SYNTHESIS OF EFFECTS OF OIL ON MARINE MAMMALS

Edited by

J.R. Geraci and D.J. St. Aubin

Department of Pathology Ontario Veterinary College University of Guelph N1G 2W1 Canada

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Battelle Memorial Institute 1431 Spinnaker Drive Ventura, California 93001 U.S.A.

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FOREWORD

This manuscript summarizes the extensive and diverse data base on subjects dealing with oil effects to marine mammals and those aspects of an animal's life history vulnerable to exposure of spilled oil. The manuscript begins with a background chapter on the composition and fate of petroleum and spill treating agents in the marine environment and is followed by separate chapters describing the ecological perspective and the physiological and toxicological effects of petroleum and spill treating agents on pinnipeds. The same treatment is provided for cetaceans, sea otters, polar bears and manatees. A separate chapter describing modeling efforts to predict oil effects on marine mammals is also included for in recent years, several attempts have been made to predict population effects from oil spill events using quantitative methods.

By necessity and design, discussion of oil effects to marine mammals is a synthesis and evaluation of previous data and in some cases includes presentation of new data or reinterpretation of old data. In certain cases, synthesis of older data has led to new interpretations. Quite noticeable is the disparity between the content and complexity of discussion in the various chapters. This disparity represents differences in the availability of data. The fact that some animals are terrestrial vs. oceanic, occupy different environments, are easier to observe, or are more complex than other, are some of the reasons for this disparity.

Several authors contributed to this manuscript. J.M. Neff authored the chapters, Composition and Fate of Petroleum and Spill-Treating Agents in the Marine Environment, and Effects of Oil on Marine Mammal Populations: Results Simulations; I.A. McLaren, Pinnipeds and Oil: Ecological of Model Perspectives; B. Wursig, Cetaceans and Oil: Ecological Perspectives; K. Ralls and D.B. Siniff, Sea Otters and Oil: Ecological Perspectives; I. Stirling, Polar Bears and Oil: Ecological Perspectives; D.J. St. Aubin and V. Lounsbury, Oil Effects on Manatees, Evaluating the Risks; and D.J. St. Aubin for the chapters describing the physiological and and J.R. Geraci toxicological effects of oil for each of the marine mammal groups.

We thank the Minerals Management Service (MMS) for funding the preparation of this manuscript. R.E. Miller and W. Lang of the MMS were especially supportive in facilitating the project whenever necessary and without them, this manuscript would not have been possible. Finally, the manuscript is intended to be useful to the MMS and to readers involved with matters pertaining to oil and gas development on the outer continental shelf. For each animal group, separate discussions are provided for their natural history vs. physiological or toxicology effects. Separate reference sections are also provided for each chapter so readers may easily pursue additional literature on topics contained within each chapter.

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Eiji Imamura Ventura, California

CHAPTER 1

COMPOSITION AND FATE OF PETROLEUM AND SPILL-TREATING AGENTS IN THE MARINE ENVIRONMENT

J.M. Neff

Battelle Ocean Sciences 397 Washington Street Duxbury, Massachusetts 02332

Introduction

The chemical properties of oil ultimately determine its effects. Some compounds are actively toxic, and are damaging to delicate tissues, such as eyes, nasal cavities and other sensitive mucus membranes. Their noxious properties are balanced by rapid dissipation and removal from the environment. At the other end of the spectrum are the persistent forms, such as tar and weathered oil, which are not as toxic but have greater potential for environmental impact because of their resistance to weathering. To evaluate the consequences of oil exposure in marine mammals, it is important to understand these properties of petroleum: its composition, how it enters the marine environment, and what happens to it once it is there. This chapter addresses these issues.

Composition and Toxicity of Petroleum

Crude petroleum, a complex mobile mixture of fossil, biogenic origin (Speers and Whitehead 1969), contains thousands of organic and a few inorganic compounds. Included within the classification are natural gas, liquid petroleum oils, resins, and asphaltenes. A more precise definition of petroleum is impossible, because no two are identical. Most crude petroleums contain the same classes of compounds, but differ in the relative amounts of each constituent.

Crude petroleum may contain organic compounds ranging in molecular weight from methane to complex polymeric structures such as asphaltenes with molecular weights of 100,000 or more (Kallio 1976). Natural gas is separated from liquid petroleum at the time of production; the oil is then distilled to produce commercial products. Each fraction is collected at a different distillation temperature (Figure 1.1), and can be refined further into a product with more desirable properties. The residue after distillation contains much of the resin and asphaltene fractions of the crude oil. It is a thick tarry liquid or solid that may be used for fuel (Bunker C residual oil, Number 6 fuel oil), or paving (asphalt).

Hydrocarbons (compounds composed only of carbon and hydrogen atoms) are the most abundant components of crude and refined petroleum (Figure 1.2). They account for more than 90 percent of natural gas and from 50 to about 98 percent of liquid crude petroleum (Kallio 1976, National Academy of Sciences 1985). Other components include sulphur, oxygen, nitrogen and a variety of metallic elements which are complexed with organic compounds or exist as inorganic salts.

Alkanes, which contain single chemical bonds between carbon atoms, are the most abundant hydrocarbons in petroleum. There are three types: normal, branched, and cyclic. The normal and branched alkanes are usually present in about equal amounts. The n-alkanes range in size from methane (C_1) to about C_{∞} , and possibly as high as C_{78} . A majority of the branched or iso-alkanes are simple 2-, 3-, and 4-methylalkanes. In addition, the branched alkanes include a series of isoprenoid hydrocarbons, based on isoprenoid building blocks, extending from

FRACTIONAL DISTILLATION DISTRIBUTION



FIGURE 1.1: BOILING POINT RANGE OF FRACTIONS OF CRUDE PETROLEUM (National Academy of Sciences, 1985).

BOILING RANGE "F

Figure 1.2

Examples of the chemical structure of some common components of crude petroleum (Miller and Connell 1982).

HYDROCARBONS



 C_{10} to about C_{40} . The most abundant isoprenoid alkanes in petroleum are pristane (C_{19}) and phytane (C_{20}) .

Cycloalkanes, also called cycloparaffins or naphthenes, may account for as much as 50 percent of the total hydrocarbons in oil. Most are cyclopentane derivatives. They may contain aromatic ring structures, normal or branched alkane substituents, or non-hydrocarbon groups, such as one or more carboxylic acid moieties.

Aromatic hydrocarbons may account for about 20 percent of the total hydrocarbons in crude oil. The basic building block of an aromatic hydrocarbon is the benzene ring, a six-member carbon ring containing nine equally shared carbon-carbon covalent bonds. Benzene occurs in small amounts in natural gas, crude and particularly the lighter fractions of refined oil. It may be linked to another benzene ring through a single carbon-carbon bond to form biphenyl. Polycyclic aromatic hydrocarbons (PAH) are composed of two to nine or more fused Naphthalene $(C_{10}H_8)$, which consists of two fused benzene rings (Neff 1979). rings, is the lowest molecular weight PAH. The abundance of aromatic hydrocarbons in petroleum usually decreases markedly with increasing molecular weight. In most cases, the one-ring (benzene) through three-ring (phenanthrene) compounds account for at least 90 percent of the aromatic hydrocarbons (Neff 1979). These may combine with cycloalkanes to form naphthenoaromatic compounds, and combine further to produce polymeric structures that are important components of the resin and asphaltene fractions of petroleum (Figure 1.2).

The resin and asphaltene fractions of crude oil have not been well characterized (Speers and Whitehead 1969, Kallio 1976). They presumably consist of high molecular weight hydrocarbons and hetero-compounds containing sulfur, oxygen or nitrogen and thermally-induced condensation products of lower molecular weight aromatics and heteroaromatics. Asphaltenes are thought to be present in colloidal suspension.

Refined Oil Products: Refined petroleum products contain all the chemical classes present in crude oil, but primarily those compounds boiling over a fairly narrow temperature range (Figure 1.1). For example, gasoline contains primarily lowboiling alkanes (C5 to C9) and monoaromatics, whereas residual oil contains high concentrations of high-boiling alkanes and polycyclic aromatic hydrocarbons, as well as most of the resins and asphaltenes originally present in the crude oil. In addition, catalytic cracking of the gasoline fraction produces a group of unsaturated compounds, alkenes and cycloalkenes, not ordinarily present at higher than trace concentrations in the original oil. The refining process may also increase the degree of alkylation of the alkane/alkene fraction. These changes improve the properties of the gasoline as a fuel.

Similar Compounds of Natural and Pyrogenic Origin: Combustion of organic material, including fossil fuels, is a major source of PAH containing three or more aromatic rings. Their formation is favored particularly if combustion takes place in an oxygen-deficient environment. Resulting PAH assemblages are complex and, unlike those in petroleum, are dominated by four-, five-, and six-ring

aromatics. These differences are useful in distinguishing between petrogenic and pyrogenic hydrocarbon assemblages in environmental samples.

Toxicity of Petroleum Compounds: Composition of a crude or refined petroleum governs its behavior and ultimate fate when spilled in the marine environment. It also affects the responses of marine organisms, including mammals, that might come in contact with spilled oil. The different chemical components of petroleum vary tremendously in their acute and chronic toxicity.

Acute toxicity of alkanes to aquatic organisms tends to increase with molecular weight. However, acutely toxic concentrations for all but lowest molecular weight alkanes are higher than their solubility, and therefore cannot occur naturally in aquatic environments (Hutchinson *et al.* 1980). Low molecular weight cyclic alkanes (naphthene cyclohexane and several alkyl cyclohexanes) appear to be more toxic to aquatic organisms than n-alkanes and benzenes of similar molecular weight (Benville *et al.* 1985). Mixtures of higher molecular weight alkanes, such as paraffin oils, are considered inert. In fact, they are used by humans as laxatives. Low molecular weight alkanes (methane through octane) have mild anesthetic properties (Crisp *et al.* 1967), and, because of their volatility, may occur in a form which can be inhaled.

Aromatic hydrocarbons are the most toxic of the major classes of compounds in petroleum. The acute toxicity of crude and refined petroleums to aquatic organisms (Neff and Anderson 1981, National Academy of Sciences 1985) and mammals (EPA 1981) correlates directly with the concentration of light aromatic hydrocarbons (benzene through phenenthrene). Chronic effects of petroleum are attributed primarily to four- and five-ring aromatic and hetero-aromatic hydrocarbons, some of which are well-known carcinogens (Karcher *et al.* 1981, Oesch 1982, Grunbauer and Wegener 1983, Later *et al.* 1983). Benzene, though a known carcinogen (Fishbein 1984), is volatile and short-lived, and probably contributes more to acute than chronic toxicity.

The acute toxicity of aromatic hydrocarbons is inversely proportional to molecular weight (Neff 1979, Hutchinson *et al.* 1980). However, because of their low solubility, aromatic hydrocarbons with four or more rings rarely exist in acutely toxic concentrations. At the other extreme, the monocyclic aromatic hydrocarbons (benzene, toluene, and xylenes), are so volatile that they are lost rapidly from water. Thus, naphthalenes and phenanthrenes, which are slightly soluble and relatively persistent, contribute most to the toxicity of crude and refined petroleum (Neff 1979). Heterocyclic compounds can have a toxicity similar to the analogous aromatic hydrocarbons (Thomas *et al.* 1981). Dibenzothiophene and several of its alkyl homologues are abundant in many crude oils, and therefore probably contribute to their toxicity.

Sources of Petroleum in the Marine Environment

Petroleum enters the marine environment from various sources. Miller and Connell (1982) estimated that, of the 3100 million metric tons of oil produced in 1981, from 4.5 to 6.1 metric tons (0.15 to 0.20 percent of production) reached the oceans. The National Academy of Sciences (1985) gives a value of 3.2 million metric tons (more than 750 million gallons) of oil entering the ocean per year (Table 1.1).

These inputs are from a wide variety of natural and anthropogenic sources (Table 1.1). Natural sources such as marine oil seeps and erosion of oil-bearing rocks are the most difficult to estimate accurately. Wilson *et al.* (1974) compiled a list of 190 known submarine oil seeps. Several more have been identified since. In U.S. outer continental shelf (OCS) waters, 54 seeps have been identified off southern California, 28 off the south coast of Alaska, three along the coast of the Gulf of Mexico, and others scattered along the Bering and Beaufort Sea coasts of Alaska. Submarine seeps also occur in Mexican waters of the Gulf of Mexico, along the Caribbean coast of South America, and the northeast coast of Canada. The rate of discharge from different seeps varies widely, with as much as 30,000 tons each year from seeps in the Santa Barbara Channel alone (Fisher 1978). Total annual discharge from all marine seeps is estimated to be 200,000 metric tons (National Academy of Sciences 1985). Erosion of oil-bearing rocks accounts for about one-fourth the amount derived from seeps.

The most important source of petroleum entering the marine environment is that associated with marine transportation (1.47 million metric tons per year) and municipal and industrial wastes (1.0 million metric tons per year) (National Academy of Sciences 1985). Volumetrically less important sources include offshore oil production activities (50,000 metric tons per year), atmospheric deposition (300,000 metric tons per year), runoff from rivers and urban areas (160,000 metric tons per year), and ocean dumping, primarily of sewage sludge and industrial wastes (20,000 metric tons per year).

Tanker operations and accidents account for most of the oil entering the ocean from marine transportation activities. The major source is from discharges of ballast water and tank washing water. Such activities are regulated by the International Maritime Organization which allows discharge of oil from cargo areas of a tanker under way in international waters at a rate of no more than 60 liters per mile, not to exceed 1/15,000 of the total cargo of older tankers and 1/30,000 of the cargo of new tankers. No such discharges are allowed in territorial waters or certain low pollution areas, such as the Red and Mediterranean Seas.

When a tanker arrives in ballast at an oil terminal, the water in segregated or dedicated ballast tanks is not contaminated with oil and can be discharged to local waters. If ballast water is carried in the cargo tanks, which is the case for many supertankers and older tankers, it may be discharged to an onshore treatment facility. There the water is separated from the oil and discharged. The treatment facility in Valdez, Alaska, during its first two years of operation, discharged to Valdez Harbor a total of 33.4 billion liters of treated

Table 1.1:	Input of petroleum hydrocarbons into the marine			
environment in millions of metric tons/yea				
	(National Academy of Sciences, 1985).			

SOURCE	PROBABLE RANGE	BEST ESTIMATE [®]
Natural sources		
Marine seens	0 02-2 0	0.2
Sediment erosion	0.005-0.5	0.2
(Total natural sources)	(0.025) - (2.5)	(0.25)
Offshore production	0.04-0.06	0.05
Transportation		
Tanker operations	0.4-1.5	0.7
Dry-docking	0.02-0.05	0.03
Marine terminals	0.01-0.03	0.02
Bilge and fuel oils	0.2-0.6	0.3
Tanker accidents	0.3-0.4	0.4
Nontanker accidents	0.02-0.04	0.02
(Total transportation)	(0.95)-(2.62)	(1.47)
Atmosphere	0.05-0.5	0.3
Municipal and industrial		•
wastes and runoff		
Municipal wastes	0.4-1.5	0.7
Refineries	0.06-0.6	0.1
Nonrefining		
industrial wastes	0.1-0.3	0.2
Urban runoff	0.01-0.2	0.12
River runoff	0.01-0.5	0.04
Ocean dumping	0.005-0.2	0.02
(Total wastes and		
runoff)	(0.585)-(3.12)	(1.18)
TOTAL	1.7-8.8	3.2

^a The total best estimate, 3.2 mta, is a sum of the individual best estimates. A value of 0.3 was used for the atmospheric inputs to obtain the total, although we well realize that this best estimate is only a center point between the range limits and cannot be supported rigorously by the data and calculation used for estimation of this input.

ballast water containing about 130 metric tons of particulate oil and 170 metric tons of volatile hydrocarbons (mainly benzenes) (Lysyj *et al.* 1981).

Tanker accidents are a dramatic source of spilled oil. In 1978, approximately 220,000 metric tons of crude oil was released and within a few weeks spread along 350 km of the Brittany coast of France after the <u>Amoco Cadiz</u> spill and in 1984, the Liberian tanker <u>Nova</u> spilled about 70,000 metric tons of Iranian crude oil, about 88 percent of the total spilled in tanker accidents that year. Less significant spills include those from accidents on oil platforms, pipeline breaks, and accidental spills at storage areas, terminals, and refineries.

Offshore oil exploration and production is viewed as a major source of spilled oil, and indeed it can be. The <u>Ixtoc-I</u> blowout in the Bay of Campeche in the Mexican Gulf of Mexico was the worst recorded oil spill of any kind. On June 3, 1979, an exploratory well about 80 km northwest of Cuidad de Carmen blew out. By the time the well was capped 290 days later on March 23, 1980, about 475,000 metric tons of oil had been lost (Jernelov and Linden 1981). Usually, platform spills are of a much smaller magnitude, on the order of 40,000 to 60,000 metric tons per year (National Academy of Sciences 1985).

In U.S. OCS waters, the performance record for offshore platforms has been quite good (Minerals Management Service 1986). Of the 5 billion barrels (690 million metric tons) of oil produced from the federal outer continental shelf in the last 15 years through 1985, about 61,000 barrels (8,400 metric tons) were spilled. This is 0.001 percent of production.

Recent spills of oil and hazardous substances from all sources have been documented for U.S. waters (U.S. Coast Guard 1987). In both 1983 and 1984, there were just over 10,000 incidents that resulted in spillage of about 87,000 and 57,000 metric tons, respectively, of oil. The largest volume of oil was spilled in the Pacific Ocean in 1983 and in the Atlantic Ocean in 1984. About 40 percent of the oil was spilled in ports and harbors and between 15 and 30 percent in territorial seas. Vessel accidents accounted for 9 percent in 1983, and 36 percent in 1984. Spillage from marine facilities was a mere one percent both years. Such accidents are the most variable source, in time, volume, and location, of oil in the marine environment.

Two types of discharges sometimes permitted by EPA from offshore exploration and production platforms may contain oil: drilling muds and produced water. Drilling muds are mixtures of clays, weighting agents and other ingredients in a water or oil-base (National Academy of Sciences 1983). They are used to lubricate the bit and offset pressure during the drilling of each well. In the North Sea and in Canadian waters, oil-base drilling muds containing up to 10 percent diesel oil have been discharged. This could represent up to about 100 tons of oil discharged for each drilled. Such practices are not permitted in U.S. OCS waters where only water-base drilling muds can be discharged. Even this form may contain small amounts of oil (usually less than about 100 mg/kg drilling mud).

Produced water is fossil water that emanates with the oil and gas from most wells. A well, during its life, yields approximately equal volumes of fossil fuel and produced water. The latter may be reinjected through another well to the reservoir, or treated to remove particulate oil and discharged. U.S. Federal standards not yet promulgated (EPA 1985) would set a maximum allowable concentration of petroleum in produced water at 59 mg/L.

The amount of produced water generated by a given well varies. A single production platform may discharge up to one million liters, and a large treatment facility up to ten million liters or more each day. The National Academy of Sciences (1985) estimated that approximately 50 billion liters of produced water are discharged to U.S. state and federal waters each year, carrying 1500 to 3000 metric tons of petroleum hydrocarbons.

Municipal and to a lesser extent industrial waste waters also deliver petroleum to the marine environment. The annual discharge of petroleum carried with sewage has been estimated to be about 13,000 tons in Hudson-Raritan Estuary (Connell 1982), 17,000 tons in the southern California Bight (Eganhouse and Kaplan 1982), and nearly 500 tons in central Puget Sound (Barrick 1982). The National Academy of Sciences (1985) estimated the total amount of petroleum discharged in municipal waste water each year to U.S. coastal waters to approach 200,000 metric tons. Industrial discharges, including those from oil refineries contribute smaller quantities of petroleum. These and several other less notable sources probably constitute little potential hazard to marine mammals.

Fate of Petroleum in the Marine Environment

The timing and relative importance of physical, chemical, and biological processes affecting the fate of oil differ with each category of discharge and petroleum product. However, the types of processes are the same. Weathering plays the most important role in determining the fate of spilled oil. Weathering processes include spreading, evaporation, dissolution, dispersion into the water column, photochemical oxidation, formation of emulsions, microbial degradation, adsorption to suspended particulate matter, and stranding on shore or sedimentation to the sea floor (Payne and McNabb 1985, Payne *et al.* 1987, Boehm 1987) (Figures 1.3 and 1.4). Weathering changes the physical and chemical properties of spilled oil, and thereby influences its toxicity to marine organisms.

Spreading and Drifting: Oil released at or near the sea surface will first be affected by spreading (Figure 1.4). If discharged below the surface, it must rise through the water column before it can form an oil slick. Under such conditions, oil droplets form and disperse, and the lower molecular weight components dissolve (Boehm and Feist 1982). Most of the petroleum discharged as part of a complex mixture such as municipal sewage never reaches the sea surface, and so is not subjected to the same weathering forces.

When oil is released on the sea surface, it spreads horizontally in an elongated pattern oriented in the direction of the prevailing wind and surface water currents (Elliott 1986, Elliott *et al.* 1986). The center of the mass of the slick may move at a rate of approximately three percent of the wind speed with a 20 to 30 degree shift to the right (in the northern hemisphere) due to

Figure 1.3

Behavior and fate of oil spilled in the marine environment (Bobra and Fingas 1986).





FIGURE 1.4: THE TIMING OF OIL WEATHERING PROCESSES FOLLOWING AN OIL SPILL ON THE SEA SURFACE. THE LENGTH OF THE LINE INDICATES THE PROBABLE TIMESPAN OF A PROCESS. THE WIDTH OF A LINE INDICATES THE RELATIVE MAGNITUDE OF THE PROCESS THROUGH TIME AND IN RELATION TO OTHER CONCURRENT WEATHERING PROCESSES (from Wheeler, 1978).

Coreolis force (Payne and McNabb 1985). Several mathematical models have been developed to predict the trajectories of oil slicks (Samuels *et al.* 1983). The major axis of the slick tends to elongate at a linear rate with time, whereas the width of the slick grows as a function of $t^{0.5}$. Spreading is more rapid on warm than on cold water due to differences in viscosity of the oil; moderate wave action also increases the rate of spread. Crude oils and heavy distillates form two phases during spreading: a thick phase (1-20 mm thick), consisting of viscous, partly emulsified oil, and a thin sheen 0.01 to 0.001 mm thick (Audunson *et al.* 1981). In addition, the leading edge of the slick tends to be thicker than the interior (Elliott 1986). The thick oil usually forms small patches, which subdivide as they continue to weather. These patches usually move downwind at a faster speed than the thinner slick, eventually leaving it behind.

The area of the ocean surface covered by an oil slick cannot be calculated based on volume of oil alone. Composition of the oil, rate of discharge, and environmental conditions all affect the thickness, and thereby the area covered by the slick. A thin iridescent sheen is about 1 to 5 μ m thick and has a concentration on the sea surface of about 1000 L/km² (National Academy of Sciences 1985), whereas the surface concentration of a 1 mm to 10 mm thick slick may be in the order of 10⁶ to 10⁷ L/km². Thus, the spill from the <u>Argo Merchant</u> on Nantucket Shoals, Massachusetts in December 1976 (29 x 10⁶ L) could occupy initially as little as 2.9 km² or as much as 29,000 km², depending on thickness. A reasonable average thickness for a crude oil slick undergoing moderate weathering would be 0.1 to 1.0 mm; such a spill would occupy 0.1 to 1.0 km/metric ton of oil.

Evaporation: For the first few days after a spill, evaporation is the most important weathering process affecting the volume and composition of oil. The type of oil, surface area of the slick, and environmental conditions influence the rate of evaporation (Wheeler 1978), which for any given substance is directly proportional to its vapor pressure (Mackay and Leinonen 1975, Wheeler 1978) and inversely proportional to molecular weight (Figure 1.5). Aromatic hydrocarbons tend to evaporate more rapidly than alkanes of similar molecular weight (Figure 1.4), despite the lower vapor pressure of the former, apparently because aromatics have higher activity coefficient than alkanes in the oil phase (Harrison *et al.* 1975). Light distillate fractions, such as gasoline, kerosene, and jet fuel may evaporate completely (Figure 1.1), and as much as 60 percent of light crude oil may evaporate within a week or so after a spill (Wheeler 1978). Owing to the inverse relationship between temperature and vapor pressure, low molecular weight hydrocarbons evaporate more slowly in cold Arctic waters (Reijnhart and Rose 1982).

Evaporation profoundly effects physical and chemical properties of a slick. The loss of volatile components increases density and viscosity, and reduces in vapor pressure and toxicity (Bobra and Fingas 1986). Tarry resin and asphaltene fractions increase, promoting the formation of water-in-oil emulsions and tar balls. These in turn slow the rate of diffusion of remaining volatile hydrocarbons. Thus, emulsified oil, tar balls, and tar mats may develop a crust composed primarily of non-volatile oil components covering a core of less

Figure 1.5

Relation between carbon number and vapor pressure of four classes of hydrocarbons in petroleum (Wheeler 1978).



Carbon number

weathered oil containing high concentrations of light hydrocarbons (Butler 1975, Boehm and Feist 1982, Payne and Phillips 1985).

Dissolution: Usually, less than 2 to 5 percent of the oil is removed by dissolving into the water column (Harrison et al. 1975, McAuliff 1976, Payne et The process may nonetheless be significant because it brings the al. 1987). most toxic hydrocarbons into contact with marine organisms in a form that is readily available. In the <u>Ixtoc-I</u> blowout, significant fractions of the lighter hydrocarbons partitioned into the water as the oil rose through the water column; benzene under the slick reached concentrations greater than 100 μ g/L (Payne et Both dissolved and dispersed hydrocarbons persisted in the water al. 1983). column for up to 40 km from the blowout site (Boehm and Feist 1982). Low concentrations of volatile aromatic hydrocarbons have also been detected in the water column 2 to 3 km from the treated ballast water discharge at Port Valdez, Alaska (Lysyj et al. 1981).

When a slick is subjected to turbulent mixing or wave action, there is a tendency for small droplets to break away from the main mass and become dispersed in the water column. If the droplets are small enough (less than 0.1 mm), they rise so slowly as to remain dispersed indefinitely (Payne and McNabb 1985), whereas larger droplets tend to coalesce, rise rapidly, and concentrate near the surface (Forester 1971).

Dispersion and Emulsion Formation: Dispersion is the most important process in the breakup and disappearance of a slick already reduced by evaporation. Dispersion begins soon after oil is discharged, reaches a peak within 10 hours (Figure 1.4), and within 100 hours overtakes spreading as the primary mechanism of transport of oil from the spill site (Wheeler 1978). The activity and effectiveness of the process is due in part to viscosity of the oil (Gordon *et al.* 1983) and to the presence of natural surfactants (Wheeler 1978) which facilitate droplet formation and inhibit coalescence.

Some oils, particularly after weathering, accumulate and retain dispersed water droplets within the oil phase (Mackay 1982). These water-in-oil emulsions, sometimes called chocolate mousse because of their appearance, may contain up to 75 percent water, and are more viscous than the parent oil. Their tendency to form depends on the concentration of heavy resin and asphaltene materials as well as endogenous surfactants (Payne and Phillips 1985). Stable emulsions form readily in the presence of sea ice (Payne and Phillips 1985). Those formed during ice breakup are not neutrally buoyant in the lower salinity water and tend to collect under the ice.

Formation of stable water-in-oil emulsions is important because it effects subsequent weathering of oil and also makes it less amenable to cleanup. Following emulsification, evaporation and dissolution of light fractions are inhibited, and photochemical and microbial degradation of the heavier fractions are slowed. Whether the slick forms a water-in-oil emulsion or an oil-in-water emulsion appears to depend on the viscosity, thickness, and chemical composition of the oil (Mackay 1982), and environmental factors. Photochemical Reactions: Solar radiation acting on oil in the water generates photochemical reactions which yield new, mostly polar organic compounds. The compounds, although in low concentrations (Ducreux *et al.* 1986), affect toxicity and behavior of the spilled oil (Payne and Phillips 1985b). The primary mechanism of photodegradation is photo-oxygenation (Larson *et al.* 1976, 1977, Thominette and Verdu 1984a), yielding such reaction products as peroxides, aldehydes, ketones, alcohols, and fatty acids (Payne and McNabb 1985) which tend to be more water-soluble and toxic than the unoxidized parent compounds (Larson *et al.* 1979). The process also yields high molecular weight by-products that are not soluble in either oil or water (Thominette and Verdu 1984b).

Direct photolysis reactions, not requiring molecular oxygen, are quantitatively the most important mechanism of light-induced transformation (Zepp and Schlotzhauer 1979, Mill *et al.* 1981). The tendency toward direct photolysis increases with increasing molecular weight of polycyclic aromatic hydrocarbons. For example, the half-life of naphthalene (two rings) in surface fresh water in sunlight equivalent to 40° N latitude in mid-summer is 71 hours, compared to a half-life of eight hours for phenanthrene (three rings), and 0.54 hours for benzo(a)pyrene (five rings). Because light intensity decreases rapidly with depth, rate of photolysis of aromatic hydrocarbons in the water column also decreases with depth.

At high latitudes, the rate of photolysis is greatly diminished due primarily to the reduced intensity and daily duration of solar irradiance during the winter (Figure 1.6). At 60° N latitude, there is an approximately ten-fold decrease in the rate of photolysis of benzo(a)pyrene between June and December (Zepp and Baughman 1978). Photolysis rates of some compounds, such as benzo(b)thiophene and carbazole, are more sensitive to light intensity than others such as benz(a)anthracene and benzo(a)pyrene (Mill *et al.* 1981).

Biodegradation: Marine bacteria and fungi play an important role in degrading and removing petroleum hydrocarbons from surface slicks, the water column, and surficial sediments. Microbial degradation begins a day or so after the spill and continues as long as hydrocarbons persist (Wheeler 1978, Lee and Ryan 1983). Rate of degradation is related to oxygen concentration, temperature, nutrients (especially nitrogen and phosphorus), salinity, the physical state and chemical composition of the spilled oil, and previous history of oil pollution at the spill site (Atlas 1981, Bartha and Atlas 1987).

Following a spill, all hydrocarbon components and classes are degraded simultaneously, but at widely different rates by indigenous water column and sediment microbiota (Atlas *et al.* 1981, Bartha and Atlas 1987). Low molecular weight n-alkanes in the ClO to C22 chain length range are metabolized more rapidly, followed by iso-alkanes and higher molecular weight n-alkanes, olefins, monoaromatics, PAH, and finally, highly condensed cycloalkanes, resins and asphaltenes. Thus, as oil weathers through a combination of physical, photochemical, and biodegradative processes, it loses low molecular weight components and becomes enriched in higher molecular weight more complex saturates, naphtheno-aromatics, PAH, resins, and asphaltenes.

Figure 1.6

Annual variation in half-life (t_{so}) of benzo(a)pyrene dissolved in near-surface water at northern latitudes (Zepp and Baughman 1977).



Month of year

Half-life (days)

Temperature profoundly effects the process of degradation. The half-life for microbial degradation of phenanthrene at an initial concentration of 25 μ g/L in seawater is 79 days at 18°C and 11,000 days at 2°C. Similarly, that for benz(a)anthracene at an initial concentration of 2.5 mg/kg in sediment is 1100 days at 15°C and 21,000 days at 4°C (Lee and Ryan 1983). The reliance on temperature was underscored by Wakeham *et al.* (1985, 1986) who showed that in summer conditions biodegradation was more important than volatilization in removing toluene, octadecane, and decane from the water column; under winter conditions, their contributions were reversed. Because both processes are markedly diminished at low environmental temperatures, the light fractions of crude and refined petroleum are very persistent in Arctic environments, especially in winter when low light intensity inhibits photo-oxidation.

Biodegradation is at best a slow process. Rates for hydrocarbons have been estimated to be 1 to 10 mg/m³/day in open-ocean waters (Butler *et al.* 1976), 30 mg/m³/day beneath the surface slick produced by the <u>Amoco Cadiz</u> spill (Aminot 1981), and 0.05 g/m²/day in the upper 5 cm of intertidal sediments along the Brittany Coast of France, impacted by the <u>Amoco Cadiz</u> spill. Extrapolating to the length of coastline affected, Atlas and Bronner (1981) estimated that it would take more than 20 years to biodegrade the estimated 64,000 tons on the Brittany coast.

In Arctic environments, biodegradation is slower still, limited by nutrients (Bergstein and Vestal 1978, Atlas 1986) and low temperatures (Cundell and Traxler 1973, Gibbs *et al.* 1975). Nevertheless hydrocarbon-degrading bacteria abound (Atlas 1986), and can be coaxed into activity by exposure to petroleum (Button and Robertson 1985).

Deposition in Sediments: Heavier fractions of oil eventually deposit in bottom sediments and persist for a long time. Sedimentation may occur by 1) adsorption of droplets on suspended (including biological) particules and transport with them to the bottom, 2) stranding or beaching of oil, followed by adsorption onto sediments or erosion of hardened oil from substrates and subsequent transport to subtidal sediments, and 3) direct sinking of heavy or weathered oils (Anderson et al. 1986, Boehm 1987).

Suspended particles interact with spilled oil in two ways. They physically collide and adhere to dispersed droplets, and adsorb and partition dissolved hydrocarbons from the water phase (Payne *et al.* 1987). A key variable in adsorption appears to be the concentration of suspended particulate matter, especially clay, in the water column. The greater the suspended sediment load, the more oil may be adsorbed and transported to the bottom (Boehm 1987). Approximately 120 to 300 mg of petroleum may adsorb to each kilogram of suspended clay (Bassin and Ichiye 1977, Meyers and Oas 1978).

Weathered oil may become heavier than seawater and sink (Boehm 1987). The process is enhanced as the density of water is lowered by influx of freshwater as runoff or from melting ice. In areas of significant downwelling, as in a polynya at the edge of an ice sheet, sinking water may carry oil droplets to the bottom. Additional oil may be fixed onto biological particles, particularly zooplankton fecal pellets.

Beached oil can also contribute to the sediment load. Erosion of the beach by seasonal storms or ice-scouring results in transport of oil-laden sand into the subtidal zone. Studies of the Baffin Island experimental oil spill (Boehm *et al.* 1985) and the <u>Amoco Cadiz</u> oil spill (Gundlach *et al.* 1983) have shown that concentrations in excess of 100 ppm oil can deposit in subtidal sediments if oil comes ashore and subsequently erodes from the beach.

Interaction of Weathering Processes: The nature and extent of interactions between different weathering processes are difficult to ascertain. Some idea of the processes can be gleaned from an analysis of the fate of the 223,000 tons of oil spilled from the <u>Amoco Cadiz</u> (Gundlach *et al.* 1983). In this spill, there was a massive beaching of oil, a return of large amounts to sediments of bays and estuaries, and to anoxic intertidal and subtidal sediments where they persisted for several years. About 36 percent of the spilled oil was deposited on the shore or in subtidal sediments during the first months. Approximately 30 percent of the oil evaporated, and about 5 percent was degraded in the water column by bacteria. More than 20 percent of the oil was unaccounted for and probably was carried away as surface slicks or tar balls. The most persistent oil residues were those incorporated into subtidal sediments of estuaries or nearshore waters, and oil that washed onto beaches and was buried in the shifting sands. Most of the oil had disappeared from the water surface and water column within a few months after the spill.

Oil Dispersants

Between 1967 and 1979, chemical dispersants were used to combat at least 16 major oil spills. These substances promote the break-up of the slick into fine droplets that disperse in the water column and can be carried away and diluted by normal ocean mixing processes. Most dispersants are composed of surface active agents (surfactants), a solvent, and stabilizing agents (Tetra Tech 1985, Canevari 1986). A surfactant contains both a hydrophilic (watercompatible) and a hydrophobic (oil-compatible) group which allows it to concentrate at the boundary between oil and water (Figure 1.7). The effect is to reduce surface tension, thereby facilitating dispersion into the water column. There are three types of surfactants categorized according to the nature of the hydrophilic group: anionic, cationic, and nonionic. Nonionic surfactants are used most frequently in dispersants. They include ethoxylated alkylphols, such as nonyl phenol-ethylene oxide, ethoxylated linear alcohols, such as oleyl alcohol, and esters formed by the reaction of fatty acids with polyhydric alcohols.

A solvent is added to lower freezing point and reduce viscosity, making it easier to apply. These include aliphatic and aromatic hydrocarbon mixtures, water or alcohols in water, glycols, and glycol ethers. Dispersants containing



Figure 1.7 Dispersion of oil droplets resulting from application of a chemical dispersant

hydrocarbon solvents tend to be more effective in treating heavy, viscous oils. They are easier to mix and apply, but are more toxic than those containing watersoluble solvents. A stabilizer may also be added to adjust pH, reduce corrosiveness, help fix the dispersion after it is formed, or counteract adverse color or odor. Dispersant stabilizers may include alkalis, phosphates, silicates, nitrates, dyes and polymerized alkyl naphthalene sulfonates.

Other Methods of Treating Spills

A variety of other chemical agents has been proposed for treating marine oil spills. These include herding agents, demulsifiers, and gelling, wicking, and sinking agents. Most of these are in the conceptual or developmental stage, and their chemical compositions are proprietary.

Herding agents have a higher surface tension, and therefore, spreading force, than petroleum (Fickling and Hann 1980). When applied around a slick, they tend to compress it and prevent it from spreading. They reportedly have relatively low toxicity to marine organisms. Demulsifiers are mixtures of surfactants and wetting agents intended to facilitate the separation of the oil and water in emulsions (Canevari 1982). Once separated, the oil is recovered and the water discharged. The environmental properties and toxicity of demulsifiers should be similar to those of dispersants. Gelling agents transform spilled oil into a semisolid mass that can be handled easily with recovery equipment. By injecting them into the oil in cargo or fuel tanks of a sunken ship, they may slow or prevent release of oil. One such agent is a high molecular weight polymer of polyisobutylene (Waters and Hodermann 1987). These compounds, apparently have low toxicity to marine organisms (Tokuda 1979).

Spilled oil can be effectively burned, particularly if fire-proof booms are used (Buist *et al.* 1983). However, water serves as a heat sink making it difficult to sustain combustion. Not all the oil burns, and the residues and airborn particles may create added problems. Wicking agents are intended to lift the oil above the sea surface, enabling it to burn more efficiently. They have not been used successfully in open water, but may prove more beneficial on ice when oil gathers in relatively deep pools (Mackay 1982).

Sinking agents are dense particles (2.4 to 3.0 g/cc) with hydrophobic surfaces, that when applied to a spill, adsorb the oil and cause it to sink. They may include sand, fly ash, powdered cement, or other minerals coated with silicones, stearates, or waxes. They effectively remove oil from sight, but they may exacerbate the impact of the spill by rapidly depositing the oil on the bottom where it may persist.

Use of Chemical Dispersants and Cleaning Agents

Dispersants may be applied to an oil slick by hand, or from a suitably equipped boat or aircraft (Fickling and Hann 1980). Small to medium-sized boats with spray booms, usually about 7 to 10 meters long extending out from each side, are used most frequently. They apply water-based dispersants at a rate of about 100 to 150 gallons per minute; concentrates and hydrocarbon-based dispersants are applied at a lower rate. Aerial spraying has the advantage of covering large areas quickly. It requires that the dispersant be used full-strength and that the aircraft fly 30 to 50 feet above the surface.

The volume of dispersant required to treat a spill depends on sea state, nature of the oil, and the method of application. The rate of administration ranges from one liter for each 10 liters of spilled oil to a rate of one to one. Generally, the rougher the seas and the fresher the oil (less weathered), the less dispersant required to break up the slick. During the <u>Ixtoc-I</u> spill, several dispersants were used, most of which were applied by plane. Up to four spraying missions were flown per day, each applying about 135,000 liters of dispersant. Additional dispersant was applied from boats. Clearly, if the amount of dispersant discharged to the oceans would be very large if this method were adopted on a wide scale.

Dispersants have also been used to loosen oil on shore so that it can be removed more easily by cleaning devices or by wave action. This practice was discouraged after the <u>Torrey Canyon</u> oil spill in 1967 on the southwest coast of Cornwall, England, because the use of dispersant caused more damage to coastal ecosystems than did the oil itself (Nelson-Smith 1968, Southward and Southward 1978). Interest is now growing to evaluate the usefulness of less toxic dispersants for shoreline cleaning, but here too the advantages are questionable. Studies on rocky shores and intertidal mud flats reveal little difference in impact between raw crude oil and crude oil that was treated with a dispersant after stranding (Little *et al.* 1981, Rowland *et al.* 1981, Crothers 1983). Results from comparable studies in a salt marsh are somewhat more encouraging (Baker *et al.* 1980).

Fate of Dispersants in the Marine Environment

Chemical dispersants applied to oil spills undergo the same types of weathering processes as the spilled oil (Tetra Tech 1985). The most important processes affecting the fate of oil dispersants in seawter are evaporation, solubilization, diffusion, biodegradation, and possibly bioaccumulation (Wells *et al.* 1982).

Much of the hydrocarbon or water-soluble solvent fraction of the dispersant is lost by evaporation during and immediately after application of the dispersant to the oil slick. Evaporation of the solvent is most rapid when the dispersant is applied as a fine spray from an airplane. When applied to a spill on the water surface, the dispersant immediately dissolves in the partitions between the oil and water phases. Mackay and Hossian (1982) estimated that the oil-water partition coefficient for the types of surfactants most frequently used in oil dispersants is about 10. Because the ratio of oil to water in nearly all spills is very low, most of the dispersant (up to about 99 percent) partitions into the water phase. Once in aqueous solution, the dispersant is diluted by diffusion and convective mixing, but surfactant components are detectable in concentrations of 1-3 ppm for over 6 hours after application to an oil spill (Bocard *et al.* 1984).

The complex fatty acid ester mixtures usually used as surfactants in modern oil dispersants are readily degraded by marine bacteria and fungi. Several types of marine water column and sediment bacteria are capable of rapid and sustained growth with oil dispersant as the sole source of carbon and energy (Liu 1983). More than 55 percent of the dispersant BP1100X was degraded in 8 days by a mixed population of microbes isolated from oil-contaminated sediments (Bhosle and Row 1983). Microbial degradation probably is the most important mechanism quantitatively for removing dispersants from the marine environment.

Although surfactants from oil dispersants are readily accumulated from the water by marine animals (Kikuchi *et al.* 1980), they are also readily metabolized by freshwater and marine animals (Payne 1982). The animals enzymatically hydrolize the surfactant to hydrophilic and hydrophobic components. Hydrophilic components probably are excreted via the gills and kidneys, whereas hydrophobic components accumulate in the gall bladder of fish and are excreted very slowly. Because of the rapid metabolism of surfactants by marine animals, there is little likelihood of food chain transfer of surfactant chemicals from marine invertebrates and fish to consumers, including marine mammals.

