerability to predation by Dungeness crabs (Pearson et al. 1981). Reduced feeding rates have been measured for lobster larvae, adult copepods, and benthic worms (NAS 1985).

One mechanism of impact of a sublethal effect is the disturbance of an organism's chemosensory ability. Dungeness crab were found to have a decreased ability to detect littleneck clams (their prey) after exposure to crude oil. The blocking or disruption of the crabs chemosensory ability was thought to be the cause (Pearson et al. 1981)

Bioaccumulation

Bioaccumulation can be defined as the uptake of a contaminant by an organism from water directly or through consumption of contaminated food. Organisms that live in a contaminated environment, for example, mussels in oiled sediments, may appear to be healthy but still contain elevated levels of petroleum compounds in their tissue. Some components of oil can be bioaccumulated by marine organisms, particularly the group of longer lasting compounds known as polycyclic aromatic hydrocarbons (PAH).

Biomagnification is defined simply as the magnification of concentrations of a contaminant over two or more trophic levels. One concern with bioaccumulation is that contaminated organisms (such as mussels) may be eaten by higher trophic level organisms (such as otters). If biomagnification was occurring, the higher level predator (the otter) could concentrate contaminants to a level which would cause toxic effects. In the case of organisms that are harvested by humans, concerns about bioaccumulation may cause restrictions on collecting shellfish or other items consumed by humans.

Bioaccumulation may cause chronic effects to the organism involved and may also cause potential food web impacts (Widdows et al. 1987). In a field study conducted in Prince William Sound after the *Exxon Valdez*, bioaccumulation of PAH in intertidal mussels, snails, and drills was measured. However, no evidence of biomagnification was found (ERCE 1991). In the case of oil components such as PAHs, the compounds do not usually reside in the tissue for long periods of time before they are depurated. Thus, biomagnification is not usually a major concern with petroleum compounds originating from oil spills.

Bioavailability and uptake

Though all animals can take up hydrocarbons from water column directly and from food, the processes of uptake vary by species group. Macroinvertebrates can take up hydrocarbons, and the majority also metabolize them readily, with the exception of the molluscs. Within invertebrates, detritus feeding bivalves usually accumulate more hydrocarbons than suspension feeders. Depuration rates vary, but can range from a few days to much longer. Levels of hydrocarbons in fish are usually higher in liver and neural tissue than in muscle tissue. Their efficiency of uptake from food may be low (NAS 1985). Fish also have enzyme systems capable of processing aromatic hydrocarbons relatively efficiently. Contaminated sediments can provide a source of hydrocarbons to benthic fish such as flatfish.

Not all contaminants that are present in the environment will be bioavailable to organisms in the habitat. Bioavailability will be determined by a set of complex physical and chemical parameters, for instance, the amount of particulates and organic matter that may bind to the petroleum compounds, or the concentration of dissolved hydrocarbons in the water column.

Ecological effects

Some ecological effects that alter predator-prey interactions may result from a spill and result in changes in species composition or relative numbers of species in an area. This may be caused by the elimination of predators due to mortality, such as was postulated in the case of the *Tsesis* spill in Sweden. Here, an increase in growth of phytoplankton was measured shortly after the spill, and this was postulated to be a result of less than normal predation by zooplankton. Since zooplankton had experienced high mortality after the spill, this represented a direct predator-prey relationship (Johansson et al. 1980).

A similar effect may result from the fact that oil spills sometimes result in temporary closures in commercial fisheries. This also removes predatory pressure on fish populations, which may result in an increase in the fish population.

Summary

- *Resources at risk*
  resident and seasonal populations, life stages

- *Toxicity*
  varies by sensitivity of organism
  - acute - immediate, of short duration
  - chronic - sublethal, of long duration

- *Bioaccumulation*
  invertebrates accumulate hydrocarbons
  fish accumulate in liver and neural tissue, not in muscle
  biomagnification is not generally found with hydrocarbons

- *Ecological effects*
  predator - prey interactions may be affected

Open water communities

Marine birds

Marine birds can be divided into six broad categories based upon their behavior and sensitivities to oil spills. These include:

- Seabirds
  - Surface-feeding pelagic seabirds—albatrosses, petrels, fulmars, and shearwaters
  - Diving pelagic seabirds—auks, murres, murrelets, puffins, guillemots, and auklets (auks and alcids)
  - Diving coastal seabirds—pelicans, cormorants, frigatebirds, tropicbirds, gannets, and boobies
  - Surface-reeding coastal seabirds—kittiwakes, skuas, and jaegers
- Gulls and terns
- Raptors—osprey, bald eagles, and peregrine falcons
- Shorebirds—plovers, turnstones, surfbirds, sandpipers, phalaropes, and oystercatchers
- Wadingbirds—herons, egrets, bitterns, rails, ibises, cranes, spoonbills, stilts, and avocets
- Waterfowl—swans, geese, diving and dabbling ducks, mergansers, coots, gallinules, loons, and grebes

Effects of oil on birds

Bird species experience a variety of documented effects when exposed to spilled oil. These effects include:

- Fouling of plumage
- Ingestion of oil
- Effects on reproduction
- Physical disturbance

These effects are outlined below.

Fouling of Plumage. The primary direct effect from exposure to oil is fouling of plumage. Oil causes disruption of the fine structure of the small strands that form the feathers, causing loss of their water-repellent characteristics. The oiled plumage becomes matted, allowing water to penetrate to the body surface, which results in chilling and hypothermia as well as a loss of buoyancy. The ultimate cause of death of heavily oiled birds is believed to be hypothermia in most cases (Fry and Lowenstine 1985; Wood and Heaphy 1991).

The quantity of oil necessary to result in death of the individual is unknown. Tuck (1961) reported that only a small spot of oil on the belly is sufficient to kill murres, and Fry and Lowenstine (1985) reported that 3-5 ml on breast feathers was able to kill two of three Cassin's auklets tested. It has been theorized that other non-pelagic species may be much less sensitive to small quantities of oiling than the more pelagic species such as auks and murres, because they do not utilize the cold, offshore waters to the same extent. Birkhead et al. (1973) reported observations of visibly oiled gulls, guillemots, and razorbills successfully cleaning themselves after several weeks.

Ingestion of Oil. Oiled birds can readily ingest oil during preening or by consuming/scavenging contaminated prey. The effects of ingested oil include anemia, pneumonia, intestinal irritation, kidney damage, altered blood chemistry, decreased growth, impaired osmoregulation, and decreased production and viability of eggs (RPI 1988; Wood and Heaphy 1991). Hemolytic anemia is defined as the most severe effect of ingested oil; anemic birds cannot dive or forage for food and starve on beaches—even after being cleaned.

The quantity of oil required to elicit the responses outlined above is highly variable. The consumption of as little as 0.5 grams of oil has been found to inhibit certain physiological responses, while others remain intact (Clark 1984). As a result, it is not clear to what extent these physiological effects contribute to mortality following oiling, given the rapidity of death from hypothermia or drowning. It is evident, however, that ingestion of oil can contribute to the overall impacts of oil spills.

Effects on Reproduction. Direct exposure of eggs to oil has the greatest potential for damage. Previous studies have shown that small quantities of oil (as little as 1 microliter) applied to eggs reduce survival in a number of species (Crocker, et al. 1974; Holmes and Cronshaw 1977; Miller et al. 1978; Ohlendorf et al. 1978; Stickel and Dieter 1979; Peakall and Gilman 1980; Peakall et al. 1981; Clark 1984; Fry and Lowenstine 1985). Exposure during the early states of incubation are considered the most toxic. It is easy to understand how oiled adult birds can transfer toxic doses of the oil to eggs during nesting. Reports of actual impacts to eggs from oiled adults indicate there is a significant potential for reduced reproductive success in oiled birds. Reproductive success has also been shown to be affected during oil spills. Adults that are exposed to sublethal doses of oil and then ingest it may produce fewer eggs or cease laying eggs altogether. Although not documented for all bird species, there is the potential for oiled birds to experience a decline in egg production. The viability of the eggs produced following ingestion may also be reduced.

Furthermore, adult Cassin's auklets and wedge-tailed shearwaters have been shown to abandon a nesting colony even when exposed to small quantities of oil. Those adults that do attempt to nest often have a delayed or failed egg production and low hatching success. Future losses may also be realized as breeding failure may result in the birds changing mates in following years and further reducing the reproductive success. The effects of oil on other bird species are assumed to be similar to those experienced by auklets and shearwaters.

Physical Disturbance. An indirect impact of an oil spill is a result of disturbances from the physical intrusion of man during cleanup efforts. The influx of personnel and machinery to a spill site can cause a disturbance to individual birds, to breeding colonies, and to roosting areas in the vicinity of the cleanup site. Disruption of breeding will result in the greatest losses to both present and future generations.

Vulnerability for Species Groups. The overall effects of an oil spill differ considerably among bird species, due largely to differences in behavior, distribution, and reproduction. These and other characteristics are used to identify or rank bird species as to their vulnerability to oil. For ease of assimilation, the bird categories have been identified as having either a high vulnerability or low vulnerability to oil spills.

Highly vulnerable bird species are those that are closely associated or are fully dependent upon the marine environment. The following list identifies characteristics which make some bird species more vulnerable to oil spills than others:

- Frequent diving for food
- Prolonged roosting on the water
- Formation of large flocks
- Formation of dense nesting colonies in oil-spill susceptible areas
- Percent of time spent on the open ocean
- Low reproduction rates and cycles

Using this list of characteristics and observations at spills, the following bird groups are considered **highly** vulnerable to oil spills:

- Seabirds:
    - auks, murres, murrelets, puffins, guillemots, and auklets
    - storm petrels
    - pelicans and cormorants
- Waterfowl:
    - diving sea ducks (eiders, scoters), geese, loons, and grebes
- Raptors:
    - bald eagles

The majority of these birds species spend up to 24 hours associated with the water. During a spill, large numbers of these individuals may be affected as they are constantly diving for food and form large flocks while roosting on the water. During the nesting season, entire breeding colonies may be affected or destroyed as they often form dense nesting colonies in areas highly susceptible to oil spills.

Presently, the alcids are considered the most susceptible of all marine birds to spilled oil. These species occur in cold offshore waters where they often form large flocks and spend much of their time swimming or floating in the water. Pelicans as well as the other seabirds listed are considered highly susceptible due to their feeding characteristics, small populations, status as an endangered species, and low reproduction rates. These birds inhabit openwater territories, where the likelihood of encountering spilled oil is relatively high.

During migration, diving sea ducks and geese are highly vulnerable to oil spills as they use offshore and coastal marine waters for staging and overwintering. These species often occur in very large flocks in relatively exposed, open-water areas. Certain species of loons and grebes are also considered highly susceptible from oil spills even though they all do not form large flocks. The western and Pacific grebes and loon species are highly adapted to aquatic existence and rarely leave the water. They occur in open-water marine habitats during much of the year. In addition, the Pacific grebe winters in large flocks in coastal marine areas of California, Oregon, and Washington.

Bald eagles are considered to be highly vulnerable to oil spills. Although they rarely enter the water and are unlikely to be oiled, they have a small population and a very long recovery rate. The major concern regarding bald eagles is their predisposition to consuming oiled prey. As mentioned previously, ingested oil can have a multitude of effects on bird populations.

Bird species which are considered as having a **low** susceptibility to oil spills are those that are seldom associated with the open marine environment or that are highly adaptable. The following list identifies characteristics which make some bird species less vulnerable to oil spills than others:

- Rarely immersed in water
- Large percent of time spent on land or sheltered water bodies
- Prolific breeders
- Able to avoid oiled areas by shifting habitats

Bird populations which are considered to have a reduced vulnerability to spilled oil include:

- Gulls and terns
- Shorebirds
- Waterfowl
  - dabbling ducks and coots
- Wading birds
  - herons, egrets, and rails

The majority of these bird species are not as reliant on marine habitats or are fairly adjustable in their habitat preferences. Although many of these bird species utilize the marine environment, their behavior is such that it is very unlikely that they would be impacted by spilled oil.

Gulls are well known for their ability to exploit a wide range of habitats and food sources, in addition to being prolific breeders. It is theorized that gulls are readily able to avoid oil spills, since so few oiled gulls have been observed during spills. Terns are also considered to have a low risk of being directly oiled, although disturbance of nesting colonies may occur during cleanup. Shorebirds rarely encounter the water and are unlikely to be directly contaminated by spilled oil. It has been shown that shorebirds will avoid oiled areas, if there are suitable, unoiled feeding and resting areas available. Shorebirds can be indirectly impacted by loss of prey on oiled beaches, especially if the oiled area is an important feeding site on a long migration route.

