Offshore Petroleum Resource Development and Marine Mammals: A Review and Research Recommendations

J. R. GERACI and D. J. St. AUBIN

Introduction

The possible effects of oil and oil-industry activities on marine mammals are a subject of great concern. All marine mammals inhabit surface water to breathe and some to feed, potentially exposing them to spilled oil by contact, inhalation, or ingestion. Nearshore accumulation of oil could directly affect inshore-dwelling cetaceans, manatees, and virtually all pinnipeds and sea otters.

Moreover, all but the manatees are high- or top-level predators, and therefore are potential accumulators of oceanic contaminants. Noise and shock waves generated by seismic surveys, drilling, construction, and support vessels potentially threaten all marine mammals by displacing them from otherwise dependable feeding grounds, migratory routes, and fragile nursing rookeries.

J. R. Geraci and D. J. St. Aubin are with the Department of Pathology, Ontario Veterinary College, University of Guelph, Guelph, Ontario, Canada N1G 2W1. Views or opinions expressed are those of the authors and do not necessarily represent the position of the National Marine Fisheries Service, NOAA.

Despite these concerns, there is little scientific data upon which to base management decisions. There have been two experimental studies on the effects of oil contact on pinnipeds and sea otters, and one on the effects of ingestion on pinnipeds. No study has been conducted on cetaceans. Thus, we continue to use intuition and information from conflicting field observations and imprecise popular news accounts.

There are nine major groups (Trichechidae, Dugongidae, Mysticeti, Odontoceti, Otariidae, Phocidae, Odobenidae, Ursidae, and Mustelidae) and more than 130 different species of marine mammals. It would not be realistic to attempt to assess the effects of oil, noise, etc., on each species or group. Data do not exist nor are they easily acquired. The animals themselves are not well enough understood, their environments and habitats undergo dynamic changes which are likely to affect their exposure to oil, and many of the animals are simply too large or otherwise unsuited for either captive or field studies.

The following research scheme (Fig. 1) is proposed to acquire some of the basic data needed to predict the effects of offshore oil development on marine mammals. It was developed by identifying potential hazards associated with each phase of offshore activity, and then establishing research needs, according to the threats perceived to be most common or most serious to marine mammal populations.

Phases of development are divided into exploration, production, and transportation, each of which has a variety of associated activities. Each activity, either through its very nature or as a result of aberrant function, generates a potential hazard, the effect of which is presumed or has been shown to be detrimental to marine mammals or their environment.

Shock Waves

Effects

Hill[1] has provided an exhaustive review of the effects of underwater

[1]Hill, S. H. 1978. A guide to the effects of underwater shock waves on Arctic marine mammals and fish. Unpubl. manuscr., 50 p. Inst. Ocean Sci., Patricia Bay, Sidney, B.C., Pac. Mar. Sci. Rep. 78-26.

ABSTRACT—The development of offshore oil and gas reserves presents a number of potential threats to marine mammals. Seismic surveys employing various high explosives can be lethal at close range. Noise is associated with all phases of petroleum exploration and production. The physical, physiological, and behavioral effects of noise disturbance on marine mammals are poorly understood and need to be investigated.

Exposure to spilled oil has been implicated as the cause of death of pinnipeds and cetaceans, however much of the evidence has been inconclusive. Surface contact is threatening to those species which rely on hair or fur for thermal insulation, such as sea otters, fur seals, and polar bears. Though cetaceans are not likely to accumulate oil on their body surfaces, the unique metabolic and physiologic properties of cetacean skin may be impaired by toxic fractions in crude oil. Marine mammals are unlikely to ingest sufficient quantities of oil to cause acute toxicity. However, the long-term effects of accumulation of petroleum fractions through the food chain are unknown. Inhalation of toxic vapors would occur in any oil spill situation, and can be life threatening in the case of prolonged exposure. The ability of marine mammals to detect and avoid oil slicks is critical to any assessment of the potential impact of oil, and yet such information is clearly lacking.

This review summarizes field observations and experimental studies of the effects of oil and oil exploration on marine mammals, identifies gaps in our knowledge, and establishes priorities for future research.

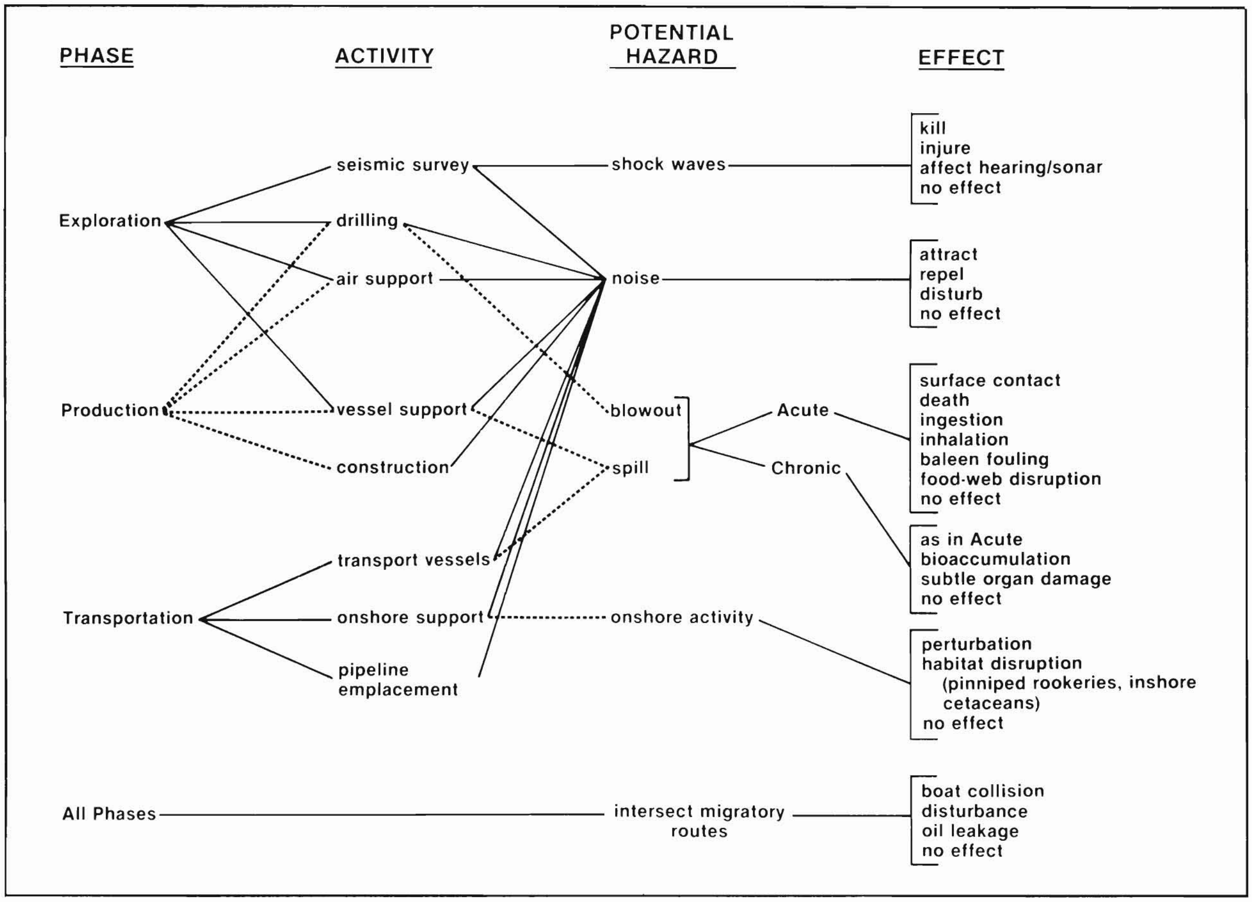

Figure 1.—Proximate factors associated with offshore oil exploration and their effects on marine mammals.

shock waves on fish, and a theoretical account of their possible effects on marine mammals. When seismic surveys are carried out at sea, sources of high-intensity sound, such as explosives and air guns, are placed directly in the water. Detonating-type or "high" explosives have been widely used. These result in a steep-fronted detonation wave which is transformed into a high-intensity pressure wave (shock wave) and an outward flow of energy in the form of water movement. There is an instantaneous rise to maximum pressure followed by an exponential pressure decrease and drop in energy.