Overview of Possible Interactions between Petroleum and Marine Mammals

Many of the properties of petroleum and its behavior and fate when spilled in the marine environment make it likely that marine mammals will come in contact with oil in some form. There is some concern that such encounters will be harmful (Geraci and St. Aubin 1980).

Physical Contact with Oil: All marine mammals spend considerable time at the surface, swimming, breathing, feeding, or resting, thereby enhancing the possibility of contact with a surface slick, water-in-oil emulsion, or tar balls. In species with heavy pelage, such as fur seals, sea otters, and polar bears, contact may lead to fouling. Polar bears and otters groom themselves regularly as a means of maintaining the insulating properties of the fur, and may thereby ingest oil. Oil would have less tendency to adhere to the surface of animals with relatively little or no pelage, such as whales, dolphins, manatees, and most seals.
Some baleen whales forage at the surface, a behavior called skim-feeding (Wursig *et al.* 1985). It affords the potential, when in an area of a slick or tar balls, to foul the feeding apparatus. Tarry residues in particular could coat the baleen plates.

In polar regions, spilled oil tends to accumulate at the ice edge, in leads, polynyas, and breathing holes (Figure 1.8), where animals such as narwhals, belugas, ringed seals, walruses, and polar bears spend much of their time. The oil tends to persist, thus setting the stage for unavoidable contact.

Oil that comes ashore is likely to foul pinnipeds that require such areas for haul-outs or nursery areas, and to lesser extent, otters and bears. Some of the oil is eventually returned in subtidal sediments, where it may transfer to species, such as the gray whale, walrus, and some seals, which feed heavily on benthic animals.

Accumulation of Oil from Air and Water: Marine mammals encountering fresh oil are likely to inhale volatile hydrocarbons evaporating from the surface slick. Such fractions contain toxic monoaromatic hydrocarbons (benzene, toluene, xylenes) and low molecular weight aliphatics with anaesthetic properties. Inhalation of these compounds is potentially dangerous (Carpenter *et al.* 1975, 1976).

Inhalation of concentrated petroleum vapors may cause inflammation of and damage to the mucus membranes of airways, lung congestion, or even pneumonia (Hansen 1985). Volatile hydrocarbons, such as benzene and toluene, that are inhaled are transferred rapidly into the bloodstream in the lungs. They may accumulate from the blood in such tissues as brain and liver, causing neurological disorders and liver damage (Geraci and St. Aubin 1982).

Marine mammals probably will not accumulate much oil directly from solution or dispersion in the water column. The skin of cetaceans seems relatively impermeable to oil (Geraci and St. Aubin 1980). Most marine mammals do not drink large volumes of seawater, so significant accumulation of hydrocarbons by this route is unlikely.

Fur-bearing marine mammals such as fur seals, polar bears, and sea otters may ingest oil during grooming. The limited data avilable indicate tht oil is not particularly toxic at least to pinnipeds when taken in by this route. Geraci and Smith (1976) showed that seals experienced no acute damage when they ingested 75mL of oil over a short period of time. However, ingestion of oil during grooming may have contributed to the death of heavily oiled polar bears (Oritsland *et al.* 1981).

Ingestion of Oil-Contaminated Food: Marine mammals, except the manatee, are carnivores that rely on invertebrates or fish for sustenance. Their feeding strategies could lead to ingestion of oil-contaminated food, because most of the prey organisms can accumulate petroleum hydrocarbons in their tissues (Neff 1979, Capuzzo 1987).





Zooplankton are a particularly important food resource, particularly for baleen whales. Some, such as copepods, euphausiids, and mysids, assimilate hydrocarbons directly from seawater and by ingesting oil droplets and oilcontaminated food (Corner 1978). Copepods are one of the few taxa in which hydrocarbon uptake appears to be more efficient from food than from water (Corner et al. 1976). There is an inverse relationship between ambient temperature and rate of accumulation of petroleum hydrocarbons by copepods (Harris et al. 1977); polar and boreal species store more lipids, and therefore hydrocarbons than those from warm environments. Planktonic crustaceans can transform aromatic hydrocarbons to polar metabolites that may be excreted or bound to tissues (Malins 1977). A fraction of hydrocarbons is also retained for days or weeks in unmetabolized or metabolized form in zooplankton (Corner et al. 1976). During this time, the hydrocarbons could be transferred to consumers of zooplankton.

Benthic invertebrates and higher forms such as the sand eel, <u>Ammodytes</u> <u>americanus</u> (an important food item of Atlantic humpback whales) (Payne *et al.* 1986), may accumulate petroleum hydrocarbons from contaminated sediments and food, and to a greater extent, from water (Neff 1984). Bivalve mollusks tend to accumulate petroleum hydrocarbons to higher concentrations and retain them longer than other taxa (Neff and Anderson 1981, Capuzzo 1987). This is due in part to their limited ability to metabolize the compounds to excretable polar metabolites; they essentially lack the mixed function oxygenase (MFO) system to do so (Lee 1981). Thus, marine mammals that rely heavily on bivalve mollusks for food, such as the walrus (Oliver *et al.* 1983), and otter share a higher risk of ingesting petroleum hydocarbons.

Benthic crustaceans, the major food of gray whales in the northern Bering Sea and the Chukchi Sea (Nerini and Oliver 1983), also accumulate oil from water, sediment and food (Neff 1979, Capuzzo 1987). However, most marine crustaceans have a well-developed MFO system (Lee 1981), and so are able to metabolize and excrete accumulated hydrocarbons quite rapidly. Thus, benthic crustaceans would provide a source of hydrocarbons to feeding gray whales for only a short period of time after a spill. However, benthic amphipods are quite sensitive to spilled oil; they are among the first marine animals killed and the slowest to recover (Spies 1987). Thus, a major spill in the northern Bering Sea in summer could affect the whales' main food resource.

Marine fish also take up petroleum hydrocarbons from water and food. The compounds induce the hepatic MFO system in liver (Stegeman 1981); within a few days after exposure, aromatic hydrocarbons are oxygenated to polar metabolites and excreted. For this reason, most fish, even in heavily oil-contaminated environments, do not accumulate and retain high concentrations of petroleum hydrocarbons, and so are not likely to transfer them to predators.

Fish may nevertheless be tainted with metabolites bound to tissue macromolecules including DNA. The metabolites are so reactive, it is unlikely that they would be released in a toxic form during digestion and absorption by the consumer, and so would not pose a serious threat.

In general, marine carnivores are inefficient assimilators of petroleum compounds in food. For this reason, and because all prey species are able to release hydrocarbons from their tissues (Neff and Anderson 1981), marine food chain biomagnification does not occur. Thus, there is no direct correlation between a marine mammal's trophic level and the concentration of residues that it might consume. In fact, top carnivores such as polar bears and killer whales that feed on large pelagic fish and seals are less likely to be exposed to petroleum in their food, than are species such as baleen whales and walrus that feed on zooplankton and benthic invertebrates.

Effects of Oil Dispersants

Excepting their use to clean oil-fouled sea otters, virtually nothing is known about the effects of oil dispersants on marine mammals. By removing spilled oil from the sea surface, dispersants obviously reduce the risk of contact. The oil remaining would be less sticky, and therefore less likely to adhere to fur, skin, baleen plates, or other body surfaces. On the other hand, the surfactants in dispersants may remove natural oils from marine mammal fur, thereby decreasing its insulating properties. Cleaning oiled beaches and rocky shores with dispersants may be an effective means of preventing oiling of pinnipeds that may wish to haul out there. More work needs to be done before we can adequately weigh the advantages or disadvantages of using dispersants in such habitats.

Distribution of Oil Inputs and Marine Mammals

The distribution of oil production and transportation activities is very uneven in U.S. coastal and outer continental shelf waters. Major tanker routes worldwide are concentrated in the Indian Ocean and South and North Atlantic, reflecting the massive export of petroleum to western Europe and the United In U.S. waters, there is significant tanker traffic in the Gulf of States. Mexico along the Texas coast, along the Pacific coast from Alaska to southern California (the main tanker route for Alaskan Prudhoe Bay oil to refineries in Washington and California), and the Atlantic coast from refineries to major urban markets. Approximately 95 percent of offshore production in U.S. waters is in the Gulf of Mexico, especially off Louisiana. The remainder is off southern California, in Alaska at Cook Inlet, and in the Beaufort Sea. Oil production is also taking place off the east coast of Canada on the Grand Banks, in the Canadian Beaufort Sea off the MacKenzie River delta, and along the Gulf coast of Mexico. In addition, virtually all major coastal cities discharge oil to local waters.

A variety of marine mammals have been reported from the Gulf of Mexico. The one most familiar along the coast of Texas is the bottlenose dolphin which frequents passes and coastal bays. A total of 20 species of marine mammals have been sited at least once in the central and western Gulf, the areas of most intense oil activities. These included the endangered fin, humpback, right, sei, and sperm whales (Wursig, Chapter 4). The West Indian manatee occurs along the Gulf coast of Florida and has been sighted occasionally along the south Texas coast.

By comparison, 29 species of cetaceans and two species of seals have been recorded off the northeast coast of the United States and Canada, 26 in the Bering Sea, and 21, including the sea otter, in Lower Cook inlet, Shelikof Strait, and the northern Gulf of Alaska (McLaren, Chapter 2; Wursig, Chapter 4). Coastal waters off California also support a rich fauna which includes 29 species of cetaceans, 5 of pinnipeds, and the sea otter.

Based on these distributions, the most likely locations of the most frequent encounters between marine mammals and potential oil spills are along the California coast, in the Gulf of Alaska, and on the Grand Banks of eastern Canada. If substantial development of offshore oil resources continues in the Beaufort Sea and tankers are used to transport the oil south, or if commercial reservoirs of oil are found and developed in the Bering Sea, then the northern Bering Sea could also become a major area of interaction between oil and marine animals.

Literature Cited

- Aminot, A. 1981. Anomalies du systeme hydrobiologique cotierapres l'echouage de l'Amoco Cadiz. Considerations qualitatives et quantitatives sur la biodegradation in situdes hydrocarbures. Pages 223-242. In <u>Amoco Cadiz</u> Consequences d'une Pollution Accidentelle par les Hydrocarbures. Fates and Effects of the Oil Spill. CNEXO, Paris, France.
- Anderson, J.W., J.M. Neff, and P.D. Boehm. 1986. Sources, Fates and Effects of Aromatic Hydrocarbons in the Alaskan Marine Environment with Recommendations for Monitoring Strategies. Environmental Protection Agency, Corvallis, OR. EPA 600/3-86 018. 123 pp.
- Atlas, R.M. 1981. Microbial degradation of petroleum hydrocarbons. An environmental perspective. Microbiol. Rev. 45: 180-209.
- Atlas, R.M. 1986. Fate of petroleum pollutants in Arctic ecosystems. Wat. Sci. Technol. 18: 59-67.
- Atlas, R.M., P.D. Boehm and J.A. Calder. 1981. Chemical and biological weathering of oil from the <u>Amoco Cadiz</u> spillage within the littoral zone. Estuar. Cstl. Shelf Sci. 12: 589-608.
- Atlas, R.M. and A. Bronner. 1981. Microbial hydrocarbon degradation within intertidal zones impacted by the <u>Amoco Cadíz</u> oil spillage. Pages 251-256. In <u>Amoco Cadiz</u> Consequences d'une Pollution Accidentelle par les Hydrocarbures. Fates and Effects of the Oil Spill. CNEXO, Paris, France.
- Audunson, V.D., J. Mathisen, J. Holdorsen and K. Krough. 1981. Slikforkast a simulation program for oil spill emergency tracking and long term contingency planning. pp. 453-459. In PETROMAR80 - Petroleum in the Marine Environment. Assoc. Europe. Ocean. EUROCEAN. Graham and Trotman Ltd., London, U.K.
- Barrick, R.C. 1982. Flux of aliphatic and polycyclic aromatichydrocarbons to central Puget Sound from Seattle (Westpoint) primary sewage effluent. Environ. Sci. Technol. 16: 682-692.
- Bartha, R. and R.M. Atlas. 1987. Transport and transformations of petroleum: Biological processes. pp. 287-341. In Long-Term Environmental Effects of Offshore Oil and Gas Development. D.F. Boesch and N.N. Rabalais (eds.). Elsevier Appl. Sci., London, U.K.
- Bassin, J.J. and T. Ichiye. 1977. Flocculation behavior of suspended sediments and oil emulsions. J. Sed. Petrol. 47: 671-677.
- Benville, P.E., Jr., J.A. Whipple, and M.B. Eldridge. 1985. Acute toxicity of seven acyclic hexanes to striped bass, <u>Morone saxatilis</u>, and bay shrimp, <u>Crangon franciscorum</u>, in seawater. Calif. Fish Game 11: 132- 1-40.
- Bergstein, P.E. and J.R. Vestal. 1978. Crude oil biodegradation in Arctic tundra ponds. Arctic 31(3): 158-169.
- Bhosle, N.B. and A. Row. 1983. Effect of dispersants on the growth of indigenous bacterial populations and biodegradation of oil. Ind. J. Mar. Sci. 12: 194-196.
- Bobra, A.M. and M.F. Fingas. 1986. The behavior and fate of Arctic oil spills. Wat. Sci. Technol. 18: 13-23.

- Bocard, C., G. Castaing and C. Gatillier. 1984. Chemical oil dispersion in trials at sea and in laboratory tests: the key role of dilution processes. pp. 125-142. In Oil Spill Chemical Dispersants: Research, Experience, and Recommendations. T.E. Allen (ed.). ASTM STP 840. Amer. Soc. Testing and Materials, Philadelphia, PA.
- Boehm, P.D. 1987. Transport and transformation processes regarding hydrocarbon and metal pollutants in offshoresedimentary environments. pp. 233-286. In Long-Term Environmental Effects of Offshore Oil and Gas Development. D.F. Boesch and N.N. Rabalais (eds.). Elsevier Appl. Sci., London, U.K.
- Boehm, P.D. and D.L. Feist. 1982. Subsurface distribution of petroleum from and offshore well blowout - the <u>Ixtoc-I</u> blowout. Environ. Sci. Technol. 16: 67-74.
- Boehm, P.D., W. Steinhauer, A. Requejo, D. Cobb, S. Duffy and J. Brown. 1985. Comparative fate of chemically dispersed and untreated oil in the Arctic: The BIOS studies 1980-1983. In Proc. 1985 Oil Spill Conf., Amer. Petrol. Inst., Washington, DC.
- Bonnell, M.L., M.O. Pierson and G.D. Farrens. 1983. Pinnipeds and sea otters of central and northern California, 1980-1983; Status, abundance, and distribution. Report. U.S. Dept. of the Interior, Minerals Management Serv., Pacific OCS Region, Los Angeles, CA. 220 pp.
- Buist, I.A., W.M. Pistruzak, S.G. Potter, N. Vanderkooy and I.R. McAllister. 1983. The development and testing of a fireproof boom. pp. 43-51. In Proc. 1983 Oil Spill Conf. (Prevention, Behavior, Control, Cleanup). Amer. Petrol. Inst., Washington, DC.
- Butler, J.N. 1975. Evaporative weathering of petroleum residues: the age of pelagic tar. Mar. Chem. 3: 9-21.
- Butler, J.N., B.F. Morris and T.D. Sleeter. 1976. The fate of petroleum in the open ocean. pp. 287-297. In Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. AIBS, Washington, DC.
- Button, D.K. and B.R. Robertson. 1985. Effect of toluene exposure time and concentration on induction of high affinity values for toluene oxidation by bacteria of estuarine seawater samples. Mar. Ecol.-Prog. Ser. 26:187-193.
- Calkins, D.G., K.W. Pitcher and K. Schneider. 1975. Distribution and abundance of marine mammals in the Gulf of Alaska. Report. U.S. Dept. Commerce, Nat. Oceanic and Atmospheric Admin. Alaska Dept. Fish and Game, Anchorage, AK. 67 pp.
- Canevari, G.P. 1982. The formulation of an effective demulsifier for oil spill emulsions. Mar. Poll. Bull. 13: 49-54.
- Canevari, G.P. 1986. Oil spill dispersants: mechanism, history, chemistry. Position Paper. Committee on Effectiveness of Oil Spill Dispersants in the Ocean. Nat. Research Council, Nat. Academy of Sci., Washington, DC. 9 pp.
- Capuzzo, J.M. 1987. Biological effects of petroleum hydrocarbons: assessments from experimental results. pp. 343-410. In Long-Term Environmental Effects of Offshore Oil and Gas Development. D.F. Boesch and N.N. Rabalais (eds.). Elsevier Appl. Sci., London, U.K.
- Carpenter, C.R., E.R. Kinkead, D.L. Geary, L.J. Sullivan and J.M. King. 1975. Petroleum hydrocarbon toxicity studies. V. Animal and human reponses to vapors of mixed xylenes. Toxicol. Appl. Pharmacol. 33: 543-558.

Carpenter, C.R., E.R. Kinkead, D.L. Geary, L.J. Sullivan and J.M. King. 1976. Petroleum hydrocarbon toxicity studies. XIII. Animal and human response to vapors to toluene concentrate. Toxicol. Appl. Pharmacol. 36: 473-490. Connell, D.W. 1982. An approximate petroleum hydrocarbon budget for the

Hudson-Raritan Estuary - New York. Mar. Poll. Bull. 13: 89-93.

Corner, E.D.S. 1978. Pollution studies with marine plankton. Part I. Petroleum hydrocarbons and related compounds. Adv. Mar. Biol. 15: 289--380.

Corner, E.D.S., R.P. Harris, C.C. Kilvington and S.C.M. O'Hara. 1976. Petroleum compounds in the marine food web: short-term experiments on the fate of naphthalene in Calanus. J. Mar. Biol. Ass. U.K. 56: 121-133.

Crisp, D.J., A.O. Christie and A.F.A. Ghobashy. 1967. Narcotic and toxic action of organic compounds to barnacle larvae. Comp. Biochem. Physiol. 22: 629-649.

Crothers, J.H. 1983. Field experiments on the effects of crude oil and dispersant on the common animals and plants of rocky sea shores. Mar. Environ. Res. 8: 215-239.

Cundell, A.M. and R.W. Traxler. 1973. Microbial degradation of petroleum at low temperature. Mar. Poll. Bull. 4: 125-127.

Dohl, T.P., R.C. Guess, M.L. Duman and R.C. Helm. 1983. Cetaceans of central and northern California, 1980-1983: Status, abundance, and distribution. Report. U.S. Dept. of the Interior, Minerals Management Serv., Pacific OCS Office, Los Angeles, CA. 284 pp.

Ducreux, J., F. Berthou and G. Bodennec. 1986. Etude duviellissement d'un petrole brut repandu a la surface de l'eau de mer dans des conditions naturelles. Intern. J. Environ. Anal. Chem. 24: 85-111.

Eganhouse, R.P. and I.R. Kaplan. 1982. Extractable organic matter in municipal wastewaters. I. Petroleum hydrocarbons: temporal variations and mass emission rates to the ocean. Environ. Sci. Technol. 16:180-186.

Elliott, A.J. 1986. Shear diffusion and the spread of oil in the surface layers of the North Sea. Dt. Hydrogr. Z. 39: 113-137.

Elliott, A.J., N. Hurford, and C.J. Penn. 1986. Shear diffusion and the spreading of oil slicks. Mar. Poll. Bull. 17: 308-313.

Fishbein, L. 1984. An overview of environmental and toxicological aspects of aromatic hydrocarbons. I. Benzene. Sci. Total Environ. 40: 189-218.

Fickling, J.M., Jr. and R.W. Hann, Jr. 1980. The chemical treatment of oil spills: theoretical, practical, and philosophical considerations. Unpublished Report. Texas A&M Univ., College Station, TX.

Forrester, W.D. 1971. Distribution of suspended oil particles following the grounding of the tanker Arrow. J. Mar. Res. 29: 151-170.

- Geraci, J.R. and D.J. St. Aubin (eds.). 1982. Study of the effects of oil on cetaceans. Rep. U.S. Dept. of the Interior, Minerals Management Serv., Washington, DC.
- Geraci, J.R. and T.G. Smith. 1976. Consequences of oil fouling on marine mammals. pp. 399-410. In Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Volume 2. D.C. Malins (ed.). Academic Press, New York, NY.
- Gibbs, C.F., K.B. Pugh and A.R. Andrews. 1975. Quantitative studies on marine biodegradation of oil. II. Effect of temperature. Proc. Roy. Soc. London B. 188: 83-94.

Gordon, D.C., Jr., P.D. Keizer and N.J. Prouse. 1983. Laboratory studies on the accommodation of some crude and residual fuel oils in sea water. J. Fish. Res. Board Can. 30: 1611-1618.

Grossling, B.F. 1976. An estimate of the amounts of oil entering the oceans. pp. 5-36. In Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. Amer. Inst. Biol. Sci., Washington, DC.

Grunbauer, H.J.M. and J.W.M. Wegener. 1983. The relation between chemical structure and mutagenic activity of some polycyclic aromatic sulfur heterocycles (S-PAH). Toxicol. Environ. Chem. 6: 225-239.

Gundlach, E.R., P.D. Boehm, M. Marchand, R.M. Atlas, D.M. Ward and D.A. Wolfe. 1983. Fate of <u>Amoco Cadiz</u> oil. Science 221: 122-129.

Hansen, D.J. 1985. The potential effects of oil spills and other chemical pollutants on marine mammals occurring in Alaskan waters. U.S. Dept. of the Interior, Minerals Management Serv., Alaska Outer Continental Shelf Region, Anchorage, AK. OCS Rep. MMS85-0031. 22 pp.

Harris, R.P., V. Berdugo, E.D.S. Corner, C.C. Kilvington and S.C.M. O'Hara. 1977. Factors affecting the retention of petroleum hydrocarbons by marine planktonic copepods. pp. 286-304. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. D.A. Wolfe (ed.). Pergamon Press, New York, NY.

Harrison, W., M.A. Winnik, P.T.Y. Kwong and D. Mackay. 1975. Crude oil spills. Disappearance of aromatic and aliphatic components from small sea-surface slicks. Environ. Sci. Technol. 9: 231-234.

Hood, D.W. 1983. The Bering Sea. pp. 337-373. In Estuaries and Enclosed Seas. B.H. Ketchum (ed.). Elsevier Sci. Publ. Co., Amsterdam, Holland.

Hutchinson, T.C., J.A. Hellebust, D. Tam, D. Mackay, R.A. Mascarenkas and W.Y. Shiu. 1980. The correlation of the toxicity to algae of hydrocarbons and halogenated hydrocarbons with their physical-chemical properties. pp. 577-586. In Hydrocarbons and Halogenated Hydrocarbons in the Aquatic Environment. B.K. Afghan and D. Mackay (eds.). Plenum Press, New York, NY.

Jernelov, A. and O. Linden. 1981. <u>Ixtoc-I</u>: a case study of the world's largest oil spill. Ambio. 10: 299-306.

Kallio, R.E. 1976. The variety of petroleums and their degradations. pp. 214-223. In Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. Amer. Inst. Biol. Sci., Washington, DC.

Karcher, W., A. Nelson, R. Depaus, J. van Eijk, P. Glaude and J. Jacob. 1981. New results in the detection, identification, and mutagenic testing of heterocyclic polycyclic aromatic hydrocarbons. pp. 317-328. In Chemical Analysis and Biological Fate: Polynuclear Aromatic Hydrocarbons. M. Cooke and A.J. Dennis (eds.). Battelle Press, Columbus, OH.

Katona, S., W. Steiner and H.E. Winn. 1977. Marine mammals. pp. 1-167. In Center for Natural Areas, A Summary and Analysis of Environmental Information on the Continental Shelf from the Bay of Fundy to Cape Hatteras. Volume 1, No.2. Final Report. U.S. Dept. of the Interior, Bureau of Land Management, Washington, DC.

Kennedy, R.D. and H.E. Winn. 1986. Cetacean high-use habitats of the northeast United States continental shelf. Fish. Bull. 84: 345-357.

Kikuchi, M., M. Wakabayashi and H. Kojima. 1980. Bioaccumulation profiles of 35S-labelled sodium alkylpoly(oxyethylene) sulfates in carp (<u>Cyprinus</u> <u>carpio</u>). Wat. Res. 14: 1541-1548.

- Larson, R.A., D.W. Blankenship and L.L. Hunt. 1976. Toxichydroperoxides: photochemical formation from petroleum constituents. pp. 298-308. In Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. AIBS, Washington, DC.
- Larson, R.A., T.L. Bott, L.L. Hunt and K. Rogenmuser. 1979. Photooxidation products of a fuel oil and their antimicrobial activity. Environ. Sci. Technol. 13: 965-969.
- Larson, R.A., L.L. Hunt and D.W. Blankenship. 1977. Formation of toxic products from a No. 2 fuel oil by photooxidation. Env. Sci. Technol. 11: 492-496.
- Later, D.W., R. A. Pelroy, D.D. Mahlum, C.W. Wright, M.L. Lee, W.C. Weimer and B.W. Wilson. 1983. Identification and comparative genotoxicity of polycyclic aromatic hydrocarbons and related nitrogen-containing heteroaromatic species in products from coal liquefaction processes. pp. 771-783. In Polynuclear Aromatic Hydrocarbons: Formation, Metabolism and Measurement. M. Cooke and A.J. Dennis (eds.). Battelle Press, Columbus, OH.
- Lee, R.F. 1981. Mixed function oxygenases (MFO) in marine invertebrates. Mar. Biol. Lett. 2: 87-105.
- Lee, R.F. and C. Ryan. 1983. Microbial and photochemical degradation of polycyclic aromatic hydrocarbons in estuarine waters and sediments. Can. J. Fish. Aquat. Sci. 40: 86-94.
- Little, D., J.M. Baker and T.P. Abiss. 1981. The fate and effects of dispersant-treated compared with untreated crude oil, with particular reference to sheltered intertidal sediments. Pages 117-151. In Chemical Dispersion of Oil Spills: An International Research Symposium. D.Mackay (ed.). Publ. No. EE-17, Univ. Toronto, Ontario, Canada.
- Liu, D. 1983. Fate of oil dispersants in aquatic environment. Sci. Total Environ. 32: 93-98.
- Lysyj, I., G. Perkins, J.S. Farlow and W. Lamoreaux. 1981. Effectiveness of offshore produced water treatment. pp. 63-67. In Proc. 1981 Oil Spill Conf. Amer. Petrol. Inst., Washington, DC.
- Mackay, D. 1982. Fate and behavior of oil spills. pp. 7-27. In Oil and Dispersants in Canadian Seas - Research Appraisal and Recommendations. J.B. Sprague, J.H. Vandermeulen, and P.G. Wells (eds.). Environ. Protection Serv., Environ. Emergencies Branch, Ottawa, Ont.
- Mackay, D. and K. Hossain. 1982. Interfacial tensions of oil, water, chemical dispersant systems. Can. J. Chem. Eng. 60: 546-550.
- Mackay, D. and P.J. Leinonen. 1975. Rate of evaporation of low-solubility contaminants from water bodies to atmosphere. Environ. Sci. Technol. 9: 1178-1180.
- Mackay, D. and P.G. Wells. 1983. Effectiveness, behavior, and toxicity of dispersants. pp. 65-71. In Proc. 1983 Oil Spill Conf. (Prevention, Behavior, Control, Cleanup). Amer. Petrol. Inst., Washington, DC.
- Malins, D.C. 1977. Biotransformation of petroleum hydrocarbons in marine organisms indigenous to the Arctic and sub-Arctic. pp. 47-59. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. D.A. Wolfe (ed.). Pergamon Press, New York, NY.
- McAuliffe, C.D. 1976. Evaporation and solution of C2 to C10 hydrocarbons from crude oils on the sea surface. pp. 19-35. In Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. D. Wolfe (ed.). Pergamon Press, New York, NY.

- Meyers, P.A. and T.G. Oas. 1978. Comparison of association of different hydrocarbons with clay particles in simulated seawater. Environ. Sci. Technol. 12: 934-937.
- Mill, T., W.R. Mabey, B.Y. Lan and A. Baraze. 1981. Photolysis of polycyclic aromatic hydrocarbons in seawater. Chemosphere 10: 1281-1290.
- Miller, G.J. and D.W. Connell. 1982. Global production and fluxes of petroleum and recent hydrocarbons. Intern. J. Environ. Studies 19:273--280.
- Minerals Management Service. 1986. Managing Oil and Gas Operations on the Outer Continental Shelf. U.S. Dept. of the Interior, Minerals Management Serv., Washington, DC. 60 pp.
- National Academy of Sciences. 1975. Petroleum in the Marine Environment. Nat. Academy Press, Washington, DC. 107 pp.
- National Academy of Sciences. 1983. Drilling Discharges in the Marine Environment. Nat. Academy Press, Washington, DC. 180 pp.
- National Academy of Sciences. 1985. Oil in the Sea. Nat. Academy Press, Washington, DC. 601 pp.
- Neff, J.M. 1979. Polycyclic Aromatic Hydrocarbons in the Aquatic Environment. Sources, Fates and Biological Effects. Applied Sci. Pub., London, U.K. 266 pp.
- Neff, J.M. 1984. Bioaccumulation of organic micropollutants from sediments and suspended particulates by aquaticanimals. Fres. 2, Anal. Chem. 319: 132-136.
- Neff, J.M. and J.W. Anderson. 1981. Response of Marine Animals to Petroleum and Specific Petroleum Hydrocarbons. Halstead Press, New York, NY. 177 pp.
- Nelson-Smith, A. 1968. The effects of oil pollution and emulsifier cleansing on shore life in south-west Britain. J. Appl. Ecol. 5: 97-107.
- Nerini, M.K. and J.S. Oliver. 1983. Gray whales and the structure of the Bering Sea benthos. Oecologia 59: 224-225.
- Oesch, F. 1982. Chemical carcinogenesis by polycyclic aromatic hydrocarbons. pp. 1-24. In Chemical Carcinogenesis. C. Nicolini (ed.). Plenum Press, New York, NY.
- Oliver, J.S., P.N. Slattery, E.F. O'Connor and L.F. Lowry. 1983. Walrus, <u>Odobenus rosmarus</u>, feeding in the Bering Sea: a benthic perspective. Fish. Bull. 81: 501-512.
- Oritsland, N.A., F.R. Engelhardt, F.A. Juck, R.J. Hurst and P.D. Watts. 1981. Effects of crude oil on polar bears. Northern Affairs Program Environmental Study No. 24, Dept. of Indian and Northern Affairs, Ottawa, Ont.
- Payne, J.F. 1982. Metabolism of complex mixtures of oil spill surfactant compounds by a representative teleost (<u>Salmo gairdneri</u>), crustacean (<u>Cancer irroratus</u>), and mollusc (<u>Chlamys islandicus</u>). Bull. Environ. Contam. Toxicol. 28: 277-280.
- Payne, J.R., B.E. Kirstein, G.D. McNabb, Jr., J.C. Lambach, C.DeOliveira, R.E. Jordan and W. Hom. 1983. Multivariate analysis of petroleum hydrocarbon weathering in the sub-Arctic marine environment. pp. 423-434. In Proc. 1983 Oil Spill Conf. Amer. Petrol. Inst., Washington, DC.
- Payne, J.R. and G.D. McNabb, Jr. 1985. Weathering of petroleum in the marine environment. Mar. Technol. Soc. J. 18: 1-19.
- Payne, J.R. and C.R. Phillips. 1985. Petroleum Spills in the Marine Environment. The Chemistry and Formation of Water-in-Oil Emulsions and Tar Balls. Lewis Publishers, Inc., Chelsea, MI.

- Payne, J.R., C.R. Phillips and W. Hom. 1987. Transport and transformations: water column processes. pp. 175-231. In Long-term Environmental Effects of Offshore Oil and Gas Development. D.F. Boesch and N.N. Rabalais (eds.). Elsevier Applied Sci., London, U.K.
- Payne, P.M., J.R. Nicolas, L. O'Brien and K.D. Powers. 1986. The distribution of humpback whale, <u>Megaptera novaeangliae</u>, on Georges Bank and in the Gulf of Maine in relation to densities of the sand eel, <u>Ammodytes</u> americanus. Fish. Bull. 84: 271-277.
- Reijnhart, R. and R. Rose. 1982. Evaporation of crude oil at sea. Water Res. 16: 1319-1325.
- Rowland, S.J., P.J.C. Tibbetts and D. Little. 1981. The fate and effects of dispersant-treated compared with untreated crude oil, with particular reference to sheltered intertidal sediments. pp. 283-293. In Proc. 1981 Oil Spill Conf. Amer. Petrol. Inst., Washington, DC.
- Samuels, W.B., R.B. LaBelle and D.E. Amstutz. 1983. Applications of oil spill trajectory models to the Alaskan outer continental shelf. Ocean Manage. 8: 233-250.
- Schmidly, D.J. 1981. Marine mammals of the southeastern United States coast and the Gulf of Mexico. U.S. Fish Wildl. Serv., Office of Biol. Serv., Washington, DC. FWS/OBS-80/41. 163 pp.
- Shane, S.H., R.S. Wells and B. Wursig. 1986. Ecology, behavior and social organization of the bottlenose dolphin: a review. Mar. Mamm. Sci. 2: 34-63.
- Southward, A.J. and E.C. Southward. 1978. Recolonization of rocky shores in Cornwall after use of toxic dispersants to clean up the <u>Torrey Canyon</u> spill. J. Fish. Res. Board Can. 35: 682-706.
- Speers, G.C. and E.V. Whitehead. 1969. Crude petroleum. pp. 638-675. In Organic Geochemistry: Methods and Results. G. Eglinton and M.R.J. Murphy (eds.). Springer-Verlag, Berlin.
- Spies, R.B. 1987. The biological effects of petroleum hydrocarbons in the sea: assessments from the field and microcosms. pp. 411-467. In Long-Term Environmental Effects of Offshore Oil and Gas Development. D.F. Boesch and N.N. Rabalais (eds.). Elsevier Applied Sci., London, U.K.
- Stegeman, J.J. 1981. Polynuclear aromatic hydrocarbons and their metabolism in the marine environment. pp. 1-60. In Polycyclic Hydrocarbons and Cancer, Vol. 3. H.V. Gelboin and P.O.P. Ts'o (eds.).
- Tetra Tech, Inc. 1985. Fate and effects of oil dispersants and chemically dispersed oil in the marine environment. U.S. Dept. of the Interior, Minerals Management Serv., Pacific Region OCS Office, Los Angeles, CA. MMS-85-0048. 114 pp.
- Thomas, P., H.W. Wofford and J.M. Neff. 1981. Biochemical stress responses of striped mullet (<u>Mugil cephalus</u> L.) to fluorene analogs. Aquat. Toxicol. 1: 329-342.
- Thominette, F. and J. Verdu. 1984a. Photo-oxidative behavior of crude oils relative to sea pollution. Part I. Comparative study of various crude oils and model systems. Mar. Chem. 15: 91-104.
- Thominette, F. and J. Verdu. 1984b. Photo-oxidative behavior of crude oils relative to sea pollution. Part II. Photo-induced phase separation. Mar. Chem. 15: 105-115.

- Tokuda, H. 1979. Fundamental studies on the influence of oil pollution upon marine organisms - V. The toxicity of the gelling compounds for petroleum to marine organisms. Bull. Jap. Soc. Sci. Fish. 45: 1385- 1387.
- U.S. Coast Guard. 1987. Polluting incidents in and around U.S.waters. U.S. Dept. of Transport., U.S. Coast Guard, Washington, DC. COMDTINST M16450.2G. 83 pp.
- U.S. Environmental Protection Agency. 1981. Report to Congress on listing of waste oil as a hazardous waste pursuant to Section (8)(2), Public Law 96-463. U.S. EPA, Washington, DC. 86 pp.
- U.S. Environmental Protection Agency. 1985. Development Document for Effluent Limitations Guidelines and Standards for the Offshore Segment of the Oil and Gas Extraction Point Source Category. U.S. EPA, Industrial Tech. Div., Washington, DC. EPA 440/1-85/055. 408 pp.
- Wakeham, S.G., E.A. Canuel and P.H. Doering. 1986. Behavior of aliphatic hydrocarbons in coastal seawater: mesocosm experiments with [14C] octadecane and [14C] decane. Environ. Sci. Technol. 20: 574-580.
- Wakeham, S.G., E.A. Canuel, P.H. Doering, J.E. Hobbie, J.V.K. Helfrich and G.R.G. Lough. 1985. The biogeochemistry of toluene in coastal seawater: radiotracer experiments incontrolled ecosystems. Biogeochem. 1: 307-328.
- Wells, P.G., S. Abernathy and D. Mackay. 1982. Study of oil-water partitioning of a chemical dispersant using an acute bioassay with marine crustaceans. Chemosphere 11: 1071-1086.
- Wheeler, R.B. 1978. The fate of petroleum in the marine environment. Special Report. Exxon Production Research Co., Houston, TX. 32 pp.
- Whittle, K.J., R. Hardy, P.R. Mackie and A.S. MacGill. 1982. A quantitative assessment of the sources and fate of petroleum compounds in the marine environment. Phil. Trans. Roy. Soc. Lond. B. 297: 193-218.
- Wursig, B., E.M. Dorsey, M.A. Fraker, R.S. Payne and W.J. Richardson. 1985. Behavior of bowhead whales, <u>Balaena mysticetus</u>, summering in the Beaufort Sea: a description. Fish. Bull. 83: 357-377.
- Zepp, R.G. and G.L. Baughman. 1978. Prediction of photochemical transformation of pollutants in the aquatic environment. pp. 237-263. In Aquatic Pollutants. Transformation and Biological Effects. O. Hutzinger, L.H. van Lelyveld and B.C.J. Zoeteman (eds.). Pergamon Press, New York, NY.
- Zepp, R.G. and P.F. Schlotzhauer. 1979. Photoreactivity of selected aromatic hydrocarbons in water. pp. 141-156. In Polynuclear Aromatic Hydrocarbons. 3rd Intern. Symp. on Chemistry and Biology Carcinogenesis and Mutagenesis. P.W. Jones and P. Leber (eds.). Ann Arbor Sci., Ann Arbor, MI.

CHAPTER 2

PINNIPEDS AND OIL:

ECOLOGIC PERSPECTIVES

I.A. McLaren

Biology Department Dalhousie University Halifax, Nova Scotia B3H 4J1

Introduction

Pinnipeds share many characteristics with other marine mammals, and indeed with large mammals in general, especially in demographic features (Fowler and Smith 1981), energetics (Lavigne *et al.* 1986) and social behavior (Eisenberg and Kleimán 1983). This allows us to draw on a wide range of empirical and theoretical literature to assess possible responses of pinnipeds to an environmental impact. Their amphibious nature poses special circumstances under which they face such threats.

The familiar fusiform bodies, with limbs modified as flippers, clearly reflect the pinniped's aquatic mode of life. They evolved from advanced terrestrial carnivores, related to the canid-ursid-mustelid line, perhaps from a common ancestral species. They are sufficiently coherent in most characteristics to be treated as a taxon. An excellent general account is by King (1983).

The three major kinds of pinnipeds are the hair seals (family Phocidae), the otariid seals (fur seals and sea lions; family Otariidae) and the walrus (family Odobenidae). Although intermediate in some respects, the walrus more closely resembles otariids in certain important ways. A prominent distinguishing feature of hair seals is their inability to rotate the hindflipper forward - theirs are fixed as "sculling" organs, while those of otariids and walruses can be turned forward in a more-or-less plantigrade position. The otariids and odobenids are accordingly more mobile on rough substrates. Although hair seals can "slither" quite rapidly on sand, smooth rock or, especially, ice, they must "hump" awkwardly over obstructions. When swimming, otariids use their large, propulsive foreflippers, placed close to mid-body, while hair seals and walruses rely on their hindflippers, using the foreflippers for steering. Hair seals, walruses and sea lions have short hair coats, especially sparse in the walrus. They are protected from excessive heat loss in part by a thick layer of blubber. Fur seals, have a particularly dense underfur to trap air for insulation. Both blubber and thick fur are disadvantageous at high temperatures; with a few notable exceptions, pinnipeds are found in temperate-to-polar regions.

There is general agreement that there are 34 living species of pinnipeds. The North American species are grouped in taxonomic categories on Table 2.1, which includes broad information on ranges and population status. Clearly, except for the Guadalupe fur seal, none is either very rare or excessively localized.

Distribution: Geographic distribution is a primary determinant of the probability of encounter with oil. In coastal and shelf waters of North America, pinnipeds occur from Mexico in the Pacific, up along the west coast through the Arctic Ocean and south to New England. At present only relatively small fractions of their ranges are at present leased or proposed for hydrocarbon exploration or production. Yet, because oil transport, even via the Canadian Arctic, is pervasive, I map the distributions of pinnipeds

SPECIES	BREEDING RANGE	POPULATION1	status ²	SOURCES ³
Family Odobenidae			· · · ·	
Walrus	E. Canadian Arctic	25,000?	s?	Davis et al. (1980)
•	Bering-Chukchi Seas	160,000	s?	Estes and Gol'tsev (1984
Family Otariidae				
Steller Sea Lion	California	7,000	-	Mate and Gentry (1979)
	Oregon and Washington	n 3,000	s?	Everitt and Beach (1982)
	British Columbia	5,000 (p)	s?	Obee (1984)
	Gulf of Alaska	103,000	s?	Loughlin et al. (1984)
рания (1997) 1977 — Правил Санария 1977 — Правия 1977 — Правил Санария 1977 — Правил Санария 1977 — Правил Са	Aleutians, Bering Sea	a 93,000	· - .	Loughlin et al. (1984)
California Sea Lion	California	62;000+	+	Le Boeuf et al. (1983) Bonnell and Ford (1987)
	Mexico	83,000	+	Le Boeuf et al. (1983)
Guadalupe Fur Seal Mexico		1,000+	+	Fleischer (1978)
Northern Fur Seal	Pribilof Islands	L,300,000	-	Lander (1981)
·	San Miguel Is., Ca.	7,000 (p)	+	Cooper & Stewart (1982)

Table 2.1: Pinnipeds of North America, with estimates of populations within areas of interest.

Table 2.1 cont'd.