Dabbling ducks are considered to have a low vulnerability to oil because they are rarely found in waters where oil spills occur. Their reliance on freshwater habitats in particular tends to reduce the likelihood of encountering oil spills. Wading birds have low vulnerability to spilled oil because they rarely enter the water other than to wade in shallow, sheltered waters. Wading birds feed by capturing prey near the surface of the water. Outside of contacting oil on their head/face during feeding or on their legs while wading, this category of birds are unlikely to be directly impacted by spilled oil.

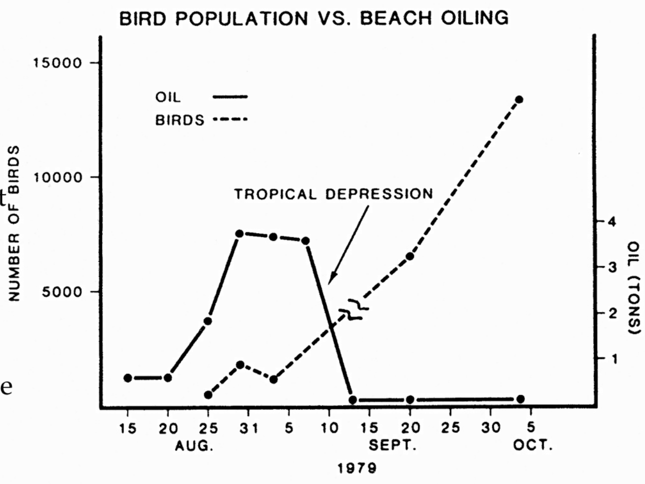
Case histories of oil spill impacts on birds. A large proportion of the knowledge we have gained regarding birds and oil are from observations at previous spills.

Ixtoc 1. On 3 June 1979, a PEMEX exploratory well, the *Ixtoc 1*, blew out in the Bay of Campeche, Mexico. This spill was not brought under control until nine months later, on 27 March 1980. An estimated 140 million bbls of oil was released during this time.

> By 6 August 1979, the *Ixtoc 1* oil began impacting the Texas coastline. "Throughout the late summer and early fall of 1979, the barrier islands along the south Texas coastline were periodically impacted by oil. Padre Island and the Laguna Madre are known to be one of the most important staging and wintering areas for waterfowl, shorebirds, and colonial waterbirds in the United States (Getter et al. 1981)."

Numerous beach bird surveys were conducted. The majority of the birds identified during these surveys were shorebirds (e.g., sanderlings and willets). The surveys determined that the bird populations responded directly to oil concentrations on the beach; as oil moved on shore, birds abandoned the affected areas of the intertidal beaches and redistributed themselves into relatively clean areas, often further back on the berm tops. By the end of August, most of the normal shorebird habitat (the intertidal beach) was oiled. As a direct result of the oil presence, the total number of shorebirds declined, however, no oiled shorebirds were ever recovered, and it has been theorized that the shorebirds shifted habitats to "secondary" areas (Fig. 4-3).

Figure 4-3. Number of birds versus beach oiling, expressed in thousands of tons, on Padre Island, Texas during the Ixtoc 1 oil spill (between 15 August and 3 October 1979). Note a steady increase in the number of birds on the beach after oil was removed from the beach during the passage of a tropical depression (Getter et al. 1981).



Birds with oiled plumage never constituted more than ten percent of the total population observed during the beach surveys. The percentage of the oiled birds increased during late August, with oil coverage ranging from slight oiling of the feet to extensive (>75 percent oiling of their bodies). Royal terns were initially the species most impacted by the oil spill. By late August, "approximately 40 percent of the observed royal terns had oil on their breast feathers. However, by mid-September, royal terns avoided the high-tide line and congregated on the berm above the tar concentrations" (Getter et al. 1981). In addition, many of the wading birds were discovered to have oiled feet from feeding in oiled areas. Great blue herons, black-crowned night herons, snowy egrets, and cattle egrets were all observed to have heavy coatings of tar/oil on their feet. In a few instances, the oiling appeared to impact the bird's natural walking and flying abilities.

After natural/assisted shoreline cleanup efforts, the shorebirds reinvaded the intertidal beaches. At first, the number of birds that returned to the beach were less than before the spill, indicating that some reduction of the shorebird populations may have occurred. Over time, however, the shorebird populations increased due to the influx of migratory birds.

Only twenty-six oiled birds were recovered and turned over to rehabilitation centers during the *Ixtoc 1* spill. "Few carcasses or oil-immobilized birds were found. Carcasses that were found were mostly pelagic species. Shorebirds that succumbed to either direct or indirect effects of oil pollution were likely eaten by coyotes...that were often observed patrolling the beaches in the early morning" (Getter et al. 1981). The majority (eight) of the birds recovered were blue-faced boobies.

Apex Houston. On 28 January 1986, the *Apex Houston* left Martinez, California, heading for Long Beach, California, under tow by the tugboat *Inca*. The *Apex Houston* was carrying a cargo of San Joaquin Valley crude oil. On 1 February 1986, the tow line broke, and upon boarding the *Apex Houston*, *Inca* personnel discovered that the hatch cover to the number four port tank was not in place and that a small but undetermined amount of the crude oil had been spilled.

Large numbers of oiled birds started appearing on beaches from Bodega Head to Monterey Bay on 1 February. Over the next few days, thousands of oiled birds were recovered. More than 10,500 marine birds were estimated to have been affected by this spill (Page and Carter 1986).

Two species of diving pelagic seabirds, common murres and rhinoceros auklets, were severely impacted by this spill, both in terms of the number of oiled birds recovered and the percentage of the local population of the species affected (Table 4-1). The data of Table 4-1 presents only the observations made during the 1-8 February 1988 period, in order to focus on the potential effect of the *Apex Houston* spill. The birds recovered during these eight days constitute 87.2 percent of the total of the oiled birds recovered during the months of January and February 1986.

This spill exemplifies how a very small amount of oil can have significant impacts to bird populations that are concentrated in a small local area.

Nestucca. On 22 December 1988, the barge *Nestucca* spilled 231,000 gallons of Bunker C just north of the Columbia River (Yaroch 1991). More than 3,000 live birds were recovered from Washington shorelines and turned in for treatment; 2,000 of these eventually died. Over 6,000 dead birds were observed along the shoreline. Common murres made up nearly 80 percent of the oiled birds recovered during this spill. Grebes and scoters were also significantly impacted (Yaroch 1991).

In Canada, nearly 3,600 seabirds were collected from the west coast of Vancouver Island. As in Washington, common murres were the major victims of this spill, making up 42 percent of the recovered birds. Cassin's auklets made up 32 percent of the oiled species (Harding and Englar 1989).

Exxon Valdez. On 24 March 1989, the oil tanker *Exxon Valdez* ran aground in Prince William Sound, Alaska, spilling approximately 11.3 million gallons of Alaskan north slope crude oil. Over the next two months, the slick encompassed approximately 25,000 km^2 of coastal and pelagic waters, home to approximately 500,000 marine birds (Piatt et al. 1990).
Following the initial notification, the International Bird Rescue Research Center (IBRRC) established four rehabilitation centers for impacted birds. During the course of their six months of operation, 1,630 oiled live birds representing 71 different species were captured and brought to the IBRRC rehabilitation facilities. An additional 36,500 carcasses were also recovered from the impacted area (Holcomb 1991; Wood and Heaphy 1991). The actual

number of birds recovered only represents a small fraction of the birds actually killed, which could range up to 300,000.

Table 4-1. Estimated number of birds debilitated or killed by oil between 1 and 8 February 1986 from Salmon Creek, Sonoma County to Point Lobos, Monterey County (from Page and Carter 1986).

Species	**Alive and Sent to Rehabilitation Centers**	**Estimated Total Dead on Beaches**	**Lost at Sea**	**Total**
Loons	123	148	—	276
Small grebes	9	106	—	115
Western/Clark's grebes	155	313	—	468
Unidentified grebes	19	—	—	19
Scoters	61	222	—	283
Common murres	2,924	3,595	969	7,488
Auklets/murrelets	9	168	29	206
(Cassin's suklets)*		(140)	(29)	(169)
Rhinoceros suklets	30	1,201	335	1,566
Other species/ Unidentified birds	29	127	—	156
TOTAL	**3,364**	**5,880**	**1,333**	**10,577**

* The number of Cassin's auklets within the auklets/murrelets category is in parentheses.

Individuals from the widespread populations of ducks and alcids that existed at the spill site were the most common type of dead birds recovered. Several of the more sparsely distributed species, such as bald eagles, puffins, cormorants, loons, murrelets, shearwaters, fulmars, and petrels, were also impacted in large numbers during this spill (Table 4-2).

It has been estimated that ten percent of the existing common murre population that previously existed in the Gulf of Alaska was affected and that more than 50 percent of the population within Prince William Sound was killed (Piatt et al. 1990).

This was the first spill at which large numbers of eagles were oiled. It was estimated that 5,000 eagles occurred in the oiled area. In 1989, 153 bald eagle carcasses were recovered. Thirty-nine live, oiled bald eagles were sent to rehabilitation centers, of which 15 expired. As a result of this problem, a 1990 Eagle Capture program was initiated as a joint effort between Exxon and the U.S. Fish and Wildlife Service.

During this study, 113 bald eagles were captured and examined for signs of oiling and for general health conditions. Of those captured, 74 were immediately released because they were not oiled and were generally healthy (Figs. 4-4 and 4-5). Thirty-eight of the birds were considered oiled to various degrees (light to heavy), however an additional 24 lightly oiled bald eagles were released immediately. Consequently, 87 percent (98) of the captured birds met release criteria. Fifteen of the captured eagles required further medical treatment and were transported to a rehabilitation center (Gibson 1991).

Observations by the capture teams indicated that the bald eagles were not hunting in oiled areas. During capture efforts, the eagles would ignore floating fish snares if they were set too near an oiled area or shoreline.

Table 4-2. Birds killed by the *Exxon Valdez* spill which were retrieved from Prince William Sound (PWS), Kenai Peninsula (KP), Barren Islands, Alaskan Peninsula (AP), and Kodiak between 25 March and 9 June 1989 (Piatt et al. 1989).

	PWS	**KP**	**Barren Islands**	**AP**	**Kodiak**
Number Retrieved	2,793	4,501	1,912	4,258	6,332
			Percent Retrieved by Bird Type		
Murres	14.9	63.2	88.4	91.1	90.7
Sea ducks	25.2	8.7	0.5	1.5	0.5
Murrelets	11.8	4.8	3.7	1.5	2.3
Grebes	11.7	1.8	0.2	0.3	0.2
Loons	8.9	2.0	0.3	0.4	<0.1
Others	27.5	19.5	6.9	5.2	>6.2

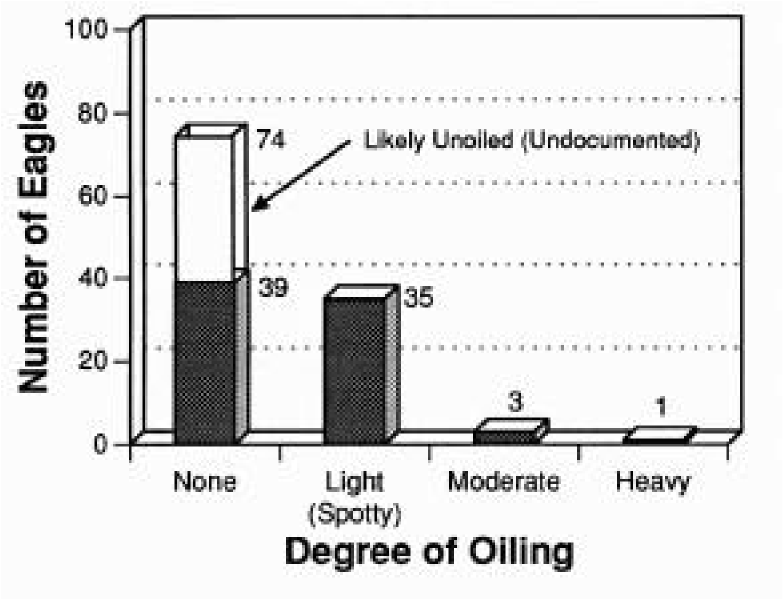


Figure 4-4. The degree of oiling for 113 eagles examined during the 1990 Eagle Capture Program as part of the *Exxon Valdez* monitoring effort (Wood and Heaphy 1991).