Shock wave reflections at an interface between tissue and an air-filled cavity can cause tissue destruction at the interface. Shock waves with high peak pressures and rapid rates of change in pressure can result in damage and death to living organisms. In mammals, gas-containing organs are affected, principally lungs and hollow viscera. Animals close enough to the site of detonation can be killed (Fitch and Young, 1948).

It is possible to calculate lethal range and minimum safe distance from an explosive charge in water. A formula has been developed using fish and land animals as subjects (Yelverton et al., 1973). Its use requires knowledge of target (animal) depth, detonation depth, and charge weight. When applied to a relatively small marine mammal such as a ringed seal, *Phoca hispida*, at a depth of 25 m, minimum safe distance from a 5 kg charge detonated at a depth of 5 m is calculated to be 359 m (Hill, footnote 1). Factors influencing the calculated range include nature of the sea floor, ice cover, and water depth. For example, the calculated safe range is underestimated if the animal is in shallow water with a rocky bottom, or if the charge is detonated under thick ice.

This "safe distance" formula (Yelverton et al., 1973) was derived using relatively small land mammals and fishes as experimental subjects. No marine mammals, or animals approaching their size, have been studied. Nevertheless, Hill (footnote 1) concluded that marine mammals would be less vulnerable to damage from underwater shock waves than are land mammals of comparable size. This primarily is due to pressure adaptations and increased protection due to thick body walls. Morever, they would be further safeguarded by their large size, which in itself protects against underwater blast.

Shock waves from conventional

seismic blasts have been associated with marine mammal mortality. Fitch and Young (1948) reported that California sea lions were killed by underwater explosions used in seismic exploration; gray whales, *Eschrichtius robustus*, in the area were apparently undisturbed. Deaths also occurred in conjunction with an underground nuclear detonation on Amchitka Island in the North Pacific. Ten sea otters, *Enhydra lutris*, and four harbor seals, *P. vitulina*, were recovered dead from the beach nearest the blast site. They were considered to have been killed instantly by an estimated overpressure of 200-300 psi (14-21 bar) followed immediately by underpressure. Death was due to overwhelming destruction of virtually all organ systems (Rausch[2]).

No survey was made of areas more distant from the Amchitka test site, so that a safe distance and pressure were not established. Pressures in the zone in which mortality occurred were at least 50-70 times greater than the safe limit calculated using Yelverton's formula. Such pressures are unrealistically high in terms of those generated during conventional seismic blasting operations.

Air guns also are used in marine seismic exploration. They are placed in arrays of several guns of different sizes, and fired simultaneously. Shock waves so produced differ from those of explosives in that peak pressures are low and both the rise time of the shock pulse and the time-constant of the pressure decay are comparatively long. Shock waves so generated are harmless to fish (Falk and Lawrence[3]; Hill, footnote 1) and would not appear to be immediately injurious to marine mammals.

Recommendations

Studies should be designed to assess physiological, psychological (behavioral), and pathological effects of small graded underwater explosions on representative pinnipeds and small odontocetes, and the data extrapolated to those species or populations which are unsuitable for study, e.g., endangered species, large whales. Experiments should include an evaluation of the startle response, profiles of hearing sensitivity, morphologic assessment of cochlear sensory cells, and detailed examination of all air/tissue interfaces.

In circumstances where explosives must be detonated underwater, the following steps should be taken:

1) Using the formula from Yelverton et al. (1973), calculate the ranges at which various levels of shock wave damage to marine mammals are likely. Data on explosion depth, depth of the animals, and the weight of the charge would be derived from the actual situation at each of the blast sites.

2) Assess behavioral patterns of those species occupying, utilizing, or migrating through potential blast areas. Determine their physical vulnerability using the calculated "safe distance" formula, and behavioral response by using reasoned predictions based on known species behavior and life history.

3) Where marine mammals are considered vulnerably close to blast areas, adopt techniques to reduce potential damage: a) modify charge and arrangement of explosives (Jakosky and Jakosky, 1956); b) detonate small "scaring charge"; c) bury charges in the sea bottom (Hubbs and Rechnitzer, 1952).

Noise

Physiological Effects

Noise is associated with all phases of offshore petroleum exploration and production. It accompanies seismic surveying, drilling, air and ship support, construction, and the operation of onshore and offshore facilities.

Effects of noise on marine mammals have not been investigated. In laboratory animals, auditory damage associated with impulse noise correlates with peak level, duration, rise time, frequency spectrum, background noise level, and number or frequency of repetitions. Noise beyond a definable threshold causes degeneration of cochlear sensory cells with associated loss of hearing. The actual damage is due to the moment of inertia created by the sudden movement of the stapes. The high energy generated brings about acoustic overstimulation and this in turn causes functional sensory cell damage. If the energy is great enough, sensory cells may degenerate and, in the extreme, dislodge from the supporting cells. Such changes are morphologically detectable (Stockwell et al., 1969), but functional correlations are difficult to establish (Henderson et al., 1973).

Most of the studies on noise-associated cochlear damage have utilized high frequency sounds., e.g., ultrasonic radiation. Resulting damage is relatively easy to detect because of the basic architecture and orderly arrangements of cells and membranes in the high frequency region of the cochlea (Ramprashad et al., 1973). However, low frequency sounds of the type which are likely to emanate from activities related to petroleum exploration and production are less destructive than high frequency sounds and their effects are more elusive (Ramprashad[4]). Low frequency sounds are analyzed in the apical portion of the cochlea. This includes a wide area along the length of the basilar membrane, within which specific cell damage is difficult to localize.

The effects of noise on nonauditory physiology of birds and mammals have been reviewed by Fletcher (1971). These appear to be stress-mediated, and involve adrenergic and cholinergic responses, possibly associated with lowered resistance to disease, increased vulnerability to environmental disturbances, and endocrine imbalances which might in turn affect reproduction. Such stress-mediated effects might well apply to marine mammals. Hyponatremia in free-ranging pinnipeds (Geraci

[2]Rausch, R. L. 1973. Post mortem findings in some marine mammals following the Cannikin test on Amchitka Island. Manuscript prepared for U.S. Atomic Energy Commission, Las Vegas, Nev., 86 p.

[3]Falk, M. R., and M. J. Lawrence. 1973. Seismic exploration: its nature and effect on fish. Fish. Mar. Serv., Winnipeg, Tech. Rep. Serv. No. CEN T-73-9, 51 p.

[4]F. G. Ramprashad, Department of Zoology, University of Guelph, Guelph, Ontario. Pers. commun. 1979.

et al., 1979) and adrenal cortical disturbances in odontocetes (Geraci et al.[5]) are conditions which may compromise the normal stress response, making affected animals more vulnerable to noise disturbance.

Behavioral/Psychological Effects

Two types of noise can be identified as potentially affecting marine mammal behavior: Impulse and chronic background noise. Impulse noise elicits a startle reflex, the characteristics of which vary with species, age, sex, and psychological status (Landis and Hunt, 1939; Moyer, 1963; Rylander et al., 1974).

The startle reflex in marine mammals has not been studied per se, but has been described through behavioral observations and anecdotal accounts. In pinnipeds, sudden disturbances cause dispersement from rookeries, often taking the form of a spontaneous mass movement, or stampede, into the water (Loughrey, 1959; Salter, 1979). This, in turn, may lead to disruption of mother-pup pair bonds and accidental injuring or killing of pups. Recolonization of the rookery may then be associated with injurious territorial aggression.

Moreover, repeated disturbances may lead to colonial pinnipeds abandoning traditional breeding areas in favor of less suitable sites. For example, underwater vocalizations of harp seals in whelping areas decreased sharply following the arrival of a vessel, but it could not be determined whether this was due to a change in behavior, or a shift in location (Terhune et al., 1979). Under most circumstances, it would seem that pinnipeds most vulnerable to the effects of noise disturbance might be perinatal females and nursing pups and calves, molting animals, and those stressed by parasitism and disease (Geraci and Smith, 1976a).