SPECIES	BREEDING RANGE	POPULATION ¹	STATUS	2 SOURCES ³
Family Phocidae			·	
N. Elephant Seal	California, Mexico	60,000+	+	LeBoeuf (1981)
Bearded Seal	E. Canadian Arctic	100,000?	s?	McLaren (1958b)
	W. Canadian Arctic	3,000+	s?	Stirling et al. (1977)
	Bering-Chukchi Seas	300,000?	s?	Burns (1981a)
Hooded Seal	E. Canada,Davis Str.	366,000 (p)	+	Bowen et al. (1987)
Ringed Seal	E. Canadian Arctic 1	,000,000?	s?	McLaren (1958c)
	Beaufort-Chukchi Seas	40,000+	s?	Frost and Lowry (1984) Stirling et al. (1977)
	Bering Sea 1	,250,000?	s?	Lowry and Frost (1981)
Spotted Seal	Bering-Chukchi Seas	225,000?	s?	Lowry and Frost (1981)
Harbor Seal	New England	10,000+	·+	Payne and Schneider (1984)
	E. Canada	13,000+	+?	Boulva and McLaren (1979)
	Labrabor	?	?	Mansfield and Sergeant (1960
	E. Canadian Arctic	100s?	-?	Mansfield (1967)
	S. Alaska	67,0000+	s?	Everitt and Braham (1980) Calkins and Pitcher (1977)

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Table 2.1 cont'd.

SPECIES			BREEDING RANGE	POPULATION ¹	STATUS	2 SOURCES ³
Harbor Seal	cont'd.		Aleutians	?	?	Burns and Gol'tsev (1984)
	•		British Columbia	35,000?	s?	Bigg (1969)
			Washington	8,000+	+?	Washington State Dept. Game (1980)
			Oregon	3,000+	s?	Everitt and Beach (1982)
			California	X,000+	s?	Stewart (1980)
	· •					
Harp Seal		•	Eastern Canada	2,250,000 (p)	+	Roff and Bowen (1983, 1986)
Ribbon Seal			Bering-Chukchi Seas	100,000?	s?	Burns (1971)
Gray Seal	<u>.</u> .		E. Canada	70,000	+	Zwanenburg et al. (198)
· · · · · · · · · · · · · · · · · · ·						

A lack of symbol indicates that the estimate is a mean based on actual counts with attempts at statistical analysis, etc.; + indicates that such mean estimates were believed by the source to be minimal; ? after a number indicates that the estimate is considered by the source to be highly approximate, or is not based on stated sampling procedures or statistical analyses; a ? without number indicates that no estimates have been found, although some information on the population is given in the source publications; (p) indicates that the estimate is based on counts of young, here multiplied by 4.5 as estimates of total populations.

2 The symbol s indicates that the source publications imply that the population is thought to be more or less stationary; + indicates that the population is thought to be increasing, and - that it is decreasing; ? indicates that uncertainty is expressed about status.

3 The source populations are generally the latest original references to population size and status. Secondary sources are used where original estimates are qualified or where the primary sources are relatively inaccessible.

Probably largely non-breeding migrants from Atlantic Canada. 4.

throughout North American waters, with emphasis on areas within the U.S. Offshore Continental Shelf and regions of present or future hydrocarbon transport (Figures 2.1-2.18).

Life Histories

General Patterns: There is a common pattern to the annual cycles and habitat use of pinnipeds; they spend much of their lives at sea, but occupy land or ice to reproduce and often to molt (Table 2.2, Figure 2.19). The timing and duration of haul-out behavior varies considerably. In species like the walrus, birth, mating and molting are spread out in various segments of the population for more than half the year (Figure 2.19). Some species are almost never "hauled out", while others spend much time ashore between feeding forays at all times of year.

A solid substrate is vital for the nurturing of young, except for pups of harbor seals (Lawson and Renouf 1987), and perhaps the walrus (Fay 1982) and the bearded seal (Burns 1978), which are able to enter water soon after birth. Many species are selective in their choice of substrate, and for that reason, entire life histories feature seasonally synchronous reproductive activities at well-established sites. This may involve long-distance homing from feeding grounds to massive breeding colonies, much in the manner of seabirds, and with the same amplified risks of exposure to pollutants. Added to this is the likelihood that some individuals with strong site fidelity, may refuse to abandon an area that has been impacted.

Birth and Care of Young: There is a dichotomy between maternal behavior of phocids, and that of otariids and walruses (Oftedal *et al.* 1987). Attendance of young hair seals may be punctuated by brief departures of females, or continuous during lactation periods that range from 4 days (Bowen *et al.* 1985) to about a month. Walruses attend their young more-or-less continuously for much longer periods, while female sea lions and fur seals undertake lengthy feeding trips between suckling bouts (Gentry and Kooyman 1986).

Growth and Maturation: Growth rates and body sizes of pinnipeds (Table 2.3) are presumably adapted to environmental circumstances, but no obvious biogeographical rules are evident. For example, the huge walrus and the much smaller ringed seal occur together in polar waters; the even larger elephant seal is found in subtropical Mexico, and the small harbor seal ranges without obvious differences in body size from the high Arctic to Baja California. As a rule, females double their length, and therefore increase their core weight about 8-fold, between birth and full size (Table 2.2). The relative weights of fully grown animals, often inaccurately recorded in the literature, can also be approximated from the cubes of lengths given on Table 2.3. Rate of growth and final body size of males are probably driven by the advantages of large size for threat and combat during breeding. This sexual dimorphism is

Distribution of the gray seal in the western North Atlantic (after Mansfield and Beck 1977).



Distribution of the harbor seal in the western North Atlantic (after Mansfield 1967).



Distribution of the harp seal (after Sergeant 1965, Davis et al. 1980).



Distribution of the hooded seal. Many extralimital records, as far as Alaska and Florida, have been omitted (after Davis *et al.* 1980, Reeves and Ling 1981).



Distribution of the ringed seal in northern Canada (after McLaren 1958c, Smith 1975, Davis *et al.* 1980, Finley *et al.* 1983).



Distribution of the bearded seal in the Canadian Arctic (after Mansfield 1967a, Davis *et al.* 1980).



Distribution of the Atlantic walrus (after Davis et al. 1980).



Distribution of the Pacific walrus in the Bering and Chukchi Seas (after Fay 1982, Frost *et al.* 1983).



Distribution of the ribbon seal (after Burns 1981a, Braham et al. 1982, Frost et al. 1983).


Distribution of the ringed seal in the Bering, Beaufort and Chukchi Seas (after Burns 1978).



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Distribution of the bearded seal in the Bering, Chukchi and Beaufort Seas (after Burns 1978, Braham et al. 1982).



Distribution of the spotted seal (after Bigg 1981, Braham et al. 1982, Davis et al. 1984).



Distribution of the northern fur seal (after Fiscus 1978, Braham *et al.* 1982).



Distribution of the harbor seal in the Pacific (after Bigg 1981, Burns and Gol'tsev 1984).



Distribution of the Steller sea lion (after Shusterman 1981).



Distribution of the California sea lion (after Odell 1981, DeMaster et al. 1982, Le Boeuf et al. 1983).

<u>j</u>a,



Distribution of the northern elephant seal (after DeLong 1978).



. .

Distribution of the Guadalupe fur seal (after Fleischer 1978).



SPECIES	BREEDING HAULOUTS	MOLTING HAULOUTS	HAULOUTS AT OTHER TIMES		AQUATIC HABITATS-RANGES ¹
			•		
Walrus	pack ice	pack ice or land	pack ice or land	coastal	<> pelagic (shelf)
Steller Sea Lion	land	not needed?	land	coastal	<> pelagic
California Sea Lion	land	not needed?	land	coastal	
Northern Fur Seal	land	not needed?	land, rarely	coastal	> pelagic
Guadelupe Fur Seal	land	not needed?	land	coastal	
Northern Elephant Seal	land	land	land, uncommonly	coastal	<> pelagic
Bearded Seal	pack ice	pack ice	pack ice, if available	coastal	<> pelagic (shelf)
Hooded Seal	pack ice	pack ice	pack ice, if available	coastal	<> pelagic
Ringed Seal	fast & pack ice	fast & pack ice	pack ice, if available	coastal	
Spotted Seal	paċk ice	pack ice	pack ice and land	pelagic	> coastal
Harbor Seal	land	land	land	coastal	
Harp Seal	pack ice	pack ice	pack ice, if available	coastal	<> pelagic
Ribbon Seal	pack ice	pack ice	pack ice, if available	pelagic	
Gray Seal	pack ice, land	land	land	coastal	<> pelagic

Table 2.2: Broad patterns of habitat use by North American pinnipeds. From various routine accounts.

¹ Migratory movements after reproduction indicated by directional arrows. Localized or short-term exchanges by doubleended arrows.

		J	, F	, M	A	, M	J	$\mathbf{J} = \mathbf{J}$	A	S	0	N	D	
Walrus Alaska	birth weaning mating molt					· · · · ·			2 y	ears ■ ?		i 5 1 1	l l l l	Fay (1982) , Fay et al. (1982)
Steller sea lion Alaska	birth weaning mating molt	?	1 1 1 (1888) ? 1 1) , ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,					1 1 1 1 1 1 1 1 1			F 	f 1 1 1	Calkins & Pitcher (1983), Pitcher & Calkins (1981)
California sea lic California	on birth weaning mating molt	?	1 1 1 1 1 1	, ?	 ? 				1 1 1 1 1			1 1 1 1 1	1 1 1 1 1	Odell (1981)
Northern fur sea Alaska	ll birth weaning mating molt		1 1 1 1 1	 	L 	E 1 1 1 1 5	• • ••••••••••••••••••••••••••••••••••		1 1 1 1 1 1 1 1 1			· · · · ·	\$ † † † †	
Guadalupe fur so Mexico	eal birth		1 6 1	1 1	в., ., . 	1 1 4	 ?	?	1 1 1	l. 	l 1 1	1 1 1	F 1	

Figure 2.19: Life history tables for pinnipeds occurring in North American OCS waters.

		J	, F		M i	Α	M		J	J	A		S	0	N	D	
Northern eleph	ant seal	<u> </u>	1	1	1		1	1	i		1	1	1				
California	birth weaning mating molt	د ر			1 1 1 1	?		1	1 1 1		· ·	1 1 1 1	. I 1 1		• [• [• •		King (1983)
Bearded seal E. Canadian Arctic	birth weaning	· · · · · · · · · · · ·	1 1 1 1	1 1 1	<u>ا</u> ا ا ا				1 1 1	 		1 1 1 1	 		• 1		McLaren (1958b)
Alaska	birth weaning mating molt	 •))) (· · · · · · · · · · · · · · · · · · ·					1 1 1 1 2			 	••• •	 	I I I I I	
Hooded seal	histh		1	I	 		I .	1	 	1	1	<i>‡</i> 1		·····	 e 1	ł	0
E. North Atlantic	weaning mating molt		1 1	i i i			 	1 				1. 1		, , ,	1 1		воwen et al. (1985), Sergeant (1974)
Ringed seal	hirth		1	1	1		1	1	<u>ئەت</u> ا.	<u>a</u>	1	1		1	ì	ł.	Mal
E. Canadian Arctic & Alaska	weaning mating molt		1	i 1 1 1						1] ! !?????	1]]	l 1 1	i 	1 2 1	 	 	мсLaren (1958a), Johnson et al. (1966), Smith (1973)
Spotted seal	hirth		I	1	1		1	I		I	1	ŀ		!	1 1	 	
Bering Sea	weaning mating		1 1 1	1 1 1	1111					i 1	1 1 1 -	1 1 1	-	- t 1	- 1 1	1	• •
	molt		1	1	1		_ <u>1</u>	1000			<u> </u>	1		l	I	1	<u> </u>

Figure 2.19 (cont'd.): Life history tables for pinnipeds occurring in North American OCS waters.

		J	F	, M	, A	M	J	J	Α	S	0	Ν	D	
Harbor seal New Englan	d birth			 	?		i i i	I		 			· · · ·	
Nova Scotia	birth weaning mating molt								?	 	 	 		Boulva & McLaren (1979)
California	birth		 						·		I I	!	·	Bigg (1969b)
Puget Sour	d birth			; <u> </u>		1		1	1 S = 1 = 10 = 5 = 1 1		1	1 f	1	Bigg (1969b)
N. British Columbia & Alaska	birth weaning mating molt				• • • • • • • • • • • • • • • • • • •				1 1 1 2 2 2 2 2 2 2 2 2 2 3 1 2 3 1 2 3 1 3 1		1 1 1 1		} 	Bigg (1969b), Calkins & Pitcher (1983)
Harp seal	hirth		1	1	1	1	1	1	1	1	1	1	1	
E. Canada	weaning mating molt		■ 		l I L L L		1 1 1	1 1 1	1 * 1 1	1 1 1	1 1 1	1 1 1	1 · · · · · · · · · · · · · · · · · · ·	
Ribbon seal	birth		1 1	1			1	1	1	1	1	1	1	
Dering Sea	weaning mating		1	1				1 1	i t	1	l I	1	1 1	
	adult molt subadult molt		1 1	F L	Hi Korana	يون بور يو مريد مريد ويو يو مريد مريد ويو	(1	1 1	1	1	1	1	
Grey seal E. Canada	birth weaning mating				1	1	1 1 1 1 1	1 6 1 1 6	1 1 1	1 1 1	1 1 1 1 1	1 1 . 1 1	• 	Boness & James (1981), W. Stobo (Pers. comm.)
	mating molt	245 g			1 1	1 Christian Side	Tett MONIT	1 1	1 · · ·	1	1 1	! !	1. ¹	(Pers. comm.)

Figure 2.19 (cont'd.): Life history tables for pinnipeds occurring in North American OCS waters.

Table 2.3: Sizes of North American pinnipeds. Lengths measured in a variety of ways in some original sources have been converted to standard lengths and asymptotic (not maximum) lengths determined by fitted growth curves by McLaren (in preparation) using methods given by McLaren and Smith (1986). Those qualified by ca. are unreliable, usually largest rather than asymptotic lengths.

SPECIES	REGION	NEWBORN LENGTH	ASYMPTOTI MALE	IC LENGTH FEMALE	SOURCES
Walrus	Alaska	115	311	256	Fay (1982)
Steller Sea Lion	Alaska	106	331	241	Fiscus (1961), Calkins and Pitcher (1982)
Calif. Sea Lion	California, Mexico	73	ca.225	ca.180	Gilmartin et al. (1976), Lluch B. (1969b)
N. Fur Seal	E. North Pacific	63	190	129	McLaren and Smith (1985)
N. Elephant Seal	California	ca.150	ca.450	ca.360	Le Boeuf (1979)
Bearded Seal	Bering-Chukchi Seas	131	223	223	Burns and Frost (1979)
Hooded Seal	Greenland-E. Canada	93	197	229	Wiig (1985), Beloborodov and Potelev (1966)
Ringed Seal	Bering Sea	63	139	132	Fedoseev (1965)
	Chukchi Sea	61	121	117	Fedoseev (1965), Johnson et al. (1966)
	Beaufort Sea	71	127	131	Smith (1987)
	S. Baffin Island	68	121	122	McLaren (1958a)

Table 2.3 cont'd.

SPECIES	REGION	NEWBORN LENGTH	ASYMPTOTIC MALE	LENGTH FEMALE	SOURCES
Spotted Seal	Bering-Okhotsk Seas	81	170	160	Tikhomirov (1968)
Harbor Seal	E. Canada	78	161	150	Boulva and McLaren (1979)
	British Columbia	82	170	156	Bigg (1969)
	S. Alaska	82	162	150	Pitcher (1977), Pitcher and Calkins (1983)
Harp Seal	E. Canada	85	165	165	Innes et al.(1981), Stewart and Lavigne (1980)
Ribbon Seal	Bering-Okhotsk Seas	81	156	156	Shustov and Yablokov (1967), Fedoseev (1973)
Gray Seal	E. Canada	108	202	228	Mansfield (1978)
• •				•	

pronounced among otariids and elephant seals, in which males may weigh 2.5-5 times as much as females, and less so in the gray seal, in which full-grown bulls weigh about 1.5 times as much. Males of highly polygynous species may be potent when quite young (Spotte and Schneider 1982), but have a sharp growth-spurt at puberty and mate effectively only after reaching much greater body size. Males of "monogamous" species are generally the same size as or even smaller than females, even those which defend underwater or under-ice breeding territories. The male hooded seal seems anomalous, weighing some 1.6 times as much as a female. Though it defends individual females on pack ice, it is not strictly monogamous; aggressive males may be capable of mating with several females sequentially.

Size differences among individuals and species could influence their response to an environmental impact. Large individuals with favorable surface-to-volume ratios might be more resilient. However, when large size is driven by sexual selection to the detriment of other components of fitness, some advantage might be lost. This is perhaps reflected in the reduced lifespans of large, polygynous species.

Diet and Feeding Tactics: Pinnipeds generally have broad opportunistic diets. The majority are piscivorous, but many also take feed on of cephalopods, planktonic crustaceans, and epibenthic organisms. Only the walrus and to a lesser extent the bearded seal feed primarily on burrowing bottom animals. Some North American pinnipeds consume seals or birds from time to time, though none is as voracious a top carnivore as the Antarctic leopard seal. Lowry and Fay (1984) document the remains of seals, mostly pups, in 8 of 645 stomachs of walruses from the Bering Strait and western Chukchi Sea. Steller sea lions sometimes prey on harbor seals (Pitcher and Fay 1982) and, perhaps regularly, on northern fur seal pups (Gentry and Johnson 1981). The literature on apparently casual predation on seabirds by pinnipeds is summarized by Lucas and McLaren (MS submitted).

In conclusion, significant amounts of hydrocarbons would probably not be consumed by pinnipeds in their food, since none of the prey is likely to accumulate residues. Exceptions are bearded seals and walruses foraging in heavily contaminated benthos and individuals of a number of species that might specialize in eating seals or birds (Lucas and McLaren, manuscript submitted), thereby consuming raw oil entrained in pelage or plumage. The probability of the latter would be enhanced if contamination rendered the prey more vulnerable to capture, as Lucas and McLaren observed with gray seals.

Habitat Use

Major Patterns of Distribution: The marine ranges of pinnipeds during the nonbreeding season can be discussed in four somewhat overlapping categories: coastal versus pelagic, and ice-using (pagophilic) versus ice-shunning (pagophobic). Each category presents specific circumstances under which a species would encounter oil.

Some coastal species migrate regularly, others disperse somewhat offshore or alongshore during the non-breeding season, while still others remain in the vicinity of breeding sites. Most species that stay inshore through the year are generalized, even opportunistic, predators, and their distributions are probably more influenced by availability of suitable hauling-out sites than On a local scale, Boulva and McLaren (1979) found a by food requirements. strong correlation between abundance of harbor seals in Nova Scotia and the number of islets along the coastline. On a regional scale, the abundance and species richness of pinnpeds around such places as the southern California islands have much to do with their suitability for safe hauling out. Of course coastlines with many islands, islets and bars also pose greater risks of oil spills through marine accidents. Furthermore, the enclosed topographies of bays, estuaries and passages used by coastal pinnipeds can lead to oil concentrations.

Among coexisting coastal species, there are some indications of niche differences. Thus, on the West Coast, the two major coastal otariids are generalized, nocturnal feeders, but the Steller sea lion ranges further offshore than the California sea lion (Fiscus and Baines 1966), and the latter is seen increasingly in estuaries (Bayer 1981). The harbor seal is also a generalist in diet, seldom ranges seaward, and is not notably nocturnal. Elephant seals evidently feed more frequently in deeper water on larger and more bottom-dwelling fishes than do the other coexisting pinnipeds (McGinnis and Schusterman 1981). On the East Coast, the gray and harbor seals are piscivores, but the former ranges over the Scotian Shelf and central Gulf of St. Lawrence, while the latter is rarely seen far out at sea. The general trend among these examples is that the larger species range farther offshore.

Pelagic species by definition spend the non-breeding seasons in offshore waters where hauling out is possible only on ice. The distribution and movements of such species are more likely to be controlled by availability of food, in turn influenced by hydrography and submarine topography. For example, the northern fur seal is concentrated in winter along the outer continental shelf from British Columbia to California, where it feeds on The ribbon seal evidently schooling fishes and squids (Kajimura 1984). summers largely near the edge of the Bering Sea shelf (Burns 1981a). These distributions may be related to high productivity, and are generally remote from oil exploration activity or concentrated oil-shipment routes. Т h е distributions of the two benthic feeders, walrus and bearded seal, are constrained within the continental shelves, but can range quite far offshore, especially in the Bering Sea.

Species that produce young on ice are accordingly limited in distribution, in spite of occasional anomalies such as the parturition of a hooded seal on land (Richardson 1975). Among North American species (Tables 2.2 and 2.4), only the ringed seal breeds on fast ice; it also uses pack ice (Finley *et al.* 1983). Post-reproductive hauling out by ice-using species is also variable (Tables 2.2 and 2.4). Some, like the hooded, bearded (with some exceptions (Burns 1981b)), ringed, and ribbon seals, haul out only on ice. They may follow and use retreating ice over long distances. Others reside in areas where the ice disappears seasonally. This independence of ice is

Table 2.4:Social organization of North American pinnipeds. These summaries are categorical,from a number of general sources and do not include many qualifications and exceptions.

SPECIES	BREEDING STRUCTURES	NON-BREEDING HAUL-OUTS	BEHAVIOR AT SEA
Walrus	Extensive mobile aquatic leks of displaying adult males attracting estrous females from pack ice.	On land, ice. Segregation of females, adult and sub-adult males.	Gregarious, groupings as in non-breeding haulouts.
Steller sea lion	Stable male territories on land before peak of arrival of gregar- ious females within them.	Often daily on land, gregar- ious, sexes and ages mixed.	Often gregarious, possible cooperative foraging.
California sea lion	Labile or stable male territories on land after peak arrival of gregarious females.	Often daily on land, gregar- ious, sexes and ages mixed.	Often gregarious, possible cooperative feeding.
Northern fur seal	Stable male territories on land before arrival of gregarious females. Some restraint by males.	Rare (pathological?)	Non-gregarious, casual associations.
Guadelupe fur seal	Females in male territories on land.	Gregarious on land. Daily(?)	(?)

Table 2.4 cont'd.

SPECIES	BREEDING STRUCTURES	NON-BREEDING HAUL-OUTS	BEHAVIOR AT SEA
Bearded seal	Solitary females and pups on ice. Females later attracted by "singing" males in under-ice territories(?) or leks(?).	Non-gregarious and opportun- istic on ice.	Non-gregarious, casual associations.
Hooded seal	Scattered in extensive "patches" on pack ice.	Large "molting patches" on female guarded by sequentially polygymous male.	Non-gregarious, casual associations?
Ringed seal	Scattered females with pupping lairs in fast (sometimes pack) ice. Mating within under-ice male territories covering one or more lairs (?).	Non-gregarious during molt and casually later, on ice.	Non-gregarious, casual associations.
Spotted seal	Scattered females pup on pack ice. Female guarded by male on mating in water. Sequentially polygymous(?).	Non-gregarious (?) molt on ice? Casual groups on land.	Non-gregarious, casual associations.
Harbor seal	Scattered females pup on land, mating in underwater male territories (?) off shorelines.	Solitary or "vigilence groups" on rocks, etc.	Non-gregarious, casual associations.

Table 2.4 cont'd.

SPECIES	BREEDING STRUCTURES	NON-BREEDING HAUL-OUTS	BEHAVIOR AT SEA
<u></u>		· · · · · · · · · · · · · · · · · · ·	
Harp seal	Females with pups, scattered or in large "patches" on pack ice, mating with males in under-ice territories(?).	Large molting assemblages near breeding ice. Casual on ice later, usually in groups.	Gregarious, herd behavior in migration.
Ribbon seal	Scattered females with pups on pack ice, mating with males in under-ice territories(2)	Non-gregarious, casually in groups on ice during molt,	Non-gregarious, casual associations.

pronounced in the ribbon seal (Burns 1981a). The walrus and the spotted seal, although dependent on ice for reproduction, may haul out on land during the ice-free season.

Habitat Features: Physical characteristics of a habitat could influence the way in which a pinniped contacts oil. Habitat features will be examined in the context of seven major categories: sandy shores, rocky shores, fast ice, pack ice, shore leads, polynyas and ocean fronts.

Oil on a <u>sandy shore</u> is readily rubbed into the pelage of a pinniped. Balancing that, I have observed on Sable Island, Nova Scotia, that clean sand can cleanse oil from pelage by adsorbance and abrasion. On open coasts, sand can also "process" beached oil rather rapidly by adsorption and dispersion, and often by burying it. Temporary burial may spread out the period of potential exposure of pinnipeds, but presumably lessens its intensity.

While completely smooth <u>rocky shores</u> might receive only a thin coating of oil during a major spill, depressions and tide pools could accumulate nearsmothering amounts. On the other hand, crevices and finer scale relief on such shores, may sequester oil away from contact by pinnipeds. In less dynamic environments, oil on rocky shores may long persist to form a hard, tarry coating.

Fast ice rarely extends beyond headlands; its distribution in Arctic waters in North America has been mapped by McLaren (1958c), Smith and Rigby (1981), Finley et al. (1983) and Frost et al. (1985). The way in which oil is incorporated into fast ice and subsequently appears in melt-pools on the surface has been outlined by Neff (Chapter 1). Some pinnipeds, notably the ringed seal, depend on fast ice at the mouths of bays and inlets (Kingsley et al. 1985) for a breeding habitat; other northern species such as the bearded seal and walrus only occasionally maintain breathing holes in fast ice (Stirling et al. 1981). There has been some concern that oil may concentrate in these breathing holes (Johnson 1983, Engelhardt 1985). Yet unless the oil were released directly under the ice or swept under by strong currents, it would not likely spread beyond the barrier presented by the edge of the ice. Instead, oil would accumulate in leads and tide cracks which penetrate into frozen bays and inlets.

<u>Pack ice</u> forms annually to fill virtually all seasonally open water from the Bering Sea, across the Canadian Arctic, to the coasts of Atlantic Canada. Old or multi-year ice, which is often very thick, predominates in the Arctic Ocean, drifting into the Bering Sea and Canadian Arctic Archipelago. The southern limits of pack ice in the Bering Sea are sketched on Figures 2.9, 2.11 and 2.12. In eastern Canada, heavy drift ice of the Labrador current is augmented further south by the outpouring of the Gulf of St. Lawrence, from which extensive ice sometimes (as in spring 1987) reaches Sable Island and Halifax, Nova Scotia. Ice from the Bay of Fundy region rarely intrudes significantly on pinniped habitat. More than half the pinniped species in North America reproduce on pack ice and use it in other ways (Tables 2.2 and 2.4). Pack ice concentrates oil between the floes (Ayers *et al.* 1974), where it could reach smothering levels. This might be especially so in thick, old pack ice. Wind, currents and proximity to land will also influence the distribution and concentration of oil within the pack, and also at the floe edge, where pinnipeds often reside (McLaren 1958a). In the Bering Sea, spotted and ribbon seals are concentrated along the southern ice front during the winter (Burns 1978). During migration and summer, young harp seals may actively seek pack ice (Sergeant 1976) and thus frequently occur along ice edges, perhaps to exploit prey (Wells and Percy 1985).

Two other ice configurations influence the distribution and activities of pinnipeds - <u>shore leads</u> and <u>polynyas</u>. Common to both are enhanced productivity because of ice-edge effects (Dunbar 1981) and the propensity to accumulate or confine oil. Also, both settings are likely to be used as lanes for shipping oil.

Depending on tides, winds and season, <u>shore leads</u> may open to varying extents at the boundary between fast ice and pack ice. Some are sufficiently recurrent and persistent in winter to qualify as polynyas. Many shore leads in the Canadian Arctic are described and discussed by Smith and Rigby (1981) and Stirling *et al.* (1981). The great spring shore lead off northwest Alaska is depicted by Davis and Thomson (1984). The distribution of polynyas in the Canadian Arctic is mapped and analyzed by Smith and Rigby (1981) and Stirling (1981) and their pattern along the Alaskan coast is depicted in Shapiro and Burns (1975).

Whenever and wherever there is any loosening of the pack ice, pinnipeds literally take advantage of the breathing space. Polynyas have important wintering concentrations of pinnipeds, especially bearded seals, immature ringed seals and walruses (Stirling *et al.* 1981) and in the eastern Canadian Arctic, harbor seals (Mansfield 1967b). The most important shore leads may be recurrent ones that facilitate traditional migration by pinnipeds into summering areas. The open-water lead off northwest Alaska is a major migration corridor for walruses and ringed, spotted and bearded seals entering the Chukchi sea in spring (Davis and Thomson 1984). Shore leads in Hudson Strait may serve the same function for walruses and harp seals (Stirling *et al.* 1981).

Oceanic fronts occur at the boundary between stable and vertically mixed water masses (Le Fèvre 1986). It has long been recognized that upwelling water can bring nutrients to phytoplankton in surface waters. It is now understood more generally that when waters are too stable, nutrients become exhausted, whereas with too much vertical mixing, phytoplankton are denied sufficient residence time in sunlit waters. Thus ideal circumstances for high production develop seasonally when mixed waters begin to stabilize, and also in persistent fronts. These may occur at the margins of major oceanic currents, where river plumes contact coastal waters, where currents round headlands, at the edges of underwater banks and most notably along margins of continental shelves. There is some dispute about the extent to which these systems physically concentrate zooplankton as opposed to enhancing its phytoplankton food (Le Fèvre 1986). However, there is no doubt that both zooplankton and the pelagic (and larval benthic) fishes that feed on it are abundant in such frontal zones.

Among North American pinnipeds, only the northern fur seal seems closely tied to such large-scale frontal production systems. It is most common during winter along the edges of the continental shelf from British Columbia to California (Fiscus 1978), where prevailing westerlies cause upwelling of deep water. The ribbon seal may also take advantage of upwelling along the southern edge of the Bering Sea shelf in summer (Burns 1981a). It is possible that harp and hooded seals follow the Labrador shelf edge during their seasonal migrations, but the former at least is taken by inshore hunters on the southward migration (Sergeant 1965). They have also been seen in schools along the edge of ice off Labrador, where they may take advantage of upwelling.

On an ephemeral or local scale, upwelling and downwelling may occur in estuaries, with currents or tidal mixing, off points and along small reefs and ridges, and everywhere in response to the Langmuir circulation of winds. At sea, areas of upwelling (marked by slicks) and downwelling (marked by flotsam) are often frequented by seabirds and mammals (Buckley *et al.* 1979). In upwellings some pinnipeds (e.g. ringed and harp seals) may feed directly on macrozooplankton (euphausiids, hyperiid amphipods) brought to the surface. Others may use the fishes that feed on such macrozooplankton or that "shelter" under seaweed and flotsam which gather in downwelling zones. Local upwelling would act to disperse surface oil, but there may be some concentration in the downwelling zones. Fresh oil and old tar balls are known to accumulate in such flotsam (Le Fèvre 1986), posing risk of ingestion by foraging pinnipeds.

Movements and Migration Patterns: Almost all pinnipeds show regular movements to and from traditional areas or sites (Table 2.2, Figures 2.1-2.19). In fact, some return repeatedly to precise locations (Pitcher and Calkins 1983). Even relatively sedentary species that haul out on land make daily forays to feed at sea. Others make coherent, far-flung migrations. All such movements complicate assessment of the probabilities that they may encounter oil.

Harbor seals (Boulva and McLaren 1979) and females and young of two westcoast sea lion species (Fiscus and Baines 1966) may have regular, once-a-day foraging schedules off their hauling out sites. Others that undertake more extensive seasonal movements may show such daily forays at times of the year. Lactating otariid females make periodic forays to feeding grounds lasting some days (Gentry and Kooyman 1986).

Some species or populations of pinnipeds (Table 2.2) show seasonal movements, but not large-scale migrations, from their coastal breeding or haul-out areas to feeding grounds further offshore. A recent study of the California sea lion in the Southern California Bight (Bonnell and Ford 1987) found about 18% of the population at sea around the breeding islands during the breeding season, compared with about 54% a month later. Most gray seals

in eastern Canada are at sea from summer through early winter (Mansfield and Beck 1977). Adult ringed seals in the eastern Canadian Arctic inhabit fast ice in winter, and move offshore in summer. Immatures spend the winter offshore, and move into the ice to molt in spring (McLaren 1958a). Animals offshore are highly dispersed and large numbers are not likely to contact a spill at sea.

Some populations that disperse offshore seasonally have considerable latitudinal movement that qualifies as migration. Harbor seals seem to move from Maritime Canada to southern New England during winter (Rosenfeld and George 1985). On the west coast, there are major northward movements of northern elephant seals (Condit and LeBoeuf 1981) and male California and Steller sea lions (Mate 1975) after the breeding seasons. Alaskan populations of Steller sea lions may move south in winter (Schusterman 1981).

Some populations of Arctic pinnipeds show seasonal migrations related to ice conditions. During autumn many immature ringed seals appear to vacate the western Canadian Arctic and spend the winter in less icebound parts of the northern Bering Sea (Burns and Eley 1977, Smith 1987). Bering Sea stocks of walruses and bearded seals move to the Chukchi Sea in summer (Figures 2.8 and 2.11). While migrating, these populations traverse a variety of environments where oil might be encountered. Except for the large herds of walrus that may move synchronously through areas subject to oil exploration (Figure 2.8), these migrations do not appear to concentrate large fractions of the total population of any particular species in localized areas. In general, such populations appear to be less at risk than are sedentary ones, given equal probabilities of an oil spill in any given area.

Large-scale, long-distance, synchronous migrations are undertaken by three north American pinnipeds. Northern fur seals move through oil-exploration areas in the southeastern Bering Sea (Figure 2.13); harp and hooded seals migrate through potential oil-production areas off Labrador (Figures 2.3-2.4). The harp seal might be particularly vulnerable because it migrates in large groups (Sergeant 1965).

Habitat Aspects of Reproduction: Characteristics of the habitat where pinnipeds mate, and produce and nurture their young may lead them to encounter oil. Pinnipeds are born on solid substrates with ready access to the sea; it is precisely at such boundaries where oil is likely to be spilled and to accumulate. Species or populations that reproduce on offshore islands (e.g. northern fur seals) or pack ice (spotted and ribbon seals) might be less subject to casual encounters with oil than those favoring inshore sheltered localities (harbor and ringed seals). Young pinnipeds, such as gray seals, born and nurtured away from the water's edge (Boness and James 1979) are less likely to encounter oil than harbor seals produced on small, sometimes tidally covered bars (Lawson and Renouf 1987). Young harp seals born near the leading margins of the ice pack (Sergeant 1976) might more likely encounter oil than would young hooded seals in the thicker, older floes (Bowen *et al.* 1987b).

Population Size and Habitat Quality: The rate of recovery of a population from a catastrophic event might depend on how close the population was to the environmental carrying capacity at the time of the event. Other than the effects of crowding in colonies of highly polygynous species, the densitydependent mechanisms involved in the regulation of pinniped populations are poorly understood (McLaren and Smith 1985). There are hints of mechanisms involving resource use in a few cases. Evidence suggests that the stable or declining population of Pacific walruses consumes approximately the net productivity of its preferred benthic prey from the Bering-Chukchi shelf (Fay 1982). The declines in recent years of the Steller sea lion in California (Cooper and Stewart 1982) and Alaska (Merrick et al. 1987) and the northern fur seal on the Pribilofs (Fowler 1982) are not understood, but can be taken as prima faciae evidence for deterioration of their habitats, whether due to natural changes in their food base, interactions with fisheries, or competition from other pinnipeds.

From the apparently higher frequency of pathological conditions among pinnipeds from the Bering Sea compared with those from the Gulf of Alaska, Fay et al. (1979) conclude "that life in the Gulf may be less precarious than in the pack ice, or that populations in the Gulf are in better equilibrium with their environment than are those in the Bering Sea." The Beaufort Sea may be an even more marginal environment, judging from large-scale, long-term secular variations in reproductive rate and body condition in ringed seals, the only pinniped that lives there in numbers all year. As noted by Geraci and Smith (1976) during "poorer" years "the effects of an environmental disturbance (on ringed seals) would presumably be more widespread, affecting entire year classes and weakened segments within the population."

Social Organization and Behavior

Among pinnipeds, social organization is not so elaborate as it is in cetaceans, and pinniped groups are often site-dependent and ephemeral. Nevertheless, bonds among individual pinnipeds may lead to multiple exposures to oil.

Although pinnipeds do exhibit elements of courtship display (even group solicitations by females, Heath 1985) and pair bonding, pre-copulation gatherings of land-breeding polygynous species seem to develop more through site fidelity and cohesiveness among females (e.g. California sea lion, Odell 1981; northern elephant seal, Schusterman 1981) than through sexual attachment to individual males. Females would therefore be unlikely to remain in a hazardous situation because of pair-bonding.

Bonding between mothers and their pups is vital when females must discriminate among masses of young (Bartholomew 1959) or when followingbehavior is important (Lawson and Renouf 1987). Even the mother ringed seal, which might only need to recognize a fixed birth site, presumably has the usual mammalian bonding with its dependent pup. The bond is broken during weaning by departure of the female from the breeding site (most species) or

by increasing indifference to the pup (Lawson and Renouf 1987). It is possible that an oiled pup would be unrecognizable to its mother and prematurely abandoned. A more serious problem might arise if females, as the demographically most important segment of the population, were loathe to abandon pups when threatened by major oil pollution.

Sea lions sometimes nurse older individuals along with the current year's pup (Odell 1981, Schusterman 1981). Francis and Heath (1985) determined that most of these older sucklings are female, which might compound the seriousness of an oil spill at a breeding colony.

Non-reproductive Groups: Many pinniped species are gregarious at times other than during breeding. Time spent on ice or ashore saves energy and permits restorative sleep. Even species that form unstructured groups may gain some advantage in surveillance (Krieber and Barrette 1984). Other species have socially structured groups that benefit individuals. For example, Harestad and Fisher (1975) found that, in a non-pupping colony, adult male Steller sea lions maintained tranquil areas within which females were free from harassment by subadult males. Disruption of such arrangements could increase energy loss and stress individuals.

Normally "solitary" species such as bearded, ringed and harbor seals form non-interactive groups at sea, usually in response to localized resources. Without cohesive ties, they might disperse from a spill. Less predictable would be the reaction of harp seals (Sergeant 1971) and sea lions (Fiscus and Baines 1966) which dive and swim synchronously, in a display of group cohesion.

Walruses are among the most gregarious of mammals. They occur as small groups at sea, and haul out in groups of up to several thousand. After suckling for two years, weaned calves form unisexual herds, particularly in the Pacific walrus (Fay 1982). Groups of young females determine the reproductive potential of the population, and hence an effect on them would far outweigh an equivalent exposure on a herd of males.

Reproductive Behavior: In some species breeding males posture and fight tenaciously to maintain status or territory. The behavior persists over long periods of time at the expense of feeding, the minimum cost of such reproductive effort is debilitation. Moreover, fighting among highly polygynous species that breed on land (LeBoeuf 1974) and in the water (Boulva and McLaren 1979) can result in severe wounding. These elements combine to heighten the level of stress, and thereby affect an animal's reaction to an environmental disturbance.

The period devoted to nurturing young varies greatly among species (Figure 2.19), from as little as 4 days in the hooded seal (Bowen *et al.* 1985) to a year or more in the walrus and sea lion. Females with shorter periods
are less restrained to the breeding habitats, and because of efficient transfer of nutrients are more robust at the time of weaning (Bowen *et al.* 1987b). Such females should be more resilient to an oil-pollution event.

Attendance pattern of nursing females will determine the frequency of exposure to oil on the water or at the ice edge. Some female phocids, for example the northern elephant seal (LeBoeuf 1981) and some land-breeding gray seals (Boness and James 1979), attend their young throughout lactation, thus lessening the risk of repeated exposure. Otariid females, in contrast, make extensive foraging trips to sea during lactation (Gentry and Kooyman 1986). Harbor seals and most ice-breeding species may return to the water several times a day between suckling bouts (Oftedal *et al.* 1987). The opportunity for repeated contact would be greater in these animals.

Circumstances surrounding weaning affect survivorship of pups. Sea lions (Odell 1981, Pitcher and Calkins 1981) and walruses (Fay 1982) continue to suckle their young after they have learned to eat other foods. Phocids and the northern fur seal are left to develop their own skills in foraging and consequently have higher mortality rates during this critcal period. Oil may compound the difficulty in establishing successful foraging patterns if it results in exclusion from favorable areas, impairs mobility or sensory capability of the pups, or redistributes suitable prey.

Grooming: Pinnipeds scratch themselves vigorously with their flippers, but do not seem to mouth or lick themselves. Although mammalian mothers routinely lick and mouth-groom their young, this seems to be almost unrecorded among pinnipeds (one example is the California sea lion on the Galapagos, Eibl-Eisenfeldt 1955). Steller sea lions may lift and carry their pups by mouth (Schusterman 1981). Play among young pinnipeds may involve the mouthing of beach debris (Schusterman 1981). None of these behaviors is likely to contribute to ingestion of significant quantities of oil.

Commensalism with Humans: Like other animals, pinnipeds can become tame when unmolested. Thus harbor seals are reappearing in numbers in harbors in eastern Canada and the west coast. Shaughnessy and Chapman (1984) document the dependence of South African fur seals on food around Cape Town docks, and their increased vulnerability to harbor pollutants.

Demography

A significant effect of oil pollution should be measurable as a population change. Therefore it is important to consider the demography of pinnipeds as a guide to understanding or even predicting such changes. Life-history Parameters: Pinnipeds have many attributes of K-selected species (Eberhart 1977). That is, they are late-maturing, slow-reproducing, longlived animals that are thought to exist in numbers close to the limits set by resources. Females do not mature until at least 3 years old, produce at most one young per year (twins rarely), and live well over 20 years (Table 2.5). There are exceptions. In some species, population limits may be set by mortality of young in dense breeding aggregations as a byproduct of sexual selection. This in turn can select for accelerated maturation rate and reduced length of adult life (McLaren 1967, Reiter 1984).

There are important differences among species in age of maturity, agespecific fertility rate, and lifespan. However, there are no simple allometric or biogeographic rules relating these parameters to body size (Tables 2.3 and 2.5). Thus, at one extreme females of the northern elephant seal, the largest and one of the more polygynous species, may produce first offspring when less than 4 years old, and annually thereafter for a rather limited lifespan. Northern fur seals, equally polygynous, live longer and do not mature as quickly, perhaps because of the more elaborate requirements of mothering. Sea lions, also highly polygynous but with lengthier periods of parental investment by females (Pitcher and Calkins 1981), mature later still and live even longer. McLaren (1967) thought that the late maturation and long lives of such "solitary" species as ringed and harbor seals were related to their need for considerable learning about specific environments and circumstances to ensure successful breeding. Mass ice-breeders such as harp and ribbon seals, with less need for such knowledge, mature earlier and have shorter lives. The walrus, and to a lesser extent the bearded seal, are interestingly anomalous: females are very late maturing, yet not very long-lived (Table 2.3). There are records of much older male walruses (34 to 38 years in Krylov 1970, 30+ years in Mansfield 1958). Is it possible that exploitation of benthic resources or life on the arctic pack ice are particularly stressful, especially to females? In this context, it is noteworthy that the walrus has a unique biennial cycle of reproduction, driven by exceptionally long devotion to the young (Fay 1982). This, along with late maturity, would make the walrus demographically the most vulnerable of all pinnipeds to population catastrophes.