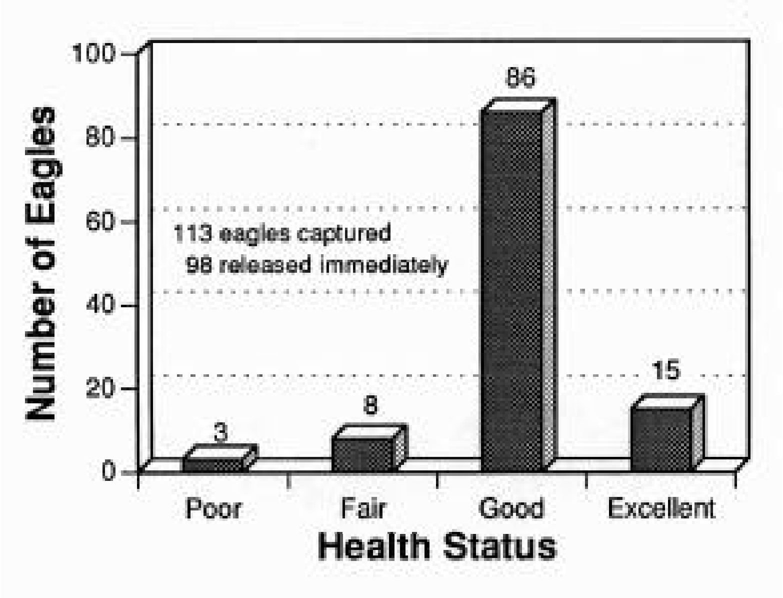


Figure 4-5. The health status of 113 eagles examined during the 1990 Eagle Capture Program as part of the *Exxon Valdez* monitoring efforts (Wood and Heaphy 1991).

Marine Mammals

Marine mammals have a number of behavioral, anatomical, and physiological adaptations that enable them to spend most or all of their lives in the ocean. As a group, they have evolved to be able to utilize nearly every marine environment along the open waters of the world. Along the North American continent, the focus of this report, many diverse marine mammal species exist in a wide range of ecosystems, from the warm, tropical waters of the Atlantic and Pacific Oceans, to the cold, often ice-covered waters of the Arctic Ocean.

In this discussion, pertinent life history data, habitat range, population status, and behavior are given for each of the following mammal groups.

- Cetaceans (whales, dolphins and porpoises)
- Pinnipeds (seals, sea lions, and walruses)
- Sea otters

Primary emphasis is on defining the interaction and effects of oil on marine mammals, which occurs primarily in three ways:

1) direct surface fouling;
2) direct and indirect ingestion with the affects of bioaccumulation; and
3) inhalation of the toxic vapors released from the petroleum hydrocarbons as they evaporate.

Additionally, any behavioral aspects of the species groups which would increase the risk of contamination are identified. A brief synopsis of all expected effects of petroleum hydrocarbons on marine mammals is given in Table 4-3; primary effects expected for oil exposure by all marine mammals are presented first, and unique effects, by marine mammal type, are listed next.

Table 4-3. List of common effects exhibited by marine mammals when exposed to oil.

	Inhalation	Surficial Contact	Ingestion
Marine Mammals (Pertains to All Species)	- Absorption into the circulatory system. - Mild irritation to permanent damage to respiratory surfaces and mucosal membranes.	- Irritation to eyes and skin. - Increased metabolism. - Inhibits thermoregulation.	**Direct Consumption** May result in irritation/destruction of: - intestinal linings. - organ damage. - neurological disorders. - bioaccumulation of toxins. **Indirect Consumption** May occur through grooming efforts. May result in: - transferral of toxins to young via lactation.
Whales and Dolphins		Little or no effect is expected. - May result in a temporary reduction in feeding efficiency for baleen whales.	- Direct consumption unlikely to occur. Exceptions include killer whales and gray whales due to their dietary preferences.
Seals, Sea Lions, and Walruses		- Destroys insulative property of fur. - Young and immature are most at risk.	- Direct consumption unlikely to occur. - Indirect consumption may occur from grooming pups.
Sea Otters	May also affect: - lungs and other organs. - nervous system	- Destroys insulative property of fur. - Young and immature are most at risk. - Often results in the death of oiled individuals.	- Direct consumption unlikely to occur. - Indirect consumption through obsessive grooming behavior has been documented causing degenerative liver lesions, kidney failure, endocrine imbalances, diarrhea, and death.

Cetaceans

Cetaceans, an order composed of whales, dolphins, and porpoises, are warm-blooded relatives of their terrestrial counterparts. Evolutionary forces have altered their four-legged bodies to their present stream-lined, nearly hairless forms. Fore and hind limbs have been replaced with flippers/fins, and broad, flat tail flukes. Thick layers of subcutaneous fat have replaced furred pelts, being a more efficient thermoregulatory aid in their watery environment.

Two suborders of cetaceans exist today:

1) Mysticeti or baleen whales. Large whales that travel in loose associations and have well established migration routes. With few exceptions, these animals have an unlimited, often worldwide, habitat range.

2) Odontoceti or toothed whales, dolphins, and porpoises. This family exhibits a broad range in size and contains the majority of the animal species within the order Cetacea. These toothed whale and dolphin species are very gregarious, often forming large, stable groups or pods with strong kinship bonds.

Table 4-4 lists both the common name and scientific names for the baleen and toothed whales, dolphins, and porpoises found in North American waters. Additionally, the global range, population estimates, and status of the species are listed. As can be seen from Table 4-4, the majority of the baleen whales exist worldwide, and are considered endangered by the United States Endangered Species Act. Additionally, toothed whales and dolphins have worldwide geographical ranges, with a few notable exceptions. However, the majority of the toothed whales, dolphins, and porpoises are not on the endangered species list.

Effects of Oil on Cetaceans

In general, whales, dolphins, and porpoises are considered to have the ability to detect and avoid oil and other petroleum hydrocarbons. Numerous studies were conducted on dolphins regarding their detection abilities (Geraci et al. 1983; Smith et al. 1983; St. Aubin et al. 1985). In all instances, the representative test animals were able to identify the presence of the pollutant and actively avoided contact with surface slicks. Other whales and dolphins

Table 4-4. Geographic range, population estimates, and status of cetaceans common to North America[1].

		Geographic Region	Population	Status*
ORDER Cetacea				
SUBORDER Mysticeti (Baleen whales)				
FAMLY Balaenida (Right whales)				
Bowhead whale	*Balaena mysticelus*	Worldwide	8,500[a]	endangered
Northern right whale	*Eubalaena glacialis*	Worldwide	3,100-3,200	endangered
FAMILY Balaenopteridae (Rorqual whales)				
Blue whale	*Balaenoptera musculus*	Worldwide	11,700	endangered
Brydes's whale	*Balaenoptera edeni*	Worldwide	30,000-56,000	not listed
Fin whale	*Balaenoptera physalus*	Worldwide	105,000-122,000	endangered
Humpback whale	*Megaptera novaengliae*	Worldwide	9,500-10,000	endangered
Minke whale	*Balaenoptera acutorostrata*	Worldwide	315,800-331,800	not listed
Sei whale	*Balaenoptera borealis*	Worldwide	48,000-63,000	endangered
FAMILY Eschrichtiidae				
Gray whale	*Eschrichtius robustus*	N.E. Pacific	21,000	endangered
SUBORDER Odontoceti (Toothed whales, dolphins, and porpoises)				
FAMILY Monodontidae				
Beluga	*Delphinapterus leucas*	Worldwide	40,000-55,000	not listed
Narwhal	*Monodon monoceros*	Worldwide	29,000[a]	not listed
FAMILY Delphinidae				
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	W.N Atlantic	24,000	not listed
Bottlenose dolphin	*Tursiops truncatus*	Worldwide	24,240-33,840[a]	not listed
Common dolphin	*Delphinus delphis*	Worldwide	+1,000,000	not listed

Table 4-4. Continued.

		Geographic Region	Population	Status*
FAMILY Delphinidae (continued)				
Hawaiian spinner dolphin	*Stenella longirostris*	Worldwide	1.1 million	not listed
Killer whale	*Orcinus orca*	Worldwide	1,000[a]	not listed
Long-finned pilot whale	*Globicephala melaena*	Worldwide	13,000-50,000[a]	not listed
Pacific white-sided dolphin	*Lagenorhyncus obliquidens*	Worldwide	50,000[b]	not listed
Risso's dolphin	*Grampus griseus*	Worldwide	10,000[a]	not listed
Spotted dolphin	*Stenella spp.*	Worldwide	3.3 million[b]	not listed
Striped dolphin	*Stenella coeruleoalba*	Worldwide	2.3 million[b]	not listed
FAMILY Phocoenidae (Porpoises)				
Dall's porpoise	*Phocoenoides dalli*	Worldwide	1.4-2.8 million	not listed
Harbor porpoise	*Phocoena phocoena*	Worldwide	18,000[a]	not listed
Vaquita	*Phocoena sinus*	Gulf of California (entire population)	200-300	endangered

[1] Modified from Geraci and St. Aubin (1990).

[*] As listed in the United States Endangered Species Act.

[a] Estimates for North American populations.

[b] Estimates for Eastern North Pacific populations.

probably would also be able to detect and avoid oil contamination. However, in their natural environment, there are many instances where whale and dolphin individuals swam directly into an affected area, not seeming to notice the oil slicks. The question of lethal and sublethal effects of oil on whale, dolphin, and porpoise species has not been successfully answered. The historical observations during actual spills on the effects of oil spills on whales, by species, are summarized in Table 4-5.

Direct Surface Fouling. Direct oiling of whales, dolphins, and porpoises is not considered a serious risk to the thermoregulatory capabilities of these animals. After extensive studies, Geraci (1990) determined that direct surface fouling poses little if any problem to these animals. Any irritation that were to occur would rapidly recover due to a resistant dermal shield found in whale, dolphin, and porpoise skin. This dermal shield has been defined as an extraordinarily thick epidermal layer which is highly effective as a barrier to the toxic, penetrating substances found in petroleum.
The baleen whales, which use baleen plates to feed, presents an area of concern regarding surface fouling. Could these plates became fouled? and if so, Would these individuals survive the oiling? It is possible that oil residues would adhere and clog the baleen plates, thereby interfering with the affected individual's feeding. To date, only one baleen whale has ever been reported as having its baleen plates fouled by oil (Brownell 1971). In an effort to determine the degree of impact, a series of tests were conducted to detect the effects of various petroleum hydrocarbons on isolated baleen plates (Braithwaite 1983; Geraci and St. Aubin 1982; 1985). The tests show that even the heaviest of petroleum compounds may only temporarily reduce a baleen whales feeding efficiency. Table 4-3 lists the expected effects of baleen fouling.

Inhalation. Geraci (1990) has theorized that "a greater threat to whales or dolphins is not the thick murky residue [of surface slicks], but the invisible gaseous compounds that escaped from it." Inhalation of the toxic volatile fractions from fresh oil spills may produce a variety of problems for these air-breathing mammals. This pathway of exposure would be a threat primarily during the first few days after the spill occurs. Table 4-3 identifies the effects that may be encountered by whales and dolphins inhaling the volatile fractions from an oil spill.

Table 4-5. Historic interactions and impacts of whales and dolphins with oil[a].

Date	Location and Source	Oil Type and Quantity	Species	Impacts
Feb. 1969	Santa Barbara, CA; Union Oil Well	Crude oil; >30 x 10^6 gal	Gray whales Pilot whales Sperm whales Common dolphins White-sided dolphins	Sixteen stranded whales and dolphins were recovered. No causal relationship was established.
Apr. 1970	Alaska Peninsula; Source unknown	Diesel fuel; quantity unknown	Killer whales	One sick and one dead killer whales were observed. No examination was conducted to determine causal relationship.
1974	Japan; Source unknown	Bunker C; 11.3 x 10^6 gal	Porpoise	One dead porpoise found.
Oct. 1976	Aransas Pass, TX; Pipeline leak	Crude oil; 15,500 gal	Bottlenose dolphins	Dolphins swam through the oil without any apparent effects.
Dec. 1976	Nantucket Shoals; *Argo Merchant*	Bunker C; 7.9 x 10^6 gal	Fin whales Pilot whales and others	Forty-three sightings were recorded for animals in and around patches of oil. No obvious reaction was observed.
Mar. 1978	France; *Amoco Cadiz*	Crude oil; 60 x 10^6 gal	White sided dolphins Common dolphins Pilot whales	Six stranded animals were recovered. No causal relationship was established.
Sept. 1978	Matagorda Bay, TX; Boat grounding	Fuel oil; 3,000 gal	Bottlenose dolphins	Twenty dolphins were observed to be swimming through the oil without any effect.
June 1979	Gulf of Mexico; *Ixtoc-I*	Crude oil; 70 x 10^6 gal	Bottlenose dolphins Spotted dolphins	Animals were sighted in areas with oil-coated debris. The animals were apparently unaffected.
June 1979	Cape Cod, MA; *Regal Sword*	Bunker C/Fuel oil; 80,000 gal/6,300 gal	Humpback whales Fin whales Minke whales Right whales White-sided dolphins	Animals were observed feeding, surfacing, and swimming through heavy concentrations of oil.