Some cetaceans respond to sudden disturbances by sounding, aggregating, or dispersing, and subsequent regrouping of the social structure (Leatherwood[6]). This is particularly true of the more gregarious odontocetes. These behaviors are adaptive and obviously designed to protect against a sudden threat. However, in some cases they may be detrimental. Some of the hypotheses used to explain mass strandings of cetaceans include acoustical confusion (Dudok van Heel, 1966), meteorological conditions (Hall et al., 1971; Stephenson, 1975), and unusual disturbances. For example, van Bree and Kristensen (1974) attributed a small mass stranding of Cuvier's beaked whales, *Ziphius cavirostris*, in the Caribbean to an underwater explosion.

Unlike the abrupt response to a sudden disturbance, most animals become habituated to low-level background noise such as would be associated with ship traffic and onshore and offshore petroleum activities. Some species with which we are familiar, e.g., humpback and gray whales, harbor and elephant seals, bottlenosed dolphins, walruses, and sea lions, seem to coexist well with human activities. Such habituation, in fact, forms the underlying basis for the success of whale watching cruises. Nevertheless, Nishiwaki and Sasao (1977) have suggested that increased ship traffic in Japanese waters had disturbed migration routes of minke whales, *Balaenoptera acutorostrata*, and Baird's beaked whales, *Berardius bairdi*.

Although the effects of noise as it might relate to oil activities are not known, the net result of any disturbance would depend upon the size and percentage of the population likely to be affected (e.g., 100 fur seals in Alaskan waters vs. 100 manatees in Florida), the ecological importance of the disturbed area (e.g., critical habitat), and the environmental and biological parameters which influence an animal's sensitivity to disturbance and stress. An additional factor which must be taken into account is the rate of recovery or recolonization by a population following a short-term disturbance, or the accommodation time in response to a prolonged disturbance.

Recommendations

Studies on the effects of noise on marine mammals must address both first and second level effects. First level effects, such as auditory damage caused by impulse noise may have an immediate impact. In this context, the question must be answered as to the effects of acoustic overstimulation on the bone conducting auditory system of pinnipeds (Ramprashad et al., 1973) and cetaceans (McCormick et al., 1970).

Marine mammals have specialized anatomical features such as distensible venous retia, dense auditory bones, a thick tympanic membrane, and a reduced ear canal (cetaceans) or one that is under voluntary control (pinnipeds). These adaptations serve to dampen the movement of the ossicular chain (McCormick et al., 1970; Ramprashad et al., 1973), particularly during diving. A study of noise effects should compare in-air and underwater audiograms of animals exposed to high intensity, variable frequency pure-tone sound (Terhune and Ronald, 1972), in order to determine any changes in hearing threshold attributed to sensory cell destruction. Precise site of damage may be confirmed histologically. These data can then be used to assess the physical-pathological impact of the noises likely to emanate from each phase of industry operation.

Most marine mammals use sound as a form of communication, or for navigation and locating prey species. Background noise may interfere with these sounds, thereby resulting in second level effects, such as social disruption and echo confusion. The immediate effects can and should be tested experimentally. However, the long-term effects can only be assessed by observation under field conditions, and might be expected to include population decline through stress-mediated disease, decreased productivity, and displacement from favorable habitats. These

[5]Geraci, J. R., S. A. Testaverde, D. St. Aubin, and T. Loop. 1976. A mass stranding of the Atlantic white-sided dolphin, Lagenorhynchus acutus: a study into pathobiology and life history. Natl. Tech. Inf. Serv., Wash., D.C., PB-289 361, 141 p.

[6]Leatherwood, S. 1977. Some preliminary impressions on the numbers and social behavior of free-swimming bottlenosed dolphin calves *Tursiops truncatus* in the northern Gulf of Mexico. *In* S. H. Ridgway and K. Benirschke (editors), Breeding dolphins, present status, suggestions for the future. Natl. Tech. Inf. Serv., Wash., D.C., PB-273 673, 29 p.

questions can best be addressed by collecting baseline behavioral and population data for a few selected species and test areas, then carefully monitoring these during all phases of oil exploration and development.

Boat Collision

Accidents associated with industrial activities can be minimized but not eliminated. Oil exploration in the regions of the outer shelf will be accompanied by ship traffic through migratory routes, and low flying aircraft in the area of the drilling platform. It should be possible to minimize disturbance to marine mammals by strategically locating onshore facilities, and by carefully planning flight paths and supply ship routes. Certain problem areas have already been identified, such as inshore and coastal Florida waters which require special consideration in order to reduce manatee mortality resulting from boat collisions, gray whale calving lagoons in Baja California, and other areas of marine mammal concentrations.

Oil

Background

Over the past 10 years, reports by the media and some scientific review articles have implicated oil fouling as the cause of death of seals, sea otters, and both small and large whales. The most noteworthy incident is that of the 1969 blowout in the Santa Barbara Channel. Accounts of the incident speculated that gray whales had died as a result of the spill. Time[7] reported the presence of a stranded dolphin with an oil-clogged blowhole and lung hemorrhage. Similar accounts involved northern elephant seals, *Mirounga angustirostris*, California sea lions, *Zalophus californianus*, and the northern fur seal, *Callorhinus ursinus*. Critical assessments of the spill did not conclusively link the marine mammal deaths with the presence of oil (Simpson and Gilmartin, 1970; Brownell, 1971; Brownell and Le Boeuf, 1971; Le Boeuf, 1971).

Reports on seals contaminated in other oil spill situations are vague. There have been two events in Alaskan coastal waters in which marine mammals, mostly hair seals (Phocidae), but including sea lions and sea otters, *E. lutris*, came into contact with oil (Anonymous, 1971a, b). No mortalities were reported in the immediate vicinity at the time of the spills. In one instance, seal hunters later observed 55 "seals" with oil-contaminated pelts, and one dead sea otter coated with oil. Associated with the second spill, "Two killer whales, one sick and one dead, were observed. Four hundred hair seals... were acting in an unusual way and had a white glazed look in their eyes.... It was not known whether the deaths of a small number of sea otters were related to the contaminant. There were no deaths among the 400 hair seals that appeared to have been affected by the contaminant but they continued to behave strangely (would not enter the water)" (Anonymous, 1971b).

During the 1967 *Torrey Canyon* spill, some seals were reported to be surfacing through oil slicks; others were found dead coated with oil (Spooner, 1967). However, precise causal relationships were not established.

Following the *Arrow* spill in 1969 at Chedabucto Bay, Nova Scotia, a small number of seals reportedly died due to suffocation caused by the plugging of vital orifices with Bunker "C", a highly viscous, refined oil (Canada Ministry of Transport, 1970). Details of these observations are not available and so the account cannot be assessed critically. In another report of a Bunker "C" spill in the Gulf of St. Lawrence, 500-2,000 harp seals, *P. groenlandica*, were observed coated with oil. Some dead seals were found but it could not be determined whether oil was the causal agent (Warner[8]).

Davis and Anderson (1976) studied differences between oiled and uncontaminated gray seals, *Halichoerus grypus*, off the west coast of Wales following an oil spill of undetermined origin. Of 25 oiled pups examined, 5 (20 percent) were dead on the beach, compared with 11 of 37 unoiled pups (30 percent). Six of the dead oiled pups submitted for postmortem examination showed no evidence of having ingested oil, supporting the investigators' conclusion that "... oiling was not a direct cause of death. ... The only deaths which could be attributed directly to oil, were those of two pups, encased in oil so that they were unable to swim and thus were drowned when washed off the beach."

As recently as April 1979, following the breakup of the tanker *Kurdestan* off the south coast of Nova Scotia, as many as 14 dead and dying phocid seals (species unidentified) were observed coated with Bunker "C" oil, which was also found fouling the shoreline (Marston[9]). Detailed necropsies were not performed and, once again, the association of oil with mortality is unsubstantiated.