The Possibility of Local Extinction: The large populations (Table 2.1) and wide geographic distributions (Figures 2.1 to 2.18) of most pinnipeds insulate them from extinction by any conceivable effect of oil pollution. However, local populations may be less secure. There is a developing empirical and theoretical literature on the subject of extinction, particularly in the context of rare, localized populations or species and the design of biological reserves.

Life-history parameters of pinniped species would determine their potential responses to negative anthropogenic influences. In general, adults of such long-lived animals are "designed" to be resilient. Furthermore, the loss of a year's reproductive output may be of little consequence in a population with many year classes and overlapping generations. However, <u>sustained</u> decreases in survival or fertility rates can lead to inexorable population declines. In late maturing, low-fertility species, decreases in

SPECIES	GEOGRAPHICAL REGION	MEAN AGE FIRST YOUNG ¹	ADULT PREG. RATE ²	MAXIMUM AGE	SOURCES
Walrus	Bering-Chukchi Seas	7.2-7.8	0.44	28	Fay (1982), Krylov 1967, 1970)
	E. Candian Arctic	8.5	0.34	20+	Mansfield (1958)
Steller Sea Lion	Gulf of Alaska	5.9	0.87	30	Pitcher and Calkins (1983)
Calif. Sea Lion	California, Mexico	ca.8	ca.1.0	31	Lluch B. (1969), Maser et al. (1981)
N. Fur Seal	E. North Pacific	4.8	0.85	26	Lander (1980), York (1980)
N. Elephant Seal	California	2.7	ca.1.0	14+	LeBoeuf an Reiter (198)
Bearded Seal	Bering-Chukchi Seas	6.4	0.88	23	Burns and Frost (1979)
Hooded Seal	Newfoundland	3.8	0.95	30+	Oritsland (1975), Oristland and
	¢				Benjaminsen (1975), Kapel (1981)
Ringed Seal	E. Canadian Arctic	7.9-8.1	0.85-0.93	43	McLaren (1958), Smith (1973)
`	Beaufort Sea	7.7	0.88	36+	Smith (1987)
	Bering-Chukchi Seas	7.9-8.3	0.93	29	Fedoseev (1965), Burns and
	•				Eley (1977)

Table 2.5: Reproductive parameters of females of North American pinnipeds.

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SPECIES	GEOGRAPHICAL REGION	MEAN AGE FIRST YOUNG ¹	ADULT PREG. RATE ²	MAXIMUM AGE	SOURCES
Spotted Seal	Bering-Okhotsk Seas	5.1+	ca.1.0	35	Tikhomirov (1966, 1968)
Harbor Seal	Atlantic Canada	5.2	0.95	32	Boulva and McLaren (1979)
	Alaska	5.4-6.2	ca.1.0	36	Calkins (1977), Pitcher and
					Calkins (1979)
Harp Seal	Atlantic Canada	4.4	0.94	30+	Bowen et al. (1981), Nazarenko
					and Timoshenko (1974)
Ribbon Seal	Bering Sea	3.5-4.0	0.95	26	Burns (19), Shustov (1965),
					Tikhomirov (1966)
Gray Seal	Atlantic Canada	5.0	0.86	44	Mansfield (1977), Mansfield and
					Beck (1977)

¹ where two values are given, they come from the two sources; a + sign indicates that the the estimate is based on ovulations rather than pregnancies.

² ca. 1.0 implies that most females are give birth annually, but that success rates have not been established.

 3 a + indicates that the source indicates that older animals were suspected.

adult survival rate can be more dangerous than a comparable decrease in fertility rate, or equivalent decrease in survival rate of young. This is exemplified using the gray seal as a model species (Figure 2.20). In a population well below equilibrium, a doubling of mortality will thwart population increase. The same result can only be achieved by reducing fertility rates to about 25% of normal. However, suspected pollution-related population declines of harbor seals (Reijnders 1986), and ringed and gray seals (Bergman and Olsson 1986) in Europe have implicated impaired reproduction rather than increased mortality.

A different kind of threat comes from the remote chance of catastrophic accident with direct, acute mortalities. This could be particularly serious in small, localized populations, already close to the level where "chance" might settle their fate. The role of chance in extinction has long attracted theoretical enquiry. Earlier models assumed that population birth and death rates were on average equal, but with variation among individuals. Under these conditions, extinction is inevitable, although large populations with reasonably small variances may persist for a long time. Recently it has become clear that it is not the "built in" variance among individuals, but variance in environmental conditions that leads rapidly to dangerously low populations.

Though pinnipeds do show attributes of K-selected species, McLaren and Smith (1985) argued that pinnipeds of extreme environments in particular may be considerably influenced by density-independent environmental factors. Thus the ringed seal in the Canadian Beaufort Sea showed a substantial drop in numbers, body condition, and reproductive success during the years 1972-1976 (Smith 1987). Coincident long-term variations in ringed seal densities have been noted along the Alaskan coast (Frost *et al.* 1985). Though not fully understood, causes of such population changes may be caused by variation in the marine "climate" and attendant changes in ice cover and food supply.

Clearly, pollution can contribute to the variance of environments in which pinnipeds live. According to Johnson (1983), the accumulation of small environmental perturbations in the Arctic is capable of generating "noise" in energy flow paths, increasing variability and possibly eliminating important stocks, among which he singles out the walrus as particularly vulnerable. His rather abstract view resists quantitative treatment at present. However. there have been some recent advances relating environmental variance to the probability of local extinctions. Strebel (1985) demonstrated formally that there is a greater probability of extinction when there is resonance between species generation length and the average interval between environmental (or resource) fluctuations. In other words, there is great resilience of longlived species like pinnipeds to normal seasonal or other short-term fluctuations. However, long-term, lower-amplitude fluctuations, whether natural or anthropogenic, might be more "attuned" to the life-cycle characteristics of pinnipeds. Goodman (1987a) has shown that, with purely individual variation, expected persistence time of a population increases as the power of the assumed population "ceiling", whereas with purely environmental variation the time increases somewhat less than linearly with the ceiling. This is a formal



Figure 2.20

Theoretical population response to changes in mortality and fertility rates. The gray seal has been used as the model species, a population well below equilibrium increasing at a rate of 8% per year. If mortality rate doubles or fertility rate decreases by 75%, there will be no net increase in population size. analysis of the commonsense view that, if some environmental event is bad for the whole population, large numbers will not be a protection.

Another determinant of persistence of a population is the extent of immigration, which obviously can counteract local tendencies toward extinction. Goodman (1987b) demonstrates theoretically, as might be expected, that scattered subpopulations, each experiencing its own environmental variation, with sufficiently high interchanges will persist longer than a single, isolated population with the same overall ceiling. Species of pinnipeds with well-developed homing or patrophilic tendencies would thus be more prone to local extinction than are those that wander unpredictably.

Another recurrent concern about rare and diminishing populations is the reduction of genetic variation that occurs from inbreeding, with its supposed consequences for individual fitness. Earlier work seemed to indicate that the northern elephant seal had indeed already experienced such genetic depauperation as a result of earlier overexploitation (Bonnell and Selander 1974). It was speculated that this would make them more vulnerable to such influences as pollution. However, it is now clear that pinnipeds are naturally homozygous at most enzyme loci (Lidicker *et al.* 1981), so that reduced genetic variance is probably not a potentially dangerous consequence of local population reductions. This conclusion may be revised with current technology for studying nuclear and mitochondrial DNA.

An excellent consideration of the above theoretical possibilities for pinnipeds is found in the study of the isolated ringed seals in Lake Saima, Finland (Jarvinen and Varvio 1986). The population is clearly endangered, with only some 130-150 individuals remaining. Thus, it is tempting to apply models of stochastic extinction. However, as Jarvinen and Varvio (1986) argue, "when one traces the history of endangered or extinct species, it is not stochastic extinction that one typically finds, but rather a tragedy of persecution and habitat deterioration" and "the absolute rule of chance in a small population is only the final stage of a long process leading to They conclude that the reduction of the seal stock is not a extinction." result of stochastic fluctuations, even amplified, in environmental conditions; but rather stems from persistent pressures. Previously high hunting mortality in adults has been succeeded by heightened mortality of pups due to artificial water-level changes, entanglement in fishing gear, and possibly pollutants.

The theoretical literature on the demography of extinction thus may not offer too many insights into processes that could lead to local extinction of populations of seals because of impacts from oil. It does seem, however, that catastrophes are likely to be less important than small, but sustained, reductions in survival and fertility. Chronic oil pollution could contribute to such effects.

Population Recovery After Catastrophe: If we take as a premise that an oilpollution catastrophe has produced a large kill of pinnipeds, it is important to consider the rate at which the population is restored to its original level. Indeed, rate of return to "normality" is often an explicit component of environmental impact statements. The rate of recovery will of course depend on the species and circumstances; a handful of direct estimates is (Table 2.6). Clearly pinnipeds populations could recover at rates of 7-17% per year, provided they were well below equilibrium levels before the catastrophe. Those closer to equilibrium should show an enhanced rate of increase following substantial reduction of numbers. However, individuals raised under the stress of overcrowding may not be capable of producing an immediate population response. Some species, such as the northern fur seal and Steller sea lion (Table 2.1), are indeed declining locally, presumably because the carrying capacity of their environments is in some way deteriorating. For these, a catastrophic kill might not be followed by population recovery even in the long term.

The rate of recovery of a seal population will also depend on the segments of the population that are killed. Table 2.7 illustrates, using the British gray seal as a demographic model, that loss of a year's offspring is more quickly compensated than is an equivalent loss of all age groups from the population, or particularly of adults. Yet even the long time for nearrecovery of populations that were at equilibrium before a catastrophe (Table 2.7) might be optimistic if individuals raised in a crowded environment fail to respond to population reduction. Table 2.6: Direct estimates of rates of increase of unexploited or lightly exploited pinniped populations thought to be recovering at high rates following earlier overexploitation, and believed to be uncomplicated by immigration. Rates of increase (X) are multiples per year.

SPECIES	LOCALITY	YEARS	INCREASE (X)	SOURCES
California sea lion	S. California	1927-1946	1.091	Chapman (1981)
N. Fur seal	Pribilof Islands, Alaska	1912-1924	1.085	Chapman (1981)
Antarctic fur seal	South Georgia	1958-1972	1.168	Payne (1977)
Subantarctic fur seal	Gough Island	1955-1977	1.149	Bester (1980)
N. elephant seal	California, various islands	1964-1981	1.146-1.793	Cooper and Stewart (1983)
Gray seal	Farnes and Outer Hebrides, Britain	1950-1976	1.067-1.073	Summers (1978)
	,			

Table 2.7: Recovery times of hypothetical seal populations after various catastrophic reductions, assumed to occur immediately after the young are born. The population is based on the same model gray seal population used for Figure 2.21.

SCENARIO	<pre>% POPULATION REMOVED</pre>	TIME TO 95% RECOVERY (YR)	
Population initially at equilibrium size	÷	· · · · · · · · · · · · · · · · · · ·	
All newborns killed	23	2	
Equal proportions all age classes killed	23	37	
Equal proportions mature age classes killed	23	43	
Population initially at one-half equilibrium size			
All newborns killed	20	1	
Equal proportions of all age classes killed	23	6	
Equal proportions of mature age classes killed	23	7	
	•	• .	

Literature Cited

Ayers, R.C., Jr., H.O. Johns and J.L. Glaseser. 1974. Oil spills in the Arctic Ocean: extent of spreading and possibility of large-scale thermal effects. Science 186: 842-845.

Bartholomew, G.A. 1959. Mother-young relations and the maturation of pup behaviour in the Alaska fur seal. Anim. Behaviour 7: 163-171.

Bayer, R.D. 1981. California sea lion in the Yaquina River Estuary, Oregon. Murrelet 62: 56-59.

Beloborodov, A.G. and V.A. Potelev. 1966. First period of life of the hooded seal in the Greenland Sea. pp. 7-8. In Proc. 3rd All-Union Conf. Mar. Mammals. Izdatel'stvo "Nauka", Vladivostok. (in Russian).

Bergman, A. and M. Olsson. 1986. Pathology of Baltic gray seal and ringed seal females with special reference to adrenocortical hyperplasia; is environmental pollution the cause of a widely distributed disease syndrome? Finnish Game Res. No. 44: 47-62.

Bester, M.N. 1980. Population increase in the Amsterdam Island fur seal <u>Arctocephalus tropicalis</u> at Gough Island. S. African J. Zool. 15: 229-234.

Bigg, M.A. 1969a. The harbour seal in British Columbia. Fish. Res. Board Can. Bull. 172. 33 pp.

Bigg, M.A. 1969b. Clines in the pupping season of the harbour seal, <u>Phoca</u> <u>vitulina</u>. J. Fish. Res. Board Can. 26: 449-455.

Bigg, M.A. 1981. Harbour seal <u>Phoca vitulina</u> Linneaus, 1758 and <u>Phoca largha</u> Pallas, 1811. pp. 1-27. In Handbook of Marine Mammals. Volume 2. S.H. Ridgway and R.J. Harrison (eds.). Academic Press, London, U.K.

Boness, D.J. and H. James. 1979. Reproductive behaviour of the gray seal (<u>Halichoerus grypus</u>) on Sable Island, Nova Scotia. J. Zool. (London) 188: 477-500.

Bonnell, M.L. and R.K. Selander. 1974. Elephant seals: genetic variation and near extinction. Science 184: 908-909.

Bonnell, M.L. and R.G. Ford. 1987. California sea lion distributions: a statistical analysis of aerial transect data. J. Wildl. Management 51: 13-20.

Boulva, J. and I.A. McLaren. 1979. Biology of the harbor seal, <u>Phoca</u> <u>vitulina</u>, in eastern Canada. Fish. Res. Board Can. Bull. 200. 24 pp.

Bowen, W.D., D.J. Boness and O.T. Oftedal. 1987a. Mass transfer from mother to pup and subsequent mass loss by the weaned pup in the hooded seal, Cystophora cristata. Can. J. Zool. 65: 1-8.

Bowen, W.D., C.K. Capstick and D.E. Sergeant. 1981. Temporal changes in the reproductive potential of female harp seals (<u>Pagophilus groenlandicus</u>). Can. J. Fish. Aquat. Sci. 38: 495-503.

Bowen, W.D., R.A. Myers and K. Hay. 1987b. Abundance estimation of a dispersed, dynamic population: hooded seals (<u>Cystophora cristata</u>) in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 44: 282-295.

Northwest Atlantic. Can. J. Fish. Aquat. Sci. 44: 282-295. Bowen, W.W., O.T. Oftedal and D.J. Boness. 1985. Birth to weaning in 4 days: remarkable growth in the hooded seal. Can. J. Zool. 63: 2481-2486. Braham, H.W., G.W. Oliver, C. Fowler, K. Frost, F. Fay, C. Cowles, D. Costa,
K. Schneider and D. Calkins. 1982. Marine Mammals. pp. 55-81. In The
St. George Basin Environment and Possible Consequences of Offshore Oil
and Gas Development. M. J. Hameedi (ed.). Proc. Synthesis Meeting
(1981). Anchorage, AK. U.S. Govt. Printing Office, Washington, DC.

Buckley, J.R., T. Gammelsrod, J.A. Johannessen, O.M. Johannessen and L.P. Roed. 1979. Upwelling: oceanic structure at the edge of the arctic pack in winter. Science 203: 165-167.

Burns, J.J. 1967. The Pacific bearded seal. Alaska Dept. Fish and Game, Juneau, AK. Annual Project Report 10. 66 pp.

Burns, J.J. 1971. Biology of the ribbon seal, <u>Histriophoca fasciata</u>, in the Bering Sea. pp. 135. In Proc. 22nd Alaska Sci. Conf., College, AK.

Burns, J.J. 1978. Ice seals. pp. 193-205. In Marine Mammals of Eastern North Pacific and Arctic Waters. D. Haley (ed.). Pacific Search Press, Seattle, WA.

Burns, J.J. 1981a. Ribbon seal <u>Phoca fasciata</u> Zimmermann, 1783. pp. 89-109. In Handbook of Marine Mammals. Volume 2. S.H. Ridgway and R.J. Harrison (eds.). Academic Press, New York, NY.

Burns, J.J. 1981b. Bearded seal, <u>Erignathus barbatus</u>, Erxleben, 1777. pp. 145-170. In Handbook of Marine Mammals. Volume 2. S.H. Ridgway and R.J. Harrison (eds.). Academic Press, New York, NY.

Burns, J.J. and T.J. Eley. 1977. The natural history and ecology of the bearded seal (<u>Erignathus barbatus</u>) and the ringed seal (<u>Phoca hispida</u>). pp. 226-302. In Environmental Assessment of the Alaskan Continental Shelf. Volume 1. U.S. Dept. Commerce, Nat. Oceanic and Atmos. Admin.

Burns, J.J. and K.J. Frost. 1983. The natural history and ecology of the bearded seal, <u>Erignathus barbatus</u>. pp. 311-. In Environmental Assessment of the Alaskan Continental Shelf. Final Report. Outer Continental Shelf Environmental Assessment Program. Volume 19. U.S. Dept. Commerce, Nat. Oceanic and Atmospheric Admin.

Burns, J.J. and V.N. Gol'tsev. 1984. Comparative biology of harbor seals, <u>Phoca vitulina</u> Linneaus, 1758, of the Commander, Aleutian, and Pribilof Islands. Nat. Oceanic and Atmos. Admin. Tech. Report Nat. Mar. Fish. Serv. 12: 17-24.

Burns, J.J., G.C. Ray, F.H. Fay and P.D. Shauhgnessy. 1972. Adoption of a strange pup by the ice-inhabiting harbor seal, <u>Phoca vitulina largha</u>. J. Mammal. 53: 594-598.

Calkins, D.G. and K.W. Pitcher. 1983. Population assessment, ecology and trophic relationships of Steller sea lions in the Gulf of Alaska. pp. 445-546. In Environmental Assessment of the Alaskan Continental Shelf. Final Report. Outer Continental Shelf Environmental Assessment Program. Volume 19. U.S. Dept. Commerce, Nat. Oceanic and Atmospheric Admin.

Calambokidis, J., R.D. Everitt, J. Cubbage and S.D. Carter. 1979. Harbor seal census for the inland waters of Washington, 1977-78. Murrelet 60: 110-111.

Cameron, A.W. 1970. Seasonal movements and diurnal activity rhythms of the gray seal (<u>Halichoerus grypus</u>). J. Zool. (London) 161: 15-23.

Chapman, D.G. 1981. Evaluation of marine mammal population models. pp. 279-296. In Dynamics of Large Mammal Populations. C.W. Fowler and T.D. Smith (eds.). John Wiley & Sons, New York, NY.

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- Condit, R. and B.J. LeBoeuf. 1981. Pelagic distribution of the northern elephant seal, <u>Mirounga angustirostris</u>. Abstract. 4th Biennial Conf. Biol. Mar. Mamm., San Francisco, CA.
- Cooper, C.F. and B.S. Stewart. 1983. Demography of northern elephant seals, 1911-1982. Science 219: 969-971.
- Cooper, C.F. and B.S. Stewart. 1982. The perils of success: implications of increasing marine mammal populations in the Southern California Bight. Manuscript. Ocean Studies Symp., Monterey, CA. and Calif. Coastal Comm.
- Davis, R.A., K.W. Finley and W.J. Richardson. 1980. The present status and future management of arctic marine mammals in Canada. Report. Sci. Advisory Board N.W.T., Yellowknife, N.W.T. 93 pp.
- Davis, R.A. and D.H. Thomson. 1984. Marine mammals. pp. 47-79. In The Barrow Arch Environment and Possible Consequences of Planned Offshore Oil and Gas Development. J.C. Truett (ed.). Outer Continental Shelf Environmental Assessment Program, Nat. Oceanic and Atmospheric Admin., Ocean Assessments Div., Anchorage, AK.
- DeLong, R.L. 1978. Northern elephant seal. pp. 207-211. In Marine Mammals of Eastern North Pacific and Arctic Waters. D. Haley (ed.). Pacific Search Press, Seattle, WA.
- DeMaster, D.P., D.J. Miller, D. Goodmand, R.L. DeLong and B.S. Stewart. 1982. Assessment of California Sea Lion Fishery Interactions. Trans. 47th N. Am. Wildl. Conf.: 253-264.
- Dunbar, M.J. 1981. Physical causes and biological significance of polynyas and other open water in sea ice. pp. 29-43. In Polynyas in the Canadian Arctic. I. Stirling and H. Cleator (eds.). Occasional Publ. No. 45. Can. Wildl. Serv.
- Eberhardt, L.L. 1977. Optimal policies for conservation of large mammals with special reference to marine ecosystems. Biol. Conserv. 4: 205-212.
- Eibl-Eibesfeldt, I. 1956. The Otariidae of the Galapagos Islands. J. Mammal. 37: 459.
- Eisenberg, J.F. and D.G. Kleiman (eds.). 1983. Advances in the study of mammalian behavior. Special Publ. Amer. Soc. Mammal. 753 pp.
- Engelhardt, F.R. 1985. Effects of petroleum on marine mammals. pp. 217-243. In Petroleum Effects in the Arctic Environment. F.R. Engelhardt (ed.). Elsevier Applied Sci. Publ., London, U.K.
- Estes, J.A. and V.N. Gol'tsev. 1984. Abundance and distribution of the Pacific walrus, <u>Odobenus rosmarus divergens</u>: results of the first Soviet-American joint aerial survey, autumn 1975. Nat. Oceanic and Atmospheric Admin. Technical Report Nat. Mar. Fish. Serv. 12: 67-76.
- Everitt, R.D. and Beach, R.J. 1982. Marine mammal-fisheries interactions in Oregon and Washington: an overview. Trans. 47th N. Am. Wildl. Conf.: 265-277.
- Everitt, R.D. and H.W. Braham. 1980. Aerial survey of Pacific harbor seals in the southwestern Bering Sea. Northwest Sci. 54: 281-288.
- Fay, F.H. 1982. Ecology and biology of the Pacific walrus, <u>Odobenus osmarus</u> <u>divergens</u> Illiger. U.S. Dept. Interior, U.S. Fish and Wildl. Serv., N. Am. Fauna No. 74. 279 pp.
- Fay, F.H., R.A. Dieterich, L.M. Schults, N.K. Murray, A. Hoover, and B.P. Kelly. 1979. Morbidity and mortality of marine mammals. Annual Report. U.S. Dept. Commerce, Nat. Oceanic and Atmospheric Admin., Environmental Assessment of the Alaskan Outer Continental Shelf. Contract No. 03-5-022-56. 34 pp.

Fedoseev, G.A. 1965. Comparative characteristics of the ringed seal populations in the coastal waters of the Chukostk Peninsula. Izvestia TINRO 59: 194-212. (in Russian).

Fedoseev, G.A. 1973. Morpho-ecological characteristics of ribbon seal populations and the basis for protection of its stocks. Trudy TINRO 86: 158-177. (Fish. Res. Board Can. Translation Series 3365.).

Finley, K.J., G.W. Miller, R.A. Davis and W.R. Koski. 1983. A distinctive large breeding population of ringed seals (<u>Phoca hispida</u>) inhabiting the Baffin Bay pack ice. Arctic 36: 162-173.

Fiscus, C.H. 1978. Northern fur seal. pp. 153-159. In Marine Mammals of Eastern North Pacific and Arctic Waters. D. Haley (ed.). Pacific Search Press, Seattle, WA.

Fiscus, C.H. 1961. Growth in the Steller's sea lion. J. Mammal. 42: 218-223.

Fiscus, C.H. and G.A. Baines. 1966. Food and feeding behavoir of Steller and California sea lions. J. Mammal. 47: 195-200.

- Fiscus, C.H., D.J. Rugh and T.R. Loughlin. 1981. Census of Northern Sea Lion (<u>Eumatopias</u> jubatus) in central Aleutian Islands, Alaska, 17 June - 15 July 1979. Nat. Oceanic and Atmospheric Admin. Tech. Memo. NMFS/NWC -17. 109 pp.
- Fleischer, L.A. 1978. Guadelupe fur seal. pp. 161-165. In Marine Mammals of Eastern North Pacific and Arctic Waters. D. Haley (ed). Pacific Search Press, Seattle, WA.
- Fowler, C.W. 1982. Interactions of northern fur seals and commercial fisheries. Trans. 47th N. Am. Wildl. Conf.: 278-292.

Fowler, C.W. and T.D. Smith (eds.). 1981. Dynamics of Large Mammal Populations. John Wiley and Sons, New York, NY. 477 pp.

- Francis, J.M. and C.B. Heath. 1985. Duration of maternal care in the California sea lion - bias by sex. Abstract. 6th Biennial Conf. Biol. Mar. Mamm., Vancouver, B.C.
- Frost, K.J. and L.F. Lowry. 1984. Trophic relationships of vertebrate consumers in the Alaskan Beaufort Sea. pp. 381-401. In The Alaskan Beaufort Sea: Ecosystems and Environments. P.W. Barnes, D.M. Schell and E. Remnitz (eds.). Academic Press, New York, NY.
- Frost, K.J., L.F. Lowry and J.J. Burns. 1985. Ringed seal monitoring: relationships of distribution, abundance, and reproductive success to habitat attributes and industrial activities. Interim Report. Contract No.: 84-ABC-00210. Nat. Oceanic and Atmospheric Admin. Project No.: RU #667. 85 pp.

Gentry, R.L. and J.H. Johnson. 1981. Predation by sea lions on northern fur seal neonates. Mammalia 45: 423-430.

Gentry, R.L. and G.L. Kooyman (eds.). 1986. Fur Seals. Maternal Strategies on Land and at Sea. Princeton Univ. Press, Princeton, NJ.

Geraci, J.R. and T.G. Smith. 1976. Direct and indirect effects of oil on ringed seals (<u>Phoca hispida</u>) of the Beaufort Sea. J. Fish. Res. Board Can. 33: 1976-1984.

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

Goodman, D. 1987a. The demography of chance extinction. pp. 000-000. In Viable Populations. M.E. Soule (ed.). Cambridge Univ. Press, Cambridge, U.K. Goodman, D. 1987b. Considerations of stochastic demography in the design and management of biological reserves. Nat. Resource Modelling: 000-000.

Harested, A.S. and H.D. Fisher. 1975. Social behavior in a non-pupping colony of Steller sea lions (<u>Eumetopias jubata</u>).

Heath, C.B. 1985. The effects of environment on the breeding system of the California sea lion (<u>Zalophus californianus</u>). Abstract. 6th Biennial Conf. Biol. Mar. Mammals, Vancouver, B.C.

Innes, S., R.A. Stewart and D.M. Lavigne. 1981. Growth in Northwest Atlantic harp seals <u>Phoca groenlandica</u>. J. Zool. (Lond.) 194: 11-24.

Jarvinen, J. and S.-L. Varvio. 1986. Proneness to extinction of small populations of seals: demographic and genetic stochasticity vs. environmental stress. Finnish Game Res. 44: 6-18.

Johnson, L. 1983. Assessment of the effects of oil on arctic marine fish and marine mammals. Can. Tech. Rep. Fish. Aquat. Sci. 1200. 15 pp.

Johnson, M.L., C.H. Fiscus, B.T. Ostenson and M.L. Barbour. 1966. Marine mammals. pp. 877-924. In Environment of the Cape Thompson Region, Alaska. N.J. Wilimovsky and J.N. Wolfe (eds.). U.S. Atomic Energy Comm., Oak Ridge, TN.

Kajimura, H. 1984. Opportunistic feeding of the nothern fur seal, <u>Callor-hinus</u> <u>ursinus</u>, in the eastern North Pacific Ocean and eastern Bering Sea. Nat. Oceanic and Atmospheric Admin. Technical Report NMFS SSRF-779. 49 pp.

Kapel, F.O. 1981. Studies of hooded seals in Greenland, 1970-1980. Northwest Atlantic Fish. Organization, Sci. Res. Document 81/X1/150, Series N462. 18 pp.

King, J. 1983. Seals of the World. Cornell Univ. Press, Ithaca, NY. 240 pp.

Kingsley, M.C., I. Stirling and W. Calvert. 1985. The distribution and abundance of seals in the Canadian High Arctic, 1980-1982. Can. J. Fish. Aquat. Sci. 42: 1189-1210.

Kooyman, G.L. 1981. Crabeater seal <u>Lobodon carcinophagus</u> (Hombron and Jacquinot, 1842). pp. 221-235. In Handbook of Marine Mammals. Volume 2: Seals. S.H. Ridgway and R.J. Harrison (eds.). Academic Press, London, U.K. 359 pp.

Krieber, M. and C. Barrette. 1984. Aggregation behaviour of harbour seals at Florillon National Park, Canada. J. Anim. Ecol. 53: 913-928.

Krylov, V.I. 1966. Sexual maturation in the female Pacific walrus. Zoologicheskii Zhurnal 45: 919-927. (Fish. Res. Board Can. Transl. Ser. 806).

Krylov, V.I. 1970. Size and weight characteristics as indicators of age and sexual dimorphism in the Pacific walrus. Moskva O-Vo Isp. Prirod. Otd. Biol. Biul 5: 18-24.

Lander, R.H. 1981. A life table and biomass estimate for Alaskan fur seals. Fish. Res. 1: 55-70.

Lavigne, D.M., S. Innes, G.A. J. Worthy, K.M. Kovacs, O.J. Schmitz and J. P. Hickie. 1986. Metabolic rates of seals and whales. Can. J. Zool. 64: 279-290.

Lawson, J.W. and D. Renouf. 1987. Bonding and weaning in harbor seals. J. Mammal. 68: 445-449.

LeBoeuf, B.J. 1974. Male-male competition and reproductive success in elephant seals. Amer. Zool. 14: 163-176.

LeBoeuf, B.J. 1979. Northern elephant seal. pp. 110-114. In Mammals of the Sea. Volume 2. Pinniped species summaries and report on sirenians. Food and Agriculture Organization of the United Nations, Fish. Series 5.

LeBoeuf, B.J. 1981. The elephant seal. pp. 291-301. In Problems in Management of Locally Abundant Wild Mammals. P.A. Jewell, S. Holt and D. Hart (eds.). Academic Press, New York, NY.

LeBoeuf, B.J., D. Aurioles, R. Condit, C. Fox, R. Gisner, R. Romero and F. Sinsel. 1983. Size and distribution of the California sea lion population of Mexico. Proc. Calif. Acad. Sci. 43: 77-85.

LeBoeuf, B.J., R.J. Whiting and R.F. Gantt. 1972. Perinatal behavior of northern elephant seal females and their young. Behavior 34: 121-156.

LeFèvre, J. 1986. Aspects of the biology of frontal systems. Adv. Mar. Biol. 23: 163-299.

Lidicker, W.Z., R.D. Sage and D.G. Calkins. 1981. Biochemical variation in northern sea lions from Alaska. pp. 231-241. In Mammalian Population Genetics. M.H. Smith and J. Joule (eds.). Univ. Georgia Press, Athens, GA.

Lluch B.D. 1969a. El lobo marino de California <u>Zalophus</u> <u>californianus</u> (Lesson, 1828) Allen, 1880. Observaciones sobre su ecologia y explotacion. pp. 1-69. In Dos Mammiferos Marinos de Baja California. Inst. Mex. Recursos Nat. Renovables.

Lluch B.D. 1969b. Crecimento y mortalidad del lobo marino de California Zalophus californianus. An. Esc. nac. Cien. biol. Mex. 18: 167-189.

Loughlin, T.R., D.J. Rugh and C.H. Fiscus. 1984. Northern sea lion (<u>Eumeto-peus jubatus</u>) distribution and abundance; 1956-1980). J. Wildl. Manage. 48: 729-740.

Lowry, L.F. and F.H. Fay. 1984. Seal eating by walruses in the Bering and Chukchi Seas. Polar Biol. 3: 11-18.

Lowry, L.F., K.J. Frost and J.J. Burns. 1980. Variability in the diet of ringed seals, <u>Phoca hispida</u>, in Alaska. Can. J. Fish. Aquat. Sci. 37: 2254-2261.

Lowry, L.F. and K.J. Frost. 1981. Feeding and trophic relationships of phocid seals and walruses in the eastern Bering Sea. pp. 813-824. In The Eastern Bering Sea Shelf: Oceanography and Resources. Volume 2. D.W. Wood and J.A. Calder (eds.). Office of Mar. Pollution Assessment, Nat. Oceanic and Atmospheric Admin., Bureau of Land Management.

Lucas, Z. and I.A. McLaren. 1988. Apparent predation by gray seals, <u>Halichoerus grypus</u>, on seabirds around Sable Island, Nova Scotia. Can. Field-Naturalist (submitted).

Mansfield, A.W. 1958. The biology of the Atlantic walrus <u>Odobenus</u> <u>rosmarus</u> <u>rosmarus</u> (Linnaeus) in the eastern Canadian arctic. Fish. Res. Board Can. Manuscript Report Series (Biol.) No. 653. 146 pp.

Mansfield, A.W. 1967a. Seals of arctic and eastern Canada. Fish. Res. Board Can. Bull. 127. 35 pp.

Mansfield. A.W. 1967b. Distribution of the harbor seal, <u>Phoca</u> <u>vitulina</u> Linnaeus, in Canadian Arctic waters. J. Mammal. 48: 249-257.

Mansfield, A.W. 1977. Growth and longevity in the gray seal <u>Halichoerus</u> <u>grypus</u> in eastern Canada. Intern. Council for the Exploration of the Sea, Mar. Mammal Committee, C.M. 1977/N:6. 11 pp.

Mansfield, A.W. 1978. Reproduction in the gray seal <u>Halichoerus</u> grypus in eastern Canada. Intern. Council for the Exploration of the Sea, Mar. Mammal Committee, C.M. 1978/M:13. 9 pp. Mansfield, A.W. and D.E. Sergeant. 1960. Harbour seal population studies. pp. 27-30. In Fish. Res. Board Can. Arctic Unit Annual Report 1959-60.

Mansfield, A.W. and B. Beck. 1977. The gray seal in eastern Canada. Environ. Can. Fish. and Mar. Serv. Technical Report No. 704. 81 pp.

- Maser, C., B.R. Mate, J.F. Franklin and C.T. Dymes. 1981. Natural history of Oregon coast mammals. U.S. Dept. Agriculture, Forestry Serv., Technical Report PNW-133. 496 pp.
- Mate, B. and R.L. Gentry. 1979. Northern (Steller) sea lion. pp. 1-4. In Mammals in the Seas. Volume 2. Pinniped species summaries and report on sirenians. Food and Agriculture Organization of the United Nations, FAO Fisheries Series No. 5.
- McGinnis, S.M. and R.J. Schusterman. 1981. Northern elephant seal <u>Mirounga</u> <u>angustirostris</u> Gill, 1866. pp. 329-349. In Handbook of Marine Mammals. Volume 2. S.H. Ridgway and R.J. Harrison (eds.). Academic Press, New York, NY..
- McLaren, I.A. 1958a. The biology of the ringed seal (<u>Phoca hispida</u> Schreber) in the eastern Canadian arctic. Fish. Res. Board Can. Bull. 118. 97 pp.
- McLaren, I.A. 1958b. Some aspects of growth and reproduction of the bearded seal, <u>Erignathus barbatus</u> (Erxleben). J. Fish. Res. Board Can. 15: 219-227.
- McLaren, I.A. 1958c. The economics of seals in the eastern Canadian arctic. Fish. Res. Board Can. Arctic Circular 1. 94 pp.
- McLaren, I.A. 1967. Seals and group selection. Ecology 48: 104-110.
- McLaren, I.A. and T.G. Smith. 1985. Population ecology of seals: retrospective and prospective views. Mar. Mammal Sci. 1: 54-83.
- Merrick, R.L., T.R. Loughlin and D.G. Calkins. 1987. Decline in abundance of the northern sea lion, <u>Eumetopias jubatus</u>, in Alaska, 1955-86. Fish. Bull. 85: 351-365.
- Naito, Y. and M. Nishiwaki. 1972. The growth of two species of harbour seals in the adjacent waters of Hokkaido. Whales Res. Inst., Sci. Rep. 24: 127-144.
- Nazarenko, Y.I. and Y.I. Timoshenko. 1974. Age structure in the White Sea population of <u>Pagophoca</u> groenlandica as an index of efficiency of protective measures. Zool. Zhur. 53: 256-262. (in Russian).

Obee, B. 1984. Steller's sea lion. Wildl. Rev. 10(9): 9-13.

- Odell, D.K. 1981. California sea lion <u>Zalophus californianus</u> (Lesson, 1828). pp. 67-97. In Handbook of Marine Mammals. Volume 1. The Walrus, Sea Lions, Fur Seals and Sea Otter. S.H. Ridgway and R.H. Harrison (eds.). Academic Press, New York, NY.
- Oftedal, O.T., D.J. Boness and R.A. Tedman. 1987. The behavior, physiology, and anatomy of lactation in the pinnipedia. Curr. Mamm. 1: 175-245.
- Oritsland, T. 1975. Sexual maturity and reproductive performance of female hooded seals at Newfoundland. Intern. Comm. for Northwest Atlantic Fish., Res. Bull. 11: 37-41.
- Oritsland, T. and T. Benjaminsen. 1975. Sex ratio, age composition and mortality of hooded seals at Newfoundland. Intern. Comm. for Northwest Atlantic Fish., Res. Bull. 11: 135-143.
- Payne, M.R. 1977. Growth of a fur seal population. Phil. Trans. Roy. Soc. (Lond.) B 279: 67-79.
- Payne, P.M. and D.C. Schneider. 1984. Yearly changes in abundance of harbor seals, <u>Phoca vitulina</u>, at a winter haulout site in Massachusetts. Fish. Bull. 82: 440-442.

Pitcher, K.W. 1977. Population productivity and food habits of harbor seals in the Prince William Sound - Copper River Delta area, Alaska. Final Report. U.S. Mar. Mammal Comm. Contract No. NM5AC0011. U.S. Nat. Tech. Info. Serv., Publ. PB 266935. 36 pp.

Pitcher, K.W. and D.G. Calkins. 1981. Reproductive biology of Steller sea lions in the Gulf of Alaska. J. Mammal. 62: 599-605.

- Pitcher, K.W. and D.G. Calkins. 1983. Biology of the harbor seal, <u>Phoca</u> <u>vitulina richardsi</u>, in the Gulf of Alaska. pp. 231-311. In Environmental Assessment of the Alaskan Continental Shelf. Final Report. Outer Continental Shelf Environmental Assessment Program. Volume 19. U.S. Dept. Commerce, Nat. Oceanic and Atmospheric Admin.
- Pitcher, K.W. and F.H. Fay. 1982. Feeding by Steller sea lions on harbor seals. Murrelet 63: 70-71.
- Reeves, R. and J.K. Lin. 1981. Hooded seal <u>Cystophora</u> <u>cristata</u> Erxleben, 1777. pp. 171-194. In Handbook of Marine Mammals. S.H. Ridgway and R.J. Harrison (eds.). Academic Press, London, U.K.
- Reijnders, P.J.H. 1986. Reproductive failure in common seals feeding on fish from polluted coastal waters. Nature (London) 324: 456-457.
- Reiter, J. 1984. Studies of female competition and reproductive success in the northern elephant seal. Ph.D. Thesis, Univ. Calif., Santa Cruz, CA.
- Richardson, D.T. 1975. Hooded seal whelps at South Brooksville, Maine. J. Mammal. 56: 698-699.
- Roff, D.A. and W.D. Bowen. 1983. Population dynamics of the Northwest Atlantic harp seal (<u>Phoca groenlandica</u>). Can. J. Fish. Aquat. Sci. 40: 919-932.
- Roff, D.A. and W.D. Bowen. 1986. Further analyses of population trends in the Northwest Atlantic harp seal (<u>Phoca groenlandica</u>) from 1967 to 1985. Can. J. Fish. Aquat. Sci. 43: 553-564.

Rosenfeld, M. and M. George. 1985. Migration in harbor seals. Abstract. 6th Biennial Conf. Biol. Mar. Mammals, Vancouver B.C.

Schusterman, R.J. 1981. Steller sea lion <u>Eumetopias</u> jubatus (Schreber, 1776). pp. 119-141. In Handbook of Mammals. S.H. Ridgway and R.J. Harrison (eds.). Academic Press, London, U.K.

- Sergeant, D.E. 1965. Migrations of harp seals <u>Pagophilus</u> groenlandicus (Erxleben) in the Northwest Atlantic. J. Fish. Res. Board Can. 22: 433-464.
- Sergeant, D.E. 1971. Migration and orientation in harp seals. pp. 123-131. In Proc. 7th Annual Conf. Biol. Sonar and Diving Mammals, Stanford Res. Inst., Menlo Park, CA.

Sergeant, D.E. 1974. A rediscovered whelping population of hooded seals <u>Cystophora cristata</u> Erxleben and its possible relationship to other populations. Polarforschung 44: 1-7.

Sergeant, D.E. 1976. History and present status of populations of harp and hooded seals. Biol. Conserv. 10: 95-118.

- Shapiro, L.H. and J.J. Burns. 1975. Major late-winter features of ice in northern Bering and Chukchi Seas as determined from satellite imagery. Univ. Alaska Geophysical Inst. Report No. UAG R-236 (Sea Grant Report No. 75-8). 7 pp.
- Shaughnessy, P.D. and P. Chapman. 1984. Commensal Cape fur seals in Cape Town docks. S. Afr. J. Mar. Sci. 2: 81-91.

Shustov, A.P. 1965. Some biological features and reproductive rates of the ribbon seal (<u>Histriophoca fasciata</u>) in the Bering Sea. Izvestiia TINRO 59: 183-192. (U.S. Fish Wildl. Serv. Transl.).

Shustov, A.P. and A.V. Yablokov. 1967. Comparative morphological characteristics of the harp and ribbon seals. Tr. PINRO 21: 51-59.