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[a] Table was developed from J.R. Geraci and D.J. St. Aubin (1990)

Table 4-5. Continued.

Date	Location and Source	Oil Type and Quantity	Species	Impacts
May 1981	Outer Banks, NC; *Hellenic Carrier*	Unknown; 3,000 gal	Porpoise	Unconfirmed report of a dead porpoise.
Mar. 1982	Rodanthe, NC; Source unknown	Tar; quantity unknown	Pilot whale	One stranded whales was recovered with a small patch of dry tar on its skin.
July 1984	Gulf of Mexico; *Alvenas*	Crude oil; >1 x 10^6 gal	Bottlenose dolphins	One dolphin was swimming in the midst of oil patches. Others were observed at the edge of the slick.
Mar. 1989	Prince William Sound, AK; *Exxon Valdez*	Crude oil; 11 x 10^6 gal	Gray whales Fin whale Minke whales Unidentified whales Harbor porpoises	The following quantities of carcasses were recovered: 25 gray, 1 fin, 2 minke, and 3 unidentified whales; 7 harbor porpoises. It is possible that these mortalities were of natural causes.
June 1990	Gulf of Mexico; *Mega Borg*	Crude oil; 4.3 x 10^6 gal	Bottlenose dolphins	Dolphins were observed to swim in the midst of oil patches while others were observed at the edge of the slicks. No observable effect was detected.

Ingestion. There are two forms of ingestion that are considered here:

1) direct ingestion or the conscious consumption of petroleum hydrocarbons; and

2) indirect ingestion of petroleum hydrocarbons through the consumption of contaminated food sources, which includes bioaccumulation.

Direct consumption of petroleum hydrocarbons is considered highly unlikely in whales, dolphins, and porpoises, and any quantity consumed is not likely to have any direct affect upon the individual. A more likely form of petroleum hydrocarbon ingestion is through the incidental consumption of contaminated food. Geraci (1990) remarks that most toothed cetaceans (with the exception of bottlenose dolphins) are predators that would not scavenge oil-killed fish and will also avoid oil-tainted fish. Baleen whales, however, are more likely to consume contaminated food sources. For most baleen whales, zooplankton comprise the majority of their diets. These small crustaceans ingest oil particles and rapidly process them. The consumption of a critical dose of petroleum hydrocarbons is a possibility for baleen whales feeding in and around an area of a fresh spill.

Marine mammals have the potential to accumulate petroleum hydrocarbons in their tissues. However, this is more likely to occur in cold environments where prey organisms, such as zooplankton or benthic invertebrates, metabolize hydrocarbons more slowly than in warmer environments (Geraci 1990; Neff 1990). Because marine carnivores generally do not assimilate petroleum compounds from food efficiently, biomagnification does not usually occur. Since invertebrates are less able to metabolize hydrocarbons than fish, mammals eating low on the food chain (such as walrus or sea otters that consume large quantities of bivalve molluscs, or baleen whales that feed on zooplankton) are more likely to accumulate hydrocarbons than are top carnivores, such as killer whales, that consume large pelagic fish (Neff 1990). To date, no sublethal effects on this animal group have ever been attributed to bioaccumulation of petroleum hydrocarbons.

Areas of Special Concern. Table 4-6 identifies the behaviors and habits which are presumed to increase the risk of exposure to petroleum hydrocarbons by whales, dolphins, and porpoises.

Table 4-6. Behaviors and habits of whales, dolphins, and porpoises that may predispose them to oil exposure.

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1) <u>Habitat Preference</u>—Spills in ice covered waters may increase the risk of exposure due to oil entrainment within the ice, and reduced weathering of the oil. Habitat fidelity is not strong among cetaceans. If an area were affected by oil, it is assumed that the animals will simply remove themselves from the area.
2) <u>Migration Routes</u>—Many species participate in annual migration cycles, often through areas of oil exploration. Pelagic species are more at risk than in previous history as man's exploration activities expands into deep water areas. Additionally, many species migrate through areas of intense petroleum transportation activities, again increasing the likelihood of exposure.
3) <u>Migration Hierarchies</u>—Many species exhibit specific migration "pecking orders," e.g., pregnant females are first to arrive to feeding/birthing grounds, then females with calves, then immature females, then adult males, and finally immature males. This migration pattern may expose an entire section of the migrating subpopulation to a spill, adversely affecting the pod.
4) <u>Dietary Preference</u>—Many species exhibit restricted diets. If a species food source were affected, it may be forced to consume contaminated food or be forced to adjust its diet. However, as mentioned above, site fidelity is not strong among cetaceans and it is assumed that the animals would simply move to another, unaffected area to feed. The major concern would be for animals feeding prior to beginning a migratory journey. The stresses associated with migration preparation may adversely affect a cetacean if further stressed by a spill.
5) <u>Social Structure</u>—Toothed species often travel in pods, acting as a unit. As in the case of mass strandings, the herd follows the lead animal. During a spill, a whole pod, or a large portion may be adversely affected.
6) <u>Reproduction</u>—The reproductive success may be reduced by exposure to a spill. Pregnant females are considered most at risk to effects.
7) <u>Natural Curiosity</u>—Curiosity in younger animals may increase their likelihood of exposure. There are many reports of juveniles "playing" with debris on the waters surface.

Pinnipeds

Pinnipeds, an order composed of walruses, seals, and sea lions, are probably the most common and well known of all marine mammals. Like other marine mammals, they are highly adapted to life in the water; they have streamlined bodies, paddle-like fore- and hindlimbs, thick layers of subcutaneous fat, and other advantageous morphological and physiological adaptations. Walruses, seals, and sea lions are highly social and routinely leave the water to congregate on sand beaches, rocky shores, and tidal flats for resting, breeding, and birthing.

Three families of pinnipeds exist today:

1) Phocidae, the true or crawling seals;
2) Otariidae, the walking seals; and
3) Odobenidae, the walruses.

Table 4-7 lists common and scientific names of the 14 species of walruses, seals, and sea lions existing in North American waters (walruses have been divided into two sub-species). The global range and population estimates of the species are also listed. Walruses, seals, and sea lions are not included on the U.S. Endangered Species list.

Effects of Oil on Pinnipeds

All walrus, seal, and sea lion species are considered to have the ability to detect and avoid oil and other petroleum hydrocarbons. To date, no studies have been conducted on these animals regarding their detection abilities, but anecdotal data indicates that they will avoid a spill. However, in the wild, there are also many contradictory incidents where seals, sea lions, and fur seals have swam directly into an affected area, not seeming to notice the oil slicks. Numerous deaths have been related to direct and indirect exposure of seals and sea lions to petroleum hydrocarbons. Table 4-8 summarizes observations of pinniped exposure to historic oil spill events.

Table 4-7. Geographic range, population estimates, and status for pinnipeds common to North America[1].

		Geographic Region	Population
ORDER Carnivora			
FAMILY Phocidae (Crawling seals)			
Bearded seal	*Erignathus barbatus*	Canadian Arctic and Bering-Chukchi Sea	400,000+
Gray seal	*Halichoerus grypus*	E. Canada	70,000
Harbor seal	*Phoca vitulina*	New England to E. Canadian Arctic California to Aleutians	157,000
Harp seal	*Phoca groenlandica*	E. Canada	2,250,000
Hooded seal	*Cystophora cristata*	E. Canada; Davis Strait	366,000
Northern elephant seal	*Mirounga angustirostris*	California, Mexico	60,000+
Ribbon seal	*Phoca fasciata*	Bering-Chukchi Seas	100,000
Ringed seal	*Phoca hispida*	E. Canadian Arctic; Bering Sea Beaufort and Chukchi Seas	2.3 million
Spotted seal	*Phoca largha*	Bering-Chukchi Seas	225,000
FAMILY Otariidae (Walking seals)			
California sea lion	*Zalophus californianus*	Mexico to California	145,000+
Guadeloupe fur seal	*Arctocephalus galapagoensis*	Mexico	1,000+
Northern fur seal	*Callorhinus ursinus*	Pribilof Islands, San Miguel Island, Calif.	1,300,000+
Steller's sea lion	*Eumetopias jubatus*	California to the Bering Sea	221,000
FAMILY Odobenidae (Walruses)			
Atlantic walrus	*Odobenus rosmarus rosmarus*	Eastern Arctic	25,000?
Pacific walrus	*Odobenus rosmarus divergens*	Western Arctic and Alaska	160,000

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[1] Modified from J.R. Geraci and D.J. St. Aubin,(1990).

Table 4-8. Historical interactions and impacts of seals, sea lions, and walruses with oil[a] .

Date	Location and Source	Oil Type and Quantity	Species	Impacts
late 1940s	Antarctic; Ship discharge	Fuel oil; quantity unknown	Unspecified seals	Bloodshot eyes. Surface fouling with tarry oil.
1949	Ramsay Island, Wales; Source unknown	Fuel oil; quantity unknown	Gray seals	Pups largely unaffected by thick coating of oil. Two fouled pups drowned.
Mar. 1967	English Channel; *Torrey Canyon*	Crude oil; 30×10^6 gal	Gray seals	Three oiled seals were recovered, confirmed deaths
Jan. 1969	Gulf of St. Lawrence; Storage tank	Bunker C; 4,000 gal	Harp seals	10-15,000 seals coasted. Unspecified number of dead recovered
Feb. 1969	Santa Barbara, CA; Union Oil Well	Crude oil; $>30 \times 10^6$ gal	Harbor seals Elephant seals Cal. seal lions	Oiled seals observed. Mortalities not linked conclusively to incident.
Nov. 1969	N. Dyfed, Wales; Source unknown	Unknown; quantity unknown	Gray seals	14 oiled. Dead pups found. No causal relationship established.
Feb. 1970	Chedabucto Bay and Sable Island, N.S.; *Arrow*	Bunker C; 4×10^6 gal	Gray seals Harbor seals	150-160 seals oiled on Sable Island; 500 seals oiled in Chedabucto Bay. 24 found dead, some with oil in mouth or stomach.
Feb-Mar 1970	Kodiak Island, AK; Ship discharge	Slop oil or oily ballast; quantity unknown	Hair seals sea lions	Estimated 500 mammals contacted. No mortalities recorded.
Apr. 1970	Alaska Peninsula; Source unknown	Diesel fuel; quantity unknown	Hair seals	400 seals exhibited unusual behavior. No mortalities recorded.
Nov. 1970	Farne Islands; Source unknown	Unknown; quantity unknown	Gray seal	Yearling seal found with oil-stained pelt and crusting around mouth. Animal was otherwise healthy.
Mar. 1972	British Columbia *Vanlene*	Bunker B; 100,000 gal	Seals	Seal herds in area were unaffected.
Sept. 1973	Repulse Bay, NWT; Ship discharge	Refuse oil; quantity unknown	Ringed seals	Hunters killed 5 oil-covered seals.

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[a] Table was developed from J.R. Geraci and D.J. St. Aubin (1990)

Table 4-8. Continued.