Oil Detection and Avoidance

Marine mammals may or may not be able to detect oil, and if so, avoid it. Yet such behavioral response is the heart of the issue. The preceding scenarios, which are by no means conclusive, show that in some cases pinnipeds and sea otters do not avoid oil whereas a cetacean has yet to be found coated with oil. The difference may be due to sensory capabilities which are more sophisticated at long range in odontocetes (Norris, 1969), perhaps enabling them to detect oil more readily. Alternately, cetacean skin is smooth and cannot accumulate oil, and unlike pinnipeds which come ashore with obvious evidence of oil, an oil-fouled odontocete may go unnoticed. In support of the latter, mysticetes have no known sonar capability (Eberhardt and Evans, 1962; Beamish, 1977), and yet have not been observed with any evidence of oil fouling.

Certain features of pinniped and sea

[7]Time, 21 February 1968, p. 21.

[8]Warner, R. E. 1969. Environmental effects of oil pollution in Canada. An evaluation of problems and research needs. Can. Wildl. Serv. Manuscr. Rep., p. 16-17.

[9]D. F. Marston, Nova Scotia Society for the Prevention of Cruelty to Animals, Halifax, Nova Scotia. Pers. commun. 1979.

otter life history may increase their vulnerability to oil. During pupping, moulting, and mating activities, their dependency on substrate may force them into repeated exposure to shoreline accumulations of oil (Davis and Anderson, 1976), despite some evidence that they are able to detect it. For example, Barabash-Nikiforov et al. (1947) reported that Japanese poachers used petroleum products to repel otters from shore rocks. The repellant effect was presumably due to repugnant petroleum odors.

Laboratory studies have not helped to resolve the question, nor can they go further than simply establishing detection capability. In the only such study to date, Williams[10] concluded that sea otters would not avoid an oil spill, but he could not determine whether the stresses of captivity and confinement were responsible for the behavior.

It is conceivable that some marine mammals may even be attracted to a spill to feed on fish and other organisms debilitated or killed by the oil. Beck (in Hill, footnote 1) observed a gray seal, *H. grypus*, feeding on injured fish in the vicinity of a shipwreck where large underwater charges were being detonated.

Recommendations

Studies should be designed to assess behavioral responses to oil. Can marine mammals detect oil? What are the sonar-echo characteristics of oil on the surface and in the water column? What is the visual response to oil? What are the limits of detection? What is the olfactory response to oil by various species? Is oiled food palatable?

Many of these questions regarding sensory perception can best be approached by experimentation under controlled laboratory conditions. However, these data must be integrated with observational data acquired during actual oil spill situations. Such events not only provide a basis for assessing the relevance of in vitro and laboratory or captivity studies, but also represent situations which cannot be experimentally duplicated.

To maximize the information yield from an otherwise disruptive ecological event, an observer team response should be organized specifically to investigate the impact of accidentally occurring oil spills, recording such factors as dispersal of oil through specific marine mammal habitat areas, e.g., rookeries, breeding or calving lagoons, as well as avoidance, feeding, reproduction, migration, and hauling-out behavior.

Behavioral Effects

The behavioral consequences of oil fouling have been noted only for pinnipeds. Kooyman et al.[11] attempted unsuccessfully to determine diving and feeding behavior in oil-fouled northern fur seals. Davis and Anderson (1976) noted reduced growth rate in oiled gray seal pups, but could not determine changes in nursing behavior as a result of oiling. Experimentally oiled sea otters spent "75% of their time underwater trying to clean their pelage" (Williams, footnote 10). Ringed seals immersed in seawater covered with light crude oil showed variable signs of irritability and increased aggression (Geraci and Smith, 1976b). When on the surface, the seals showed varying degrees of arching of the back, a behavior that was not observed in the control group or in the experimental group prior to oiling. Four days after being removed from the 24-hour oil exposure, the seals showed no behavioral or physical signs of having been oiled.

Recommendations

Critical gaps exist in our knowledge of the behavioral effects of oil fouling, and yet behavioral modifications as a result of oil contact may represent a significant impact on marine mammal populations. Changes in activities such as feeding, diving ability, mother-pup interaction, herd organization, and haul-out behavior may have immediate consequences affecting the survival of oil-fouled animals. Behavioral observations at the site of an oil spill are needed, therefore, to properly assess the effects of oil. For many species, such data are not easily interpreted due to the lack of baseline behavioral studies. Nevertheless, an accidental oil spill presents an opportunity for observations which for the most part cannot be duplicated under laboratory or captive conditions, and data so collected will be available for retrospective analysis following cleanup and restoration of the oil-fouled area.

Thermal Effects

Recent experiments have addressed some potential oil effects on thermoregulation in pinnipeds and sea otters. Kooyman et al. (1977, footnote 11) investigated the effects of oiling on thermal conductance of pelts from sea otters and four species of otariid and phocid seals. Most affected were pelts from a sea otter pup and two subadult northern fur seals in which conductance doubled. No change was noted in a California sea lion, and bearded seal, *Erignathus barbatus*, pelts. An oiled Weddell seal, *Leptonychotes weddelli*, pelt showed an intermediate increase in conductance. Control values for phocid seal and sea lion skins were high. The investigators concluded that fouling of fur in sea otters and fur seals would have serious consequences and, if the insulative properties of the pelts were not restored through grooming, these species probably could not endure prolonged immersion in cold water.

In an unrelated and less convincing study, two sea otters were placed in a holding pen in which Alaska crude oil covered one-half of the surface (Williams, footnote 10). One otter was removed to a clean holding pen, and was found dead 9 hours later. Williams (footnote 10) speculated that the animal had died of hypothermia. His conclusion is not supported by physiological or pathological data, but seems reasonable based on the Kooyman et al. (1977, footnote 11) studies.

[10]Williams, T. D. 1978. Chemical immobilization, baseline hematological parameters and oil contamination in the sea otter. U.S. Marine Mammal Commission Report MMC-77/06, 27 p. Natl. Tech. Inf. Serv., Springfield, Va.

[11]Kooyman, G. L., R. L. Gentry, and W. B. McAllister. 1976. Physiological impact of oil on pinnipeds. Processed rep., 23 p. Northwest Fisheries Center, Natl. Mar. Fish. Serv., NOAA, Seattle, Wash.

Studies were conducted on ringed seals, *P. hispida*, immersed in seawater covered with light crude oil for 24 hours and on newly weaned harp seal pups, *P. groenlandica*, coated with crude oil for 7 days (Smith and Geraci, 1975). In all cases, body temperatures remained stable within the normal range. In vitro examination of the pelts from these studies showed that thermal conductance was not changed as a result of oil. The major effect on the fur was to increase solar heating capacity.

Recommendations

All evidence indicates that animals which rely on hair or fur for thermal insulation will be adversely affected by surface contact with oil. By experimentation and extrapolation, we may consider sea otters, fur seals, and polar bears in this category. Phocid seals are more resistant to the thermal effects of oil, likely due to their reliance on blubber and vascular mechanisms for thermal insulation. Cetaceans would be similarly resistant to mechanical interference with thermoregulation, particularly because the smooth body surface would substantially reduce the likelihood of physical fouling by even the heavier adhesive fractions. Further studies on thermal effects of surface fouling should therefore be afforded low priority.

A study directed toward testing various solvent-emulsifiers which might be used to clean oiled marine mammals would also be considered low priority. Application of such techniques in the field are impractical, not likely to reduce mortality significantly, and in fact may be detrimental as a result of excessive handling (Davis and Anderson, 1976) or interference with natural oils on the fur (Williams, footnote 10).

Noxious Effects

Some anticipated effects of surface contact with oil are irritation and inflammation of eyes, skin, and sensitive mucous membranes. The nature of the damage has been adequately demonstrated in ringed seals immersed in oil-covered seawater (Geraci and Smith, 1976b). Seven or eight minutes after oiling, one of the seals began to lacrimate excessively, and would frequently open and close its eyes. Soon eye irritation became apparent in the other seals. They lacrimated profusely, yet at first there was no attempt to close their eyes to avoid the oil. Twenty minutes into the study, however, some of the seals seemed to have difficulty keeping their eyes open; the conjuctiva of the eyes were obviously reddened and inflamed. Within 4 hours, all of the seals were lacrimating and squinting.