Smith, T.G. 1973. Population dynamics of the ringed seal in the eastern Canadian arctic. Fish. Res. Board Can. Bull. 181. 55 pp.

Smith, T.G. 1975. Ringed seals in James and Hudson Bay: population estimate and catch statistics. Arctic 28: 170-182.

Smith, T.G. 1987. The ringed seal, <u>Phoca hispida</u>, of the Canadian Western Arctic. Can. Bull. Fish. and Aquat. Sci. 216. 81 pp.

Smith, M. and B. Rigby. 1981. Distribution of polynyas in the Canadian arctic. pp. 7-28. In Polynyas in the Canadian Arctic. I. Stirling and H. Cleator (eds.). Occasional Paper No. 45 Can. Wildl. Serv.

Spotte, S. and J. Schneider. 1982. Early functional maturity of captive male elephant seals (<u>Mirounga angustirostris</u>). Zoo Biol. 1: 355-358.

Stewart, B.S. 1980. Historical and present populations of pinnipeds in the Channel Islands. pp. 45-98. In Potential Effects of Space Shuttle Sonic Booms on the Biota and Geology of the California Channel Islands: Research Reports. J.R. Jehl, Jr. and C.F. Cooper (eds.). Tech. Report 80-2. Center for Mar. Studies, San Diego State Univ., San Diego, CA.

Stewart, R.A.E. and D.M. Lavigne. 1980. Neonatal growth of Northwest Atlantic harp seals, <u>Pagophilus</u> groenlandicus. J. Mammal. 61: 670-680.

Stirling, I. 1981. Introduction. pp. 5-6. In Polynyas in the Canadian Arctic. I. Stirling and H. Cleator (eds.). Can. Wildl. Serv. Occasional Paper No. 45.

Stirling, I., R. Archibald and D. DeMaster. 1977. Distribution and abundance of seals in the eastern Beaufort Sea. J. Fish. Res. Board Can. 34: 976-988.

Stirling, I., H. Cleator and T.G. Smith. 1981. Marine mammals. pp. 45-58. In Polynyas in the Canadian Arctic. I. Stirling and H. Cleator (eds.). Can. Wildl. Serv. Occ. Pap. No. 45.

Strebel, D.E. 1985. Environmental fluctuations and extinction - single species. Theor. Pop. Biol. 27: 1-26.

Summers, C.F. 1978. Trends in the size of British gray seal populations. J. Appl. Ecol. 15: 395-400.

Tikhomirov, E.A. 1966. On the reproduction of seals belonging to the family Phocidae in the North Pacific. Zoologicheskii Zhurnal 45: 275-281. (Fish. Res. Board Can. Transl. Series 1889).

Tikhomirov, E.A. 1968. Body growth and development of reproductive organs of the North Pacific hair seal. pp. 213-241. In Pinnipeds of the North Pacific. Izvestiia TINRO 68: 216-243. (Israel Program for Sci. Transl., Keter Press, Jerusalem, Isreal).

Wells, P.G. and J.A. Percy. 1985. Effects of oil on arctic invertebrates. pp. 101-156. In Petroleum Effects in the Arctic Environment. F.R. Engelhardt (ed.). Elsevier Applied Sci. Publ., London, U.K.

Wiig, O. 1985. Morphometric variation in the hooded seal (<u>Cystophora</u> <u>cristata</u>). J. Zool. (Lond.) A 206: 497-508.

York, A. 1983. Average age at first reproduction of the northern fur seal (<u>Callorhinus ursinus</u>). Can. J. Fish. Aquat. Sci. 40: 121-127.

Zwanenburg, K., W.D. Bowen and D.E. Sergeant. 1985. Assessment of northwest Atlantic gray seal (<u>Halichoerus grypus</u>) pup production for 1977 to 1984. Can. Dept. Fish. Oceans Sci. Advisory Committee Atlantic Fish. Res. Document 85/67. 16 pp.

CHAPTER 3

PHYSIOLOGIC AND TOXICOLOGIC EFFECTS

ON PINNIPEDS

D.J. St. Aubin

Department of Pathology Ontario Veterinary College University of Guelph Guelph, Ontario N1G 2W1

Historical Notes

The record of encounters between pinnipeds and oil spans four decades and comprises at least 27 events, covering Europe, the Antarctic and the Pacific, Atlantic and Arctic coasts of North America. Armed with information from such diverse habitats, we should have little difficulty in predicting the consequences of oil exposure for most pinniped species. Yet the quality of the reports is variable. Early accounts are often vague or brief, and some of the more recent efforts, undertaken in an emotionally charged atmosphere, are less than objective. Though incomplete, the record provides a clear indication of selective vulnerability to oil.

Well blow-outs and tanker accidents attract considerable attention, while more insidious sources such as vessels that intentionally discharge fuel can in fact be as damaging. During the late 1940's, there were two instances in which seals were affected by petroleum presumed to have been deliberately released from ships. In the Antarctic, Lillie (1954) observed "half-grown seals covered in a sticky, tarry mess, their eyes bloodshot with irritation". Davies (1949) reported that two seal pups encased in oil drowned when washed out to sea near Ramsay Island off the coast of Wales; other oiled pups were apparently unaffected. Waste oil dumped from vessels may account for other incidents of fouling (Table 3.1), when there has been no reason to suspect a well blow-out or a tanker accident as the source of contamination. Generally, reports of these events are limited to recovery of 2 or 3 oil-stained animals, with little evidence to determine whether the seals were fouled before or after death.

A systematic study was performed following one such event along the coast of Wales in 1974 (Davis and Anderson 1976). Oil from an unknown source fouled gray seal rookeries at the onset of pupping season, when the animals are considered to be most vulnerable. On Skomer Island, 25 pups and 23 adults were wholly or partly oiled, and pup mortality was higher than at other less affected sites. However, there was no significant difference in mortality rate between oiled and clean pups on Skomer Is., and necropsy examinations did not reveal gross evidence of ingested petroleum. Cows continued to nurse oiled pups, though these had lower average peak weights at weaning than their unoiled counterparts. Attempts to clean fouled animals met with limited success, since cleaned pups were often recontaminated by their mothers. Furthermore, the disturbance associated with cleaning operations may have interfered with nursing, and contributed to the lower peak weights of these seals. The only deaths directly attributed to fouling were those of two pups so encased with oil which they drowned when washed off the beach.

Tanker groundings have resulted in major oil spills that have affected pinnipeds. The first such event was the sinking of the <u>Torrey Canyon</u> off the coast of England in 1967. Two or three gray seals were observed surfacing in the oil slick, and three oiled animals were recovered dead or dying (Gill *et al.* 1967); Spooner (1967) reported that as many as 12 seals (species not indicated) had died. In view of the magnitude of the spill and the extent of clean-up activities which involved the use of over 10 million liters of relatively toxic dispersants, the impact of this event on pinnipeds was minor.

Date	Location & Source	Oil Type & Quantity	' Species	Impact	Reference
late 1940's	Antarctic Ship discharge	Fuel oil Quan. ?	unspecified seals	bloodshot eyes; surface fouling with tarry oil	Lillie 1954
1949	Ramsay Island, Wales Source unknown	Fuel oil Quan. ?	gray seal	Pups largely unaffected by thick coating of oil. Two fouled pups drowned.	Davies 1949
Mar. 1967	English Channel <u>Torrey Canyon</u>	Crude oil >100,000 tons	gray seal	Seals observed surfacing through slick. 3 oiled seals found dead or dying. Up to 12 confirmed deaths.	Gill <u>et al</u> . 1967, Spooner 1967
Jan. 1969	Gulf of St.Lawrence Storage tank	Bunker C 4,000 gal.	harp seal	10-15,000 seals coated. Unspecified number of dead seals recovered.	Warner 1969 Sergeant 1987
Feb. 1969	Santa Barbara,CA Union Oil well	Crude oil >100,000 tons	harbor seal elephant seal Calif. sea lion	Oiled seals observed on Channel Islands and along mainland coast. Mortalities not conclusively linked to oil.	LeBoeuf 1971, Brownell and LeBoeuf 1971, Simpson 1970, and others.
Nov. 1969	N. Dyfed, Wales Source unknown	Type ? Quan. ?	gray seal	14 oiled, dead pups found. No causal relationship.	Anon. 1970b
Feb. 1970	Chedabucto Bay, Sable Is., N.S. <u>Arrow</u>	Bunker C 16x10 ⁶ L	gray seal harbor seal	50-60 harbor seals and 100 gray seals oiled on Sable Is. 500 oiled seals in Chedabucto Bay. 24 found dead, some with oil in mouth or stomach.	Anon. 1970a, 1971b

ა ... Table 3.1: Reports of pinnipeds associated with oil.

Table 3.1 (cont'd.):

Reports of pinnipeds associated with oil.

Date	Location & Source	Oil Type & Quantity	Species	Impact	Reference
Aug. 1974	Strait of Magellan <u>Metula</u>	Crude oil, 47,000 tons Bunker C, 3-4000 tons	S. sea lion S. Am. fur seal	Sea lions and fur seals in the area apparently unaffected.	Baker 1976
Aug. 1974	Coast of France Source unknown	Fuel oil Quan. ?	harbor seal gray seal	Oil in intestine of 1 harbor seal. 3 oiled gray seals, 1 ingested oil.	Duguy and Babin 1975
Sept. 1974	Pembrokeshire, Wales. Source unknown	Type ? Quan. ?	gray seal	2 heavily oiled pups drowned when washed off beach. 25 pups and 23 adults fouled.	Davis and Anderson 1974
Jan. 1975	Ireland African Zodiac	Bunker C 2700 barrels	seals	Seals in the area were apparently unaffected.	ESL 1981
Aug. 1977	Greenland USNS <u>Potomac</u>	Bunker C 380 tons	ringed seal other seals	16 oiled seals observed 1 month after spill.	Grose <u>et</u> <u>al</u> . 1979
Mar. 1978	France Amoco <u>Cadiz</u>	Crude oil 200,000 tons	gray seals	2 of 4 dead seals coated with oil. No causal relatinship.	Prieur and Hussenot 1978

	Location	Oil Type			
Date	& Source	& Quantity	Species	Impact	Reference
Feb Mar. 1970	Kodiak Is., AK Ship discharge	Slop oil or oily ballast	hair seals sea lions	Est. 500 mammals contacted; No mortality.	Hess and Trobaugh 1971
Apr. 1970	Alaska Peninsula Source unknown	Diesel fuel Quan. ?	hair seals	400 seals exhibited unusual behavior. No mortalities.	Anon. 1971a
Nov. 1970	Farne Islands Source unknown	Type ? Quan. ?	gray seal	Yearling seal found oil- stained pelt and crusting around mouth. Otherwise healthy.	Bonner and Hickling 1971
Mar. 1972	British Columbia <u>Vanlene</u>	Bunker B 2400 barrels	seals	Seal herds in area unaffected	ESL 1981
Sept. 1973	Repulse Bay, NWT Ship discharge	Refuse oil Quan. ?	ringed seal	Hunters killed 5 oil- covered seals.	Muller-Willie 1974
1973	Dutch coast Source unknown	Type ? Quan. ?	harbor seal	Patches of oil incon- clusively associated with skin lesions.	Van Haaften 1973
1974-1979	Cape Town, S.A. Ships and industry	Chronic discharge	Cape fur seals	Fur seals lingering in polluted harbor without	Shaughnessy and Chapman

Table 3.1 (cont'd.): Reports of pinnipeds associated with oil.

Table 3.1 (cont'd.): Reports of pinnipeds associated with oil.

<u></u>	Location	Oil Type	······································		
Date	& Source	& Quantity	Species	Impact	Reference
May 1978	Great Yarmouth, U.K. <u>Eleni</u> <u>V</u>	Heavy fuel oil. 24000 barrels	seals	20 oiled seals observed.	ESL 1981
Oct. 1978	South Wales Christos Bitas	Crude oil 20,000 barrels	seals	Mortality of 16 of 23 oiled	Bourne 1979
Dec. 1978	Shetland Is., Scotland Esso Bernicia	Bunker C 8800 barrels	seals	Some seals oiled. No deaths reported.	Anderson 1981
Feb. 1979	Latvia Antonio Gramsci	Crude oil 36,500 gallons	seal	One seal killed by oil.	ESL 1981
Mar. 1979	Cabot Str., N.S. <u>Kurdistan</u>	Bunker C 7500 tons	gray seal harbor seal	At least 4 gray and 6 harbor seals found dead coated with oil. No causal relationship. Oiled seals on Sable Is.	Parsons <u>et a.</u> 1980. Marston (pers. comm.
Nov. 1979	Pribiloff Is.; AK F/V <u>Ryuyo</u> <u>Maru</u>	Fuel oil 290,000 gallons	northern fur seal	Some oiled, dead pups found. Causal relationship not demonstrated.	Reiter 1981
Feb. 1984	Sable Is., N.S. Well blow-out	Gas condensate	gray seal	4 oiled seals observed on Sable Is. No mortality.	Anon. 1984

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Subsequently, major spills from the <u>Arrow</u>, <u>Amoco Cadiz</u>, <u>Christos Bitas</u> and <u>Kurdistan</u> had similar consequences. Harbor and gray seals were fouled in Chedabucto Bay, Nova Scotia, where the tanker <u>Arrow</u> released 16 million liters of Bunker C fuel oil in February, 1970 (Figure 3.1). On Sable Island, 200 km to the south, most of the 50-60 harbor and 100 gray seals occupying the beaches were fouled to some degree. A few animals were thought to have suffocated because vital orifices had been plugged (Anon. 1970a). Nine years later, the tanker <u>Kurdistan</u> sank in Cabot Strait, 200 km northeast of the wreck of the <u>Arrow</u>, and oiled gray and harbor seals were again observed on Sable Island (Parsons *et al.* 1980) (Figure 3.1). Investigators found no evidence of mortality or physical impairment despite the fact that some seals were heavily oiled. Along the nearby coast of Nova Scotia, however, 4 dead gray seals and 6 dead harbor seals were found coated with oil.

Following the sinking of the <u>Amoco Cadiz</u> in March 1977, two of four dead gray seals recovered were fouled with oil; autopsies were not performed to confirm the cause of death (Prieur and Hussenot 1978). In October 1978, the grounded <u>Christos Bitas</u> discharged over 2 million liters of Iranian crude oil in the same area where Davis and Anderson had investigated a spill five years earlier. Reports that 16 gray seal pups died acutely were not confirmed, and subsequent necropsy examinations of a limited number of specimens (Bourne 1979).

Oiled seals have been observed following the breakup of at least seven other vessels, with mortalities reported in two of the events. An unspecified number of oil-fouled dead fur seal pups were recovered in the Pribiloff Islands after the grounding of the fishing vessel F/V <u>Ryuyo Maru</u> (Reiter 1981), and a single seal (species not identified) presumably died after contacting crude oil spilled from the <u>Antonio Gramsci</u> in the Baltic Sea (ESL 1981). In neither instance was a detailed examination performed on an animal.

No incident involving marine mammals and spilled oil has sparked as much controversy as the blowout of Union Oil's A-21 well in the Santa Barbara Channel (Figure 3.2) on January 28, 1969 (Easton 1972). The magnitude and duration of the spill and its occurrence near a densely populated coast drew national attention for several months. Residents who perceived the spill as an irreversible blow to the economic and aesthetic value of the coastal environment confronted industry and federal representatives, as conflicting reports of the extent of the spill and its impact on marine life were presented and challenged. Studies that found minimal effects were dismissed by the public as inadequate, whereas media reports were often overstated and sensational, and found little favor with the scientific community. From this large body of diverse and often conflicting documentation, some attempt has been made to evaluate the impact on pinnipeds.

Along the mainland coast, there was little evidence of impact. Ten days after the blowout, the Santa Barbara News-Press published a photograph of an oiled harbor seal that had been "rescued" and presented for cleaning. By February 21, Time (Anon. 1969a) reported that six dead seals had washed up on California beaches. Seven more were recovered during the following month.



Figure 3.1 Location of three oil spills in Northeast Canada





Most of the attention and controversy centered around rookeries on the channel islands - San Miguel, San Nicholas, Santa Cruz, and Anacapa (Figure 3.2) - that are occupied throughout the year by several species of pinnipeds. From early February until the end of June, the islands were surveyed on at least 15 occasions by groups representing the California Department of Fish and Game, the University of California (Santa Barbara and Santa Cruz), the Defenders of Wildlife, the Santa Barbara Museum of Natural History and various press agencies, including Time magazine. Their observations and interpretation of the events form the basis of the controversy.

The principal inhabitants of the islands are California sea lions and elephant seals, both of which use the islands for breeding. Elephant seal pups are born in early January and most were weaned when oil reached the islands one week after the blowout. On March 17, LeBoeuf (1971) observed over 100 elephant seal pups coated with oil, sand and detritus. Fifty-eight of these were tagged, along with an equal number of unoiled animals. During the next 15 months, 40% of the oiled group and 25% of the controls were resighted. Conclusions about survivorship are tenuous, since there was no assurance that seals that were clean when tagged did not subsequently encounter oil. Later, LeBoeuf and Peterson reported that they had also observed four dead elephant seals lying in pools of oil (Anon. 1969b). During the first two weeks in April, Simpson and Gilmartin (1970) surveyed the rookery on four occasions and found three dead seals, with no evidence of oil contamination. No hydrocarbon residues were detected in tissues collected from two of these, nor in blood samples from two live seals.

The effect on California sea lions was the subject of particular concern and disagreement. Though peak pupping season for the sea lions does not occur until late May through June (McLaren, Chapter 2), observers were confounded by an apparently large number of premature births, beginning in February. Counts ranged from 25 in late March (Brownell and LeBoeuf 1971) to 200 in mid-May (Snell 1969), just before the onset of the normal parturition season. Arguments arose over whether the incidence of abortions was representative of normal mortality. No hydrocarbon residues were detected in tissue samples from aborted fetuses (Simpson and Gilmartin 1970, Simpson 1970), and the association between pup mortality and the oil spill remained circumstantial. Subsequent investigations of premature births among sea lions show that the incidence observed in 1969 was not unusual. DeLong et al. (1973) counted 242 dead pups on April 25, 1970 and 348 on May 18, 1971 on San Miguel Island; Odell (1970) reported 442 on San Nicholas Island between January 17 and May 3, 1970. More recent studies have shown possible associations with infectious organisms and organochlorine residues (Gilmartin et al. 1976), and it is possible that the stress of oil exposure may have had an additive effect. To summarize, there was no clear evidence directly implicating oil as the principle cause of mortality among sea lion pups.

Concurrent with the Santa Barbara spill, a much less publicized incident in Canadian waters had a far greater impact on pinnipeds. A ruptured storage tank on Cape Tormentine, New Brunswick, discharged 18,000 L of Bunker C oil into the Gulf of St. Lawrence (Figure 3.1), fouling the sea ice where harp seals were about to begin pupping. During March and early April, observers reported 10-15,000 oil-fouled adults and pups so heavily contaminated that they were almost unrecognizable (Sergeant 1987). Hundreds of pups were tagged as part of an annual effort by Canadian Fisheries biologists, and the relatively high tag return during this season suggested an increase in mortality rate. An unspecified number of dead seals were found on the ice floes, in the water and along the beaches of Bell Island (Warner 1969). Oil-fouled pups migrated normally towards the Strait of Belle Isle, despite the heavy coating which observers felt would impede swimming (Sergeant 1987). A telling clue to their condition, however, was that the pups were easily taken weeks later by seal hunters who reported that the animals uncharacteristically would not leave the ice floes (Sergeant 1987). This incident represents the worst possible combination of viscous residual oil in an ice-infested, cold water environment at a particularly vulnerable period in the life of a pinniped.

Detection and Avoidance of Oil

Pinnipeds are physiologically and anatomically well-equipped to detect the presence of oil, though no study has addressed this question experimentally. They have reasonably acute vision (Nachtigall 1986), particularly underwater over a wide range of light intensities. A large pupil and extensive summation of rod-type receptors facilitate discrimination under such low light conditions (Jamieson and Fisher 1972), and a well-developed tapetum further enhances this ability. Pinnipeds take advantage of these adaptations to feed at night (Renouf *et al.* 1980) or at great depths. In ice-covered seas, where ambient light is further reduced, Arctic seals readily travel between breathing holes, and are able to detect incongruities at the surface.

Pinnipeds appear to have a good sense of smell. They use olfaction to identify their young (Sandegren 1970, Fogden 1971, Renouf *et al.* 1983), and seals basking on ice floes test the air while maintaining their vigil against predators. We might expect that their olfactory sense is keen enough to detect hydrocarbon vapors.

It is unlikely that any pinniped has an acoustic sense as sophisticated as that found in some odontocetes. Studies on the ability of seals to echolocate (Renouf *et al.* 1980, Renouf and Davis 1982) have been challenged (Wartzok *et al.* 1984). Blind pinnipeds can survive for some time in the wild, presumably by taking maximum advantage of acoustic cues. However this provides no insight as to whether a seal can detect oil beyond its ability to see or smell it.

If they can detect it, why do some pinnipeds remain within its reaches long enough to become fouled? Perhaps they were unable or unwilling to avoid it, or that they did eventually, but only after coming in contact with it. We can judge the relative strength of the avoidance response in pinnipeds from observations following some of the major oil spills.

Most of the several thousand resident gray and harbor seals apparently left Chedabucto Bay, Nova Scotia, after the grounding of the <u>Arrow</u> (Mansfield 1970), though their response may have been as much to the marked increase in human activity as to the oil itself. Harbor seals temporarily abandoned Yell Sound in the Shetland Islands, Scotland, when Bunker C oil from the <u>Esso Bernicia</u> escaped from containment booms (Anderson 1981). The seals returned several weeks later, after most of the oil had beached. Native hunters from Wainwright, Alaska, reported that a chronic fuel spill which resulted in a 5 km-long slick was responsible for low numbers of seals in the area (Cowles *et al.* 1981), though their absence may have related more to changes in food distribution and abundance. Relatively few seals were observed in the vicinity of oil spilled from the <u>USS Potomac</u>, due more to the lack of sea ice than to presence of oil (Grose *et al.* 1979).

Such indirect and inconclusive evidence for oil avoidance behavior in pinnipeds is balanced by observations of seals, sea lions and fur seals swimming in the midst of oil slicks. After the Torrey Canyon spill, two gray seals were seen "deliberately" diving and surfacing in a patch of oil (Spooner 1967). Seals and sea lions did not abandon rookeries fouled after the oil well blowout in the Santa Barbara Channel, and showed no reluctance to enter oiled waters surrounding Anacapa and Santa Cruz Islands when disturbed by personnel from the California Department of Fish and Game (Battelle Memorial Institute 1969). In Alaskan waters, fur seals were apparently indifferent to small slicks of oil and mousse released from the <u>Ryuyo</u> <u>Maru</u> (Reiter 1981). Under confined laboratory conditions, three ringed seals placed in a pen containing seawater with a 1-cm thick slick made no attempt to use a haul-out platform. However, the platform was not provided until the animals had been in the pen for 20 minutes, and by then the seals may have been too excited or disoriented to notice its presence (Geraci and Smith 1976a).

A most intriguing account of the response of pinnipeds to oil comes from observations made over a five year period in Table Bay Harbour, Cape Town, South Africa (Shaughnessy and Chapman 1984). There, in inner reaches of the harbor where petroleum residues accumulate at the surface and in the water column, Cape fur seals regularly come to feed on fish inadvertently discharged from trawlers. The authors could not determine how long individuals remained within the harbor, or whether more seals would have been present if pollution levels were lower. Nevertheless, their observations demonstrate that a pinniped intent on a ready meal is not discouraged by the mere presence of oil.

Behavioral Effects

Oil spills could have a disruptive effect on individuals or populations by interfering with normal behavior patterns. Of particular concern is the effect on maternal behavior. Pinnipeds appear to rely on scent to establish a motherpup bond (Sandegren 1970, Fogden 1971), and oil-coated pups may not be recognizeable. On San Miguel Island, media representatives reported that female sea lions were biting and tossing pups which might have been their own (McMillan 1969). J. Bennett of the University of California, Santa Barbara, Museum of Zoology, observed in a limited survey that females appeared to ignore pups that attempted to suckle (Santa Barbara News-Press, June 29, 1969). In a systematic study of nursing behavior in oiled gray seals, Davis and Anderson (1976) concluded that mother-pup interactions were normal, though oiled pups had lower peak weights at weaning. Frequent attempts by the researchers to clean the pups likely disturbed nursing behavior more than did the oil itself. Earlier, Davies (1949) had noted that gray seals continued to nurse pups that were heavily contaminated with fuel oil.

Cape fur seals feeding within the heavily polluted Table Bay Harbour were observed to behave normally (Shaughnessy and Chapman 1984). An unusual behavior, noted on four occasions during the five-year observation period, was an uncharacteristic swimming posture in which a seal carried its head, neck and trunk above water for extended periods of time. No conclusion could be made as to whether these animals were responding to irritating substances in the water.

Fouled seals may be reluctant to enter the water, according to observers in the Gulf of St.Lawrence (Sergeant 1987) and Alaska (Anon. 1971). The seals in Alaskan waters had "a glazed look in their eyes", and were possibly disoriented after contacting a spill of light diesel fuel. The young harp seals in the Gulf, though weaned and mature enough to swim, were impeded by a heavy coating of Bunker C which stuck their flippers to their sides.

Surface Contact - Eyes and Mucous Membranes

The most sensitive tissues exposed to the environment are the mucous membranes that surround the eyes and line the oral cavity, respiratory surfaces, and anal and urogenital orifices. Petroleum hydrocarbons, particularly volatile aromatics and short-chain fractions, are irritating to these and other delicate tissues such as the cornea. People exposed to hydrocarbon vapors report irritation of eyes and respiratory epithelium at relatively low concentrations (Davis *et al.* 1960).

Ringed seals experimentally placed in crude oil-covered water showed a similar reaction (Smith and Geraci 1975). Within minutes after exposure to oil, the seals began to lacrimate profusely, and eventually had difficulty keeping their eyes open. By 24 hours, they developed severe conjunctivitis, swollen nictitating membranes, and corneal abrasions and ulcers. The inflammation subsided soon after the seals were placed in clean water. It is reasonable to assume that continued exposure could have resulted in permanent damage.

Similar effects have been observed in the natural setting (Lillie 1954). In addition, pinnipeds contacting highly weathered petroleum face persistent contamination of periocular tissues because of the tenacity of these viscous substances. Further compounding the problem is the tendency for tar to entrap debris, such as sand and sticks, to the point where some animals may have difficulty opening their eyes (Anon. 1969a). We can conclude that pinnipeds, with their relatively large, often protruding, eyes would be particularly vulnerable to such effects.

Surface Contact - Integument

Though not as sensitive as mucous membranes, epidermis can also be damaged by petroleum, particularly the low-molecular weight fractions (Walsh *et al.* 1974, Hansbrough *et al.* 1985). These components remove protective lipids from the skin surface, penetrate between epidermal cells, disrupt cellular membranes, and elicit an inflammatory response in the dermis (Lupulescu *et al.* 1973). Necrotic epidermis is generally sloughed, leaving ulcers. In humans, this can occur after contact for less than an hour (Klauder and Brille 1947, Tagami and Ogino 1973).

Despite the potential for cutaneous damage, such lesions have rarely been noted on oil-fouled seals. Van Haaften (1973) supposed that skin lesions on harbor seals recovered in Dutch waters resulted from contact with oil, but acknowledged that similar lesions occur without evidence of oil contamination. In a controlled experiment, Geraci and Smith (1976b) found no indication of skin damage in ringed seals immmersed in oil-covered water for 24 hours. Perhaps their dense wetable underfur prevented much of the oil from contacting the epidermis. Without evidence, we can only speculate that there would be a greater opportunity for contact and perhaps greater risk in species with relatively sparse pelage, such as the California sea lion and the walrus.

Of greater concern is the potential effect of surface fouling on thermoregulation. The marine environment is particularly demanding energetically, due to low temperatures and high specific heat of the medium. Pinnipeds are highly adapted to withstand immersion in near-freezing seas, using anatomic features and physiological mechanisms to maintain core body temperature. For insulation, they rely on a thick layer of subcutaneous fat (blubber), dense fur, or both. In an <u>in vitro</u> experiment, Kooyman *et al.* (1976, 1977) compared thermal conductance through pelts from northern fur seals, bearded and Weddell seals and California sea lions. The dense pelage of the northern fur seal provided the greatest resistance to heat transfer, whereas specimens from bearded seals and the sea lion had much higher conductance values.

Fur is an effective thermal barrier because it traps air and repels water. Petroleum reduces its insulative value by removing natural oils that waterproof the pelage. The rate of heat transfer through fur seal pelts can double after oiling (Kooyman *et al.* 1976, 1977), adding an energetic burden to the animal. In fact, fouling of approximately one-third of the body surface resulted in 50% greater heat loss in fur seals immersed in water at various temperatures (Kooyman *et al.* 1976).

Pinnipeds other than fur seals are less threatened by thermal effects of fouling, if at all. Oil has no effect on the relatively poor insulative capacity of sea lion and bearded and ringed seal pelts; oiled Weddell seal samples show some increase in conductance (Oritsland 1975, Kooyman *et al.* 1976, 1977). In oil-fouled ringed seals and weaned harp seal pups, core body temperature remained within the normal range, though it was not determined whether there was a compensatory increase in the animals' metabolic rate (Smith and Geraci 1975, Geraci and Smith 1976a). If we presume that blubber provides sufficient insulation in these species, we need only be concerned about the thermal effects of oil fouling of newborn phocids, which have little subcutaneous fat and are thought to rely on their lanugo, or birth coat, for insulation. Yet these animals are metabolically equipped to survive birth under rigorous Arctic or sub-Arctic conditions. By utilizing brown fat stores, newborn phocid seals can compensate for the relative ineffectiveness of lanugo made wet by amnionic fluid (Blix *et al.* 1979). It would be important to know whether these adaptations might offset the potentially deleterious effects of oil fouling until the pups establish adequate blubber.

A coating of oil may have other more obvious effects. Fouling can interfere with locomotion, particularly in young animals. Davis and Anderson (1976) observed two gray seal pups drowning, their "flippers stuck to the sides of their bodies such that they were unable to swim". Similar observations were made following a spill of heavy Bunker C oil in the Gulf of St. Lawrence, where the effect was compounded by low ambient temperatures. A larger stronger seal should be able to resist drowning, but may endure other effects of increased buoyancy due to a tarry coat. Oil might also impair the movements of more delicate structures such as eyelids and vibrissae.

Oil Ingestion

Petroleum is composed of a wide variety of hydrocarbons, some of which are toxic if ingested (Neff, Chapter 1). Aromatics and other low molecular weight fractions can be absorbed from the intestine and transported via the bloodstream to various target organs. Depending on the amount and composition of the ingested oil, the effects can range from acute death to subtle, progressive organ damage. Ingested hydrocarbons can irritate or destroy epithelial cells that line the stomach and intestine, thereby affecting motility, digestion and absorption. The effect might be compounded by pre-existing lesions or ulcerations, which frequently occur in pinnipeds infected with gastric nematodes (Geraci and St. Aubin 1987). Disruptions in the integrity of the mucosa could also facilitate the direct movement of petroleum fractions into the bloodstream. Effects on pinnipeds would presumably parallel those in other mammals.

Ingestion of petroleum hydrocarbons has been implicated in the deaths of a number of stranded gray and harbor seals along the coast of France (Duguy and Babin 1975, Babin and Duguy 1985). On post mortem examination, oil was grossly evident within discolored loops of intestine, and its presence was confirmed by gas chromatography in three of seven specimens analysed. Histopathologic changes in liver and intestine were seemingly correlated with the presence of oil in the gut. Yet, the authors admitted that carcasses were autolyzed, and their diagnosis might have been obscured.

The effects of crude oil ingestion have been examined in three studies on two species of phocid seals (Smith and Geraci 1975, Geraci and Smith 1976a, Engelhardt 1982). In all three experiments, relatively small doses of oil were used to duplicate conditions that might realistically occur in the wild; no attempt was made to establish lethal thresholds. Sensitive biochemical tests were used to monitor organ function and detect subtle changes in metabolic processes. No overtly deleterious effect was noted in harp seal pups given a single dose of up to 75 mL (1-3 mL/kg) of crude oil or in ringed seals given 5 mL of crude oil daily for up to five days. Harp seal pups ingesting oil vocalized more than control seals, and remained active for several hours after control pups had fallen asleep. Within 1.5 hours, oil was apparent in their feces, suggesting increased gastrointestinal motility. Analysis of tissue-specific enzyme activity in blood revealed mild liver damage in one of six seals given 75 mL of crude oil. The seals were killed and examined at scheduled intervals over a ten-day period following ingestion; no relevant lesions were noted.

Two similar studies on ringed seals focused on absorption, tissue distribution and clearance of petroleum hydrocarbons. Isotope-labelled benzene (Engelhardt *et al.* 1977) or naphthalene (Engelhardt 1982) was added to the oil, and tissues and body fluids were analyzed for levels of radioactivity. Labelled fractions were readily absorbed into the blood stream, and were detected in liver, blubber and muscle biopsies first collected two days after the initial dose of oil. Hepatic and renal enzyme systems were presumably responsible for the conversion of the labelled fractions to polar metabolites detectable in plasma and urine (Engelhardt 1982). In the liver of one of four seals tested, activity of aryl hydrocarbon hydroxylase (AHH) was apparently induced to levels four to five times higher than in the other seals; AHH activity was elevated in the kidneys of the other three. Tissue levels of radioactivity declined rapidly within two weeks (Engelhardt *et al.* 1977), but were still present in trace amounts after four weeks.

Plasma activity of tissue-specific enzymes in the seals remained within normal ranges throughout the ten-day monitoring period after oil ingestion (Smith and Geraci 1975). After four daily doses of crude oil, plasma cortisol levels were markedly increased (Engelhardt 1982), though without adequate controls it is not possible to ascertain whether this was a consequence of oil ingestion or the stress of repeated handling as the oil was administered. Similarly, the apparent increase in cortisol turnover evident in two of three seals cannot be interpreted as a direct consequence of oil ingestion, since there were no controls for the superimposed stresses of handling.

These limited studies demonstrated that phocid seals can tolerate small To predict the amount of petroleum which might quantities of ingested oil. potentially be toxic, we must extrapolate from data derived for terrestrial species. In rats, the LD_{so} for ingested fuel oils ranges between 5 and 25 mL/kg (Elars 1980 a-d). Thus, a small phocid such as a ringed or harbor seal weighing 50 kg might have to ingest approximately 1 L of fuel oil to be at risk; for an adult male elephant seal, the quantity would be 30 L or more. It is unrealistic to assume that pinnipeds would consume such large volumes of oil during the course of normal feeding. Nor would grooming present a potential route for ingestion; this activity is relatively uncommon in pinnipeds (McLaren, Chapter 2). Davis and Anderson (1976) found no evidence of ingested oil in the stomachs of heavily oiled gray seal pups, and no hydrocarbon residues were detected in blood and tissues collected from seals and sea lions at the time of the Santa Barbara spill (Simpson and Gilmartin 1970). Viscous oil and tar have been noted in the mouths of seals (Anon 1970a) and sea lions (Calkins 1979), though in these instances the effect would more likely be mechanical interference with feeding than metabolic toxicity.
Chronic ingestion of sub-toxic quantities of petroleum may have subtle effects which would only become apparent through long-term monitoring. A11 pinnipeds examined to date have the enzyme systems necessary to convert absorbed hydrocarbons into polar metabolites which can be excreted in urine (Engelhardt 1982. Addison and Brodie 1984, Addison et al. 1986). However, some proportion of the non-polar fractions will be deposited in lipid-rich tissues, particulary blubber. The occurrence of petroleum residues has been noted in several species of pinniped (Risebrough et al. 1978, Geraci and St. Aubin 1985), though there is no direct evidence of associated pathologic or metabolic effects. Nor is there evidence that such compounds will accumulate with repeated exposure. Other pollutants that do, including PCB's and DDT, have been implicated in reproductive disorders affecting ringed seals in the Baltic Sea (Helle et al. 1976) and California sea lions (DeLong et al. 1973, Gilmartin et al. 1976), and petroleum hydrocarbon residues might enhance this effect. Mobilization of fat stores during annual molting and reproductive periods could lead to release of residues, and possibly enhance toxicity at those times. Transfer of petroleum fractions via lipid-rich milk is also a potential route of exposure to pups, which have significantly lower levels of some of the detoxifying enzymes (Addison et al. 1986).

Inhalation

There has been no study to assess the effects of inhaled hydrocarbon vapors in pinnipeds. However, indirect evidence from immersion studies and data extrapolated from terrestrial mammals can be used to predict possible consequences in these species. We begin with the basic assumption, for which evidence is accumulating, that pinnipeds have metabolic systems similar to those in other mammals for detoxifying absorbed hydrocarbons.

Ringed seals placed in a pen containing oil-covered water for 24 hours had levels of petroleum hydrocarbons up to several ppm in blood and tissues (Engelhardt *et al.* 1977). Since there was no postmortem evidence of ingested oil, the investigators concluded that uptake of hydrocarbons had occured across the respiratory epithelium. One of the six seals had histological evidence of renal tubular necrosis and fatty degeneration in the liver; a second seal had kidney lesions only (Smith and Geraci 1975). The occurence of these lesions correlated with tissue concentrations of petroleum hydrocarbons; the nature of the damage was similar to that observed in laboratory species (Nau *et al.* 1966). Plasma levels of a liver-specific enzyme, alanine aminotransferase, were mildly elevated in three of the seals, including the one with morphologic evidence of liver damage; there was no consistent pattern in any of the other plasma chemical constituents analyzed.

Vapor concentrations in the experimental setting were not measured. However, exposure conditions were intensified to some degree by the design of the pen, which had plywood walls extending 60-70 cm above water, thereby retarding the dissipation of volatile fractions. Yet the absence of pathologic changes in the lungs of the seals would suggest that the levels were less than 500 ppm. Twenty-four hour exposure to more concentrated vapors generally results in hemorrhage, inflammation and congestion in the lungs of a variety of laboratory species (Carpenter *et al.* 1975, 1976).

In a subsequent immersion study, three ringed seals acclimated to captivity for two months died within 71 minutes after oil was introduced to their pool (Geraci and Smith 1976a). Exposure to gasoline vapor concentrations in excess of 10,000 ppm is rapidly fatal in humans (Machle 1941), yet it was highly unlikely that such levels could have been attained in the open setting of this experiment. The seals' death was interpreted as the cumulative effect of a variety of stresses associated with transportation, captivity and the experimental regime. The proximate cause of death was likely cardiac fibrillation triggered by the synergistic effects of high circulating levels of epinephrine and hydrocarbons. Similar occurrences have been noted occasionally in humans who have been chased after intentionally sniffing gasoline (Bass 1986).

This observation has significant implications for free-ranging pinnipeds stressed by parasitism or other pre-existing metabolic disorders. In such animals, brief exposure to relatively low concentrations of hydrocarbon vapors might be fatal if combined with other stimuli eliciting a major adrenal response. Parasitic lung disease, a relatively common finding in pinnipeds (Geraci and St. Aubin 1987), would further complicate the effects of even mild irritation of respiratory tissues. For most pinnipeds, particularly in northern habitats, it is unlikely that petroleum vapors could become sufficiently concentrated to represent a threat. However, selected individuals within a given population may be particularly sensitive and thus be predisposed to the deleterious effects of inhaled hydrocarbon vapors.

Summary

Oil fouling has been implicated in the deaths of pinnipeds, though much of the evidence has been circumstantial. Large-scale mortality has occurred rarely, even after some of the more catastrophic spills. In general, the prediction that spilled oil would have its greatest impact on young pinnipeds in cold, ice-bound waters has been borne out following the discharge of residual oil in the Gulf of St. Lawrence in 1969.

Pinnipeds are not unduly sensitive to the noxious characteristics of oil. Incidental ingestion during feeding, exposure to vapor concentrations that might be expected under natural conditions at sea, and surface fouling with relatively fresh oil do not appear to cause significant distress. Pinnipeds trapped near the source of a spill, or forced to emerge in heavy accumulations of oil in leads and around rookeries will undoubtedly exhibit the most severe effects. For fur seals, experimental studies indicate that surface fouling will decrease the insulative value of the pelt, possibly leading to thermal and energetic stress. Individuals of all species and groups that are compromised by pre-existing disease, or stressed by pressures of an unfavorable habitat, intra-specific competition, or unusual environmental conditions may be the most sensitive to the effects of oil exposure.

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Literature Cited

- Addison R.F. and P.F. Brodie. 1984. Characterization of ethoxyresorufin O-de-ethylase in gray seal <u>Halichoerus grypus</u>. Comp. Biochem. Physiol. 79C: 261-263.
- Addison, R.F., P.F. Brodie, A. Edwards and M.C. Sadler. 1986. Mixed function oxidase activity in the harbour seal (<u>Phoca vitulina</u>) from Sable Is., N.S. Comp. Biochem. Physiol. 85C (1): 121-124.
- Anderson, S.S. 1981. Seals in Shetland waters. Proc. Royal Soc. Edinburgh. 80B: 181-188.
- Anon. 1969a. The dead channel. Time (February 21), pp. 23.
- Anon. 1970a. Report of the Task Force- Operation Oil -to the Minister of Transport. Information Canada 2: 46-47.
- Anon. 1970b. Nature in Wales. Mammals. 12(2):110.
- Anon. 1971. Alaska Peninsula oil spill. Smithsonian Inst. Center for Short-Lived Phenomena. Annual Report (1970). Event No. 36-70. pp. 154-157.
- Babin P. and R. Duguy. 1985. Intoxication due aux hydrocarbures ingeres par <u>Halichoerus grypus</u> et <u>Phoca vitulina</u>. Conseil Intn. L'Exploration de la Mer. London. CM1985/N:12.
- Bass, M. 1986. Sniffing gasoline. J. Amer. Med. Assoc. 255 (19): 2604-2605.
- Battelle Memorial Institute. 1969. Review of Santa Barbara Channel oil pollution incident. Report for Dept. of the Interior and Dept. Transportation. Contract No. 14-12-530. 157 pp.
- Blix, A.S., H.J. Grav and K. Ronald. 1979. Some aspects of temperature regulation in newborn harp seal pups. Am. J. Physiol. 236 (3): R188-R197.
- Bourne, W.R.P. 1979. The <u>Christos Bitas</u> affair. Mar. Pollution Bull. 10 (5): 122-123.
- Brownell, R.L., Jr., and B.J. Le Boeuf. 1971. California sea lion mortality: natural or artifact? Biol. and Bacteriol. 1: 287-306.
- Calkins, D.G. 1979. Marine mammals of Lower Cook Inlet and the potential for impact from outer continental shelf oil and gas exploration, development and transport. Final Report. Outer Continental Shelf Environ. Assessment Program. pp. 171-264.
- Carpenter, C.R., E.R. Kinkead, D.L. Geary, L.J. Sullivan and J.M. King. 1975. Petroleum hydrocarbon toxicity studies. V. Animal and human responses to vapors of mixed xylenes. Toxicol. Appl. Pharmacol. 33: 543-558.
- Carpenter, C.R., E.R. Kinkead, D.L. Geary, L.J. Sullivan and J.M. King. 1976. Petroleum hydrocarbon toxicity studies. XIII. Animal and human response to vapors to toluene concentrate. Toxicol. Appl. Pharmacol. 36: 473-490.
- Cowles, C.J., D.J. Hansen and J.D. Hubbard. 1981. Types of potential effects of offshore oil and gas development on marine mammals and endangered species of the northern Bering Sea and Arctic Ocean. Tech. Paper No. 9, Bureau of Land Management, Alaska OCS Office, Anchorage, AK. 23 pp.