Date	Location and Source	Oil Type and Quantity	Species	Impacts
1973	Dutch coast; Source unknown	Unknown; quantity unknown	Harbor seal	Patch of oil inconclusively associated with skin lesions.
1974-1979	Cape Town, SA; Ships and industry	Chronic discharge	Cape fur seals	Fur seals lingering in polluted harbor without obvious effect.
Aug. 1974	Straits of Magellan; *Metula*	Crude oil; 14×10^6 gal	S. seal lions S. Am. fur seals	Seal lions and fur seals in the area apparently unaffected.
Aug. 1974	Coast of France; Source unknown	Fuel oil; quantity unknown	Harbor seals Gray seals	Oil in intestine of one harbor seal. Three oiled gray seals, one with ingested oil.
Sept. 1974	Pembrokeshire, Wales; Source unknown	Unknown; quantity unknown	Gray seals	Two heavily oil pups drowned when washed off beach. 25 pups and 23 adults were fouled.
Jan. 1975	Ireland; *African Zodiac*	Bunker C; 1.1×10^6 gal	Seals	Seals in the area were apparently unaffected.
Aug. 1977	Greenland; *USNS Potomac*	Bunker C; 1×10^6 gal	Ringed seals other seals	16 oiled seals were observed one month after the spill.
Mar. 1978	France; *Amoco Cadiz*	Crude oil; 60×10^6 gal	Gray seals	Two of four dead seals were coated with oil. No causal relations was established.
May 1978	Great Yarmouth; *UK Eleni V*	Heavy fuel; 1×10^6 gal	Seals	20 oiled seals were observed.
Oct. 1978	South Wales; *Christos Bitas*	Crude oil; 840,000 gal	Seals	Mortality of 16 of 23 oiled individuals.
Dec 1978	Shetland Is., Scotland; *Esso Bernicia*	Bunker C; 370,000 gal	Seals	Oiled seals were observed. No mortalities were reported.
Feb. 1979	Latvia; *Antonio Gramsci*	Crude oil; 36,500 gal	Seals	One seal killed by oil.
Mar. 1979	Cabot Str., N.S.; *Kurdistan*	Bunker C; 2.1×10^6 gal	Gray seals Harbor seals	At least 4 gray and 6 harbor seals were found dead and coated with oil. No causal relationship was established. Oiled seals were found on Sable Island

Table 4-8. Continued.

Date	Location and Source	Oil Type and Quantity	Species	Impacts
Nov. 1979	Pribilof Is., AK; *F/V Ryuyo Maru*	Fuel oil; 290,000 gal	Northern fur seals	Some oiled dead pups were found. Causal relationship was never demonstrated.
Feb. 1984	Sable Is., N.S.; Well blow out	Gas condensate; quantity unknown	Gray seals	Four oiled seals were observed on Sable Island. No mortalities were reported.
Jan. 1989	Anvers Is., Antarctica; *Bahia Paraiso*	Diesel fuel; 233,000 gal	Crabeater seals Elephant seals Southern fur seals	Two crabeater seals were affected. Elephant seals and fur seals were oiled, but unharmed.
Mar. 1989	Prince William Sound, AK; *Exxon Valdez*	Crude oil; 11 x 10^6 gal	Harbor seals Fur seals Stellar's seal lions	Seals were observed swimming in the oil. Thirty-one harbor seals, two fur seals, and 14 seal lion carcasses were recovered with some oil fouling.

Direct Surface Fouling. Surface fouling effects on walruses, seals, and sea lions are summarized in Table 4-3. Furred species, such as the northern fur seals, are most likely at risk during an oil spill. However, lesser furred seals and sea lions are less threatened by surface oiling. Thick layers of blubber retain the animals core temperature. Anecdotal information has shown that adult and ringed seal pups are able to survive surficial oiling without suffering from hypothermia. This fact has been attributed the thick layers of blubber in adults and the utilization of brown fat stores in newly born pups (Blix et al. 1979)

Inhalation. No studies have been conducted on walruses, seals, and sea lions regarding the effect or impact of inhaling volatile hydrocarbon fractions. It is assumed that these animals would exhibit similar effects experienced by other marine mammals.

Ingestion. There are two forms of ingestion considered here. The consumption of petroleum hydrocarbons has been implicated in numerous seal and sea lion deaths. Experimental results have revealed a wide variety of effects that may result from oil ingestion by specific species. These effects are assumed to apply to all walruses, seals, and sea lions, and they vary by the amount consumed and the composition of the ingested oil. These studies have determined that walruses, seals, and sea lions would be able to tolerate the ingestion of small quantities of oil. Symptoms related to oil ingestion by walruses, seals and sea lions range from organ diseases to permanent damage or death (Table 4-3).

Animals with a dense fur coat or pelage for insulation have two major pathways in which indirect ingestion of petroleum hydrocarbons may occur—the consumption of oil-tainted foods and by grooming oil-fouled coats. The principal diet of most seals and sea lions consist of cephalopod molluscs and fish; these prey items are not likely to accumulate petroleum hydrocarbons. However, notable exceptions do exist; walrus and bearded seals feed primarily on burrowing bottom animals which do accumulate petroleum hydrocarbons. Additionally, some seal and sea lion species in North America are also known to consume other seals (primarily pups) and birds. When oiled, furred seal and sea lion species begin grooming their coats to maintain its insulative properties. It is highly likely that these animals will ingest oil through grooming activities. Oiled pups are groomed by their mothers, thus increasing the mother's chance of indirectly ingesting petroleum hydrocarbons. Furthermore, there is also the possibility of hydrocarbon transferral to pups through ingesting their mother's lipid-rich milk.

All walrus, seal, and sea lion species are assumed to have the necessary enzymes available within their systems to "convert absorbed hydrocarbons into polar metabolites which can be excreted into urine. However, some proportion of the nonpolar fractions will be deposited in lipid-rich tissues, particularly blubber" (St. Aubin 1990a). To date, no evidence of deleterious effects related to bioaccumulation of petroleum hydrocarbons have been documented.

Areas of Special Concern. Table 4-9 identifies the behaviors and habits which are presumed to increase the risk of exposure to petroleum hydrocarbons by walruses, seals, and sea lions. These include habitat preferences, reproductive strategies, recognition and avoidance behaviors in adult females, and the impact of human activity on this animal group.

Sea otters

Sea otters are the smallest marine mammals and are related to weasels, badgers, and other members of the Mustelidae. They inhabit marine environments in rocky coastal areas from Alaska to California, although most live in Alaska. Table 4-10 identifies the current population estimates for the sea otter colonies in North America. Like other marine mammals, sea otters have streamlined bodies and broadly flattened paws for swimming. However, sea otters have no subcutaneous blubber layers and depend entirely on fur for insulation. This dense fur pelage is nearly two times as dense as found on the Phocid fur seals. Additional adaptations include modified dentition which is well suited for consuming their preferential prey, hard-shelled mussels, clams, and other macroinvertebrates.

Table 4-9. Behaviors and habits of walruses, seals, and sea lions that may predispose them to oil exposure.

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1) Habitat Preference—Habitats of choice are often within or near areas of oil exploration and transportation; the habitats include: sandy and rocky shores, fast ice, pack ice, shore leads, polynyas, and oceanic fronts. Many of these areas increase an animals risk of exposure due to oil characteristics when interacting with particular habitats. For example, pack ice, polynyas, and floe areas may entrain the oil and the cold may slow weathering. These factors would act to increase the possible duration of exposure to individual animals.

2) Maternal Recognition—Maternal recognition may be hampered if a pup becomes oiled. This loss of olfactory recognition may result in the pup being abandoned. Oiling of nursery haulouts may result in major losses to a breeding subpopulation. Additionally, pups which are cleaned at rehabilitation centers may no longer be accepted by the mother, again resulting in abandonment.

3) Reproduction—Contact with oil during the breeding season is thought to reduce the reproductive success of the colony. Additionally, theories suggest that exposure to oil during the breeding season may result in mass, premature delivery of pups (or spontaneous abortions) due to stresses during early delivery season in California sea lions.

   Fur seal and sea lion breeding males and elephant seals do not eat during the entire breeding season, thus are physiologically stressed and weak at the end of the season and more susceptible to any kind of stress or contamination.

4) Interactions with Humans—Cleanup activity during a spill may result in abandonment of haulout areas. In certain species, pups may be permanently abandoned, while others will eventually return to their young.

   Walrus populations often remain in large groups, anywhere from several hundred to several thousand in one area. These groups are easily startled while on land, resulting in mass stampedes. Any oil response operations near walrus haulouts must be conducted with extreme care to avoid unnecessary encounters with large groups of animals.

5) Thermoregulation—Furred seals are most at risk from surface oiling. Insulative properties of their thick pelage are quickly lost when oiled, resulting in a rapid heat loss. In the wild, few animals are expected to survive even the lightest oiling. Although pups are considered most at risk, experiential knowledge has shown that even extreme oiling of Phocid or Otariid pups does not always result in death.

Table 4-10. Geographic range, population estimates, and status for sea otters in North America.

Geographic Range	Population Estimate	Source
Alaska	100,000 - 200,000	Rotterman and Simon Jackson 1988
Prince William Sound	16,000	DeGange et al. 1990
Washington	260	Benz, personal communication 1991
California	2,000	
Pismo Beach to Pt. Año Neuevo	~2,000	Benz, personal communication 1991
Purisima Point	< 10	Benz, personal communication 1991
San Nicholas Island	12	Benz, personal communication 1991

The sea otters primarily inhabit rocky coastal areas near shore, although they often assemble in offshore waters. Sea otters are often found resting among the kelp canopy in nearshore waters. These kelp blades are suspected of affording protection, as well as reducing drifting during resting periods (Ralls and Siniff 1990). Intense site fidelity is often encountered by investigators; although the individuals may range from the area, they often return to a particular area. In Alaska, migrations occur as individuals travel from breeding to wintering areas; this habit is not observed in the California sea otters.

Sea otters are polygamous, with males courting females within their territorial ranges. Outside of breeding periods, the animals often associate in large groups, with designated male areas and female/female with pup areas. These associations often result in large “rafts” of individuals, often exceeding 100 individuals, all resting together on the water surface. These and other sea otter characteristics increase their risk of exposure during oil spills.

Effects of oil on sea otters

There are many examples of the devastating effects of oil on sea otter individuals and populations. Geraci and Williams (1990) have determined that the sea otter is the mammal most likely to be harmed by oil, both immediately and in the long-term. A recent report released by the U.S. Fish and Wildlife Service (1991) has estimated that 3,500 to 5,500 sea otters were killed in Prince William Sound and the Gulf of Alaska as a direct result of the *Exxon Valdez* spill.

As with other marine mammals, sea otters are considered to have the ability to detect and avoid oil and other petroleum hydrocarbons. A study by Siniff (1982) analyzed sea otter detection abilities and reaction to the presence of oil. The test animals were able to identify the oil and primarily avoided contact with surface slicks. However, during this test, the animals investigated the slick and became contaminated. In the wild, there are many instances where sea otters swam directly into an affected area, not seeming to notice the slicks. Numerous deaths have been related to direct and indirect exposure of sea otters to petroleum hydrocarbons.

Direct Surface Fouling. The greatest concern regarding surface fouling of sea otters is the effect on the animal's thermoregulatory system, regardless of age. The sea otter has little subcutaneous fat and relies almost exclusively on its thick pelage for insulation. Additionally, eyes and mucous membranes are expected to be impacted by surface fouling (Table 4-3).

Inhalation. Sea otters are affected in numerous ways by inhaling the toxic vapors of fresh petroleum hydrocarbons. The effects range from mild irritation to permanent damage or even death (Table 4-3).

Ingestion. Sea otters are at risk of direct consumption of petroleum hydrocarbons via contaminated prey, particularly molluscs. They also constantly groom their pelage, and would ingest oil during grooming. Many of the prey items are thought to rapidly process hydrocarbons, but the potential for bioaccumulation exists. The effects of oil ingestion are presented in Table 4-3.

Areas of Special Concern. Foremost is the effect of oiling on the metabolic and physiologic makeup of the sea otters. Table 4-11 outlines the areas of special concern when sea otters are at risk to petroleum hydrocarbon exposure. Additional behaviors and habits that often predispose sea otters to exposure include: habitat fidelity, grooming behavior, daily habits, and rigid metabolic requirements.

Table 4-11. Behaviors and habits of sea otters that may predispose them to oil exposure.