After 24 hours of exposure, examination of the eyes revealed severe conjunctivitis, swollen nictitating membranes, and evidence of corneal erosions and ulcers. Within 3 hours of being placed in a clean seawater pen, most of the eye squinting and lacrimation had subsided, and by 20 hours, the eyes showed no signs of irritation.

There were no other surface effects noted in the immersed seals, nor have skin lesions been unequivocally linked with accidental or experimental exposure to oil. Although oil-fouled cetaceans have not been observed, the nature of their skins suggests that they may be particularly vulnerable to the noxious effects of surface contact with oil.

Cetacean epidermis is a unique organ, having no counterpart in other mammals (Ling, 1974). The outermost layer is not keratinized, but consists of flattened viable cells with elongated nuclei and prominent organelles, including mitochondria. The epidermal cells are rich in enzymes creatine kinase, sorbitol dehydrogenase, and aspartate aminotransferase (Geraci and St. Aubin, 1979). These enzymes are respectively involved with high energy phosphate conversion, hexose metabolism, and transamination of amino acids. Cetacean epidermis is also rich in vitamin C (St. Aubin and Geraci, in press), the antioxidant properties of which may serve to protect the enzymatically active intracellular environment.

These findings support other biochemical evidence of high metabolic activity (Tinyakov et al., 1973; Dargoltz et al., 1978) but as yet the reason or reasons for this activity is not understood. Nevertheless, physical or chemical disruption might be expected to have immediate and far-reaching metabolic consequences, perhaps affecting vital ionic regulation and water balance. Cetacean skin is virtually unshielded from the environment, and it may respond to noxious substances such as oil in a manner approaching sensitive mucous membranes.

Recommendations

The irritating properties of oil on the ocular and periocular tissues were well documented in the ringed seal immersion experiment (Geraci and Smith, 1976b). By reasoned interpretation, we can predict that petroleum hydrocarbons will be similarly harmful to other marine mammal species. As such, a study to quantify ocular damage as a result of oil contact would appear unnecessary.

Experiments to determine the noxious effects of oil contact on cetacean skin should be given high priority. The morphologic and metabolic nature of cetacean epidermis demands that biochemical and physiological studies rather than physical-thermal studies be carried out to assess the effects of oil contact. Such studies should also include an assessment of the effects of dispersant-treated oils, as these will likely be contacted by marine mammals during oil clean-up operations.

Ingestion and Accumulation

Marine mammals exposed to a spill may ingest and accumulate oil. Ingestion might occur incidental to surface activities, in association with surface feeding in the case of large whales, or with grooming in sea otters. A less direct route of accumulation might be through feeding on contaminated prey species.

It is also conceivable that ingested oil could foul baleen plates. Crude oils are complex mixtures of hydrocarbons. Lighter fractions evaporate quickly, so that crude oil density and viscosity increase with weathering. The heavier weathered fractions, as well as heavy refined products such as Bunker "C", presumably would present the most serious threat with regard to possible baleen fouling in surface feeding whales. The threat probably would diminish dramatically with time as the oils disperse. Raw crude oil or lighter oil fractions might have quite a different effect. Although they may have less fouling potential, they are volatile and destructive to tissue, and might thereby damage the structural integrity of the baleen plates or horny tubes that compose the food-filtration mechanism.

Ingested oil is potentially toxic. Acute cytotoxic damage, associated with low molecular weight volatile fractions, has been observed in most animal species which have been studied, while more subtle organ damage may be associated with repreated ingestion of less volatile fractions (Moore and Dwyer, 1974).

In testing acute toxicity of ingested oil to marine mammals, Geraci and Smith (1976a) performed a series of experiments on phocid seals. They found that ringed seals rapidly absorbed crude oil hydrocarbons into body tissues and fluids, ultimately excreting the compounds via bile and urine (Engelhardt et al., 1977). Harp seals given up to 75 ml of crude oil, far in excess of that calculated to have been swallowed by the ringed seals immersed in oil-covered water for 24 hours, showed no clinical, biochemical, or morphological evidence of tissue damage (Geraci and Smith, 1976a).

Thus, relatively large quantities of oil accidentally ingested over a short period of time were not associated with acute organ damage. These findings cannot be extrapolated to greater quantities of oil or to other groups of marine mammals. Yet the findings from these studies tend to dampen the fear that accidental oil ingestion associated with feeding would be necessarily harmful to carnivorous marine mammals. Sirenia, on the other hand, might respond quite differently. They are herbivores, and ingestion of oil-contaminated food might be expected to harm the gut flora or interfere with secretory activity of the gastric glands (Kenchington, 1972), thus affecting digestion and perhaps survival.

Any study on oil ingestion must address long-term effects associated with fractions persistent in the food chain. Benthic invertebrates accumulate aromatic hydrocarbons in varying degrees, both from seawater (Stegeman and Teal, 1973), and from bottom sediments (Roesijadi et al., 1978). In the soft-shell clam, *Mya arenaria*, maximum tissue levels are attained within 1 week (Stainken, 1978). In another deposit-feeding clam, *Macoma inguinata*, and the suspension feeding clam, *Protothaca staminea*, hydrocarbon concentrations continue to increase with exposure (Roesijadi et al., 1978).

Generally deposit feeders accumulate hydrocarbons to a greater extent than suspension feeders. Representatives of this group compose a significant portion of the walrus diet (Vibe, 1950). For this reason walruses would seem to provide a natural field model for determining effects of long-term hydrocarbon accumulation.

Levels of hydrocarbons in benthic organisms vary due to animal species, nature of the substrate, and hydrological conditions. In seven benthic invertebrates representing five phyla, hydrocarbon levels decreased after initial exposure to contaminated sediments (Grahl-Nielson et al., 1978). Yet in the case of the Chedabucto Bay oil spill off Nova Scotia, hydrocarbon levels in the soft-shell clam, *M. arenaria*, were found to exceed 200 μg/g, 6 years after the event (Gilfillan and Vandermeulen, 1978). These high tissue concentrations correlated with persistent high hydrocarbon levels in the sediment. This raises the interesting question of the possible effects that pipeline and platform construction, or other forms of physical disturbance might have on resuspending contaminated sediments, thus making them more available to benthic invertebrates and fish in critical feeding grounds for bottom feeders such as walruses, sea otters, and bearded seals.

Persistence of hydrocarbons in at least some mollusks is due to their apparent lack of the degrading enzyme aryl hydrocarbon hydroxylase (Vandermeulen and Penrose, 1978). Fish have this enzyme, and within 2 months of exposure, metabolize 98 percent of the accumulated hydrocarbon load, retaining naphthalenes and tetramethylbenzene (McCain et al., 1978), the components ultimately transferred to top level predators.

The long-term effects of ingestion of these compounds by marine mammals are unknown, but Hodgins et al. (1977), in their review of the literature, provided unequivocal evidence that certain petroleum hydrocarbons, such as benzopyrene, are potent carcinogens in a wide variety of invertebrate and vertebrate species. Although marine mammals would likely suffer the same consequences, the issue is rather academic, as any experiment designed to test the hypothesis would draw upon unrealistic circumstances of selective feeding on specific carcinogenic fractions.

More realistic, and perhaps more important to population health and stability, are the subtle and elusive effects of functional impairment of those organ systems which can be evaluated only with time, e.g., the central nervous and reproductive systems. In an historical analysis of cetacean strandings on the coast of the Netherlands, van Bree (1977) has associated two periods of sudden decline in the number of strandings to an increase in pollutant levels in the North Sea. He reported that, "The first probably took place around 1946" and there is a "...possibility that this... is linked to the dumping of war chemicals at that period or by the increase in the use of oil....[the] second decrease is clearly related to the increase of pollution of the North Sea...."

The conclusion is intriguing, and though still subject to discussion, it draws on 45 years of carefully documented observations on the frequency of strandings. If true, then it calls attention to the reason or reasons underlying the population decline, and the possible role of pollutants, including petroleum hydrocarbons, on reproductive success.