Davies, J.L. 1949. Observations on the gray seal (<u>Halichoerus grypus</u>) at Ramsey Island, Pembrokeshire. Proc. Zool. Soc. London, 119: 673-692.

Davis, A., L.J. Schafer and Z.G. Bell. 1960. The effects on human volunteers of exposure to air containing gasoline vapors. Arch. Environ. Health 1: 548-554.

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

DeLong, R.L., W.G. Gilmartin and J.G. Simpson. 1973. Premature births in California sea lions: association with high organochlorine pollutant residue levels. Science 181:1/68-1/70.

Duguy, R. and P. Babin. 1975. Acute intoxication by hydrocarbons observed in a harbor seal (<u>Phoca vitulina</u>). Conseil Intern. L'Explor. de la Mer, Comite de Mammiferes Marins. Report C.M. 1975/N:5.

Easton, R. 1972. Black tide: the Santa Barbara oil spill and its consequences. Delcorte Press, New York, NY. 336 pp.

Elars Bioresearch Laboratories, Inc. 1980a. Acute toxicity tests of API 78-2 No. 2 home heating oil (30% Cat). Project 1443. Amer. Petro. Inst. Med. Res. Publ. 2732771. 48 pp.

Elars Bioresearch Laboratories, Inc. 1980b. Acute toxicity tests of API 78-7 No. 6 heavy fuel oil (API gravity 17.1/0.8% S). Project 1443. Amer. Petro. Inst. Med. Res. Publ. 2732774. 45 pp.

Elars Bioresearch Laboratories, Inc. 1980c. Acute toxicity tests of API 79-2 No. 6 heavy fuel oil (API gravity 5.2/1.2% S). Project 1443. Amer. Petro. Inst. Med. Res. Publ. 2732813. 52 pp.

Elars Bioresearch Laboratories, Inc. 1980d. Acute toxicity tests of API 78-6 No. 6 heavy fuel oil (API gravity 11.7/2.7% S). Project 1443. Amer. Petr. Inst. Med. Res. Publ. 2732814. 47 pp.

Engelhardt, F.R. 1982. Hydrocarbon metabolism and cortisol balance in oilexposed ringed seals, <u>Phoca hispida</u>. Comp. Biochem. Physiol. 72C: 133-136.

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

Environmental Sciences Ltd. 1981. A prospectus on the biological effects of oil spills in marine environments. Dome Petro. Ltd., Calgary. Document No. BEISSD 13.

Fogden, S.C.L. 1971. Mother-young behavior at gray seal breeding beaches. J. Zool. 164: 61-92.

Geraci, J.R. and T.G. Smith. 1976a. Direct and indirect effects of oil on ringed seals (<u>Phoca hispida</u>) of the Beaufort Sea. J. Fish. Res. Board Can. 33 (9): 1976-1984.

Geraci, J.R. and T.G. Smith. 1976b. Behavior and pathophysiology of seals exposed to crude oil. Proc. Symp. Sources, Effects and Sinks of Hydrocarb. the Aquatic Environ. Amer. Inst. Biol. Sci., Washington, DC. pp. 448-462.

Geraci, J.R. and D.J. St. Aubin. 1985. Study of the effects of oil on cetaceans. Final Report. U.S. Dept. of the Interior, Bureau of Land Management, Washington, DC. Contract No. AA551-CT9-29. 274 pp.

Geraci, J.R. and D.J. St. Aubin. 1987. Effects of parasites on marine mammals. Int. J. Parasit. 17 (2): 407-414.

Gill, C., F. Booker and T. Soper. 1967. The Wreck of the <u>Torrey Canyon</u>. David & Charles Publ., Newton Abbot, U.K. 128 pp.

- 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.
- Grose, P.L., J.S. Mattson and H. Petersen. 1979. Marine mammals and sea birds. Nat. Tech. Inf. Serv. Publ. No. PB80-173727. pp. 9-1 - 9-8.
- Hansbrough, J.F., R. Zapata-Sirvent, W. Dominic, J. Sullivan, J. Boswick and X-W. Wang. 1985. Hydrocarbon contact injuries. J. Trauma 25: 250-252.
- Helle, E., M. Olsson and S. Jensen. 1976. PCB levels correlated with pathological changes in seal uteri. Ambio 5: 261-263.
- Jamleson, G.S. and H.D. Fisher. 1972. The pinniped eye: a review. pp. 245-261. In Functional Anatomy of Marine Mammals. Volume 1. R.J. Harrison (ed.). Academic Press, London, U.K. 451 pp.
- Klauder, J.V. and F.A. Brille. 1947. Correlation of boiling ranges of some petroleum solvents with irritant action on the skin. Arch. Dermatol. Syph. 56: 197-215.
- Kooyman, G.L., R.L. Gentry and W.B. McAllister. 1976. Physiological impact of oil on pinnipeds. Report N.W. Fisheries Center, Natl. Mar. Fish. Serv., Seattle, WA. 23 pp.
- 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. pp. 151-157. In Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D.A. Wolfe (ed.). Pergammon Press, New York, NY.
- Le Boeuf, B.J. 1971. Oil contamination and elephant seal mortality: a "negative" finding. Biol. and Bacteriol. 1: 277-285
- Lillie, H. 1954. Comments in discussion. Proc. Intern. Conf. Oil Pollution (1953), London. pp. 31-33.
- Lupulescu, A.P., D.J. Birmingham and H. Pinkus. 1973. An electron microscopic study of human epidermis after acetone and kerosene administration. J. Invest. Derm. 60: 33-45.
- Machle, W. 1941. Gasoline intoxication. J. Am. Med. Assoc. 117: 1965-1971.
- Mansfield, A.W. 1970. Field report of seal investigations in Chedabucto Bay and at Sable Island, Nova Scotia 2 March-7 April 1970. Fish. Res. Board Can., Arctic Biol. Stn., Ste. Anne de Bellevue, P.Q. 3 p.
- McMillan, I.I. 1969. Another look at the big slick. Defenders of Wildl. News 44: 149-153.
- Nachtigall, P.E. 1986. Vision, audition, and chemoreception in dolphins and other marine mammals. pp. 79-113. In Dolphin Cognition and Behavior: A Comparative Approach. R.J. Schusterman, J.A. Thomas and F.G. Wood (eds.). Lawrence Erlbaum Assoc., Publ., Hillsdale, NJ. 393 pp.
- Nau, C.A., J. Neal and M. Thornton. 1966. C9-C12 fractions obtained from petroleum distillates. An evaluation of their potential toxicity. Arch. Environ. Health 12: 382-393.
- Odell, D.K. 1970. In Proc. 7th Annual Biosonar and Diving Mammal Conf., Stanford Res. Inst., Menlo Park, CA.

- Oritsland, N.A. 1975. Insulation in marine mammals: the effect of crude oil on ringed seal pelts. pp. 48-67. In The Effect of Contact and Ingestion of Crude Oil on Ringed Seals of the Beaufort Sea. T.G. Smith and J.R. Geraci (eds.). Beaufort Sea Project. Inst. of Ocean Sci., Sidney, British Columbia. Technical Report No. 5.
- Parsons, J., J. Spry and T. Austin. 1980. Preliminary observations on the effect of Bunker C fuel oil on seals on the Scotian shelf. Proc. Workshop, Bedford Inst. Oceanography, Dartmouth, Nova Scotia. pp. 193-202.
- Prieur, D. and E. Hussenot. 1978. Marine mammals stranded during the <u>Amoco Cadiz</u> oil spill. Penn ar Bard 11 (94): 361-364.
- Reiter, G.A. 1981. Cold weather response F/V <u>Ryuyo Maru</u> No. 2, St. Paul, Pribiloff Islands, Alaska. pp. 227-231. Proc. Oil Spill Conf., Amer. Petrol Inst.Publ. No. 4334, Washington, DC. 742 pp.
- Renouf, D. and M.B. Davis. 1982. Evidence that seals may use echolocation. Nature 300 (5893): 635-637.
- Renouf, D., G. Galway and L. Gaborko. 1980. Evidence of echolocation in harbour seals. J. Mar. Biol. Asso. 60: 1039-1042.
- Renouf, D., J. Lawson and L. Gaborko. 1983. Attachment between harbor seal (<u>P. vitulina</u>) mothers and pups. J. Zool. 199: 179-187.
- Risebrough, R.W., W. Walker II, A.M. Springer, J.R. Clayton, E.F. Letterman, J.R. Payne and T.T. Schmidt. 1978. A search for pollutants of petroleum origin in tissues of harbor seals, <u>Phoca vitulina</u>, in San Francisco Bay. Marine Mammal Commission, Final Report. Contract No. MM7AC007. 41 pp.
- Sandegren, F.E. 1970. Breeding and maternal behavior of the Steller sea lion (<u>Eumetopias jubata</u>) in Alaska. M.Sc. Thesis, Univ. Alaska, Anchorage, AK.
- Sergeant, D.E. 1987. Harp seals, man and ice. Unpublished manuscript.
- Shaughnessy, P.D. and P. Chapman. 1984. Commensal Cape fur seals in Cape Town docks. S. African J. Mar. Sci. 2: 81-91.
- Simpson, J.G. 1970. Elephant seals and California sea lions apparently not killed by Santa Barbara oil spill. Biol. Conserv. 2 (2): 89.
- Simpson, J.G. and W.G. Gilmartin. 1970. An investigation of elephant seal and sea lion mortality on San Miguel Island. BioSci. 20 (5): 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 Project. Inst. of Ocean Sci., Sidney, British Columbia. Technical Report No. 5.
- Snell, D. 1969. Iridescent gift of death. Life 66 (23): 22-27.
- Spooner, M.F. 1967. Biological effects of the <u>Torrey Canyon</u> disaster. J. Devon Trust Nat. Conserv. pp. 12-19.
- Tagami, H. and A. Ogino. 1973. Kerosene dermatitis; factors affecting skin irritability to kerosene. Dermatologica 146: 123-131.
- van Haaften, J.L. 1973. Die Bewirtschaftung von Seehunden in den Neiderlanden [Seal management in the Netherlands]. Beitrage zur Jagd - und Wildfurschung 8: 345-349.
- Walsh, W.A., F.J. Scarpa, R.S. Brown, K.W. Ashcraft, V.A. Green, T.M. Holder and R.A. Amoury. 1974. Gasoline immersion burn. New Engl. J. Med. 291: 830.
- Warner, R.E. 1969. Environmental effects of oil pollution in Canada: an evaluation of problems and research needs. Report Can. Wildl. Serv., Ottawa. 30 pp.

Wartzok, D., R. Schusterman and J. Gailey-Phipps. Seal echolocation. 1984. Nature 308: 753.

CHAPTER 4

CETACEANS AND OIL:

ECOLOGIC PERSPECTIVES

B. Wursig

Moss Landing Marine Laboratory P.O. Box 450 Moss Landing, California 95039-0450

Introduction

Cetaceans are derived from terrestrial protoungulates, having diverged from the ungulate stock over 50 million years ago (Barnes 1984). As a group, cetaceans have invaded water more extensively than have other marine mammals. They now occur in all oceans, from the tropics to the ice edges, and one family is found in some major river systems as well. Only pelagic depths are unavailable to them, although the sperm whale is known to dive to depths over one kilometer (Gaskin 1964).

The order Cetacea is divided into two suborders: the mysticetes or baleen whales and the odontocetes or toothed whales, dolphins, and porpoises. The baleen whales comprise 11 species in three families: the Balaenidae or right and bowhead whales (four species), the Balaenopteridae or rorqual whales (six species), and the Eschrichtidae or gray whale. All baleen whales are large. They range in size from the little-known pygmy right whale, about 5 m long to the blue whale, from 25 to 30 m in length - the largest living animal.

All baleen whales feed by taking small invertebrates or fish into their mouths and expelling water through baleen plates, which hang from the upper jaw. The Balaenidae are generally slow feeders that move through the water column with mouths open, all the while straining water through their long, fine baleen. The rorquals are more active feeders, often rapidly lunging through clouds of prey, taking in huge gulps of water and prey while distending their throats, then partially closing the mouth and squirting water through short, coarse baleen. The gray whale filters invertebrates from the bottom substrate (and at times from the water column), and does so in less energetic fashion than the very active lunge feeding rorqual whales. Baleen whales travel and feed in groups, and solitary animals are the exception.

The toothed whales, dolphins, and porpoises comprise a large and diverse taxonomic group, from the small river dolphins and coastal porpoises to the sperm whale, the largest toothed animal on earth. Although taxonomic schemes vary, most identify 68 species in six families: Physeteridae or sperm whales (three species), Monodontidae or narwhal and beluga (two species), Ziphiidae or beaked whales (18 species), Delphinidae or coastal and oceanic dolphins (34 species), Phocoenidae or true porpoises (six species), and Platanistidae or river dolphins (five species) (Rice 1977). Diet can vary, even between populations of the same species, but overall, fishes and squid are preferred by odontocetes. Most toothed whales are gregarious, usually occurring in groups numbering a few to many dozens of individuals. Pelagic Delphinidae sometimes occur in groups of several thousand animals (Nishiwaki 1975) reminiscent of herds of terrestrial ungulates.

Distribution: Cetaceans occur worldwide, yet most species are geographically confined. For example, the odontocete genus <u>Lagenorhynchus</u> has six species occurring in separate or partially overlapping areas. Two of these species occur in the northern North Atlantic, one in the northern North Pacific, two in various areas of the South Pacific, and one is confined to coastal waters of southern South America. This antitropical distribution is shared with of other genera:

northern and southern hemisphere right whales, true porpoises, and right whale dolphins. Only two families, the Eschrichtidae and the Monodontidae are restricted to one (the northern) hemisphere.

In keeping with the focus of this analysis, I will give an account of the distribution of cetacean species that commonly occur in North American Outer Continental Shelf waters. For the sake of convenience, I will proceed geographically, covering Arctic waters, then the North Pacific, North Atlantic, and the Gulf of Mexico.

Bowhead whales are the northernmost mysticetes, always living near ice in the Bering - Chukchi - Beaufort Sea of the western Arctic, and in the Baffin Bay - Hudson Bay - Labrador Sea area of the eastern Arctic (Figure 4.1). They have well-defined migration routes, often restricted by extensive ice cover (Reeves et al. 1983, Braham et al. 1984). Oil development activities occur along their main migratory and feeding routes in the western Arctic (Richardson et al. 1987). Narwhals and belugas co-exist with bowheads in part of their range. Narwhals are mainly restricted to Canadian waters of the eastern Arctic, while belugas occur on both sides of the continent, as far south as British Columbia on the Pacific side and along the Canadian maritime provinces on the Atlantic side (Reeves and Katona 1980), with one discrete stock in the Gulf of St. Lawrence (Sergeant 1973, Sergeant and Hoek 1974).

Gray whales occur in the Bering, Chukchi and occasionally the Beaufort Sea (Rugh and Fraker 1981, Berzin 1984) in summer, and as far south as mid-Mexico in the Pacific Ocean in winter (Figure 4.2) (Norris *et al.* 1983). Blue, fin, and humpback whales may be found anywhere from the lower Bering Sea to the shores of Mexico, but seem to concentrate seasonally in certain areas. For example, blue and humpback whales are seen around the Farallon Islands off southern California in late summer (Dohl *et al.* 1983); humpback whales occur in the Gulf of Alaska and in fjords of the Alaskan panhandle in summer (Figure 4.3) (Hall 1979, Rice and Wolman 1981); fin whales occur in the northern Gulf of California year-round (pers. observ.). Minke whales are almost cosmopolitan; they are widely distributed in the Bering Sea, Gulf of Alaska, Puget Sound, and along the United States west coast. They are seldom seen north of the Bering Strait (Rice 1974). Sei whales occur from California northward to the Gulf of Alaska, but they favor oceanic over coastal waters (Masaki 1977, Leatherwood *et al.* 1982).

A number of odontocete species range along the Pacific coast. Harbor porpoises occur close to shore in bays and estuaries from the Bering Strait south to Point Conception, California (Norris and Prescott 1961, Gaskin *et al.* 1974), and Dall's porpoises from the northern Bering Sea to the Mexican border (Morejohn 1979, Jefferson, in press). Pacific white-sided dolphins range from the Aleutian chain to the southern tip of the Baja Peninsula (Leatherwood *et al.* 1984); northern right whale dolphins have a similar distribution, although they do not frequent waters north of British Columbia or south of Central Baja (Leatherwood and Walker 1979). Dall's porpoises, Pacific white-sided dolphins, and northern right whale dolphins inhabit generally deeper water than harbor porpoises, ranging hundreds of kilometers from the coast, occasionally coming close to shore over submarine canyons and off headlands (Leatherwood *et al.* 1982). Common dolphins occur from the tropics to the limits of warm temperate



Figure 4.1 Distribution of bowhead whales

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Figure 4.2 Distribution of gray whales



Figure 4.3 Distribution of humpback whales, North Pacific

waters in all oceans, as far north as northern California in the summer (Evans 1982a, Dohl *et al.* 1986). Risso's dolphins (Leatherwood *et al.* 1980) and shortfinned pilot whales (Norris and Prescott 1961) have a similar distribution in the Pacific, while bottlenose dolphins rarely venture north of Point Conception, California (Walker 1981). Killer whales are cosmopolitan but relatively rare anywhere nearshore except in Puget Sound, Washington, and in the Gulf of Alaska, where they feed on abundant stocks of salmon (Matkin and Leatherwood 1986, Heyning and Dahlheim 1988).

The distribution of cetaceans along the western North Atlantic is not unlike that in the eastern North Pacific, except that the Gulf Stream allows warm temperate species to extend to higher latitudes in the Atlantic. Humpback (Figure 4.4), fin, sei, and minke whales can be found anywhere from Florida to the Canadian maritime provinces, but tend to concentrate seasonally in certain areas such as the Gulf of St. Lawrence and the banks off New England (Caldwell and Golley 1965, Sergeant *et al.* 1970, Sergeant 1977). Northern right whales, reduced to less than one thousand individuals in the North Atlantic (Winn *et al.* 1981), apparently are increasing in numbers (Kraus 1985). They congregate close to shore off New England in summer and off Georgia and Florida in winter (Kraus *et al.* 1986).

Short-finned pilot whales range from the tropics to Delaware Bay; longfinned pilot whales prefer cold temperate waters north of Cape Hatteras (Mitchell 1975, Leatherwood et al. 1976), whereas white-beaked and Atlantic white-sided dolphins are found still further north. Bottlenose dolphins occur from the Canadian maritime provinces southward along the United States coastline, as two An inshore group with a more southerly distinguishable subpopulations: distribution, and a pelagic stock which ranges further north. Risso's dolphins share the same distribution as the offshore bottlenose dolphins. Harbor porpoises occupy cold temperate waters from North Carolina to the Arctic, always close to shore. Common, spotted, and striped dolphins occur throughout the tropical and warm temperate Atlantic, with striped dolphins generally far Spinner dolphins are mainly tropical and subtropical and hardly ever offshore. venture north of Florida. Killer whales occasionally visit along the North Atlantic coastline (Reeves and Mitchell 1987).

The Gulf of Mexico is home to many cetacean species, including the tropical Bryde's whale, short-finned pilot whale, several species of the genus <u>Stenella</u> (spotted, striped and spinner dolphin), common dolphin, Risso's dolphin, and sperm whale. The most numerous inshore inhabitat is the widely studied Atlantic bottlenose dolphin (Figure 4.5) (Shane 1980, Wells *et al.* 1980, Shane *et al.* 1986).

This brief overview provides some indication of the richness and diversity of cetacean fauna along the shores of North America. In addition, there are several species that tend to stay in deep, usually pelagic, waters. These include sperm whales, several species of beaked whales, and pelagic dolphins. Although contact with oil by these species is a possibility, especially as oil exploration moves into deeper water on the continental slope and rise, the chances are considerably less than for inshore forms.









Life Histories

Cetaceans give birth to single young, after gestation periods varying from about 11 months in the small harbor porpoise (Gaskin *et al.* 1984) to 15 months in the much larger pilot, killer and sperm whales (Best *et al.* 1984, Kasuya and Marsh 1984). Most of the medium-sized odontocetes, such as the bottlenose dolphin, have a gestation time of approximately 12 months (Sergeant *et al.* 1973). Duration of pregnancy tends to increase with size in the toothed whales, a correlation that does not hold for baleen whales which are constrained to gestation periods of less than one year. Seasonal migrations take them to coldwater feeding grounds in the summer, where calving is unsuitable, leaving only a narrow seasonal window for reproductive activity.

This migratory cycle of baleen whales also places constraints on duration of lactation which in baleen whales is completed in less than a year (Tyack 1986). In odontocetes, lactation ranges from about seven months in the harbor porpoise to well over one year in most others Short gestation and lactation periods in baleen whales are part of a tremendously rapid growth which continues to adulthood. The large blue whale, for example, has a gestation period of 11 months, is weaned at seven months, and is sexually mature at five years (Lockyer 1984). Sperm whales, on the other hand, are born after 15 months gestation, are weaned at approximately two years (with some suckling as long as 13 years), and take from nine years (females) to 20 years (males) to become sexually mature (Best *et al.* 1984).

Toothed whales larger than dolphins and porpoises tend to have inter-calf intervals greater than three years (with six years the norm for sperm whales), but most baleen whales give birth every two years. Bowhead and right whales are an exception; they have inter-calf intervals generally three years or longer (Payne and Dorsey 1983, Nerini *et al.* 1984). Rapid development and high calf production in most baleen whales would indicate they are relatively short-lived, but aging techniques are not sufficiently reliable to test the hypothesis. Slower developing odontocetes, such as sperm, killer, and pilot whales, can reach ages of 50 years, and possibly more (Best 1979, Perrin and Reilly 1984).

Mysticetes generally have a restricted diet. Gray whales feed mainly on bottom-dwelling tube worms and ampeliscid amphipods (Nerini 1984), Bowhead and right whales consume clouds of euphasiid crustaceans and calanoid copepods (Lowry and Frost 1984), whereas smaller rorquals prefer schools of fishes (such as menhaden <u>Brevoortia tyrannus</u>, capelin <u>Mallotus villosus</u> and sandlance <u>Ammodytes</u> sp.), and larger rorquals, euphausiid crustaceans (Pivorunas 1979). However, most are opportunistic and will take advantage of a wider range of prey.

A restricted diet is characteristic of some toothed whales as well, particularly sperm and beaked whales which feed mainly on squid. Coastal and oceanic dolphins have more catholic diets, and their prey selection may vary seasonally between different populations of the same species, and between feeding sessions throughout the day. For example, Hawaiian spinner dolphins, Pacific white-sided dolphins, and pilot whales feed on a variety of mesopelagic fishes and squid. In Argentina, dusky dolphins feed on bottom-dwelling fishes in winter, and on schools of southern anchovy <u>Engraulis anchoita</u> during summer (Wursig and Wursig 1980). Off New Zealand, the same species concentrates on nonschooling mesopelagic prey throughout the year, since schooling fishes are unavailable (Cipriano 1985, Wursig 1986).

The diet of toothed whales is not limited to fishes and squid. Bottomdwelling invertebrates may also be taken by bottlenose dolphins, belugas and harbor porpoises, among others. Transient killer whales of the Pacific Northwest eat harbor seals (Heimlich-Boran 1987), and off Argentina feed on elephant seals, sea lions, and Magellanic penguins (<u>Spheniscus magellanicus</u>) (Lopez and Lopez 1985).

Habitat Use

Habitat Features: Whales and dolphins utilize most oceanic habitats. Some, such as coastal shallows or offshore feeding banks, estuaries, bays, nearshore submarine canyons, and the ice-edge might restrict their movements and therefore their ability to avoid contaminated waters in those habitats. Bowheads, gray whales, belugas and narwhals are particularly vulnerable to exposure as they pass through confined leads in heavy ice. In the North Atlantic, right, humpback, and fin whales concentrate much of their activity on the Continental Shelf to within several kilometers of shore. Right whales winter and apparently calve in coastal waters from Cape Hatteras, North Carolina, to Miami, Florida, with peak abundance in January through March (Winn 1984, Kraus et al. 1984, Kraus 1985). From March to April, they occupy Cape Cod Bay, where they feed and may also calve (Watkins pers. comm.). Thereafter, through November, they concentrate in the Bay of Fundy and the southern Nova Scotian Shelf (Mitchell et al. 1986). Humpback and fin whales also occur in shallow waters, nearshore and on banks off Cape Cod, where their concentrations relate to the distribution of sandlance (Hain et al. 1982).

During winter, gray whales of the North Pacific inhabit coastal lagoons and bays of Baja California, Mexico, migrate close to shore between Mexico and Alaska during spring and fall, and in summer feed on infaunal benthic invertebrates in coastal shallows of the northern Bering and southern Chukchi Seas (Oliver *et al.* 1983, Jones and Swartz 1984, Mate and Harvey 1984). Ice may also limit the movements of gray whales during the fall in some years.

Bowhead whales in the western Arctic are similarly constrained. They winter along the ice edge and in open leads (polynyas) in the mid- to northern Bering Sea, migrate through the Bering Strait and into the Chukchi and Beaufort Seas in spring, and spend the summer feeding in the Beaufort Sea (Braham *et al.* 1984). Summer habitat varies within and between seasons, depending on winds and currents which affect the distribution of copepods and euphausiids. Thus it is not possible to predict their precise location within the summer range (Richardson *et al.* 1987). Little is known about their distribution patterns along the ice edge in the Bering Sea in winter. Killer whales, belugas, bottlenose dolphins, and harbor porpoises occur close to shore and in restrictive bays and waterways. Their ranges overlap considerably with areas of oil production and shipping activities (Neff, Chapter 1). Some examples are killer whales in Puget Sound and the Gulf of Alaska, bottlenose dolphins in the Gulf of Mexico, and beluga whales and harbor porpoises in northern bays and fjords. Other more pelagic toothed whales and dolphins may encounter spilled oil from offshore ship traffic, or when they venture close to shore following deep water channels, as do white-sided dolphins when feeding in the Bay of Fundy.

Home Range and Site Fidelity: Strong attraction to specific areas may override any tendency for a cetacean to avoid noxious stimuli of oil. Few cetaceans have truly restricted ranges, although in many areas, populations may stay in one general region year-round. Bottlenose dolphins of the Sarasota-Bradenton area of west Florida are year-round residents (Wells et al. 1980, Wells 1986). Indo-Pacific humpback dolphins appear to be non-migratory in Plettenberg Bay of South Africa (Saayman and Tayler 1973, 1979). Resident killer whales of Puget Sound have shown remarkable site fidelity for at least the past 20 years (Bigg 1982), while killer whales of the North Atlantic undergo distinct migrations as they follow herring schools (Jonsgaard and Lyshoel 1970). Individual minke whales of Puget Sound have also been seen in the same areas year after year (Dorsey 1983), and exhibit similar site fidelity in other nearshore areas (pers. observ.). Fin whales may reside in the central Gulf of California year-round (Tershy et al. in press), and individual right whales have been resighted in the same bays of Argentina over a span of 17 years to date (R. Payne pers. comm.).

Most species have the behavioral flexibility to search out new areas when old ones become unusable. The question is whether other habitat is available. This may depend on the geographic extent of the disturbance keeping the animals from a particular site. For example, site-tenacious cetaceans such as minke whales of Puget Sound will probably be able to adapt if only one restricted bay or channel is affected. On the other hand, a disturbance that affected all avenues of calving lagoons off Baja, California, would obviously impede calving success of gray whales.

Migrations: Many cetacean species migrate, potentially exposing them to spilled oil along the route. Since migration is a necessary event in their life history, oil in their path may modify but is not likely to override the impulse (Evans 1982b). The "classic" examples of long-distance migrators are gray, bowhead, right, and humpback whales (Gaskin 1982). Beyond the general trend to move between feeding and calving grounds, there are important differences in the migration patterns of various species and populations, and even of segments within a population. For example, cued by day lengths of less than 8.5 hours, female humpback whales with newborn calves are last to arrive and first to leave Antarctic feeding grounds, and do not leave until day length is 6.5 hours or less. Similarly, migrating gray whales may be segregated according to age, sex and reproductive status (Rice and Wolman 1971). First to reach the calving lagoons are females with near-term fetuses, followed by those which have ovulated and are presumed to have recently weaned a calf. The procession follows with immature females, adult males, and finally immature males. Such spatial and temporal segregation would expose different segments of the population to oil at any given time. Clearly, the greatest concern would be for pregnant females, because of their vital contribution to that year's production and for the young calves.

Migratory habits of toothed whales are less well defined. Some, such as bottlenose dolphins along the Texas coast (Shane 1980, Gruber 1981), Pacific white-sided dolphins off California (Leatherwood and Walker 1982), and harbor porpoises in the Bay of Fundy (Gaskin *et al.* 1985), migrate only partially. That is, individuals may be resident while others show vague inshore-offshore movements. These partial migrations are usually limited to distances on the order of dozens of hundreds instead of thousands of kilometers.

Trophic Levels and Feeding Habits: Cetaceans feed at several trophic levels, each with a specific potential to retain and transfer hydrocarbon residues. Some benthic invertebrates, such as clams and polychaete worms, tend to concentrate petroleum hydrocarbons in their tissues. Teleosts, and to a lesser extent, crustaceans, metabolize and rapidly excrete accumulated hydrocarbons and so rarely become heavily contaminated even after a major spill (Neff, Chapter 1). Thus food web biomagnification of petroleum hydrocarbons does not occur, and animals feeding at the top of a food chain, such as killer whales, are in fact less likely to ingest oil-contaminated food than baleen whales feeding on planktonic or benthic crustaceans. Gray whales (Nerini 1984), and to some extent bowheads (Lowry and Burns 1980), face an additional route of exposure while feeding on bottom sediments where oil may eventually deposit after a spill. Thus, the potential for ingesting oil-contaminated food is greatest in benthicfeeding whales, followed by plankton-feeding baleen whales and finally the high level odontocete predators.

Cetaceans with monotypic diets or those that depend on seasonally abundant food, might be affected by destruction of local stocks. However, most species of cetaceans are capable of making adjustments in their diet. Therefore, the occurrence and magnitude of nutritional effects will depend on the intensity and geographic coverage of oil, and the amount of detrimental impact on alternative prey species. Increased competition for remaining prey may particularly affect species that do not habitually move great distances, such as harbor porpoises, perhaps minke whales, and several species of nearshore odontocetes such as Hector's dolphins or Commerson's dolphins of the southern hemisphere. Yet, as we have seen, the typically sedentary bottlenose dolphin off southern California displayed great behavioral flexibility during the 1982-83 "El Niño". They responded to the incursion of warm water and food scarcity by going 500 km beyond their range, and returning when conditions normalized (Wells et al. 1984). There is no information on their diet at this time; presumably they shifted to locally abundant forms.

Reproduction: The prospect that oil might disrupt reproduction and associated behaviors in offshore species is remote. There is greater likelihood that animals carrying out these activities closer to shore will be affected. Grav whales give birth and nurture their newborn along the California-Baja California shoreline (Rice and Wolman 1971). The same pattern exists for humpback whales in Hawaii and the Caribbean, bowheads along the shores of the Bering and Beaufort right whales in shallow bays of Argentina (Payne 1980, Payne and Seas. and Dorsey 1983) and along the North American coastline (Kraus et al. 1986). The reason for their attraction to warm coastal waters is unclear. The habitat is sheltered from oceanic swells and storms, and may be relatively free of large predatory sharks. It has also been suggested (Payne and Dorsey 1983) that mothers and calves retreat to shallow waters to evade the boisterous mating attempts of males. Because births are usually sharply seasonal in baleen whales. disruption of preferred habitat could interfere with normal reproductive events. Shallow water is also an important breeding habitat for some odontocetes, such as spinner dolphins, bottlenose dolphins, harbor porpoises, beluga whales, and narwhals. The latter two concentrate breeding and calving activities within a very short season and therefore are more vulnerable to disruption at these times, but less likely to be disturbed during most of the year.

Social Organization and Behavior

Group Structure and Social Behavior: Group structure is fundamentally different in baleen whales and toothed whales. The former tend to migrate, feed, and breed as loose aggregations, with individuals often separated by hundreds of meters. Ignoring mother-calf pairs, their social bonds last only a matter of hours or days. Members of such loose aggregations probably communicate and may react collectively to a threat. Southern right whales huddle close together, all flailing their tails at the approach of killer whales (Payne pers. comm.), and bowhead whales were reported to behave similarly when startled by seismic blasts (Reeves *et al.* 1984). Whalers observed the same reaction to the presence of their own vessels during the early days of hunting (Scammon 1874). During such times, social cohesion may be greater than is generally supposed for this group.

Recent data on balaenopterid whales suggest that general social organization may be strongly influenced by feeding mode. Thus, blue and fin whales, which are planktivorous, tend to range over large areas while searching for sporadically abundant prey. Smaller balaenopterids, such as Bryde's and minke whales, are more resident while feeding on schools of fishes that may be locally abundant. Whereas the larger species of whales tend to travel in loose social units of several animals, Bryde's and minke whales are more solitary (in most nearshore localities), possibly in order to avoid intraspecific competition (Tershy and Breese 1987). A similar size-related trend in diet, habitat use, and social organization was first noted in African antelopes (Jarman 1974).

In sharp contrast to the loose aggregations typical of baleen whales, most toothed whales are gregarious, usually living in relatively stable groups, in which bonds of kinship are probably widespread. This is certainly so for killer whales of Puget Sound (Bigg 1982, Heimlich-Boran 1986, Bigg *et al.* 1987), bottlenose dolphins (Wursig 1978, Shane *et al.* 1986, Wells 1986), and many other coastal and pelagic dolphin species (Wells *et al.* 1980, Norris and Dohl 1980, Morozov 1970, Wursig and Wursig 1980, Cipriano 1985). This schooling behavior could result in large numbers of animals coming in contact with oil during a spill. Because these animals are constantly communicating as a unit, enhanced sensory integration may also allow them to more efficiently detect oil, and therefore avoid it as a group.

Group structure and social behavior vary diurnally and seasonally for at least some dolphins that habitually come within sight of shore. For example, dusky dolphins off Argentina spend winter in groups of about ten animals within one kilometer of shore as they feed on bottom-dwelling prey. In spring, summer, and fall, however, they hunt for inshore schooling fish in small groups in the morning, and aggregate temporarily into large, offshore feeding and socializing groups of up to 300 animals around mid-day (Wursig and Wursig 1980). Groups of 10 to 100 Hawaiian spinner dolphins rest in protective bays in the daytime, and at night, aggregate to feed on mesopelagic fishes and squid two to ten kilometers from shore (Norris et al., in press). Similarly, dusky dolphins off New Zealand feed on mesopelagic fishes and squid in deep water at night and rest close to shore in the daytime (Wursig et al., in press). However, this pattern is more pronounced off New Zealand in spring and summer than in the seasonally uniform Hawaiian waters. I have noted a similar cycle in Pacific white-sided dolphins off the California coast, but detailed studies have not yet been performed. It is clear, however, that risk of exposure to oil can change considerably as a function of diurnal and seasonal changes in behavior patterns.

The composition of aggregations and social groups is not necessarily uniform by age and sex. As a result, segments of the population may be differentially exposed to oil. Gray and right whale mothers and calves tend to segregate themselves in nursing areas, and gray whales do so during migration as well (Rice and Wolman 1971). Sperm whale males travel either alone or in bachelor herds, often far from females and young (Best 1979). Pilot whales may also form ageand sex-segregated groups, as may dolphins that live in transitory societies or subgroups that only come together at times (bottlenose dolphins, Wells *et al.* 1980; dusky dolphins, Wursig and Wursig 1980). In bottlenose and dusky dolphins, segregation may occur at feeding times.

In spite of obvious advantages, social cohesion has its weaker side. Some species of odontocetes, notably pilot whales, false killer whales, white-sided dolphins and sperm whales remain together to their ultimate demise, a behavior clearly evident in mass strandings (Geraci and St. Aubin 1979). A herd of these animals approaching an oil spill will probably react as a unit, with great probability that the last one to respond to the oil will do so in the same way as the first.

Reproductive Behavior: Disruption of herd structure may affect elements of the social order that relate to reproductive success. In many odontocete species, attendant females have important nurturant roles to female-calf pairs (Caldwell and Caldwell 1972). So-called "auntie" dolphins assist during parturition by

helping to lift the calf to the surface and supporting it there (McBride and Kritzler 1951). Females cooperate to supervise calves, allowing each other in turn to forage away from the herd (Tavolga and Essapian 1957). When threatened by aggressive males, older females protect calves by herding them to the center of the school.

Aggression features in the establishment and maintenance of social hierarchy, and in turn governs the reproductive activities of the males. Norris and Prescott (1961) commented on the high frequency of scars, presumably inflicted by older bulls, in young male Pacific pilot whales. In bottlenose dolphins, dominant males also direct their aggression toward females that have withdrawn from the herd to calve (McBride and Kritzler 1951). The integrity of the social order likely contributes to the collective safety of the group, and as such plays an important role in survival. Disruption of the heirarchy, by oil or any other significant environmental disturbance, might trigger a cascade of events affecting mother, calves, or vital social bonds.

Feeding Behavior: Cetaceans use a variety of feeding strategies, as expected from the diversity of their prey. Because of differences in food dispersion patterns, fish-eaters tend to be more solitary than those feeding on krill (Tershy and Breese 1987). When feeding on schooling fishes, dolphins and toothed whales often coordinate their activities to herd and contain prey. Apparently organized attacks by killer whale pods on seals (Smith *et al.* 1981) and a blue whale (Tarpy 1979) have been described. Baleen whales generally feed alone, although apparent cooperation during feeding has recently been described in humpback (Baker and Herman 1985), fin (Tershy *et al.*, in press), right (Kraus, pers. comm.) and bowhead (Wursig *et al.* 1985) whales.

The way in which a cetacean feeds will determine the likelihood of its ingesting oil. One might expect that knowledge of the feeding strategy of a species would allow some level of prediction as to how it might ingest oil. Pivorunas (1979) has suggested that each major group of mysticetes has a characteristic feeding strategy: right whales skim the surface, rorquals gulp in the water column, and gray whales scour the bottom. However, under more intensive observation, these feeding tactics are becoming less clearly defined. Bowheads also filter bottom sediments (Wursig *et al.* 1985), rorquals break the surface at the end of a feeding lunge, and gray whales sometimes eat fish (Rice and Wolman 1971). Thus, this information does not allow us to predict by taxon, only to hypothesize that whales feeding in the water column are less apt to be exposed than those feeding at the surface or bottom.

The same would be true of odontocetes, with equally diverse feeding strategies. Most probably feed within the water column, though some such as belugas exploit benthic organisms (Vladikov 1946). Dolphins that toss fish through an oiled surface or work as a group to herd them there, risk contaminating their prey. Other Behaviors: Whales and dolphins are curious, and play with objects at the surface. Hawaiian spinner dolphins approach floating plastic strips washed from onshore pineapple fields (Norris et al., in press); dusky dolphins may play with loose strands of kelp for long periods of time (Wursig and Wursig 1979); and bowhead whales play with logs and other debris on the surface of the water (Wursig et al. 1985). A bowhead calf was observed orienting to and playing within a surface area fouled by the chemical marker fluorescein. Another calf oriented along a long line of surface debris caused by a current boundary, and repeatedly opened its mouth while swimming through the debris (Wursig et al. 1985). The latter incidents occurred while the mother was below the surface, probably feeding, and the calf was left alone to explore on its own. These observations illustrate what is known for young mammals in general: they are especially curious and are prone to getting into mischief when a parent is not present. Bowheads probably are not the only cetaceans to leave their calves in this manner, though others have not been adequately studied to properly assess this point. Deep-diving species such as sperm whales, pilot whales, and some pelagic dolphins may also leave their calves behind. In such situations, curious calves could be drawn to oil slicks or emulsions on the sea surface.

Summarizing the Risk

Many aspects of cetacean behavior, diet and habitat use may lead them into contact with spilled oil. Given the host of interacting variables, it is difficult to state precisely which species or individual's might be most vulnerable from an ecological standpoint, however several broad and meaningful categorizations can be made.

Species that occur in restricted areas for at least part of their lives are more likely to encounter oil than those that range widely. Examples are breeding and feeding humpback, gray, right, bowhead, and beluga whales, narwhals, bottlenose dolphins, harbor porpoises, and river dolphins. Cetaceans with large ranges may contact some oil as they move quickly through a fouled area, but with little potential for long-term exposure.

Cetaceans that feed either at the surface or at the bottom are more likely to contact oil than those that generally feed in the water column. These include skim-feeding right and bowhead whales, surface-lunging rorquals, and the bottomfeeding gray whales, in other words, all mysticetes, except possibly the minke whale. Harbor porpoises and some dolphins may contact oil at times, when they feed on flatfish and other bottom-dwelling prey. Dolphins that habitually force schools of prey to the surface may also be at risk.

As a group, baleen whales appear to be the most vulnerable in view of low population sizes in some (right and bowhead), feeding strategies generally, and dependence on selected, restrictive habitats for feeding and reproduction. Among the odontocetes of the North American Continental Shelf, restrictive habitat increases the risk of exposure for belugas, narwhals, harbor porpoises and bottlenose dolphins. For the most part, other toothed whales and dolphins are too mobile for oil to present much of a threat.

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Literature Cited

Baker, S.C. and L.M. Herman. 1985. Whales that go to extremes. Nat. Hist. 10: 52-60.