1) Habitat Preference—Sea otters often demonstrate excessive habitat fidelity. During the course of their life, sea otters may travel periodically, often traveling hundreds of miles, or remain in an area without leaving for extended periods. During a spill, sea otters may be endangered by remaining in their preferred habitat even with the threat of contamination. Even the presence of man may not be enough to motivate a sea otter into relocating. Animals which are physically relocated during a spill may return before response activities are completed.
   Additionally, sea otters often prefer to rest within kelp canopies. It has been speculated that this behavior affords the sea otter some form of protection from predators and prevents the sea otters from drifting. The kelp canopy also entrains oil, therefore increasing the risk of exposure.
2) Metabolic Requirements—Sea otters have little subcutaneous fat; they rely entirely on their pelage for insulation. As a result, their strict metabolic requirement must be continually satisfied These small mammals must consume between 22-33 percent of their body weight per day (Costa 1978) to maintain their high metabolism. This extensive food requirement cannot be interrupted or the animal will suffer severe stress, which induces an increased metabolism, which further depletes their reserves, and so on. Any factor or force which reduces the sea otters ability to forage for food may prove fatal.
3) Grooming Behavior—Due to the extreme necessity of maintaining their pelage, sea otters expend a large portion of each day grooming their coats. An animal which becomes even slightly oiled will obsessively groom trying to reestablish the insulative properties of the fur, to the exclusion of all else, even their young. The very act of grooming tends to spread the contamination as well as increase indirect ingestion of oil. Additionally, female sea otters may spend 20 percent of their day grooming their pups; if a pup becomes fouled, the mother will not only spread the oil on the pup, but will most likely become contaminated herself as well as ingesting oil during the grooming process. In most instances, surface oiling results in the death of the individual.
4) Normal Behavior—Sea otters exhibit a vast array of normal behavioral patterns which may predispose them to surface oiling. These behaviors include: surface feeding, grooming, resting, and swimming. As a result of these behaviors, an entire subpopulation may be affected/destroyed if they encounter oil.

Table 4-11. Continued.

Feeding behavior—Sea otters forage for food by diving and returning to the surface to feed. While lying on their backs, the otter will prepare its meal (often consisting of breaking open an invertebrate's shell with rocks). Animals having to expend additional energy foraging for food in marginal feeding areas would be more affected by surface oiling as their metabolic requirements were already elevated.

Resting behavior—Sea otters often come together to form living rafts while resting on the waters surface. These rafts may contain hundreds of individuals.

Swimming—Sea otters enjoy swimming as part of their daily routine. Swimming activities are not limited to areas near their preferred habitat; sea otters may travel for several days only to return to their home. Both offshore and nearshore waters are utilized.

5) Susceptibility to Oil—Of all marine mammals, sea otters suffer the greatest effects when impacted by a spill. Pups are the most susceptible to oil as they are totally reliant upon their mothers until weaned. Animals that are already experiencing stress (dietary, physical, etc.) may succumb to oil impacts more quickly than other individuals. Physical contact with oil (through surface fouling, ingestion, or inhalation) is almost always fatal. Animals recovered for cleaning during response operations have a greater chance for survival due to initiation of new clean-up techniques utilized during the *Exxon Valdez* oil spill.

Pelagic species

Effects of oil on pelagic communities are supported by a relatively sparse body of information. This is partly because effects on pelagic biota are considered to be relatively short lived, and because the dilution factor in the open ocean is thought to rapidly reduce any toxic concentrations that may be present under an oil spill. Effects on planktonic communities are also difficult to document because effects of oil must be separated from the high natural variability and seasonality found in these systems. In addition, there are analytical problems with detecting low levels of hydrocarbon concentrations in water, and with differentiating the source of these hydrocarbons.

Pelagic ecosystems do support a number of species groups, and concerns about impacts to these are raised periodically, especially when response actions such as dispersants are considered. Pelagic resources will be discussed in the following two categories:

1. Plankton
   bacterioplankton, phytoplankton, and zooplankton

2. Fish
   adults, eggs, and larvae

Plankton

Phytoplankton. Phytoplankton are generally less sensitive to the effects of oil than zooplankton, but they do experience acute and chronic effects from oil at concentrations ranging from 1-10 mg/l (ppm). Unicellular algae can take up and metabolize both aliphatic and aromatic hydrocarbons. Sensitivity to oil varies by species, as documented by a series of studies conducted in mesocosm enclosures by Lee et al. (1987). This series of experiments measured the effects of oil on plankton communities over a period of 20 days. Certain species of phytoplankton were found to be more resistant to the effects of oil (nanoflagellates and small-celled diatoms) than other species (centric diatoms). Since the regeneration time is very short for algal cells (9-12 hours), any impacts to these populations would probably be very short-lived (NAS 1985).

Oil can affect the rate of photosynthesis in phytoplankton, and thus inhibit algal growth. However, at very low concentrations (less than 0.1 mg/l), enhancement of growth rates has been recorded (NAS 1985). Measurements of plankton taken at the *Tsesis* oil spill in Sweden (No. 5 fuel oil) found an increase in phytoplankton populations after the spill. This apparent anomaly could have been caused by high mortalities of zooplankton and thus, decreased grazing pressure on the phytoplankton population (Johansson et al. 1980).

Bacterioplankton. The bacterial component of the phytoplankton increases after an oil spill. This was measured in the *Tsesis* oil spill in Sweden, as was evidence of a rapid biodegradation of hydrocarbons in the water column (Johansson et al. 1980). Concentrations of bacterioplankton showed large increases after the addition of petroleum or its derivatives in the same mesocosm experiments discussed above (Lee et al. 1987). (Nutrients were also added to the mesocosms in these experiments).

Zooplankton. Zooplankton are quite sensitive to the effects of oil, and toxic effects can be seen at concentrations ranging from 0.05 to 9.4 mg/l (NAS 1985). This sensitivity is higher for dispersed and dissolved petroleum constituents, and less for floating oils (NAS 1985). Short term effects of oil on zooplankton include possible decreases in biomass (usually temporary), as well as lower rates of feeding and reproduction. Some species such as tintinnids may increase in abundance. This may be due at least in part to an increased food supply, since these zooplankton feed on bacteria and small phytoplankton (Lee et al. 1987). Long term effects of oil on zooplankton, such as changes in community structure, have not been found.

Zooplankton can take up oil directly from the water, from food, and by direct ingestion of oil particles. Zooplankton are thought to play a role in the sedimentation of oil in the water column. Oil droplets, as well as oil attached to particulates, can be ingested by zooplankton, and later excreted as unmodified oil in fecal pellets, which may then sink, and cause a redistribution of oil from the pelagic zone to the benthic zone (Conover 1971).

Fish

Adult fish. Adult fish do not generally experience acute mortality at oil spills, and it is rare to find fish kills after a spill, especially in open water environments. (Enclosed habitats such as marshes or lakes may concentrate oil enough to cause conditions acutely toxic to fish). Fish can take up hydrocarbons through the water column directly and through food, but there is no evidence of biomagnification of hydrocarbons in fish. There is a commonly held belief that pelagic fish can avoid contamination, but little evidence was found to support this generalization in the NAS review (1985).

There are several studies documenting effects from petroleum hydrocarbons to benthic fish species. Many of these studied species such as flatfish that live in intimate contact with chronically contaminated sediments. Pelagic fish species are less likely to come in contact with dissolved hydrocarbons at toxic concentrations from oil spills except for short time periods, and are thus unlikely to experience acute or chronic effects.

Fish eggs and larvae. Fish eggs and larvae experience toxic effects at low concentrations of hydrocarbons, ranging from 1-10 ppm (Kuhnhold et al. 1978). In most cases, eggs and larvae are more sensitive than adults, though some exceptions exist. For example, pink salmon eggs were found to be very tolerant to benzene and and water-soluble petroleum (Moles et al. 1979). A study of eggs and larvae of winter flounder found significant decreases in viable hatch of eggs when exposed to 100 ppb No. 2 fuel oil during gonad maturation, fertilization, and incubation. Larvae were found to be more sensitive than eggs (Kuhnhold et al. 1978).

Summary

1. Plankton
    a. Short-lived effects (of duration one month or less)
    b. Zooplankton are more sensitive than phytoplankton

2. Fish
    a. Limited impacts to adults
    b. Eggs and larvae are more sensitive

<u>Note</u>: Effects on pelagic communities are difficult to document due to high seasonal and natural variability

Nearshore communities

Intertidal

Since the intertidal zone is an area often impacted by oil that strands on shorelines, intertidal resources and how they are valued will directly impact many decisions about shoreline cleanup. Intertidal biota can be categorized into the following groups:

1. *plants*
   including algae and wetland plants
2. *infauna*
   animals that live buried in sediments
3. *epifauna*
   animals that live on the sediment surface or attached to rocks
4. *fish*

Plants

The main plants in the intertidal zone are the attached macroalgae. Though macroalgae may be subject to smothering by oil, they can be quite resilient and survive even heavy oiling. A survey of shorelines done after the *World Prodigy* spill in Narragansett Bay in 1989 noted few dead plants, even in heavily oiled areas. However, some short term effects on reproduction of two species of *Fucus* were documented. These lasted only for a period of less than one month after the spill (Thursby et al. 1990).

At the Santa Barbara blowout in 1969, shoreline surveys were conducted using transects along which intertidal algae were identified. The results of this survey were difficult to interpret since there was a strong confounding of the impacts from oil impacts with severe storms and increased freshwater runoff during the time period immediately after the blowout (Foster et al. 1971). Observers noted that surf grass (*Phyllospadix*) growing in the intertidal zone was heavily oiled at some sites, and that these plants turned brown and died (Foster et al. 1971).

NOAA studies of intertidal communities impacted by the *Exxon Valdez* spill in Alaska found that attached macroalgae, specifically *Fucus* survived oiling at numerous sites, but were heavily impacted by hot water washing of shorelines to remove oil (Houghton et al. 1991).

Infauna

Polychaetes and other burrowing invertebrates can play an important role in the biodegradation of residual oil in sediments. Lugworms (*Arenicola*) were tested in a lab with contaminated sediments from the *Arrow* spill of bunker C oil that occurred in Nova Scotia in 1970. Sediment reworking by lugworms substantially reduced amounts of hydrocarbon in sediments, probably by the mechanisms of aerating soil and by providing an environment conducive to the growth of bacteria in their tubes. *Arenicola* could not survive in sediments with concentrations of hydrocarbons of 600 ug/g (ppm) or greater (Gordon et al. 1978).

Oligochaetes, especially species such as *Capitella capitata,* are known as opportunistic species that are commonly found in polluted areas. They colonize oiled sediments at high densities, as was observed after the *Florida* spill in West Falmouth, Massachussetts in 1969. At this site, *Capitella* was measured at high densities in oiled areas 7 months after the spill (Sanders 1978).

Copepods appear to be one group of crustaceans that are less sensitive to oil. A field experiment using Prudhoe Bay crude oil added to mudflats in Valdez, Alaska did not impact populations of three species of copepods when monitored for 30 days (Feder et al. 1990).

Clams, in contrast, often show long-lasting impacts from oil contamination, partly because they usually inhabit fine sediments in low-energy environments where oil is likely to be slow to weather and therefore remain for long periods of time. Populations of *Mya arenaria,* a soft shelled clam, were studied six years after the *Arrow* spill in Nova Scotia (Gilfillan and Vandermeulen 1978). Clams from areas still contaminated with oil had concentrations of hydrocarbons in their tissue of up to 200 ug/g (ppm).

Clam populations from oiled areas had fewer total numbers, fewer mature adults, and a 1-2 year lag in tissue growth, compared with clams from a control, unoiled population.

These soft-shelled clams were thought to be particularly sensitive to the adverse effects of oiling since their physiology makes them unable to completely close their shells. This means that the clam's mantle and gill surfaces are always exposed to sediments and interstitial water, and thus, to any contaminants in those media.

Epifauna

Epifauna includes attached organisms such as mussels and barnacles, as well as motile organisms such as snails and other gastropods and crabs. A study from the Arthur Kill in New Jersery following a spill of No. 2 fuel oil in 1990 found both acute and chronic effects on fiddler crabs (*Uca Pugnax*). Chronic effects resulted in behavior changes that were significantly different from control crabs, and which would detrimentally affect the crabs' ability to survive and compete (Burger et al. 1991).

Mussels (*Mytilus edulis*) have been observed to survive heavy oiling without apparent acute effects in Alaska. They are frequently used as indicators of bioaccumulation for various contaminants, partly because the species occurs widely, and is therefore a convenient test organism. Mussels subjected to chronic, repeated exposures of hydrocarbon fractions of diesel oil were found to have reduced feeding rates and food absorption efficiency (Widdows et al. 1987).

Barnacles, like other crustacea, are acutely sensitive to oil and often experience high mortality rates when impacted by oil on shorelines. At the Santa Barbara spill, high mortalities were observed for intertidal barnacles (*Chthamalus fissus*) (Foster et al. 1971).