Helle et al. (1976) found that about 40 percent of a sample of Baltic ringed seal females of reproductive age showed pathological changes in the uterus, associated with unusually high levels of DDT and PCB substances. Premature parturition in California sea lions has been correlated with high tissue levels of DDT and PCB's, in association with disease agents and trace element imbalances (Gilmartin et al., 1976). Data on tissue hydrocarbon burdens in free-ranging marine mammals, such as would be required to realistically interpret these findings, are not presently available.

Recommendations

Laboratory experiments should be conducted to determine the fouling properties of various crude oil fractions on baleen. These studies must address factors such as filtration rate and efficiency, structural integrity of baleen plates, and recovery time. Interpretation of the findings is complicated by a general lack of understanding of the mechanisms and characteristics of baleen feeding, but until such data are available, we must rely on extrapolation from in vitro studies. Insight into the potential problem of baleen fouling would be significantly enhanced by observations and sample collection from dead mysticetes, stranded or floating near the site of an oil spill.

Limited studies of the acute effects of ingested oil on predatory marine mammals have been done. Geraci and Smith (1976a) demonstrated that consumption of a substantial quantity of oil had no observable harmful effect on harp seals although pathological changes could no doubt have been induced by increasing the dose. In an equivalent experiment which did produce pathological changes, 10 liters of a light Texas crude oil were administered to bovine calves the same size as an adult *Tursiops* (Rowe et al., 1973). Although it would seem inappropriate to repeat this study on larger pinnipeds or cetaceans, stomach contents and tissue burdens of dead or moribund animals in the area of spills should be examined as a matter of course.

Sirenians, though conceivably more vulnerable to acute effects of oil ingestion, are unsuitable for experimentation by virtue of their reduced numbers. Dead and debilitated manatees recovered from the Florida canal systems should be utilized for studies of tissue hydrocarbons, and for in vitro effects of petroleum hydrocarbons on gastrointestinal flora and digestive enzymes.

Although ingestion studies are not required, there is a need to determine the potential for bioaccumulation of petroleum hydrocarbons in marine mammals. The problem can be attacked from another direction: By assessing the functional capacity of enzyme systems to metabolize hydrocarbons, and by analyzing for the presence of hydrocarbons and metabolites in marine mammals known or suspected to have come into contact with oil.

Studies should also be directed toward assessing the effects of long-term ingestion and accumulation of oil fractions, particularly those transferred through the food chain. Baseline data on the type and concentration of hydrocarbons in food organisms are available, and could be used for preliminary studies on conventional laboratory animals. Such experiments could not feasibly be carried out on marine mammals, due to the numbers of animals which would be required to obtain statistically meaningful data for a variety of compounds and doses.

The long-term effects of persistent hydrocarbons on marine mammal organ systems can only be addressed through continued surveillance of free-ranging animals, particularly stranded specimens. Through a monitoring program, it may be possible to relate functional or behavioral changes in marine mammals to tissue and environmental levels of hydrocarbons, such as have already been described for certain other pollutants (Gilmartin et al., 1976; Helle et al., 1976; van Bree, 1977).

Inhalation

Studies on ringed seals showed that during the 24-hour immersion in oil-covered water, some volatile hydrocarbons were likely absorbed through the respiratory tract (Geraci and Smith, 1976a). That is, tissue hydrocarbon concentrations were higher than could be accounted for by the imperceptible quantities calculated to have been swallowed (Engelhardt et al., 1977). Transient kidney and possible liver lesions were observed, but there was no associated lung pathology. The experimental setting within the confined holding pen (Smith and Geraci, 1975) provided a more concentrated exposure to volatile fractions than would normally be encountered in an oceanic spill. Thus, short-term inhalation is not necessarily harmful either in terms of structural damage or gas exchange.

Effects of prolonged inhalation have not been examined in marine mammals. However, it is likely to have the same consequences as have been observed in rats, i.e., central nervous system disturbance, bronchopneumonia, and death (Carpenter et al., 1978). Such prolonged inhalation will feature prominently in a major spill or in one in which animals tend to remain.

Some concern has been expressed over the possibility of oil clogging the cetacean blowhole. This seems unlikely as the typical breathing cycle of cetaceans involves an explosive exhalation followed by an immediate inspiration and abrupt closure of the muscular plug. This mechanism has evolved to prevent inhalation of water and would be as discriminatory of oil.

Recommendations

Experiments specifically directed at assessing inhalation effects would not yield more than can be deduced from a reasoned interpretation of existing literature on oil properties, oil effects, and marine mammal biology. Notably, the net effects of inhaled vapors will depend on the composition of oil; duration of exposure; environmental conditions affecting evaporation, dissolution, and dissipation (Cretney et al., 1978; Moore and Dwyer, 1974); and the health of the animal. It is reasonable to expect that prolonged exposure to petroleum vapors, particularly highly volative fractions, can be life threatening.

Oil Countermeasures

Oil cleaning operations are associated with unprecedented human activity, and aerial and ship traffic. Case studies of the Santa Barbara blowout and spills of the *Torrey Canyon*, the oil barge *Florida* in Buzzards Bay, Mass., *Arrow* in Chedabucto Bay, Nova Scotia, and *Argo Merchant* in Nantucket shoals show that clean-up operations are justified on the basis of the importance of coastal recreational amenities and potential damage to the fish and shellfish industry. The mechanics of such operations at present involve activities that may have greater impacts on marine mammals than oil itself.

For example, the *Torrey Canyon* clean-up involved an initial bombing with 160,000 pounds of high explosives, 10,000 gallons of aviation kerosene, 3,000 gallons of napalm, and rockets. Subsequently, 2.5 million gallons of eight different solvent emulsifiers were used. Shore operations included burning with flamethrowers, magnesium powder, and high-temperature flares, and physical removal with the aid of heavy equipment, booms, suction devices, straw, and other absorbent material, and steam cleaning (Gill et al., 1967; Butler et al.[12]). More recent operations have been somewhat less rigorous.

Recommendations

Oil countermeasures should be dictated to some extent by the presence or proximity of marine animals. This is particularly true of areas surrounding pinniped rookeries, such as the Leeward Islands in the Hawaiian chain (monk seals) and Sable Island in the North Atlantic (gray and harbor seals), the sea otter range in California, the manatee range in Florida, and open leads occupied by migrating belugas, *Delphinapterus leucas*, and bowhead whales, *Balaena mysticetus*.

Oil countermeasures should consider the effects of solvent-emulsifiers, which may be more harmful to marine mammals than exposure to oil alone (Davis and Anderson, 1976; Williams, footnote 10). Studies should be undertaken to determine the effects of surface contact of oil/solvent-emulsifier mixtures, particularly on cetaceans.

Indirect Effects

The most noteworthy finding from the phocid seal studies was that captive ringed seals immersed in light crude oil-covered water, under similar conditions as had been carried out in the field, died within 71 minutes (Geraci and Smith, 1976a). The investigators concluded that the marked difference in results was due to the added stress of captivity in the second experiment, and that oil or another environmental stressor may have a selective effect on stressed or otherwise weakened members of a population.

In this context, marine mammals might be more vulnerable to the effects of oil when naturally stressed during moult, reproduction, times of low food availability, or when weakened by parasites and disease. For example, the effects of inhalation may be particularly harmful to inshore dwelling harbor porpoises, *Phocoena phocoena*, and harbor seals, *Phoca vitulina*, infected with debilitating lungworms and heartworms (Geraci[13]). Also vulnerable would be moulting pinnipeds in a fasting state, and cetaceans whose excursions into low salinity environments may lead to an exaggerated skin response (Harrison and Thurley, 1974).

The ultimate effects of oil will depend on the interaction of physical factors such as location, season, and weather and water conditions with biological variables associated with life history and individual and species responses to oil. Physical factors can be defined, predicted, and controlled to some extent; the biological variables are more elusive, and must be clarified through research.