Barnes, L.G. 1984. Whales, dolphins and porpoises: origin and evolution of the Cetacea. In Mammals: Notes for a Short Course. T.W. Broadhead (ed.). Univ. Tennessee Studies in Geology, No. 8.

Berzin, A.A. 1984. Soviet studies of the distribution and numbers of the gray whale in the Bering and Chukchi Seas, from 1968 to 1982. In The Gray Whale, <u>Eschrichtius robustus</u>. M.L. Jones, S.L. Swartz and S. Leatherwood (eds.). Academic Press, New York.

Best, P.B. 1979. Social organization of sperm whales, <u>Physeter macrocephalus</u>. pp. 227-289. In Behavior of Marine Animals. Vol. 3: Cetaceans. H.E. Winn and B.L. Olla (eds.). Plenum Press, New York.

Best, P.B., P.A.S. Canham and N. MacLeod. 1984. Patterns of reproduction in sperm whales, <u>Physeter macrocephalus</u>. pp. 135-148. In Reproduction in Cetaceans. Rep. Int. Whaling Comm. Spec. Issue No. 6.

Bigg, M. 1982. An assessment of killer whale (<u>Orcinus</u> orca) stocks off Vancouver Island, B.C. Rep. Int. Whaling Comm. 32: 655-666.

Bigg, M.A., G.M. Ellis, J.B. Ford and K.C. Balcomb. 1987. Killer Whales. Phantom Press, Nanaimo, B.C. 79 pp.

- Braham, H.W., B.D. Krogman and G.M. Carroll. 1984. Bowhead and white whale migration, distribution and abundance in the Bering, Chukchi and Beaufort Seas, 1975-78. U.S. Dept. Commerce, NOAA Tech. Report No. NMFS SSRF-778. 39 pp.
- Caldwell, M.D. and D.K. Caldwell, 1972. Behavior of marine mammals. pp. 419-465. In Mammals of the Sea: Biology and Medicine. S.H. Ridgway (ed.). C.C. Thomas Press, Springfield, IL.
- Caldwell, D.K. and F.B. Golley. 1965. Marine mammals from the coast of Georgia to Cape Hatteras. J. Elisha Mitchell Sci. Soc. 81: 24-32.
- Cipriano, F. 1985. Dusky dolphin research at Kaikoura, New Zealand: a progress report. Mauri Ora 12: 151-158.
- Dawbin, W.H. 1966. The Seasonal Migratory Cycle of Humpback Whales. In Whales, Dolphins, and Porpoises. K.S. Norris (ed.). Univ. California Press, Berkeley, CA.
- Dohl, T.P., M.L. Bonnell and R. Glenn Ford. 1986. Distribution and abundance of common dolphin, <u>Delphinus</u> <u>delphis</u>, in the southern California Bight: A quantitative assessment based upon aerial transect data. Fish. Bull. 84: 333-343.
- Dohl, T.P., R.C. Guess, M.L. Duman and R.C. Helm. 1983. Cetaceans of central and northern California, 1980-83. In Book 2: Status, Abundance and Distribution. Vol. III. U.S. Minerals Management Serv. Univ. California, Santa Cruz, CA. Final Report No. 84-0045.
- Dorsey, E.M. 1983. Exclusive adjoining ranges in individually identified minke whales (<u>Balaenoptera acutorostrata</u>) in Washington state. Can. J. Zool. 61: 174-181.

- Evans, W.E. 1982a. Distribution and differentiation of stocks of <u>Delphinus</u> <u>delphis</u> Linnaeus in the northeastern Pacific. In Mammals in the Seas. Vol. IV. Small Cetaceans, Seals, Sirenians, and Otters. FAO Fisheries Series No. 5. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Evans, W.E. 1982b. A study to determine if gray whales detect oil. pp. 47-61. In Study of the Effects of Oil on Cetaceans. J.R. Geraci and D.J. St. Aubin (eds.). Final Report. U.S. Dept. of the Interior, Bureau of Land Management, Washington, DC. Contract No. AA 551-CT9-29.
- Gaskin, D.E. 1982. The Ecology of Whales and Dolphins. Heinemann Press, London. 459 pp.
- Gaskin, D.E. 1964. Recent observations in New Zealand waters on some aspects of behavior of the sperm whale (<u>Physeter macrocephalus</u>). Tuatara 12: 106-114.
- Gaskin, D.E., P.W. Arnold and B.A. Blair. 1974. <u>Phocoena</u> phocoena. Mammalian Species 42: 1-8.
- Gaskin, D.E., G.J.D. Smith, A.P. Watson, W.Y. Yasui and D.B. Yurick. 1984. Reproduction in the porpoises (Phocoenidae): implications for management. Rep. Int. Whal. Commn., Special Issue No. 6: 135-148.
- Gaskin, D.E., A.J. Read, P.F. Watts and G.J.D. Smith. 1985. Population, dispersal size, and interactions of harbor porpoises in the Bay of Fundy and Gulf of Maine, U.S.A. and Canada. Can. Tech. Report Fish. Aquat. Sci. 1291: 1-28.
- Geraci, J.R. and D.J. St. Aubin (eds.). 1979. Biology of Marine Mammals: Insights through Strandings. Nat. Tech. Inf. Serv., Springfield, VA. PB293-890. 343 pp.
- Gruber, J.A. 1981. Ecology of the Atlantic bottlenosed dolphin (<u>Tursiops</u> <u>truncatus</u>) in the Pass Cavallo area of Matagordo Bay, Texas. M.Sc. Thesis, Texas A&M Univ., College Station, TX.

Hain, J.H.W., G.R. Carter, S.K. Kraus, C.A. Mayo and H.E. Winn. 1981. Feeding behavior of the humpback whale, <u>Megaptera novaeangliae</u>, in the western north Atlantic. Fish. Bull. 80 (2): 259-268.

Hall, I.D. 1979. A survey of cetaceans of Prince William Sound and adjacent vicinity--their numbers and seasonal movements. Report. U.S. Minerals Management Serv., Reston, VA. Contract No. RU-481.

Heimlich-Boran, J.R. 1987. Habitat use patterns and behavioral ecology of killer whales (<u>Orcinus orca</u>). M.Sc. Thesis, Moss Landing Marine Lab, Moss Landing, CA. 59 pp.

Heimlich-Boran, S.L. 1986. Cohesive relationships among Puget Sound killer whales. In Behavioral Biology of Killer Whales. B.C. Kirkkevold and J.S. Lockard (eds.). Alan R. Liss, Inc., New York, NY.

- Heyning, J.E. and M.E. Dahlheim. 1988. <u>Orcinus orca</u>. Mammalian Species 304: 109.
- Jarman, P.J. 1974. The social organization of antelope in relation to their ecology. Behavior 58: 215-267.

Jefferson, T. <u>Phocoenoides</u> <u>dalli</u>. Mammalian Species 319 (in press).

Jones, M.L. and S.L. Swartz. 1984. Demography and phenology of gray whales and evaluation of whale-watching activities in Laguna San Ignacio, Baja California Sur, Mexico. pp. 309-374. In The Gray Whale, <u>Eschrichtius</u> <u>robustus</u>. M.L. Jones, J.S. Leatherwood and S.L. Swartz (eds.). Academic Press, New York, NY. Jonsgaard, A. and P.B. Lyshoel. 1970. A contribution to the biology of the killer whale, <u>Orcinus orca</u> (L.). Norw. J. Zool. 18: 41-48.

Kasuya, T. and H. Marsh. 1984. Life history and reproductive biology of the short-finned pilot whale <u>Globicephala macrorhynchus</u> off the Pacific coast of Japan. Rep. Int. Whaling Comm. Spec. Issue No. 6: 259-310.

- Kraus, S.D. 1985. A review of the status of right whales (<u>Eubalaena glacialis</u>) in the western North Atlantic, with a summary of reserach and management needs. U.S. Marine Mammal Commission, Washington, DC. Final Report No. MMC-84/08. 61 pp.
- Kraus, S.D., J.H. Prescott and A.R. Knowlton. 1986. Wintering right whales (<u>Eubalaena glacialis</u>) along the southeastern coast of the United States, 1984-1986. Report. U.S. Minerals Management Serv., Reston, VA. 15 pp.
- Kraus, S.D., J.H. Prescott and G.S. Stone. 1984. Right whales (<u>Eubalaena glacialis</u>) in the western North Atlantic: a summary of research conducted from 1980 to 1984. U.S. Marine Mammal Commission, Washington, DC. Report No. MMC-442.
- Leatherwood, S., D.K. Caldwell and H.E. Winn. 1976. Whales, dolphins, and porpoises of the western North Atlantic. NOAA Technical Rep. No. 396. U.S. Dept. Commerce, Nat. Mar. Fish. Serv., Seattle, WA.
- Leatherwood, S., W.F. Perrin, V.L. Kirby, C.L. Hubbs and M. Dahlheim. 1980. Distribution and movements of Risso's dolphin, <u>Grampus griseus</u> in the eastern North Pacific. Fish Bull. 77: 951-963.
- Leatherwood, S., R.R. Reeves, A.E. Bowles, B.S. Stewart and K.R. Goodrich. 1984. Distribution, seasonal movements, and abundance of Pacific whitesided dolphins in the eastern North Pacific. Sci. Rep. Whales Res. Inst. 35: 129-157.
- Leatherwood, S., R.R. Reeves, W.F. Perrin and W.E. Evans. 1982. Whales, dolphins, and porpoises of the eastern North Pacific and adjacent Arctic waters. NOAA Tech. Rep. No. 444. U.S. Dept. of Commerce, Nat. Mar. Fish. Serv., Seattle, WA.
- Leatherwood, S. and W.A. Walker. 1982. Population biology and ecology of the Pacific white-sided dolphin, <u>Lagenorhynchus obliquidens</u>, in the northeastern Pacific. Part I: Distribution, seasonal movements and abundance, with a bibliography and summary of specimen material. Nat. Mar. Fish. Serv., Southwest Fish. Cntr, La Jolla, CA. Admin. Report No. LJ-82-18C.
- Leatherwood, S. and W.A. Walker. 1979. The northern right whale dolphin, <u>Lissodelphis</u> <u>borealis</u> Peale, in the eastern North Pacific. In Behavior of Marine Mammals. Vol. 3: Cetaceans. H.E. Winn and B.L. Olla (eds.). Plenum Press, New York.
- Lockyer, C. 1984. Review of baleen whale (<u>Mysticeti</u>) reproduction and implications for management. Rep. Int. Whaling Comm. Spec. Issue No. 6: 27-50.
- Lopez, J.D. and D. Lopez. 1985. Killer whales (<u>Orcinus orca</u>) of Patagonia, and their behavior of intentional stranding while hunting nearshore. J. Mammal. 66: 181-183.
- Lowry, L.F. and J.J. Burns. 1980. Food utilized by bowhead whales near Barter Island, Alaska, autumn 1979. Mar. Fish. Rev. 42: 88-91.
- Lowry, L.F. and K.J. Frost. 1984. Food and feeding of bowhead whales in western and northern Alaska. Sci. Rep. Whales Res. Inst. 35: 1-16.
- Masaki, Y. 1977. The separation of the stock units of sei whales in the North Pacific. Rep. Int. Whaling Comm., Special Issue No. 1: 71-79.

Mate, B.R. and J.T. Harvey. 1984. Ocean movements of radio-tagged gray whales. pp. 577-590. In The Gray Whale, <u>Eschrichtius robustus</u>. M.L. Jones, J.S. Leatherwood and S.L. Swartz (eds.). Academic Press, New York, NY.

Matkin, C.O. and S. Leatherwood. 1986. General biology of the killer whale, <u>Orcinus</u> orca: A synopsis of knowledge. In Behavioral Biology of Killer Whales. B.C. Kirkevold and J.S. Lockard (eds.). Alan R. Liss, Inc., New York, NY.

McBride, A.F. and H. Kritzler. 1951. Observations on pregnancy, parturition and post-natal behavior in the bottlenose dolphin. J. Mammal. 32: 251-266.

Mitchell, E. 1975. Porpoise, Dolphin and Small Whale Fisheries of the World: Status and Problems. IUCN Monograph No. 3. Morges, Switzerland.

Mitchell, E., V.M. Kozicki and R.R. Reeves. 1986. Sightings of right whales, <u>Eubalaena glacialis</u>, on the Scotia shelf, 1966-1972. Rep. Int. Whaling Comm. Spec. Issue No. 10: 83-107.

Morejohn, G.V. 1979. The natural history of Dall's porpoise in the north Pacific Ocean. In Behavior of Marine Animals. Vol. 3: Cetaceans. H.E. Winn and B.L. Olla (eds.). Plenum Press, New York.

Morozov, D.A. 1970. Dolphins hunting. Rybnoe Khozyaistvo 46: 16-17. Transl. by Lillian Vlymen, Nat. Mar. Fish. Serv., La Jolla, CA.

Nerini, M.K. 1984. A review of gray whale feeding ecology. pp. 423-450. In The Gray Whale, <u>Eschrichtius robustus</u>. M.L. Jones, J.S. Leatherwood and S.L. Swartz (eds.). Academic Press, New York, NY.

Nerini, M.K., H. Braham, W. Marquette and D. Rugh. 1984. Life history of the bowhead whale. J. Zool. 204: 443-468.

Nishiwaki, M. 1975. Ecological aspects of smaller cetaceans, with emphasis on the striped dolphin (<u>Stenella coeruleoalba</u>). J. Fish. Res. Board Can. 32: 1069-1072.

Norris, K.S. and T.P. Dohl. 1980. The behavior of the Hawaiian spinner dolphin, <u>Stenella longirostris</u>. U.S. Fish. Bull. 77: 321-349.

Norris, K.S. and J.H. Prescott. 1961. Observations on Pacific cetaceans of Californian and Mexican waters. Univ. Calif. Publ. Zool. 63: 291-402.

- Norris, K.S., B. Villa-Ramirez, G. Nichols, B. Wursig and K. Miller. 1983. Lagoon entrance and other aggregations of gray whales, <u>Eschrichtius robus-</u> <u>tus</u>. In Behavior and Communication of Whales. R. Payne (ed.). AAAS Sel. Symp. 76: 259-293.
- Norris, K.S., B. Wursig, R.S. Wells, M. Wursig, S.M. Brownlee, C. Johnson and J. Solow. The Behavior of the Hawaiian Spinner Dolphin, <u>Stenella</u> <u>longirostris</u>. Univ. Calif. Press, Berkeley, CA (in press).
- Oliver, J.S., P.N. Slattery, M.A. Silberstein and E.F. O'Connor. 1983. A comparison of gray whale, <u>Eschrichtius robustus</u>, feeding in the Bering Sea and Baja California. Fish. Bull. 81: 513-522.
- Payne, R.S. 1980. Research on the behavior of various species of whales. Nat. Geog. Soc. Res. Rep. 12: 551-564.
- Payne, R. and E.M. Dorsey. 1983. Sexual dimorphism and aggressive use of callosities in right whales (<u>Eubalaena australis</u>). In Behavior and Communication of Whales. R. Payne (ed.). AAAS Sel. Symp. 76: 295-329.
- Perrin, W.F. and S.B. Reilly. 1984. Reproductive parameters of dolphins and small whales of the family Delphinidae. Rep. Int. Whaling Comm. Spec. Issue No. 6: 97-133.

Pivorunas, A. 1979. The feeding mechanisms of baleen whales. Am. Sci. 67: 432-440.

Reeves, R.R., D.K. Ljungblad and J.T. Clarke. 1984. Bowhead whales and acoustic seismic surveys in the Beaufort Sea. Polar Rec. 22: 271-280.

Reeves, R.R. and S.K. Katona. 1980. Extralimital records of white whales (<u>Delphinapterus leucas</u>) in eastern North American waters. Can. Field-Naturalist 94: 239-247.

Reeves, R.R. and E. Mitchell. 1987. Cetaceans of Canada. Underwater World 59: 1-27. (Publ. by Dept. Fisheries and Oceans, Ottawa, Ont.)

- Reeves, R., E. Mitchell, A. Mansfield and M. McLaughlin. 1983. Distribution and migration of the bowhead whale, <u>Balaena mysaticetus</u>, in the eastern North American Arctic. Arctic 31: 5-64.
- Rice, D.W. 1974. Whales and whale research in the eastern North Pacific. In The Whale Problem: A Status Report. W.E. Schevill (ed.). Harvard Univ. Press, Cambridge, MA.
- Rice, D.W. 1977. A list of the marine mammals of the world. Nat. Mar. Fish. Serv. Tech. Report No. SSRF-711. 15 pp.
- Rice, D.W. and A.A. Wolman. 1971. The life history and ecology of the gray whale (<u>Eschrichtius robustus</u>). Amer. Soc. Mammal Spec. Bull. No. 3. 142 pp.
- Rice, D.W. and A.A. Wolman. 1981. Summer distribution and numbers of fin, humpback, and gray whales in the Gulf of Alaska. U.S. Minerals Management Serv., Reston, VA. Contract Report No. RU-592.
- Richardson, W.J., R.A. Davis, C.R. Evans, D.K. Ljungblad and P. Norton. 1987. Summer distribution of bowhead whales, <u>Balaena mysticetus</u>, relative to oil industry activities in the Canadian Beaufort Sea, 1980-1984. Arctic 40: 93-104.
- Rugh, D.J. and M.A. Fraker. 1981. Gray whale (<u>Eschrichtius</u> robustus) sightings in Eastern Beaufort Sea. Arctic 34 (2): 186-187.
- Saayman, G.S. and C.K. Tayler. 1973. Social organization of inshore dolphins (<u>Tursiops aduncus and Sousa</u>) in the Indian Ocean. J. Mammal. 54: 993-996.
- Saayman, G.S. and C.K. Tayler. 1979. The socioecology of humpback dolphins (Sousa sp.). pp. 165-226. In Behavior of Marine Animals. Vol. 3: Cetaceans. H.E. Winn and B.L. Olla (eds.). Plenum Press, New York, NY.
- Scammon, C.M. 1874. The Marine Mammals of the North-Western Coast of North America, Described and Illustrated: Together with an Account of the American Whale-Fishery. J.H. Carmany & Co., San Francisco, CA. 319 pp.
- Sergeant, D.E. 1973. Biology of white whales (<u>Delphinapterus leucas</u>) in western Hudson Bay. J. Fish. Res. Board Can. 30: 1065-1090.
- Sergeant, D.E. 1977. Stocks of fin whales <u>Balaenoptera</u> <u>physalus</u> L. in the North Atlantic Ocean. Rep. Int. Whaling Comm. 27: 460-473.
- Sergeant, D.E., D.K. Caldwell and M.C. Caldwell. 1973. Age, growth and maturity of bottlenosed dolphins (<u>Tursiops truncatus</u>) from northeast Florida. J. Fish. Res. Board Can. 30: 1009-1011.
- Sergeant, D.E. and W. Hoek 1974. Seasonal distribution of bowhead and white whales in the eastern Beaufort Sea. In the Coast and Shelf of the Beaufort Sea. J.C. Reed and J.E. Sater (Eds.). Arctic Inst. of North Amer., Arlington, VA.

Sergeant, D.E., A.W. Mansfield and B. Beck. 1970. Inshore records of Cetacea of eastern Canada, 1949-68. J. Fish. Res. Board Can. 27: 1903-1915.

Shane, S.H. 1980. Occurrence, movements and distribution of the bottlenose dolphin, <u>Tursiops</u> truncatus, in southern Texas. Fish. Bull. 78: 593-601.

- Shane, S.H., R.S. Wells and B. Wursig. 1986. Ecology, behavior, and social organization of the bottlenose dolphin: a review. Mar. Mamm. Sci. 2: 34-63.
- Smith, T.G., D.B. Siniff, R. Reichle and S. Stone. 1981. Coordinated behavior of killer whales, <u>Orcinus</u> orca, hunting a crabeater seal, <u>Lobodon</u> <u>carcinophagus</u>. Can. J. Zool. 59 (6): 1185-1189.

Tarpy, C. 1979. Killer whale attack. Natl. Geogr. 155 (4): 542-545.

- Tavolga, M.C. and F.S. Essapian. 1957. The behavior of the bottlenosed dolphin (<u>Tursiops truncatus</u>): mating, pregnancy, parturition, and mother-infant behavior. Zoologica 42: 11-31.
- Tershy, B.R. and D. Breese. 1987. Body size, diet, habitat use and social behavior in <u>Balaenoptera</u> whales in the Gulf of California, Mexico. Abstract 7th Biennial Conf. Biol. Mar. Mamm., Miami, FL. Obtained from B. Tershy, Moss Landing Marine Labs, P.O. Box 450, Moss Landing, CA 95039.
- Tershy, B., D. Breese and C. Strong. Abundance, seasonal distribution and population composition of balaenopterid whales in the Canal de Ballenas, Gulf of California, Mexico. Spec. Issue Series, IWC Reports, Cambridge, U.K. (in press).
- Tyack, P.T. 1986. Population biology, social behavior, and communication in whales and dolphins. Trends in Ecol. and Evol. 1: 144-150.
- Vladykov, V.D. 1946. Etudes sur les mammifères aquatiques. IV. Nourriture du marsouin blanc ou béluga (<u>Delphinapterus</u> <u>leucas</u>) du fleuve Saint-Laurent. Report. Can. Dept. Fish. and Oceans, Quebec.
- Walker, W.A. 1981. Geographical variation in morphology and biology of bottlenose dolphins (<u>Tursiops</u>) in the eastern North Pacific. NMFS Report No. LJ-81-03C. Nat. Mar. Fish. Serv., S.W. Fish. Center, La Jolla, CA. 92038.
- Wells, R.S. 1986. Structural aspects of dolphin societies. Ph.D. Dissertation, Univ. California, Santa Cruz, CA. 234 pp.
- Wells, R.S., T.P. Dohl, L.J. Hansen, A.B. Baldridge and D.L. Kelly. 1984. Extraordinary movements of bottlenose dolphins (<u>Tursiops</u> sp.) along the coast of California. Publ. Abstract. 64th Mtg. Amer. Soc. Mamm., Arcata, CA. 45 pp.
- Wells, R.S., A.B. Irvine and M.D. Scott. 1980. Social ecology of inshore odontocetes. pp. 263-317. In Cetacean Behavior: Mechanisms and Functions. L.M. Herman (ed.). Wiley Interscience, New York, NY.
- Winn, H.E. 1984. Development of a right whale sighting network in the southeastern U.S. NTIS Publ. PB 84-240548. 12 pp.
- Winn, H.E., D.R. Goodale, M.A.M. Hyman, R.D. Kenney, C.A. Price and G.P. Scott. 1981. Right whale sightings and the right whale minimum count. pp. 49-51. In A Characterization of Marine Mammals and Turtles in the Mid- and North-Atlantic Areas of the U.S. Outer Continental Shelf. Cetacean and Turtle Assessment Program, Univ. Rhode Island, Kingston, RI.
- Wursig, B. 1978. Occurrence and group organization of Atlantic bottlenose porpoises (<u>Tursiops truncatus</u>) in an Argentine Bay. Biol. Bull. 154: 348-359.
- Wursig, B. 1986. Delphinid foraging strategies. pp. 347-359. In Dolphin Cognition. J. Thomas, R. Schusterman and F. Wood (eds.). L. Erlbaum Publ., Hillsdale, NH.

Wursig, B. and M. Wursig. 1979. The day and the night of the dolphin. Nat. Hist. 88: 60-67.

- Wursig, B. and M. Wursig. 1980. Behavior and ecology of dusky porpoises, <u>Lagenorhynchus obscurus</u>, in the south Atlantic. Fish. Bull. 77: 871-890.
- Wursig, B., F. Cipriano and M. Wursig. Dolphin movement patterns: information from radio and theodolite tracking studies. In Odontocete Cetacean Field Studies. K. Pryor and K. Norris (eds.). Univ. California Press, Berkeley, CA. (in press).
- Wursig, B., E.M. Dorsey, M.A. Fraker, R.S. Payne and W.J. Richardson. 1985. Behavior of bowhead whales, <u>Balaena mysticetus</u>, summering in the Beaufort Sea: a description. Fish. Bull. 83: 357-377.

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CHAPTER 5

PHYSIOLOGIC AND TOXICOLOGIC EFFECTS

ON CETACEANS

J.R. Geraci

Department of Pathology Ontario Veterinary College University of Guelph Guelph, Ontario N1G 2W1

Historical Notes

January 28, 1969 marked the first incident calling attention to the possibility that oil pollution might harm a cetacean. Union Oil's undersea well off Santa Barbara, California sprung a leak. A flurry of activity followed, with estimates and counter-estimates of the size and duration of the spill, and of the types and numbers of animals being affected. Union Oil calculated that about 250,000 gallons of oil had leaked into the channel by February 8 when the well was sealed with cement (Santa Barbara News-Press, March 15, 1969). Oil continued to seep through new leaks and by April 1969, as much as three million gallons may have been released (Santa Barbara News-Press, April 26, 1969; Straughan 1972).

What happens to whales and dolphins when 800 square miles (Santa Barbara News-Press, February 6, 1969) of travel routes and feeding grounds are contaminated with oil? The picture is not clear. At the time of the spill, gray whales were just beginning their annual migration northward through or to the west of the fouled area (Brownell 1971). One airplane pilot saw a group of whales moving northward through the slick, blowing as they went (Easton 1972).

The Santa Barbara News-Press of March 13, 1969 reported that by the sixth week of the spill, three dead gray whales had come ashore in northern California. The mouth and baleen plates of one were coated with a light film of oil, later interpreted as an unremarkable finding in a carcass that had floated at sea for some time (Brownell 1971). Another whale covered with oil was seen "floating listlessly" in the Santa Barbara Channel. By March 15, the number of dead whales was placed at six (Santa Barbara News-Press, March 15, 1969), only two of which were fresh enough for necropsy examination. Oil was not found in either, and the whales were thought to have died from natural causes (Santa Barbara News-Press, May 15, 1969); one, in fact, may have been harpooned (Brownell 1971).

Gray whales were the focus of attention for their obvious size, and possibly because they were protected after a long history of exploitation (Rice and Wolman 1971). But they were not the only cetacean to arouse concern during the Union Oil spill. An unidentified porpoise "coated with old oil" stranded on a sandbar. Two other stranded porpoises were examined by representatives of the California State Department of Fish and Game, who found no evidence that oil was related to the animal's deaths (Battelle Memorial Institute 1969). Eyewitnesses, referring to one of the porpoises, a common dolphin (Brownell 1971), said its "breathing hole was clogged with oil and its lungs were ruptured" (Easton 1972). Time magazine (February 21, 1969), published a similar account. Yet Brownell (1971) and his colleagues examined five of six dolphins stranded from February through May 1969, and found no evidence of oil contamination.

The final tally? Carcasses recovered from January 28 through March 31, 1969 included six gray whales, one sperm whale, one pilot whale, five common dolphins, one Pacific white-sided dolphin, and two unidentified dolphins. With these figures, Brownell (1971) concluded that 3 to 4 gray whales and a number of dolphins of various species strand annually on California shores, and that increased survey effort in 1969 had led to higher counts. The Smithsonian Institution Center for Short-lived Phenomena (Anon. 1970) summarized the event: "a few sea mammals were found dead; however, for the most part, they seemed to avoid direct contact with the oil". An independent report went a step further in concluding that: "The whales were either able to avoid the oil, or were unaffected when in contact with it" (Battelle Memorial Institute 1969).

The Santa Barbara incident dwarfs all succeeding oil spills in public reaction toward the threat to whales and dolphins. It is not surprising. The oil flowed for a period of months in full view of a newly aroused public. Until that time, there had been little thought as to why an occasional whale or dolphin might come ashore. Now, the need for such information had become crucial, and without that background, or an established protocol to determine how a pollutant might fit into the picture, the stage was set for weak and arguable interpretations.

Most of the recent incidents have been minor by comparison, and still less informative (Table 5.1). Following a spill of light diesel fuel along the Alaskan shore, two killer whales, one sick and one dead, were reported. There was no additional detail (Anon. 1971). A ruptured storage tank released $36 \times 10^{\circ}$ L of hot Bunker C oil into Japan's Inland Sea. A press report revealed that one porpoise had died (Nicol 1976). After the <u>Amoco Cadiz</u> ran aground spilling $300 \times 10^{\circ}$ L of light crude oil along the coast of the Brittany region of France, six badly decomposed cetacean carcasses were examined for evidence of oil. Prieur and Hussenot (1978) noted that one may have shown signs of oil contamination; the remainder were species which typically strand, and concluded that any relationship between the oil spill and the death of the animals would have been difficult to establish. The <u>Hellenic Carrier</u> collided with a ship on the outer banks off Nags Head, North Carolina, and sank, spilling 11,000 L of oil. An anonymous report (1981) told of a porpoise that was killed.

On March 21, 1982, the decomposed carcass of a male pilot whale was found stranded in Rodanthe, North Carolina. On its skin was a 10 x 20 cm patch of dry tar (Anon. 1982). No detail was provided. While conducting a survey of cetaceans in the western North Atlantic, a dead <u>Grampus</u> was spotted a few kilometers away from an extensive oil sheen (Sorensen let al.1 <u>al</u>. 1984).

What conclusions can be drawn from these observations? It seems that unlike sea otters, polar bears, and some seals, there is no gripping evidence that oil contamination has been responsible for the death of a cetacean.

Reactions of Cetaceans to Oil: The Battelle Memorial Institute's (1969) summary of the Santa Barbara spill concluded that whales may have been able to avoid the oil. That casual observation, it now appears, may have some empirical footing. Fragmentary data from subsequent spills support the notion that whereas some cetaceans may avoid oil, others, willing or not, enter it without obvious peril. Shane and Schmidly (1978) studied a group of <u>Tursiops</u> in

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Table 5.1: Reports of cetaceans associated with oil.

Date	Location & Source	Oil Type & Quantity	Species	Impact	Reference
Feb. 1969	Santa Barbara, CA Union Oil well	Crude oil >100,000 tons	gray whale pilot whale common dolphin sperm whale white-sided d.	16 stranded whales and dolphins recovered. No causal relationship.	Brownell 1971
Apr. 1970	Alaska Peninsula	Diesel fuel Quan. ?	killer whale	1 sick and 1 dead animal observed. No examination.	Anon. 1970
1974	Japan	Bunker C 270,000 barrels	porpoise	1 dead porpoise found.	Nicol 1976
Oct. 1976	Aransas Pass, TX Pipeline leak	Crude oil 16,000 gal.	bottlenose d.	Dolphins swam through oil without apparent effect.	Shane and Schmidly 1978
Dec. 1976	Nantucket Shoals <u>Argo Merchant</u>	Bunker C 189,000 barrels	fin whale pilot whale others	43 sightings of animals in and around patches of oil. No obvious reaction.	Grose and Mattson 1977
Mar. 1978	France <u>Amoco</u> <u>Cadiz</u>	Crude oil 200,000 tons	white-sided d. common dolphin pilot whale	6 stranded animals with no firm evidence of oil	Prieur and Hussenot 1978
Sept. 1978	Matagorda Bay, TX Boat grounding	Fuel oil 10,000 L	bottlenose d.	20 dolphins swimming through oil without effect.	Shane 1981

Table 5.1 (cont'd.): Reports of cetaceans associated with oil.

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Date	Location & Source	Oil Type & Quantity	Species	Impact	Reference
June 1979	Gulf of Mexico <u>IXTOC-I</u>	Crude oil 10 billion liters?	bottlenose d. spotted dolphin	animals sighted in areas with oil-coated debris. Apparently unaffected.	Bergey 1979
June 1979	Cape Cod, MA <u>Regal Sword</u>	Bunker C 300,000 L Fuel oil 24,000 L	humpback, fin minke, right whales. white- sided dolphins	Animals feeding, surfacing and swimming through heavy concentrations of oil.	Goodale <u>et al</u> .
May 1981	Outer Banks, NC <u>Hellenic</u> Carrier	Type ? 11,000 L	porpoise	unconfirmed report of dead porpoise.	Anon. 1981
Mar. 1982	Rodanthe, NC Source ?	Tar	pilot whale	stranded whale with small patch of dry tar on skin.	Anon. 1982
July 1984	Gulf of Mexico <u>Alvenas</u>	Crude oil $4 \times 10^6 \text{ L}$	bottlenose d.	1 dolphin swimming in the midst of oil patches. Others at the edge of the slick.	Owen 1984
Aransas Pass, a few kilometers north of Corpus Christi, Texas (Figure 5.1). On October 14, 1976, 60,000 L of crude oil leaked from pipelines along Aransas Channel and into Morris and Cummings Cut. "The dolphins swam regularly through the oil slick, although they were not observed surfacing in the heaviest concentrations of oil. [They] began feeding and mating once they reached cleaner water. The oil had no obvious effect upon them." That incident was soon paralleled by an event which took place in Matagorda Bay, 100 km north of Aransas Pass (Figure 5.1). A tugboat ran aground spilling some 10,000 L of fuel oil into Pass Cavallo where Gruber (1981) was studying the behavior of <u>Tursiops</u>. She noted that 20 dolphins, including one calf, would swim back and forth through "large globules" of oil in an extremely polluted section of the intracoastal waterway. The animals repeatedly surfaced in the midst of the thickest concentrations, while playing and tossing fish to one another. Most of the dolphins were precisely in the areas where the slicks were abundant.

Farther north, events were unfolding on a larger scale. On December 15, 1976, the <u>Argo Merchant</u> ran aground off Nantucket Island in Massachusetts, spilling 28 x 10⁶L of No. 6 fuel oil. Between December 28, 1976 and January 13, 1977, aerial observers recorded 43 separate sightings of cetaceans, including 21 finbacks, two other unidentified rorquals, seven unidentified dolphins, and 13 to 15 pilot whales. On one occasion, two finback whales were in a heavily oiled area, showing no apparent reaction to it. Limited data showed that there was no bias in the animals' distribution in relation to oil. No marine mammal was seen in obvious distress or in direct physical contact with oil pancakes or sheen (Grose and Mattson 1977).

A University of Rhode Island research group known by the acronym CETAP (Cetacean and Turtle Assessment Program) conducted a 3-year systematic survey of a 210,000 $\rm km^2$ area of the western North Atlantic. They spotted oil 94 times, and cetaceans were twice seen within oil. Both sightings were of pods of common dolphins. They noted no behavior other than swimming (Sorensen et al. 1984). On June 18, 1979, the CETAP team was on scene to investigate the aftermath of a collision between two tankers southeast of Cape Cod, Massachusetts. One, the <u>Regal Sword</u>, sank, liberating 320,000 L of Bunker C and No. 2 fuel oil. Over the next week, at least three and possibly four species of cetaceans were seen within the slicks. Humpback and finback whales were observed feeding at the surface, some in the middle of a heavy slick. One whale, tentatively identified as a right whale, repeatedly surfaced in oil. Whales and a large number of white-sided dolphins swam, played, and fed in and near the slick. Dolphins were seen in oil slicks and sheens during eight of the 10 flight passes made over the most heavily polluted areas. The investigators reported that there was no difference in behavior between cetaceans within the slick and those beyond it (Goodale et al. 1981).

The tanker <u>Alvenas</u> ran aground and ruptured off the coast of Louisiana, (Figure 5.1) spilling nearly four million liters of crude oil (Owen 1984). Aerial observers found heavy slicks extending two miles offshore. One <u>Tursiops</u> was sighted amid patches of oil inshore; several others were offshore at the outer edge of the slick. There were no dolphins in the immediate vicinity of the vessel.



Figure 5.1 Location of oil spills in the Gulf of Mexico

It is ironic that the search for marine mammals surrounding the largest recorded oil spill was, by any standard, modest. Between June 3, 1979 and March 23, 1980 the <u>Ixtoc-I</u> oil well in the Bay of Campeche, in the Gulf of Mexico (Figure 5.1), had a blow-out which leaked 5 x 10^6 L of oil daily. Spinner dolphins, bottlenose dolphins and unidentified porpoises were observed in areas containing oil-coated debris; all appeared healthy and free of oil. Porpoises that were bow-riding veered to avoid tar balls, their only obvious reaction to oil (Bergey 1979).

Evans (1982) from Hubbs-Seaworld Research Institute led a team of investigators to study the reaction of migrating gray whales to natural oil seeps emanating from the sea floor. Thus, our story begins and ends with the gray whale. The team established four observatories on land, and one on an offshore drilling rig, along a 50 km stretch of the California coast from Point Conception to Coal Oil Point. Within the study area, there were at least four seeps within a 5 km radius of each observation site. The most active seep, near Coal Oil Point, releases a minimum of 30 barrels of oil daily.

From the observatories and from aircraft, the investigators documented swimming speeds, surface behavior, dive times and respiratory rates of small groups of whales, and found that when entering oiled waters, the animals would modify their swimming speeds and occasionally their direction with no consistent pattern. In oiled waters, they seemed to spend less time at the surface, blowing less frequently but at a faster rate.

If this reaction is interpreted as an avoidance response, it suggests that gray whales can detect oil. Those showing no response either could not detect the amount or type of oil present, or were indifferent to it. The investigators were careful to point out that comparisons are tenous, as it was not possible to follow specific whales into and out of oiled areas. That should be the subject of future experiments and could well be incorporated into ongoing studies on the behavior of radio-tagged gray whales during their annual migration.

These observations summarize the attempts to determine what cetaceans do when they confront spilled oil. None provides a complete picture, as one might expect from empirical studies. But each account gives a clue to behaviors, some more consistent than others, on which hypotheses can be constructed and tested in subsequent oil spill accidents. The drama of certain mortality no longer seems reasonable. Instead, we find whales and dolphins in the vicinity, and some in the midst of a spill, behaving quite normally. The questions now are: were the animals able to detect oil; given the choice, would they have avoided it; might they have been drawn unwittingly to the heart of a spill, perhaps in search of prey organisms attracted by the oil's protective shadow; how might such excursions through oil affect the health of a whale or dolphin? These questions have been addressed through an assortment of speculative writings (Sergeant 1970, Butler et al. 1974, Fraker et al. 1978, Calkins 1979, Geraci and St. Aubin 1980, Cowles et al. 1981) and more recently, by a series of experiments.

Detection and Avoidance

From 1980 through 1983, we carried out three successive studies to determine how bottlenose dolphins react to oil films in their environment (Geraci et al. 1983, Smith et al. 1983, St. Aubin et al. 1985). The first of these tested the hypothesis that surface oil presents a visual target to an animal. Most crude oils are dark, and as they weather, become thicker and darker still. We intended to learn whether a bottlenose dolphin would be able to detect oils of this kind, and diluted preparations with less apparent visual properties. In all, two dolphins were presented with 12 different oils and 22 mixtures.

The studies were carried out in the relatively natural setting of an enclosed lagoon in the Gulf of Mexico, in the Florida Keys. Early into the training, each dolphin learned to position itself on a fixed underwater station at a depth of 1 m, and look upward to view a short open-ended cylinder confining various materials and objects at the surface (Figure 5.2). The animal would leave the station to press a paddle only when it detected something in the cylinder besides water. If the dolphin correctly detected nothing, it would remain stationary until called to be rewarded. The behavior was shaped using solid objects made of wood and plastic, and an assortment of buoyant fruits, selected according to the palate of each trainer. After the animal mastered the technique, the objects were gradually replaced with oil, until the cylinder contained only oil. Once trained to detect solid objects, it took only three days for the dolphins to respond to the presence of oil alone.

Through a long series of randomized presentations of different objects and types and thicknesses of oil, the experiment demonstrated that the dolphins quite easily discriminated between oil and the uncontaminated surface of the water. The darker the substance, the easier it was to detect, down to an optical density that corresponded to 1-mm thick films of the three types We interpreted these findings as evidence that the of crude oils tested. dolphins can see the thicker formations of oil that typically occur at the source of a spill, and weathered fractions which form "pancakes" of much thicker viscous oils. In fact, while blindfolded, one of the dolphins was able to detect 12-mm thick patches of heavy oil churned so as to entrain air bubbles, presumably by echolocating. Lighter fractions, which spread into thin sheens and typically comprise most of a spill area, would not be detected easily if at all, nor would lightly colored refined products such as gasoline, diesel fuel, and solvents which disperse very rapidly into surface films. Patterns of weathering and spread of oil are covered in detail by Neff (Chapter 1).

The study answered a fundamental question, and quite naturally raised several others. If dolphins can see oil, why do they enter the region of a spill? Might they have a compelling reason to be there? Perhaps they do reject the silhouettes of thicker oil, and penetrate only the less visible sheens. This, of course, could bring them into contact with volatile, more acutely harmful substances. These concerns were incorporated into the design of the next experiment.





- (a) The trainer calls the animal to the resting dock while an examiner prepares up to three test cylinders in a canal concealed within the trial dock.
- (b) On command, the dolphin swims to the trial dock, stations on a stirrup, and
- (c) Examines the contents of the cylinder.

It leaves the station to press the paddle only when it detects there is something (oil) in the cylinder besides water. The study demonstrated that dolphins quite easily discriminate between oil and the uncontaminated surface of the water (from Geraci <u>et al</u>. 1983).

The objective was to determine if bottlenose dolphins would avoid a detectable slick. To begin with, three dolphins that, as far as we knew, had not been exposed to oil, were allowed to roam freely in an oceanic pen, with the surface divided into three equal areas by oil-containment booms (Figure 5.3). Observations were made while the animals were in the pens, either alone or as a group. We thereby established their individual swimming and surfacing behaviors and their desire, if any, to occupy one of the three subdivisions. Following the observation period, the dolphins were removed while an oil slick 1 cm thick was added to one of the subdivisions, then re-introduced individually or as a group. To avoid harming the dolphins or complicating the experiment, only odorless, tasteless, non-toxic, highly refined mineral oil was used. It was mixed with a black colorant to match the optical density of crude oils that dolphins had been able to detect in the previous study.

After re-entering the pen individually, all three dolphins avoided the oiled subdivision for at least 5 minutes, and one for up to 52 minutes. This initial reluctance was regarded as a probable response to any new stimulus, and not to oil <u>per se</u>. Within an hour, however, each dolphin emerged in the oil either accidentally, or as part of an investigative process. Each reacted immediately and overtly with a startle response and behavior normally associated with stress or annoyance. Yet the oil was innocuous, indicating that another physical property of the oil, viscosity perhaps, had been enough to disturb them. The behavior suggested that tactile sense may have played a role in the dolphins' reaction to oil.

After the intitial contact, the dolphins never again emerged in oil, even when re-introduced to the experimental setting four days later. In fact, their aversion to it prevented them from swimming beneath the oil to adjacent uncontaminated pens.