Fish

Concerns about impacts from oil contamination to fish in the intertidal environment usually involve species that use the intertidal habitat for spawning. This includes Pacific herring, fish that spawn on rocky substrates, or on fronds of *Fucus* or other algae growing on rocky substrates. Spawning herring populations were a concern in *Exxon Valdez* in Alaska, and important commercial stocks spawn in areas such as San Francisco Bay.

A study comparing herring eggs from oiled sites with herring eggs from unoiled sites in Prince William Sound found no statistically significant differences in viability of larvae or survival rates for the two groups of eggs. The study did find an overall effect on biology of eggs from oiled sites, including a younger age of hatch from oiled sites. Confounding factors in this study were the patchy distribution of oil at the impacted sites, and temperature and depth differences (TRS 1990).

Other intertidal spawners that have been of concern at oil spills include surf smelt and pink salmon.

Summary

1. Plants
   Macroalgae are quite resistant to effects of oiling
   Wetland plants are susceptible, but effects vary

2. Infauna
   a. Some invertebrates survive in heavily oiled sediments, including copepods, polychaetes, oligochaetes.
   b. Polychaetes may facilitate biodegradation processes.
   c. Buried bivalves are susceptible to impacts from oiling, and often bioaccumulate contaminants.

3. Epifauna
   a. Mussels, and other attached bivalves often survive oiling, but also bioaccumulate
   b. Many crustaceans, including barnacles and crabs, are sensitive to acute and chronic effects of oiling

4. Fish
   Main concerns are for intertidal spawners

Subtidal

Introduction

Nearshore subtidal habitats can include shallow, soft bottom communities such as those found in enclosed bays, as well as eelgrass beds and offshore kelp communities. Subtidal habitats are often only lightly affected by oil spills, if at all.

Much of the scientific literature on the effects of oil on soft bottom communities comes from studies conducted near offshore oil drilling rigs and platforms. While these give some indication of the potential effects of petroleum hydrocarbons, they are more indicative of ongoing, chronic releases, typical of a continuous source of hydrocarbons rather than a single event more typical of an oil spill. However, repeated, long term impacts may be important to consider in harbors and areas with heavy vessel traffic.

Eelgrass beds and kelp beds are of special interest because of their high habitat value for marine organisms, including their use as nursery areas for many species. These habitats are, in most cases, not impacted by oil spills, but can be impacted by cleanup activities.

Effects on submerged benthic habitats

Soft bottom, fine sediments. A study conducted by Gray et al. (1990) investigated ecological effects on benthic communities near two drilling rigs in the North Sea, one in operation for many years, and another recently constructed. Changes in the diversity and number of species were noted in the area within 500-1000 m of the rigs. Opportunistic species were more dominant in these areas. Initial impacts of the newly constructed rig included an increased abundance of some species, and changes in the presence and absence of rare species.

An experiment was conducted in subtidal soft bottom habitats in Norway. Field plots were treated with low level exposures of oil and compared with control plots. One result was a significant decrease in colonization by amphipods in the oiled plots. This could have been the result of mortality of newly settled larvae or juveniles, or of avoidance by adult amphipods (Bonsdorff et al. 1990).

Studies conducted ten years after the *Amoco Cadiz* spill examined populations of several species of peracarid amphipods in different subtidal habitats (Dauvin and Gentil 1990). Immediately after the spill in 1979, heavy mortalities of amphipods occurred, with the greatest short term impacts in areas with fine sediments. Since these amphipods do not produce pelagic larvae, the researchers were interested to find out if the populations had been able to recover to levels similar to those measured prior to the spill. Their conclusions were that most populations had recovered after ten years, with the greatest differences seen in the fine sediment habitats.

Subtidal stations monitored after the *Florida* spill in Massachusetts in 1969 were found to be only lightly impacted by oil and showed little variation in species composition or density during a three-year period after the spill (Sanders 1978).

Seagrass beds. Seagrass beds occur both intertidally and subtidally. Seagrasses in subtidal beds are rarely impacted by oil spills, since they usually do not come in direct contact with the oil, while intertidal plants are at greater risk of oiling. In Santa Barbara, after the blowout in 1969, intertidal surf grass (*Phyllospadix torreyi)* turned brown and died after oiling (Foster et al. 1971). At the *Amoco Cadiz,* "almost no" effects were found on a partially oiled seagrass bed of *Zostera marina*. The main impacts to seagrass beds appeared to be with the associated fauna (Zieman et al. 1984).

One reason why seagrasses appear to be less vulnerable to oil impacts is that 50-80% of their biomass is in their rhizomes, which are buried in sediments, thus less likely to be adversely impacted by oil. Thus, even if the fronds are affected, the plant may still be alive and able to regrow (Zieman et al. 1984).

Shallow seagrass beds in tropical habitats, composed of *Thalassia sp.* were impacted by a spill in Puerto Rico in 1973. Strong winds and wave action in shallow waters was thought to carry oil into the vegetation, causing the plants to die. Subsequently, erosion increased in areas with dead plants. Renewed plant growth was observed between one and two years after the spill (Nadeau and Bergquist 1977).

Treatment impacts. Sometimes, the main impacts to seagrass beds during a spill are physical impacts associated with response activities. Several authors have suggested that hot water washing of intertidal shorelines may move oil into subtidal areas, potentially impacting seagrass habitats. This has been mentioned in connection with the *Exxon Valdez* in Alaska (Houghton et al. 1991) and at Santa Barbara (Foster et al. 1971).

At Fidalgo Bay, Washington, a refinery pipeline spill in 1991 impacted a shallow bay with extensive eelgrass beds. Though all efforts in spill cleanup attempted to protect the eelgrass, it was thought that outboard engines on small boats used as part of response activities may have cut some of the grass blades.

Kelp beds. Offshore kelp beds are similar to eelgrass beds in that they support extensive benthic and pelagic communities and serve as nursery grounds for numerous species. While the benthic community beneath the kelp is rarely impacted by oil spills, the kelp fronds often float on the water surface and may become oiled or entrain oil. Observers have noted, however, that oil rarely sticks to kelp fronds in the water.

A study conducted after the *World Prodigy* spill in Narragansett Bay in 1989 examined two species of subtidal kelp that had been studied prior to the spill. For both species, *Laminaria saccharina* and *L. digitata,* oiling had no effect on growth rates, or on general condition of the plants.

Observations were made by divers in *Macrocystis* beds offshore of areas impacted by the 1969 spill in Santa Barbara. No evidence of oil impacts to benthic habitats in kelp beds was observed. Oil was contained on the surface in floating fronds, but did not stick to the plants (Foster et al. 1971).

Treatment effects. At the *Tenyo Maru* spill, which occurred off the Pacific coast of Washington in 1991, *Nereocystis* (bull kelp) beds located just offshore were observed to be containing floating oil at the surface amongst floating fronds. Based on the concern that this oil could pose a threat to sea otters, it was proposed that the kelp be cut at the base. This proposal was considered and rejected on the basis that kelp removal would adversely impact the associated benthic and pelagic communities during their summer growing season.

Summary

1. Soft-bottom communities
    a. Chronic impacts can occur from repeated dosages (such as near drilling rigs).

    b. Oil spills have limited impacts subtidally, though some sensitive species (amphipods) may show long-term effects.

2. Seagrass beds
    Usually not impacted if subtidal, treatments can adversely affect these habitats.

3. Kelp beds
    Usually little-to-no impact on these habitats

Seafood contamination

Background

An issue of concern which arises in nearly every oil spill incident of any significance is that of contamination of seafood resources in the affected area. The importance of an explicit consideration of potential impacts cannot be overstated, as the implications to diverse interests are substantial. Real and potential contamination of seafood resources and the closing of harvesting activities affect commercial and recreational fishing interests, peripheral activities that support them, and subsistence users, for whom harvested items may represent a substantial portion of the diet. The loss of revenue resulting from harvest closures and/or the loss of seafood markets carry with them widespread implications for economic, social, and possibly cultural disruption, as well as litigation for recovery of damages.

The extent to which an organism may be contaminated results from the combination of several factors, including the product to which seafood resources are exposed, the route of exposure, the metabolic detoxification systems present in organisms of interest, and the tissues eaten by the human consumer.

Nature of the product

As noted in the oil chemistry sections of this course, the crude oil and partially refined petroleum products can be very complex mixtures of hydrocarbons that vary from region to region (and within regions, as well). Focusing on the aromatic hydrocarbons as a group, it is of some importance to note that while they are considered to be hydrophobic, aromatics possess a wide range of solubilities. The degree to which a given constituent of interest is soluble in water not only determines how and how much an organism might be exposed, but also is a major factor in how the compound behaves in a biological system.

The nature of the product also is of importance from another perspective. Davis et al. (1984) noted that higher molecular weight constituents of petroleum hydrocarbons can be relatively low in acute toxicity, but may have a high potential for causing tumors or cancers:

> These high molecular weight (four- and five-ring) compounds need careful consideration since potential exists for food web transfer from fisheries to consumer, which implies a potential change from resource impact to human health risk.

Route of exposure

There are three principal ways in which hydrocarbons may interact with an organism to become contaminated (Connell and Miller 1981):

1. Ingestion of food contaminated with product.
2. Absorption of dissolved hydrocarbons through respiration, i.e., through gill tissues.
3. Absorption of dissolved hydrocarbons from the water through the skin.

The route of exposure can be influenced by a number of related and unrelated parameters, including feeding strategy, fat content of the organism, the solubility of the product(s), physical characteristics of the water mass, reproductive state of the organism, etc.

A related factor that is also important is the length of exposure. Obviously, this will affect not only potential tissue contamination of the organism, but also whether the animal experiences any direct acute or chronic toxicity.

Metabolic detoxification systems

To varying degrees, all organisms are capable of metabolizing foreign compounds in order to render them more easily excretable. The presence or absence of enzyme systems capable of processing specific materials in large part determines the ease with which hydrocarbons are processed and passed from an organism.

Some invertebrates such as bivalves do not carry the biochemical machinery necessary to metabolize petroleum hydrocarbons. As a consequence, aromatic hydrocarbons are not readily excreted and instead tend to accumulate in body tissues. It is for this reason that bivalves such as mussels, clams, and oysters are often used as "sentinel" organisms to assess environmental exposure to contaminants.

The fact that these organisms can concentrate hydrocarbons from the environment is of concern from a seafood perspective. Although shellfish may not be able to rapidly metabolize aromatic hydrocarbons, human consumers are generally able to do so owing to the presence of efficient enzyme systems. However, the by-products resulting from metabolism of some aromatic compounds can be highly reactive and are known to induce cancers or other toxicological effects.

In contrast to bivalves, fish are considered to be rapid metabolizers of aromatic hydrocarbons. This is thought to be attributable to the presence of certain enzyme systems (e.g., cytochrome P-450-dependent mixed function oxidase, epoxide hydrolase; glutathione-S-transferase) that facilitate the removal of the hydrocarbons and metabolites from their bodies. As a result, fish will generally not accumulate aromatic hydrocarbons in their flesh. In the subsequent discussion of subsistence seafood concerns, other approaches to evaluating fish exposure to hydrocarbons are described.

Tissues eaten by human consumers

Although it is somewhat obvious that specific portions of a seafood organism are favored for human consumption, ethnic and cultural differences in consumption patterns must be considered. For example, although contamination of muscle tissue of fish would be addressed as a problem in most spill situations, the fact that representatives of certain ethnic groups also use other parts such as the liver, reproductive organs, or head may necessitate a more conservative approach.

The higher lipid, or fat, content of viscera relative to muscle tissue may increase the extent of exposure to lipophilic ("fat-loving") compounds such as aromatic hydrocarbons. However, this appears to be less of a concern with respect to petroleum-related hydrocarbons than it is for such persistent organic compounds as the chlorinated pesticides or polychlorinated biphenyl mixtures, primarily because for many animals, aromatics are metabolized and removed from tissues more readily than other hydrocarbons.

Tainting

Tainting has been variously defined, but generally is considered to be the development of flavors or odors in seafood that are not typical of the seafood itself. Although causes for tainting are not necessarily limited to exposure to hydrocarbons—spoilage, for example, can cause a familiar "off" smell or taste—in the context of this discussion, the term will refer to that arising from petroleum hydrocarbons.