A Monitoring Program

The nature and direction of research on oil effects ultimately will be influenced by field observations at the site of oil spills or blowouts. The question of detection and avoidance/attraction is critical to an understanding of potential oil impact, yet there are presently no data available on which to base management decisions. For most species, such data can only be gathered through detailed investigation of oil spill situations. Regional response teams having expertise in marine mammal behavior, ecology, and pathology should be organized to participate in oil spill task forces, and assess the impact of all phases of cleanup and recovery on marine animals.

A monitoring program should be extended to include investigation of critical habitats in advance of any oil or gas related activities. Population surveys and behavioral observations are necessary in many areas where baseline data are lacking. Interpretation of future oil impacts may be hampered by the absence of such information. Careful and consistent documentation of marine mammal strandings, with emphasis on frequency, location, and pathology, will also be critical to a proper assessment of oil-related mortality.

Background data on tissue hydrocarbon levels can be obtained from stranded animals or any marine mammals taken as part of, or incidental to, commercial fishery operations (e.g., porpoise-tuna, harp seals, northern fur seals, mysticetes trapped in fishing weirs). Pathological and toxicological findings in marine mammals recovered in or near an oil spill or from chronically polluted waters could then be more meaningfully interpreted. This approach may be the only alternative which will provide data on the effects of long-term bioaccumulation of petroleum hydrocarbons.

Acknowledgments

This manuscript was submitted originally to the U.S. Marine Mammal Commission (MMC) in August 1979. It is the outcome of a seeding thought by R. J. Hofman, MMC, and the gentle but relentless "encouragement" by L. Jones, MMC. We also thank D. Chapman, University of Washington; P. Dayton, Scripps Institution of Oceanography; L. Jones, MMC; G. L. Kooy-

[12]Butler, M. J. A., F. Berkes, and H. Powles. 1974. Biological aspects of oil pollution in the marine environment. A review. Manuscr. rep. 22A, 133 p. Mar. Sci. Cent., McGill Univ., Montreal, Quebec.

[13]Geraci, J. R. 1979. The role of parasites in marine mammal strandings along the New England coast. *In* J. R. Geraci and D. J. St. Aubin (editors), Biology of marine mammals: Insights through strandings, p. 85-91. Natl. Tech. Inf. Serv., Wash., D.C., PB 293 890.

man, Scripps Institution of Oceanography; J. H. Prescott, New England Aquarium; M. Fraker, L. G. L. Ltd., Vancouver; and especially R. J. Hofman, MMC, for their critical reviews of earlier drafts.

Literature Cited

Anonymous. 1971a. Kodiak Islands oil pollution. Event No. 26-70. *In* Smithsonian Institution Center for Short-Lived Phenomena, Annu. Rep. 1970, p. 150-153.

________. 1971b. Alaska Peninsula oil spill. Event No. 36-70. *In* Smithsonian Institution Center for Short-Lived Phenomena, Annu. Rep. 1970, p. 154-157.

Barabash-Nikiforov, I. I., V. V. Reshetkin, and N. K. Shidlovskaya. 1947. The sea otter (Kalan). (Translated by Isr. Program Sci. Transl., 1962, 227 p.; available Natl. Tech. Inf. Serv., Springfield, Va., as OTS 61-31057.)

Beamish, P. 1977. Evidence that a captive humpback whale (*Megaptera novaeangliae*) does not use sonar. Deep-Sea Res. 25:469-472.

Brownell, R. L., Jr. 1971. Whales, dolphins and oil pollution. *In* D. Straughan (editor), Biological and oceanographical survey of the Santa Barbara Channel oil spill 1969-1970. Vol. 1, Biology and bacteriology, p. 255-276. Allan Hancock Found., Univ. South. Calif., Los Ang.

________, and B. J. Le Boeuf. 1971. California sea lion mortality: natural or artifact? *In* D. Straughan (editor), Biological and oceanographical survey of the Santa Barbara Channel oil spill 1969-1970. Vol. 1, Biology and bacteriology, p. 287-306. Allan Hancock Found., Univ. South. Calif., Los Ang.

Canada Ministry of Transport. 1970. Seals. *In* Report of the task force - operation oil (Clean-up of the Arrow oil spill in Chedabucto Bay) to the Minister of Transport, Vol. 1, p. 46-47. Inf. Can., Ottawa.

Carpenter, C. P., D. L. Geary, Jr., R. C. Myers, D. J. Nachreiner, L. J. Sullivan, and J. M. King. 1978. Petroleum hydrocarbon toxicity studies XVII. Animal response to n-nonane vapor. Toxicol. Appl. Pharmacol. 44:53-61.

Cretney, W. J., C. S. Wong, D. R. Green, and C. A. Bawden. 1978. Long-term fate of a heavy fuel oil in a spill-contaminated B.C. coastal bay. J. Fish. Res. Board Can. 35:521-527.

Dargoltz, V. G., E. V. Romanenko, and V. E. Sokolov. 1978. Oxygen consumption by skin in dolphins and problem of cutaneous respiration in cetaceans. Zool. Zh. 57:768-776.

Davis, J. E., and S. S. Anderson. 1976. Effects of oil pollution on breeding grey seals. Mar. Pollut. Bull. 7:115-118.

Dudok van Heel, W. H. 1966. Navigation in cetacea. *In* K. S. Norris (editor), Whales, dolphins and porpoises, p. 597-606. Univ. Calif. Press, Berkeley.

Eberhardt, R. L., and W. E. Evans. 1962. Sound activity of the California gray whale, *Eschrichtius glaucus*. J. Aud. Eng. Soc. 10: 324-328.

Engelhardt, F. R., J. R. Geraci, and T. G. Smith. 1977. Uptake and clearance of petroleum hydrocarbons in the ringed seal, *Phoca hispida*. J. Fish. Res. Board Can. 34:1143-1147.

Fitch, J. E., and P. H. Young. 1948. Use and effect of explosives in California coastal waters. Calif. Fish Game 34:53-70.

Fletcher, J. L. 1971. Effects of noise on wildlife and other animals. U.S. Environ. Prot. Agency, Wash., D.C., EPA-NTID 300.5, 74 p.

Geraci, J. R., and D. J. St. Aubin. 1979. Tissue sources and diagnostic value of circulating enzymes in cetaceans. J. Fish. Res. Board Can. 36:158-163.

________, ________, and T. G. Smith. 1979. Influence of age, condition, sampling time, and method on plasma chemical constituents in free-ranging ringed seals, *Phoca hispida*. J. Fish. Res. Board Can. 36:1278-1282.

________, and T. G. Smith. 1976a. Direct and indirect effects of oil on ringed seals (*Phoca hispida*) of the Beaufort Sea. J. Fish. Res. Board Can. 33:1976-1984.

________, and ________. 1976b. Behavior and pathophysiology of seals exposed to crude oil. *In* Sources, effects & sinks of hydrocarbons in the aquatic environment, p. 447-462. Am. Inst. Biol. Sci., Wash., D.C.

Gilfillan, E. S., and J. H. Vandermeulen. 1978. Alterations in growth and physiology of soft-shell clams, *Mya arenaria*, chronically oiled with Bunker C from Chedabucto Bay, Nova Scotia, 1970-1976. J. Fish. Res. Board Can. 35:630-636.

Gill, C., F. Booker, and T. Soper. 1967. The wreck of the Torrey Canyon. David and Charles, Newton Abbot [Engl.], 128 p.

Gilmartin, W. G., R. L. Delong, A. W. Smith, J. C. Sweeney, B. W. DeLappe, R. W. Risebrough, L. A. Griner, M. D. Dailey, and D. B. Peakall. 1976. Premature parturition in the California sea lion. J. Wildl. Dis. 12:104-115.

Grahl-Nielsen, O., J. T. Staveland, and S. Wilhelmsen. 1978. Aromatic hydrocarbons in benthic organisms from coastal areas polluted by Iranian crude oil. J. Fish. Res. Board Can. 35:615-623.

Hall, J. D., W. G. Gilmartin, and H. L. Mattsson. 1971. Investigation of a Pacific pilot whale stranding on San Clemente Island. J. Wildl. Dis. 7:324-327.

Harrison, R. J., and K. W. Thurley. 1974. Structure of the epidermis in *Tursiops*, *Delphinus*, *Orcinus* and *Phocoena*. *In* R. J. Harrison (editor), Functional anatomy of marine mammals, Vol. 2, p. 45-71. Acad. Press, Lond.

Helle, E., M. Olsson, and S. Jensen. 1976. PCB levels correlated with pathological changes in seal uteri. Ambio 5:261-263.

Henderson, D., R. P. Hamernik, and R. W. Sitler. 1973. Audiometric and histological effects of exposure to 40-μ sec high level impulses. J. Acoust. Soc. Am. 53:348.

Hodgins, H. O., B. B. McCain, and J. W. Hawkes. 1977. Marine fish and invertebrate diseases, host disease resistance, and pathological effects of petroleum. *In* D. C. Malins (editor), Effects of petroleum on Arctic and Subarctic marine environments and organisms, Vol. II. Biological effects, p. 95-173. Acad. Press, N.Y.

Hubbs, C. L., and A. B. Rechnitzer. 1952. Report on experiments designed to determine effects of underwater explosions on fish life. Calif. Fish Game 38:333-366.

Jakosky, J. J., and J. Jakosky, Jr. 1956. Characteristics of explosives for marine seismic exploration. Geophysics 21:969-991.

Kenchington, R. A. 1972. Observations on the digestive system of the dugong, *Dugong dugon* (Erxleben). J. Mammal. 53:884-887.

Kooyman, G. L., R. W. Davis, and M. A. Castellini. 1977. Thermal conductance of immersed pinniped and sea otter pelts before and after oiling with Prudhoe Bay crude. *In* D. A. Wolfe (editor), Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms, p. 151-157. Pergammon Press, Oxf.

Landis, C., and W. A. Hunt. 1939. The startle pattern. Farrar & Rinehart Inc., N.Y., 168 p.

Le Boeuf, B. J. 1971. Oil contamination and elephant seal mortality: a "negative" finding. *In* D. Straughan (editor), Biological and oceanographical survey of the Santa Barbara Channel oil spill 1969-1970. Vol. 1, Biology and bacteriology, p. 277-285. Allan Hancock Found., Univ. South. Calif., Los Ang.

Ling, J. K. 1974. The integument of marine mammals. *In* R. J. Harrison (editor), Functional anatomy of marine mammals, Vol. 2, p. 1-44. Acad. Press, Lond.

Loughrey, A. G. 1959. Preliminary investigation of the Atlantic walrus, *Odobenus rosmarus rosmarus* (Linnaeus). Dep. Northern Affairs and Natural Resources, Can. Wild. Serv., Wildl. Manage. Bull. Ser. 1, No. 14, 175 p.

McCain, B. B., H. O. Hodgins, W. D. Gronlund, J. W. Hawkes, D. W. Brown, M. S. Myers, and J. H. Vandermeulen. 1978. Bioavailability of crude oil from experimentally oiled sediments to English sole (*Parophrys vetulus*), and pathological consequences. J. Fish. Res. Board Can. 35:657-664.

McCormick, J. G., E. G. Wever, J. Palin, and S. H. Ridgway. 1970. Sound conduction in the dolphin ear. J. Acoust. Soc. Am. 48:1418-1428.

Moore, S. F., and R. L. Dwyer. 1974. Effects of oil on marine organisms: A critical assessment of published data. Water Res. 8:819-827.

Moyer, K. E. 1963. Startle response: habituation over trials and days, and sex and strain differences. J. Comp. Physiol. Psychol. 56:863-865.

Nishiwake, M., and A. Sasao. 1977. Human activities disturbing natural migration routes of whales. Sci. Rep. Whales Res. Inst. 29:113-120.

Norris, K. S. 1969. The echolocation of marine mammals. *In* H. T. Anderson (editor), The biology of marine mammals, p. 391-423. Acad. Press, N.Y.

Ramprashad, F., S. Corey, and K. Ronald. 1973. The harp seal, *Pagophilus groenlandicus*, (Erxleben 1777). XIV. The gross and microscopic structure of the middle ear. Can. J. Zool. 51:589-600.

Roesijadi, G., J. W. Anderson, and J. W. Blaylock. 1978. Uptake of hydrocarbons from marine sediments contaminated with Prudhoe Bay crude oil: influence of feeding type of test species and availability of polycyclic aromatic hydrocarbons. J. Fish. Res. Board Can. 35:608-614.

Rowe, L. D., J. W. Dollahite, and B. J. Camp. 1973. Toxicity of two crude oils and of kerosene to cattle. J. Am. Vet. Med. Assoc. 162:61-66.

Rylander, R., S. Sorenson, B. O. Andrae, G. Chatelier, Y. Espmark, T. Larrson, and R. I. Thackray. 1974. Sonic booms exposure effects—A field study on humans and animals. J. Sound Vib. 33:471-486.

St. Aubin, D. J., and J. R. Geraci. In press. Tissue levels of ascorbic acid in marine mammals. Comp. Biochem. Physiol.

Salter, R. E. 1979. Site utilization, activity budgets, and disturbance responses of Atlantic walruses during terrestrial haul-out. Can. J. Zool. 57:1169-1180.

Simpson, J. G., and W. G. Gilmartin. 1970. An investigation of elephant seal and sea lion mortality on San Miguel Island. BioScience 20:289.
Smith, T. G., and J. R. Geraci. 1975. The effect of contact and ingestion of crude oil on ringed seals of the Beaufort Sea. Beaufort Sea Tech. Rep. 5, 67 p.
Spooner, M. F. 1967. Biological effects of the "Torrey Canyon" disaster. J. Devon Trust Nat. Conserv. (Suppl.), p. 12-19.
Stainken, D. M. 1978. Effects of uptake and discharge of petroleum hydrocarbons on the respiration of the soft-shell clam, *Mya arenaria*. J. Fish. Res. Board Can. 35:637-642.
Stegeman, J. J., and J. M. Teal. 1973. Accumulation, release and retention of petroleum hydrocarbons by the oyster *Crassostrea virginica*. Mar. Biol. (Berl.) 22:37-44.
Stephenson, A. B. 1975. Sperm whales stranded at Muriwai Beach, New Zealand. N.Z. J. Mar. Freshwater Res. 9:299-304.
Stockwell, C. W., H. W. Ades, and H. Engstrom. 1969. Patterns of hair cell damage after intense auditory stimulation. Ann. Otol., Rhinol. Laryngol. 78:1144-1168.
Terhune, J. M., and K. Ronald. 1972. The harp seal, *Pagophilus groenlandicus* (Erxleben, 1777). III. The underwater audiogram. Can. J. Zool. 50:565-569.
________, R. E. A. Stewart, and K. Ronald. 1979. Influence of vessel noises on underwater vocal activity of harp seals. Can. J. Zool. 57:1337-1338.
Tinyakov, G. G., V. P. Chumakov, and B. A. Sevastianov. 1973. Some patterns of skin microstructure in cetaceans. Zool. Zh. 52:399-407.
van Bree, P. J. H. 1977. On former and recent strandings of cetaceans on the coast of the Netherlands. Z. Saeugetierkd. 42:101-107.
________, and I. Kristensen. 1974. On the intriguing stranding of four Cuvier's Beaked Whales, *Ziphius cavirostris* G. Cuvier, 1823, on the Lesser Antillean Island of Bonaire. Bijdr. Deirkd. 44:235-238.
Vandermeulen, J. H., and W. R. Penrose. 1978. Absence of aryl hydrocarbon hydroxylase (AHH) in three marine bivalves. J. Fish. Res. Board Can. 35:643-647.
Vibe, C. 1950. The marine mammals and the marine fauna in the Thule District (Northwest Greenland) with observations on ice conditions in 1939-41. C. A. Reitzels Forlag, Kobehavn, 115 p.
Yelverton, J. T., D. R. Richmond, E. R. Fletcher, and R. K. Jones. 1973. Safe distances from underwater explosions for mammals and birds. Lovelace Found. Med. Educ. Res., Albuquerque, N.M., 63 p.