It should be noted that by definition, tainting comprises those examples of seafood contamination that are identifiable through normal human sensory systems such as taste or smell. Tainting, therefore, is determined by *organoleptic* analysis--which is a multisyllabic way of saying the detection of oil through taste or smell. The lighter fractions of a petroleum hydrocarbon mixture are those that would be most likely to be detected through organoleptic sampling; the heavier weight aromatic hydrocarbons, many of which have been identified as having carcinogenic implications, would remain undetected through smell or taste analyses. An additional implication of this is that organoleptic tests would be of greatest use early in a spill event, before weathering reduces the more volatile components.

Because it is a sensory phenomenon, tainting is difficult to quantify. It is dependent on both the sensitivity as well as the preference of the individual, both of which obviously can be quite variable. Perception, too, enters into the determination of tainting. Tidmarsh and Ackman (1986), in an excellent review discussion on the subject, note:

> Fear of tainting can be as serious a problem as an actual tainting incident. Consumer resistance, closures imposed by regulatory authorities, and embargoes on harvesting activities by producers resulting from even the remote possibility that seafoods are tainted can cause severe economic losses.

In an oil spill situation, real or perceived tainting will result in a tremendous amount of public and business interest concern, and inevitably, political posturing. There are likely to be pressures to improve the measurement of the extent of contamination, which will lead to chemical analyses.

Chemical analysis

Organoleptic methods of seafood testing are not only limited as to the chemical compounds that can be detected (e.g., low vs. high molecular-weight aromatic hydrocarbons), but also are limited by a "detection limit," below which even a sensitive evaluater cannot smell or taste evidence of tainting. An approximate lower limit for organoleptic detection of emulsifiable oil is 15 ppm, although certain crude oil constituents are detectable at lower levels (e.g., kerosene at 0.1 ppm, naphthalene at 1.0 ppm, toluene at 0.25 ppm). Other references cited in Connell and Miller (1981) found that tainting is caused by levels of refined or crude petroleum products in the range of 4 to 300 ppm. These levels are generally well above established levels of concern for a number of hydrocarbon compounds.

In order to avoid the detection limitations of organoleptic methods, to eliminate the large degree of subjectivity involved, and to elicit relatively repeatable quantitative results that can serve as the basis for comparison for regional or time-series analyses, chemical methods are used. While chemical analyses require laboratory facilities and can be very expensive, they vastly improve the range of compounds measurable and the levels to which results can be quantified.

Case history

There have been many oil spills where commercial fishing concerns have arisen, impacts on fishing activities realized, and severe financial burdens imposed. During the *Amoco Cadiz* incident, for example, the oyster industry in Brittany was forced to destroy in excess of $2 million worth of seafood (Tidmarsh and Ackman 1986), while total costs to the oyster industry were estimated at nearly $26 million (Sorenson 1983). Both fish and shellfish were reported to have been tainted in the wake of the *Torrey Canyon* spill (Connell and Miller 1981). Closer to home, Blumer et al. (1970) described and studied the tainting and chemical contamination of edible shellfish following a spill of No. 2 fuel oil in Buzzards Bay, Massachusetts.

Much less common are spills where subsistence seafood concerns become an issue, and in most state waters, these would not be expected to be as significant as they were in Alaska, or in the recent *Tenyo Maru* spill off the coast of Washington state. However, subsistence harvesting is not necessarily limited to Native American peoples; certain ethnic groups, including recent immigrants from Europe or Asia, may rely heavily on subsistence seafoods. For the sake of convenience and because the example is a fairly recent one, the *Exxon Valdez* spill is used here as a case history that included both commercial fishing concerns, as well as significant subsistence seafood issues.

Exxon Valdez

Commercial fishing impacts

From the beginning of the spill in March 1989, concerns were voiced about possible contamination of commercial fishing harvests in the affected area. The implications to the seafood industry in Alaska were obvious: Prince William Sound and the Gulf of Alaska produce the largest tonnage of halibut in the U.S.; Kodiak has consistently ranked as a leading U.S. port in terms of catch landing weights as well as values; Prince William Sound alone had been expected to produce a salmon harvest worth $70 to 100 million (NOAA 1990). Other fishing-related activities contributed additional millions of dollars of activity to the state economy.

Although little hard evidence existed that oil was contaminating commercial fisheries resources, the Alaska Department of Fish and Game and the Department of Environmental Conservation reacted in two ways to allay fears about contamination of fish and shellfish:

1. Closure of commercial fisheries in the area most heavily affected by oil, where oil was evident on the water surface or on adjacent shorelines;

2. Adoption of a "zero tolerance" policy for fish catches, under which any visible tainting of commercial catches would result in closure of the affected fishery.

There was evidence that some of the oil sightings which resulted in commercial fishing closures were attributable not to the oil spill, but ironically, to leakage of refined products from fishing vessels themselves. Trajectory models and previous experience of NOAA scientists had suggested a low probability that the oil sighted was from the Exxon Valdez, and subsequent chemical analysis confirmed that this was true.

Additional efforts by the U.S. Coast Guard and NOAA provided overflight information and trajectory analyses to commercial fisherman in order that known or projected areas of contamination could be avoided during fishing activities. All of these steps were taken primarily to prevent the market perception of contamination and to maintain public confidence in the quality of Alaskan seafood.

Subsistence seafood issues

(Material for this summary was provided by L. Jay Field, NOAA, and is drawn largely from Field and Walker 1990).

The area affected by the *Exxon Valdez* spill included 18 mostly rural communities with a combined population of over 15,000 residents. Although the towns and villages included larger fishing ports such as Kodiak, Seward, and Cordova, most of the communities were small, predominantly Alaskan Native villages. Residents of the villages relied heavily on subsistence fish, shellfish, birds, and mammals to provide protein in their diets. Because of this, the oil spill had the potential to affect health and lifestyles in a fundamental way, and levels of concern in the villages were understandably high.

One of the first responses to subsistence concerns was the formation of the Alaska Oil Spill Health Task Force (OSHTF), an interagency group chaired by an Indian Health Service physician with representatives from state and federal agencies, native organizations, and Exxon. The task force served as the focal point for discussion and for activities to assess the extent of seafood contamination.

Meanwhile, in May and July of 1989, the state of Alaska epidemiologist released bulletins discussing health implications of the spill, and advising residents to use organoleptic means for determining the safety of harvested seafoods: i.e., if the seafood did not appear to be contaminated by visual observation, smell, or taste, it was probably safe to eat.

Concerns of villagers remained high. In early summer of 1989, Exxon began planning a study to analyze large numbers of subsistence fish and shellfish for aromatic hydrocarbon contamination. At the same time, the U.S. Coast Guard and the OSHTF requested that NOAA take an active role in addressing subsistence seafood concerns of Native villagers. A result of these events was an agreement between Exxon and NOAA to cooperatively study the potential contamination of subsistence seafoods collected in areas traditionally fished by communities. NOAA and Exxon biologists would make the field collections in consultation with representatives from the various villages, with chemical analyses performed by the National Marine Fisheries Service Environmental Conservation Division laboratory in Seattle. The OSHTF reviewed the study objectives and was instrumental in determining means of communication of goals and results to affected villages.

Collections of shellfish, bottomfish, and salmon were made in approximately 13 subsistence areas, with control samples also collected in unoiled regions. Edible tissues from fish and shellfish were analyzed for aromatic hydrocarbon contaminants, selected to reflect the constituents found in Prudhoe Bay crude oil and to include those that were considered to be persistent in the environment with implications for long-term human health impacts. Bile from fish was also collected, as fish rapidly metabolize aromatic hydrocarbons and the by-products are concentrated in bile prior to excretion. Bile analyses were used as a rapid screening test for indications of exposure to hydrocarbons.

In 1989, when levels of exposure to the organisms would have been highest, 143 samples of shellfish (mussels, clams, chitons) and 210 samples of fish (three species of salmon, and halibut) were analyzed. Shellfish from two areas showed relatively high levels (>1000 ppb) of total aromatic hydrocarbons. One area was Windy Bay, a site on the Kenai Peninsula which had been heavily oiled. The other was Near Island, which is adjacent to the boat harbor in Kodiak. Two other areas (Chenega and Old Harbor) yielded shellfish with levels >100 ppb, while samples from the remainder of the sites were generally <10 ppb and comparable to uncontaminated control samples.

The high concentrations of hydrocarbons in Windy Bay samples were clearly associated with the *Exxon Valdez* spill. Those from Near Island, however, were much more questionable in origin, as they were found in an area not known to have been directly impacted by the spill. Moreover, the collection site was adjacent to a busy boat harbor, where small spills of fuel and other petroleum products are common. Examination of the ratios between lower-weight aromatic hydrocarbons and higher-weight aromatic hydrocarbons supported the idea that hydrocarbons contaminating the shellfish near Kodiak were not of *Exxon Valdez* origin. Similarly, samples from the Chenega site, which showed moderately elevated hydrocarbon levels, were collected in an area with many derelict wooden pilings that had been treated with creosote, and an area that had also experienced an unrelated fuel oil spill in the recent past.

Generally speaking, tissue hydrocarbon levels in finfish were about an order of magnitude less than those found in shellfish. Although bile analysis in salmon indicated some exposure to hydrocarbons, of the 210 samples of edible fish tissue analyzed in 1989, only 11 samples exceeded 10 ppb total aromatic hydrocarbons in edible tissues, and only one exceeded 100 ppb.

The significance of the hydrocarbon levels found in the subsistence seafoods was an extremely difficult issue to address. No advisory levels or other guidelines for the safety of foods contaminated with oil were available at the time of the spill, and a review of literature showed that little information existed on the health effects of oil-contaminated seafood. To interpret the study results, NOAA convened two meetings of specialists from several disciplines related to human health implications of eating contaminated seafood. Representatives included scientists from the U.S. Food and Drug Adminstration (FDA), the National Institutes of Environmental Health Sciences, the Agency for Toxic Substances and Disease Registry, the University of Alaska, NOAA, and Exxon Biomedical Research Sciences.

The group concluded that finfish from all areas were safe to consume, but that shellfish from areas that contained the relatively highest concentrations (i.e., Windy Bay and Near Island) should be avoided. These recommendations were included in newsletters sent to all villages, and OSHTF representatives visited each affected community to present and explain the findings, and to answer questions.

A direct request from the OSHTF to the FDA to perform a risk analysis based on the analytical chemistry results and the known patterns of subsistence seafood consumption resulted in the issuance of a highly qualified opinion that the additional cancer risk imposed by consumption of oil contaminated subsistence seafoods—even the most heavily contaminated shellfish from Windy Bay and Near Island—was low.

The success of the risk communication efforts to the villages was mixed. The chemistry data and interpretation of results were not successful in allaying concerns about subsistence seafood safety. As Field and Walker noted:

> The high degree of alarm experienced by the village communities about subsistence food safety made them unreceptive to reassurances based on qualitative measures such as organoleptic testing. In addition, their apprehensions were reinforced by the long interval between the collection of tissue samples for analysis and the communication of interpreted results. A risk communication workshop. . .with representatives from six villages revealed differences between individuals in the effectiveness of the conclusions about food safety. The consensus, however, was that communications efforts need to begin immediately following a spill and continue at frequent intervals, and that those affected should be directly involved in the process. A variety of approaches should be used that include a mix of written and face-to-face communication techniques.

The *Exxon Valdez* experience illustrates many of the problems that may be unavoidable even with well-planned and well-funded efforts to address concerns about contaminated seafoods, both from commercial fishing and subsistence user perspectives. The suspicion and tendency to disregard analytical results from analysis of potentially contaminated seafood that was evident with Native communities in Alaska may to some extent reflect reactions that could be expected from the public at large in the event of an oil spill occurring in an area with important fisheries resources. Noting the critical nature of *perception* in dealing with sensitive markets, the concept of highly visible efforts to prevent potentially contaminated seafood from reaching the market is worth considering, even if the chances for contamination is realistically considered to be low.

In a summary of the *Exxon Valdez* experience, Walker and Field (1991) observed that initial oil spill response activities have generally assigned a lesser priority to human health concerns that might arise from contamination of seafood. This was attributed to the low probability that fish would be exposed to high levels of hydrocarbons, the ability of fish to relatively rapidly metabolize petroleum-related compounds, and the ability of human consumers to detect tainted seafood through smell and taste. Because the risk to human health has been considered to be low, the National Contingency Plan does not provide guidance to planners and responders. As a result, fisheries and human health issues are not raised explicitly until fishermen, fisheries agencies, or the public do so. Because of the potential for substantial impacts attributable to seafood concerns, planners and responders would be well-advised to anticipate these considerations and incorporate them into regional or local contingency plans.

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