The dolphins had developed an aversion to oil, not unexpected perhaps of a creature genetically driven to regard the water's surface as a secure portal to clean air. But what surprised us was the apparent ability of the animals to "feel the oil". We undertook a study to determine how sensitive was the tactile response, and how thin or clear an oil slick would have to be for a dolphin to disregard it.

We used the same experimental setting, but this time tested the dolphins' response to oils we thought would be less obvious. We kept testing their reaction to the dark colored mineral oil, more or less as a control, to see whether they might eventually become accustomed to it - they apparently did not because they consistently avoided it. We also presented two of the dolphins the same mineral oil without the colorant. Both contacted it a total of four times within 15 minutes of exposure, each time showing a marked startle response. They never again touched the clear oil on that or subsequent trial days. We established a sheen of 0.1 mm nominal thickness, using automotive motor oil. In that setting, their behavior was erratic - a dolphin would surface there 100 times in a 1-hour session, and not at all in another, perhaps due to the inevitable discontinuities of such a thin sheen, or to reduced cutaneous stimulus presented by the membraneous film.

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Figure 5.3

Test setting to determine a dolphin's reaction to an oil-covered sector (1, 2 or 3). Each of three dolphins, introduced into the setting, avoided the oiled subdivision for up to 52 minutes. Then each emerged in the oil once on the first day, and never again for the duration of the study.



We repeated the study under vastly subdued light in order to reduce some of the visual properties of the oiled surface. This was done by covering the study pools with a large tent made of polypropylene shade fabric designed to screen out 92% of incoming light (Figure 5.4). At night, there was now insufficient light to activate a conventional light meter. In the pitch-black setting, while observers were stumbling about, dolphins were nimbly avoiding both the colored and clear mineral oil preparations. It appeared that the colorant had been incidental to the studies; the principal cue was cutaneous detection of oil. Their reaction to oil sheens under these conditions was the same as in daylight. One dolphin avoided the area containing the sheen, the other two swam into it but less frequently.

It became clear through these studies, that bottlenose dolphins are able to detect and avoid a variety of oils both during the day and at night. To accomplish this, they rely predominantly on vision, and to some extent, echolocation when facing thick transparent slicks. Once a dolphin surfaces in oil, irrespective of light conditions, its response thereafter is to avoid it. That behavior, it seems, is triggered or reinforced by the sensation that oil creates on the animals' skin.

It is not certain how broadly these findings relate to free-ranging animals. A case can be made for <u>Tursiops</u>, and probably other odontocetes with which it shares common sensory features. Using cautious analogies, certain of these data may be applied to mysticete whales as well. The key element is whether an animal has the sensory capacity to detect oil as the dolphins did, using vision and touch. Studies show that odontocetes have effective underwater vision, and aerial vision comparable to that of many terrestrial carnivores (Spong and White 1971, Pepper and Simons 1973, Dawson 1980, Madsen and Herman 1980).

The mysticete eye is proportionately smaller, and may not function as effectively as that of an odontocete at comparable depths (Mann 1946, Walls 1963, Waller 1984). But at or near the surface, their eyesight seems to be Indeed, mysticete whales may rely on visual cues for quite respectable. "Scouting" and "spy-hopping" by some is a typical behavior orientation. whereby a whale may rear or bob out of the water, apparently viewing surface features and the shoreline (Cummings and Thompson 1971, Eberhardt and Evans 1962, Pike 1962). Bowhead whales have been seen preoccupied with floating logs, and with bright green sheens of flourescent dye (Wursig et al. 1982). Echelon swimming, whereby whales move in unison, appears also to rely on visual signals, as does the ability of humpbacks to pace whale-watching vessels, and of bowheads to punch holes selectively in newly forming ice (Ljungblad et al. 1983). Such evidence indicates that mysticete whales have evolved with odontocetes to rely on vision for spatial orientation and navigation to some extent. Should oil be present in a form which sufficiently alters the optical properties of the surface, a variety of cetacean species seem to have the visual capability of detecting it.

There are many lines of evidence to show that cetaceans generally have well developed cutaneous sensitivity - it is moot to discuss whether it may be sensitive enough to detect oil as well as <u>Tursiops</u> did. The evidence is

Figure 5.4

Test pool to determine, under subdued light, a dolphin's reaction to an oil-covered sector (1, 2 or 3). The shade canopy screened out 92% of moon- and starlight. While the observers. were stumbling about, dolphins nimbly avoided both colored and clear mineral oil preparations (St. Aubin *et al.* 1985).



based on the presence, in odontocete skin, of nerve endings which in other mammals function in part as mechano-receptors (Palmer and Weddell 1964, Schmidt 1977, Agarkov et al. 1974, Slijper 1979, Purves and Pilleri 1983). The structures are found particularly in the head region and in the skin of the lips, rostrum, and melon. It would be useful to know whether these nerve endings are responsible for receiving the cutaneous signals that reinforced the oil-avoidance behavior by <u>Tursiops</u>. If so, it might be possible to predict more accurately the probable response to oil by a particular cetacean with similarly endowed skin (Herman and Tavolga 1980). Receptor-like structures have also been observed in the integument of mysticetes, including the fin whale (Giacometti 1967). Virtually the entire surface of the mouth of baleen whales contains modified Golgi-Mazzoni corpuscles considered by Ogawa and Shida (1950) to be highly tactile organs. Vibrissae along the snout of mysticetes (Yablokov et al. 1974) and non-myelinated nerve fibers within dermal papillae of the bowhead whale (Haldiman et al. 1985) are also thought to be related to epidermal sensation.

Hence, it seems that the skin of the great whales is suitably equipped to receive cutaneous signals. It is not surprising in view of their obvious responsiveness to touch. In fact, this sensory mode may underly basic affiliative and courtship behaviors (Herman and Tavolga 1980), and for certain species like the bowhead whale, a sensitive tactile response would be a useful aid when navigating through vast fields of ice. Research into the nature and sensitivity of these and other sensory receptors would ignite a new level of thinking while providing fundamental data needed to extrapolate to species which cannot be tested experimentally.

Surface Contact

We assume that a whale or dolphin must be affected by contacting crude oil or a petroleum compound. But how? Without fur, there is no concern for loss of insulation. Instead we suggested that cetacean skin might, because of its unusual properties, respond to noxious substances in a manner approaching sensitive mucous membranes, with consequent effects on ionic regulation and water balance (Geraci and St. Aubin 1980). The literature on humans accidentally contacting oil products provided some clues as to how studies on cetaceans might be developed.

Petroleum compounds, especially the short-chain fractions in gasoline, typically irritate skin and mucous membranes (Dutton 1934, Hansbrough *et al.* 1985). The effects are due in part to solubilizing and removing cutaneous lipids (Wolfram *et al.* 1972, Cornish 1980), triggering an inflamatory response which first appears as reddening of the skin. (Hansbrough *et al.* 1985). Persistent contact causes necrosis (Walsh *et al.* 1974) and inflammation reactions which can be mapped and described quantitatively.

With that background, we designed a number of experiments to test how exposure to petroleum hydrocarbons would affect the functional integrity of the cetacean envelope (Geraci and St. Aubin 1982, 1985). We took a cautious approach, which began by applying crude oil to discrete areas of skin of four species of odontocetes. Contact for up to 45 minutes was ineffective, in marked contrast to similar tests in human volunteers. We then progressed to longer exposures, up to 75 minutes, with gasoline. At this point it became clear that even unrealistically long contact times could not elicit the kind of severe reaction that typically occurs in other mammals (Hunter 1968, Hansbrough *et al.* 1985). Subtle changes that did occur were evident only histologically, and in each case, resolved within a week.

The studies pointed to the effectiveness of cetacean epidermis as a barrier to the noxious substances found in petroleum. Whereas these normally damage the skin by permeating intercellular spaces and dissolving protective lipids, their penetration in cetacean skin was impeded by tight intercellular bridges, the vitality of the superficial cells, and the extraordinary thickness of the epidermis. The intercellular and intracellular lipids which are abundant in cetacean epidermal cells, and which we had assumed to be a vulnerable target for petroleum, were unaffected. In fact, they are protected well enough that after exposing skin from a white-sided dolphin to gasoline for 16 hours <u>in vitro</u>, we could not detect a change in lipid concentration (Geraci and St. Aubin 1985).

By then, we had completed a study on repair of superficial wounds in the skin of <u>Tursiops</u>. An important finding was that following a cut, newly exposed epidermal cells degenerate to form a devitalized zone which shields the underlying cells from seawater during healing. We wanted to determine how oil might affect this process. For 30 minutes we massaged cuts with crude oil or tar. The substances had no effect on healing. Applied in the same manner, lead-free gasoline caused an exaggerated inflammatory response which by 24 hours subsided and was indistinguishable from control cuts. We concluded that the devitalized shield had protected underlying tissue from gasoline in the same way it repels osmotic attack by seawater.

Biochemical and metabolic probing did reveal subtle reversible changes in cells exposed to petroleum. Each of these effects could have been explored in greater depth, but the exercise would not have provided a clearer understanding of the issue. Already the studies had progressed beyond a probable scenario for oil contact at sea. A script can be created in which a dolphin or whale is trapped in fresh oil rich with volatile short-chain fractions which are toxic when inhaled or ingested. Effects on mucous membranes would be inevitable, but of lesser concern. Spilled crude oil exists in this form only briefly. A cetacean is more likely to contact weathered oil, which is far more persistent but contains little of the more toxic light hydrocarbon fractions. Studies show that realistic contact with oil would be less harmful than we and others had proposed (Geraci and St. Aubin 1980, Albert 1981).

Inhalation

To some, oil spills conjure an image of a sea blackened with a thick coagulum which can endanger a whale by clinging to its surface and preventing it from feeding. The scene may reflect our own experience with tar ball-strewn beaches, but a greater threat to whales or dolphins is not the thick murky residue, but the imperceptible gaseous compounds that left it behind. Vapors arise from volatile fractions in fresh crude oils and many of the refined products (Neff, Chapter 1). They irritate and damage soft tissues such as mucous membranes of the eyes (Carpenter *et al.* 1977) and airways. Depending on the concentration of vapors and duration of exposure, their effects range from mild irritation (Valpey *et al.* 1978) to sudden death (Wang and Irons 1961).

On a positive note, vapors dissipate rapidly from the environment. Few investigators have analyzed vapor concentration or characteristics associated with a spill, perhaps because there has been little concern regarding their effect on humans. A cetacean, however, must draw its breath from the narrow blanket of air immediately overlying the surface of oil (or water), thereby intensifying its exposure. What will it inhale? In a previous exercise (Geraci and St. Aubin 1982), we calculated the concentrations of hydrocarbons associated with a theoretical spill of a typical light crude oil. We made the improbable assumption that all of the volatile substances in a 5-mm slick would evaporate instantaneously and completely into a 1-m layer of static air above the surface, thereby exposing an animal to an artificially maximized For each volatile compound, we calculated vapor concentration of vapors. pressure and concentration, then graphed the findings with those from toxicity studies on experimental animals. The results showed that vapor concentrations can reach critical levels for the first few hours after a spill.

A whale or dolphin unable to leave the scene during that time would inhale vapors and might be harmed. For a given exposure, the effect would depend on the health of the animal, the state of its lungs and its response to stress (Thomson and Geraci 1986). A panicking whale or swiftly moving dolphin would breathe rapidly and probably inhale more vapors. If this were compounded by excessive release of adrenalin, sudden mortality could result, as has been observed occasionally in humans (Bass 1986). More likely, the animals would experience some irritation of respiratory membranes and absorb hydrocarbons into the blood stream, a process which might be facilitated by their habit of submerging with full lungs. Whatever the mechanism, it is clear that for the short time they persist, vapors are one feature of an oil spill that can threaten the health of a cetacean.

Baleen Fouling

There has been a great deal of interest in the possibility that residues of oil may adhere to baleen plates so as to block the flow of water and interfere with the feeding mechanism of mysticetes. The concerns are largely speculative (Fraker et al. 1978, Calkins 1979, Albert 1981, Fritts et al. 1983, Hansen 1985), as there is only one relevant report, that of a gray whale found dead during the Santa Barbara oil spill with a light film of oil and dirt on its baleen plates (Brownell 1971). Yet such an effect might be imperceptible to an observer, while leading to subtle and perhaps long-term consequences to the affected animal. With that in mind, two independent studies have been undertaken on the effects of oil fouling on baleen whales.

The feeding apparatus consists of two rows of fringed horny plates set into the gum tissue of the upper jaw. The plates are formed of hair-like tubules embedded in tough flexible keratin. The tongue of the animal rubs against the inner margin of the plates, abrading them and exposing the hairs which entwine to form a dense sieve. After the animal has taken a mouthful of food, pressure of the tongue against the plates drives water through the sieve leaving behind the mass of food which the tongue delivers to the esophagus.

The baleen feeding apparatus is versatile. Right whales typically skim the surface, while rorquals (eg. fin, blue, and humpback whales) gulp their food. Gray whales are unlike other mysticetes in scouring the bottom in search of infaunal benthic species which they gather along with silt, sand, and gravel (Rice and Wolman 1971). Pivorunas (1976, 1979) has written a detailed account of the relationship between baleen structure and feeding habits, and Wursig (Chapter 4) has examined the flexibility of feeding strategies within each group.

A safe assumption would be that any substance which affects the characteristics of the plates, the integrity of the hairs, or the porosity of the sieve may jeopardize the nutritive condition of the animal. A series of studies was conducted to determine whether petroleum compounds were capable of such mischief (Braithwaite 1981, Geraci and St. Aubin 1982, 1985, St. Aubin *et al.* 1984).

Our studies began by evaluating the effects of various petroleum hydrocarbons on isolated baleen plates. Samples from seven species of whales were soaked in gasoline, crude oil or tar, some for unrealistically long periods of time so as to exaggerate changes which might otherwise have been difficult to detect. For example, plates were exposed to crude oil for 8 hours, gasoline for up to 14 days, and roofing tar (our commercially available equivalent of weathered oil) for 21 days. Subsequently, the plates were tested for their breaking strength using a tensiometer, analyzed for keratin integrity using x-ray diffraction, and finally ground, ashed and subjected to elemental analysis by atomic absorption spectrophotometry and colorimetry.

Immersion in gasoline for 90 minutes or in crude oil for 8 hours had no effect on protein structure or breaking strength of the plates. After 21 days in tar, x-ray diffraction patterns showed no change related to protein degradation (St. Aubin *et al.* 1984). Nitrogen concentrations increased in all immersed samples, likely resulting from the loss of lipids which normally comprise up to 10% of the dry weight of baleen. There was also a consistent decrease in concentrations of manganese, copper, boron and iron in exposed baleen hairs, but not the intact plates of fin and gray whales. Right whale samples were unaffected. There was no tensiometric evidence of increased plate fragility associated with these changes. We concluded the study at this point, and directed our emphasis toward determining the effects of oil on baleen function.

There is very little information on how the baleen apparatus actually operates. This obviously complicates the design of an experiment to determine how oil fouling affects its function. The main difficulties in this study were in estimating water flow rates and pressure across the baleen filter, 'mpediments to flow under normal conditions of feeding, regional use patterns, and the functional reserve capacity of the system. In other words, at what point does a loss in function constitute a hazard to the animal? Thus, even the most carefully considered approach to the study has shortcomings, and findings are not easily generalized.

In the only study on bowhead whale baleen, Braithwaite (1983) used horizontally mounted plates to filter brine shrimp, Artemia salina, from a volume of chilled water discharged onto the upper fringed margins of the plates. Flow rates were established as the maximum volume that could pass through the baleen filter preparation in a 1-minute test. Water pressure was curiously low; the system was gravity-fed by a constant water column of only 7.5 cm over the baleen plates. After control values were established, the baleen hairs were brushed to uniform orientation, then light or medium crudes were brushed on to a nominal thickness of 0.5 to 1 mm, or poured to achieve a 1-cm thick layer. An experimental run was considered valid only if the thickness of the oil coating remained uniform during the test. That was required for the purpose of analyzing data, and was not intended to be a realistic portrayal of a fouling pattern. After the plates were fouled, the volume of water flowing through the preparation was measured and compared with control values. A quantity of brine shrimp was then introduced and water flow was measured once again.

Details of the experimental protocol are not entirely clear. It appears that most of the 45 or more oil-fouling tests were performed with a single sample of baleen with no information on whether control values were reestablished following each successive fouling test. Results showed a 5 to 10% decrease in filtration efficiency after the plates had been fouled.

We used another approach to evaluate the fouling effects of oil (Geraci and St. Aubin 1982, 1985). In a preliminary study, specimens from fin and gray whales were mounted in their natural hanging, or inverted position in a continuous-flow water flume (Geraci and St. Aubin 1982). Each preparation was oriented so that water flowed from the medial (lingual) to lateral surface, simulating the water expulsion - food retention phase of feeding. The flume contained freshwater at 15-20°C, and provided uniform flow with a velocity of 5-15 cm/second. Water movement was measured simultaneously along the incurrent and excurrent surfaces of the preparation, and between the plates using thermistor flowmeters. Once the flow pattern through a preparation was determined, the system was fouled either with a light or medium crude oil, or Bunker C. These were added to the water and thus struck the baleen preparation as a churned mixture, possibly the way it would under natural conditions. For some tests, roofing tar was applied directly to the fringed surface of the plates. Flow rates were again measured. Light to medium oils caused transient changes in water flow, which returned to normal within 40 seconds. Repeated oiling of the same preparation did not produce an additive effect. Bunker C had a more pronounced impact, restricting water flow for up to 15 minutes. Thereafter, though the plates were still noticeably fouled, normal flow patterns were restored.

The study set the stage for a more detailed evaluation, using a system which allowed for testing in salt water over temperatures ranging from 0 to 20°C and velocities up to 350 cm/second (Figure 5.5). Samples from humpback and sei whales were tested along with new material from fin and gray whales. Pressure transducers were used to monitor water velocity at various points within the elliptical flume; resistance to flow could thus be calculated and served as the index of functional change in the sample. As expected from the pilot study, Bunker C had the greatest impact on water flow through baleen, particularly at temperatures of $0-5^{\circ}$ C. Resistance to flow more than doubled in some humpback samples, whereas the effect in fin and sei whale specimens was an increase of less than 75%; gray whale samples were relatively unaffected. Medium weight oil had little effect at any temperature.

Selected samples were rinsed in continuously flowing salt water for 32 hours; samples of baleen fibers were removed periodically and analyzed for residual oil (Figure 5.6). Over 70% of the oil was lost within 30 minutes. In 8 of 11 trials, over 95% of the oil was cleared after 24 hours. We could not detect any change in resistance to flow in baleen after that time.

Combined evidence from the studies can be interpreted to suggest that a spill of heavy oil or residual patches of weathered oil could for several days at least, interfere with the feeding efficiency of the fouled plates. Effects would likely be cumulative in an animal that feeds in a region so rich in weathered oil that the rate of cleansing is outpaced by fouling. That condition could describe the heart of a spill, or a contaminated bay or lead a risky environment in any case.

One can only speculate on consequences for a whale that occasionally eats a tar ball or engulfs a mouthful of weathered oil. The degree of fouling or damage required to impair feeding cannot be calculated with any precision, but in general, organs have some functional reserve. It seems that baleen does as well; robust whales have been observed with damaged (Pivorunas 1976) or rudimentary (Rice 1961) plates. Judging from the relatively low level immediate impact in Braithwaite's (1981) study, and the rapid clearance of oil in ours (Geraci and St. Aubin 1985), it would appear that the concern for such whales is becoming less tangible, and may be outweighed by the cost and technology required to continue laboratory studies on fouling.

Figure 5.5

Tests were conducted in an elliptical tunnel with an outboard motor to circulate the water. Pressure transducers were positioned upstream and downstream from the baleen sample. Baleen specimens were mounted in a wooden frame for testing.



Figure 5.6

Amount of oil, as a percentage of initial coating, on fouled baleen preparations rinsed for up to 32 hours. Data are shown for one sample each from fin (\triangle) , sei (\blacktriangle) and gray (\blacksquare) whales. Over 70% of the oil was lost within 30 minutes. In 8 of 11 trials, over 95% was cleared after 24 hours.



Rinsing time (h)

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Ingestion and Accumulation

Consumed petroleum hydrocarbons are toxic to a wide variety of mammals. The subject evokes considerable interest because of the prevalence and devastating effects of accidental hydrocarbon ingestion by young children (U.S. Dept. Health and Welfare 1978 a&b). The compounds are systemically harmful, the degree depending on their chemical composition. Those with low viscosity and surface tension irritate the gastrointestinal tract, and induce vomiting which leads to aspiration of the material into the lungs causing pneumonia and death (Zieserl 1979). Larger quantities, as much as 140 times the aspirated dose (Gerarde 1964) can be tolerated if the substance remains in the gastrointestinal tract, but that is harmful as well. Hydrocarbons can be directly toxic to the mucosal epithelium (Rowe *et al.* 1973), and when absorbed distribute throughout the body and produce their greatest effects on the central nervous system.

There has been some speculation that cetaceans could consume oil while feeding. Fraker et al. (1978) suggested that bowheads, because of their feeding behavior, could ingest damaging quantities of oil. Hansen (1985) affirmed that baleen whales that skim the surface and water column are more likely to ingest oil than gulp-feeders or toothed whales. Gray whales, because of their versatile feeding habits could conceivably consume floating tar balls (Calkins 1979) or contaminated bottom sediments (Hansen 1985). Virtually any species might ingest oil by feeding on contaminated prey. The assumptions are logical, and one could fairly believe that of the vast quantities of oil discharged at sea (Neff, Chapter 1), at least a gulp or two must find its way into the gullet of a hungry whale. Yet these animals bear no evidence obvious enough to have drawn attention. As far as we know, the literature consists of only a threadbare notation that "hydrocarbons" were found in the intestines of two bottlenose dolphins along the coast of France (Duguy and Toussaint 1977).

There has also been a study to determine how small quantities of refined petroleum oil consumed over a fairly long period of time would affect the health of <u>Tursiops</u> (Caldwell and Caldwell 1982). It was an attempt to establish whether machine oil accidentally seeping into a pool might have been responsible for an unprecedented increase in mortality of captive dolphins. The only notable clinical finding had been elevated circulating levels of the enzyme glutamic pyruvic transaminase, suggesting that the liver might have been injured.

In the experiment, one dolphin was given the same machine oil in capsule form, at a rate of 5 mL/day, 5 days/week, for a total of 335 mL in 14 weeks. Another dolphin, used as a control was given mineral oil under the same conditions, for a total of 225 mL in 10 weeks. The animals were examined for clinical, hematological and blood chemical changes during the study. None was found, nor was there evidence of any relevant effects on necropsy examination of the test dolphin when it was euthanized one month later for reasons unrelated to the study. The results are not surprising. The quantity of oil consumed by the dolphin was substantially lower than the toxic dose for other mammals. Seals had also shown no effect after ingesting similar quantities (Geraci and Smith 1976). In fact, the amount of substance considered to be critical is higher than one would reasonably wish to administer to a cetacean. In mice, it is in the order of 5 to 25 mL/kg for heavy fuel oils, and 14 to 20 mL/kg for ligher fuel oils (Elars 1979 a,b; 1980 a-d). Let us assume that a cetacean would be at risk after taking a quantity of fuel oil at a mid-range concentration of 15 mL/kg. To achieve that, an adult harbor porpoise would have to consume one liter, a bottlenose dolphin three to four liters, and a pilot whale thirty liters. A forty-ton whale would require an estimated 600 L or roughly 150 U.S. gallons.

Could a cetacean realistically ingest such quantities of oil? It would be impossible to predict the behavior of an excited animal unavoidably confronting a spill. It may swallow oil accidentally, or as we observe in terminally stressed odontocetes, drink seawater liberally, and with that, consume oil. Otherwise, it would seem unlikely, that in the normal course of events, that a whale or dolphin would ingest much floating oil. A dolphin may drink 500 to 1500 mL of seawater daily (Ridgway 1972 p. 632). If contaminated, only a small portion of that would be oil. Odontocetes are predators that normally would not scavenge oil-killed fish, except perhaps for some Tursiops that have learned to forage behind fishing boats for a netspilled meal. And lessons from captivity suggest that they would probably disregard it if tainted. Mysticetes in the area of a spill are more likely to ingest oil-contaminated food, particularly zooplankters which actively consume oil particles. Assuming toxic oils to comprise 10% of the estimated 1600 kg of food consumed in a day by a forty-ton fin whale, the total quantity of ingested oil would be 160 kg. This approaches the critical dose calculated for highly toxic fuel oils. The question is, would fin whales feed around a spill of fresh volatile oil long enough to accumulate such quantities? There is no evidence from observational studies or stranding records to suggest that they do.

Petroleum hydrocarbons persist in the food chain, particularly in species that have a low capacity to detoxify. Molluscs and other benthic invertebrates can accumulate residues from bottom sediments and remain contaminated for many years (Gilfillan and Vandermeulen 1978). Gray whales and other bottom-feeding cetaceans might therefore ingest petroleum long after a spill has dissipated.

To predict the consequences of chronic ingestion of sub-lethal quantities of oil, we should know whether a cetacean can detoxify petroleum compounds, or metabolites that persist in tissues of fish and other prey (McCain *et al.* 1978). Cytochrome P450, an iron-containing protein in liver cells, is part of a dynamic enzyme system involved in that metabolic process. It has been identified in liver from the bottlenose dolphin, white-sided dolphin, harbor porpoise and minke whale (Geraci and St. Aubin 1982, Goksoyr *et al.* 1986), and is probably common to cetaceans generally. A pilot study on rats has shown that oil is a potent inducer of P450 (Geraci and St. Aubin 1982), and we would expect it to have a comparable effect in a cetacean. These findings call for expanded studies on detoxifying systems in cetaceans. At present, an animal suspected to have been exposed to oil should be analyzed for cytochrome P450.

It is also possible to examine tissues for metabolites of petroleum hydrocarbons. We undertook a search for naphthalene in samples of liver and blubber from 15 species of whales which either had stranded, been taken as part of a fishery, or died in captivity. The analytical procedure was not particularly sensitive owing to limitations on methods for extracting naphthalene from tissue homogenates. Nevertheless, certain trends were Highest levels were found in the blubber of small odontocetes; evident. values in mysticetes were considerably lower. The pattern of accumulation seemed to be consistent with the habitat of the animals. Beluga whales and narwhals, which had the highest concentrations, live in a cold environment which retards hydrocarbon metabolism in fish (Collier et al. 1978), potentially leaving more available to be consumed. Mysticetes generally feed on organisms that accumulate and depurate relatively rapidly (Neff et al. 1976). Alternatively, the difference in the levels of naphthalene residues in odontocetes and mysticetes could reflect specific hydrocarbon detoxification capabilities in the two groups. These possibilites should be tested, and to do so, it will be necessary to develop a sensitive method for analyzing naphthalene and its metabolites in marine mammal tissue, correlate levels with controlled ingestion of petroleum compounds, then analyze tissues from animals available through strandings or other opportunities. Data from these studies will provide the means to test the hypothesis that a cetacean may ingest oil, and perhaps be harmed by it.

Summary

An oil spill at sea would add an element of risk to the environment of a whale or dolphin. Fresh crude oil or volatile distillates release toxic vapors that can damage sensitive tissues, harmful fractions may be swallowed or consumed through contaminated prey, and thicker tarry substances with entrapped debris linger at the surface, threatening to plug the vital baleen and digestive apparatus of whales that engulf them.

In spite of numerous spills in which cetaceans have been observed at sea, none of these effects has been detected, or recorded at least with any certainty. Experimental evidence shows that dolphins can see oil at the surface; they can also feel it, and prefer to avoid it. Other cetaceans seem to be comparably equipped to detect oil, yet in the wild, whales and dolphins have been observed swimming and feeding in its presence, without apparent ill effect. Not a strong enough adverse stimulus perhaps, or maybe they disregard oil for more consuming matters. Unlike furbearers, there is no avenue for uncontrolled heat loss through fouling of the skin. Furthermore, cetacean epidermis is nearly unpenetrable even to the highly volatile compounds in oil, and when skin is breached, realistic exposure to these fractions does not impede the progress of healing. Though encounters are likely, there is no evidence that oil or tar balls foul the feeding apparatus of baleen whales, and laboratory studies suggest such an effect would be transient.

Current technology provides the means to probe deeper in search of effects, to the molecular level, if necessary. That may serve our scientific curiosity, but would not bring us closer to an understanding of the central question. On the whole, it is quite improbable that a species or population of cetaceans will be disabled by a spill at sea, whatever the likelihood that one or a few animals might be affected or even killed. Yet, some habitats and, therefore, their residents, are more vulnerable than others. The iceedge, refuge for bowheads, narwhals and beluga whales, is a riskier trap than pelagic waters. And coastal areas with bustling oil production activity might see dolphins as the unwitting sentinals of a deteriorating environment. The stage is now set for decisions to identify, wisely utilize, and monitor such habitats.

Literature Cited

Agarkov, G.B., B.G. Khomenko, V.G. Khadzhinskiy. 1974. Morphology of Delphinidae. Moscow: Naukova-Dumka (available JPRS 66036).

Albert, T.F. 1981. Some thoughts regarding the effect of oil contamination on bowhead whales, <u>Balaena mysticetus</u>. pp. 945-953. In Tissue Structural Studies and other Investigations on the Biology of Endangered Whales in the Beaufort Sea. T.F. Albert (ed.). Appendix No. 9. Report to U.S. Bureau of Land Management, Washington, DC.

Anon. 1970. Santa Barbara oil spill. Smithsonian Inst. Cntr. Short-lived Phenomena. Annual Report (1969). Event No. 9-69. pp. 88-97.

Anon. 1971. Alaska Peninsula oil spill. Smithsonian Inst. Cntr. Short-lived Phenomena. Annual Report (1970). Event No. 36-70. pp. 154-157.

Anon. 1981. Oil spills off N.C. Boston Globe, May 9.

ł

Anon. 1982. Stranded, tarred pilot whale. Smithsonian Inst. Sci. Event Alert Network (SEAN) Bull. 7 (3): 26.

Bass, M. 1986. Sniffing gasoline. J. Amer. Med. Assoc. 255 (19): 2604-2605.

Battelle Memorial Institute. 1969. Review of Santa Barbara channel oil pollution incident. Res. Report Dept. of the Interior, Fed. Water Pollut. Control Admin. and Dept. of Trans., U.S. Coast Guard. Contract No. 14-12-530. 157 pp.

Bergey, M. 1979. The <u>Ixtoc</u> oil spill - effects on marine mammals and turtles. Report by author aboard Res. Vessel Oregon II on 22-day shrimp tagging expedition. 49 pp.

Braithwaite, L.F. 1981. The effects of oil on the feeding mechanism of the bowhead whale. Final Report. Contract No. AA851CT055. Bringham Young Univ., Provo, UT. 43 pp.

Braithwaite, L.F. 1983. The effects of oil on the feeding mechanism of the bowhead whale. Final Report. U.S. Dept. of the Interior, Washington, DC. Contract No. AA 851-CT0-55. 45 pp.

Brown, W.R., J.R. Geraci, B.D. Hicks, D.J. St. Aubin and J.P. Schroeder. 1983. Epidermal cell proliferation in the bottlenose dolphin (<u>Tursiops</u> <u>truncatus</u>). Can. J. Zool. 61 (7): 1587-1590.

Brownell, R.L., Jr. 1971. Whales, dolphins and oil pollution. pp. 255-276. In Biological and Oceanographic Survey of the Santa Barbara Channel Oil Spill 1969-1970. Volume 1. Biology and Bacteriology. D. Straughan (ed.). Allan Hancock Foundation, Sea Grant Publ. No. 2.

Butler, M.J.A., F. Berkes and H. Pawles. 1974. Biological aspects of oil pollution in the marine environment: a review. Mar. Sci. Cntr., McGill Univ., Montreal, P.Q. Manuscript Report No. 22. 133 pp.

Caldwell, M.C. and D.K. Caldwell. 1982. A study of the effects of oil ingestion on a bottlenose dolphin, <u>Tursiops truncatus</u>. pp. 224-237. In Study of Effects of Oil on Cetaceans. J.R. Geraci and D.J. St. Aubin (eds.). Final Report. U.S. Dept. Interior, Bureau of Land

Management, Washington, DC. Contract No. AA 551-CT9-29. 274 pp.

Calkins, D.G. 1979. Marine mammals of Lower Cook Inlet and the potential for impact from outer continental shelf oil and gas exploration, development and transport. Final Report. Outer Continental Shelf Environ. Assess. Program. Research Unit 243. pp. 171-264.

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Carpenter, C.P., D.L. Geary, Jr., R.C. Myers, D.J. Nachreiner, L.J. Sullivan and J.M. King. 1977. Petroleum hydrocarbon toxicity studies. XIV. Animals and human response to vapors of high aromatic solvent. Toxicol. Appl. Pharmacol. 41 (2): 235-249.

Collier, T.K., L.C. Thomas and D.C. Malins. 1978. Influence of environmental temperature on disposition of dietary naphthalene in coho salmon (<u>Oncorhynchus kisutch</u>): isolation and identification of individual metabolites. Comp. Biochem. Physiol. 61C: 23-28.

Cornish, H.H. 1980. Solvents and vapors. pp. 468-496. In Toxicology. 2nd Edition. Casarett and Doull (eds.). MacMillan Publ. Co. Inc., New York, NY.

Cowles, C.J., D.J. Hansen and J.D. Hubbard. 1981. Types of potential effects of offshore oil and gas development on marine mammals and endangered species of the northern Bering Sea and Arctic Ocean. Tech. Paper No. 9, Bureau of Land Management, Alaska OCS Office, Anchorage, AK. 23 pp.

Cummings, W.C. and P.O. Thompson. 1971. Gray whales, <u>Eschrichtius</u> robustus, avoid the underwater sounds of killer whales, <u>Orcinus</u> orca. Fish. Bull. 69: 525-530.

Dawson, W.W. 1980. The cetacean eye. pp. 53-100. In Cetacean Behavior: Mechanisms and Functions. L.M. Herman (ed). John Wiley & Sons Inc., New York, NY.

Duguy, R. and P. Toussaint. 1977. Recherches sur les facteurs de mortalite des cetaces sur les cote de France. Conseil Intern. L'Explor. de la Mer, Comite de Mammiferes Marins. Report C.M. 1975/N:5.

Dutton, W.F. 1934. Petroleum dermatitis. Med. Rec. 140: 550-552.

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

Easton, R. (ed.). 1972. Black Tide: The Santa Barbara Oil Spill and Its Consequences. Delcorte Press, New York, NY. 336 pp.

Elars Bioresearch Laboratories, Inc. 1979a. Acute toxicity tests of API178-3 No. 2 home heating oil (10% Cat). Project No. 1443. API Med. Res. Publ. 2732773. 52 pp.

Elars Bioresearch Laboratories, Inc. 1979b. Acute toxicity tests of AP178-4 No. 2 home heating oil (50% Cat). Project No. 1443. API Med. Res. Publ. 2732772.

Elars Bioresearch Laboratories, Inc. 1980a. Acute toxicity tests of API 78-2 No. 2 home heating oil (30% Cat). Project 1443. Amer. Petro. Inst. Med. Res. Publ. 2732771. 48 pp.

Elars Bioresearch Laboratories, Inc. 1980b. Acute toxicity tests of API 78-7 No. 6 heavy fuel oil (API gravity 17.1/0.8% S). Project 1443. Amer. Petro. Inst. Med. Res. Publ. 2732774. 45 pp.

Elars Bioresearch Laboratories, Inc. 1980c. Acute toxicity tests of API 79-2 No. 6 heavy fuel oil (API gravity 5.2/1.2% S). Project 1443. Amer. Petro. Inst. Med. Res. Publ. 2732813. 52 pp.

Elars Bioresearch Laboratories, Inc. 1980d. Acute toxicity tests of API 78-6 No. 6 heavy fuel oil (API gravity 11.7/2.7% S). Project 1443. Amer. Petro. Inst. Med. Res. Publ. 2732814. 47 pp.

Evans, W.E. 1982. A study to determine if gray whales detect oil. pp. 47-61. In Study of the Effects of Oil on Cetaceans. J.R. Geraci and D.J. St. Aubin (eds.). Final Report. U.S. Dept. of the Interior, Bureau of Land Management, Washington, DC. Contract No. AA 551-CT9-29.

- Fraker, M.A., D.E. Sergeant and W. Hoek. 1978. Bowhead and white whales in the southern Beaufort Sea. Beaufort Sea Project Technical Report No. 4: 114 pp.
- Fritts, T.H., A.B. Irvine, R.D. Jennings, L.A. Collum, W. Hoffman and M.A. McGehee. 1983. Turtles, birds, and mammals in the northern Gulf of Mexico and nearby Atlantic waters. Report U.S. Fish Wildl. Serv., Office of Biol. Sci. Publ. FWS/OBS-82/65.
- Geraci, J.R. and D.J. St. Aubin. 1980. Offshore petroleum resource development and marine mammals: a review and research recommendations. Mar. Fish. Rev. 42: 1-12.
- Geraci, J.R. and D.J. St. Aubin. 1982. Study of the effects of oil on cetaceans. Final Report. U.S. Dept. of the Interior, Bureau of Land Management, Washington, DC. 274 pp.
- Geraci, J.R. and D.J. St. Aubin. 1985. Expanded studies of the effects of oil on cetaceans.. Final Report. Part I. U.S. Dept. of the Interior, Minerals Management Serv., Washington, DC. 144 pp.
- Geraci, J.R., D.J. St. Aubin and R.J. Reisman. 1983. Bottlenose dolphins, <u>Tursiops</u> truncatus, can detect oil. Can. J. Fish. Aquat. Sci. 40 (9): 1515-1522.
- Geraci, J.R. and T.G. Smith. 1976. Direct and indirect effects of oil on ringed seals (<u>Phoca hispida</u>) of the Beaufort Sea. J. Fish. Res. Board Can. 33 (9): 1976-1984.
- Gerarde, H.W. 1964. Kerosine experimental and clinical toxicology. Occup. Health Rev. 16: 17-21.
- Giacometti, L. 1967. The skin of the whale (<u>Balaenoptera physalus</u>). Anat. Rec. 159: 69-76.
- Gilfillan, E.S. and J.H. Vandermeulen. 1978. Alterations in growth and physiology of soft-shell clams, <u>Mya</u> <u>arenaria</u>, chronically oiled with Bunker C from Chedabucto Bay, Nova Scotia, 1970-76. J. Fish. Res. Board Can. 35: 630-636.
- Goksoyr, A., J.E. Solbakken, J. Tarlebo and J. Klungsoyr. 1986. Initial characterization of the hepatic microsomal P-450-system of the piked whale (minke) <u>Balaenoptera</u> <u>acutorostrata</u>. Mar. Env. Res. 19: 185-203.
- Goodale, D.R., M.A. Hyman and H.E. Winn. 1981. Cetacean responses in association with the <u>Regal Sword</u> oil spill. Cetacean and Turtle Assess. Program, Univ. Rhode Island. Annual Report (1979). U.S. Dept. of the Interior, Washington, DC. pp. XI-1 - XI-6.
- Grose, P.L. and J.S. Mattson (eds.). 1977. The Argo Merchant spill: a preliminary scientific report. NOAA Environ. Res. Lab., Boulder, CO. 133 pp.
- Gruber, J.A. 1981. Ecology of the Atlantic bottle-nosed dolphin (<u>Tursiops</u> <u>truncatus</u>) in the Pass Cavallo area of Matagorda Bay, Texas. M.Sc. Thesis, Texas A&M Univ., College Station, TX. 182 pp.
- Haldiman, J.T., W.G. Henk, R.W. Henry, T.F. Albert, Y.Z. Abdelbaki and D.W. Duffield. 1985. Epidermal and papillary dermal characteristics of the bowhead whale (<u>Balaena mysticetus</u>). Anat. Rec. 211: 391-402.
- Hansbrough, J.F., R. Zapata-Sirvent, W. Dominic *et al.* 1985. Hydrocarbon contact injuries. J. Trauma 25 (3): 250-252.
- Hansen, D.J. 1985. The potential effects of oil spills andother chemical pollutants on marine mammals occurring in Alaskan waters. U.S. Dept. of the Interior, Minerals Management Serv., Alaska OCS Region, Anchorage, AK. Report MMS 85-0031.

Herman, L.M. and W.N. Tavolga. 1980. The communication system of cetaceans. pp. 149-209. In Cetacean Behavior: Mechanisms and Functions. L.M. Herman (ed.). John Wiley & Sons Publ., New York, NY.
Hunter, G.A. 1968. Chemical burns of the skin after contact with petroleum.

Hunter, G.A. 1968. Chemical burns of the skin after contact with petroleum. Br. J. Plast. Surg. 21: 337-341.

- Ljungblad, D.K., S.E. Moore and D.R. Van Schoik. 1983. Aerial surveys of endangered whales in the Beaufort, eastern Chukchi, and northern Bering Seas, 1982. Alaska OCS Office, Minerals Management Serv., Report No. NOSC TR1046. 382 pp.
- Madsen, C.J. and L.M. Herman. 1980. Social and ecological correlates of cetacean vision and visual appearance. pp. 101-148. In Cetacean Behavior: Mechanisms and Functions. L.M. Herman (ed.). John Wiley & Sons, Inc., New York, NY.
- Mann, G. 1946. Oyo y vision de las ballenas. Biologica 4: 23-71.
- 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 oils from experimentally oiled sediments to English sole, <u>Parophrys vetulus</u> and pathological consequences. J. Fish. Res. Board Can. 35: 657-664.
- Neff, J.M., B.A. Cox, D. Dixit and J.W. Anderson. 1976. Accumulation and release of petroleum-derived aromatic hydrocarbons by four species of marine animals. Mar. Biol. 38: 279-289.
- Nicol, C.W. 1976. The Mizushima oil spill a tragedy for Japan and a lesson for Canada. Environ. Canada. Environ. Protection Serv. Report No. EPS-8-EC-76-2.
- Ogawa, T. and T. Shida. 1950. On the sensory tubercles of lips and of oral cavity in the sei and fin whale. Sci. Rep. Whales Res. Inst., Tokyo 3: 1-16.
- Owen, R.E. 1984. Oil spill from the British tanker <u>Alvenas</u>. Nat. Mar. Fish. Serv., Southeast Fish. Cntr., Miami, FL. Unpublished Report. 3 pp.
- Palmer, E. and G. Weddell. 1964. The relationship between structure, innervation, and function of the skin of the bottlenose dolphin, <u>Tursiops</u> truncatus. Proc. Zool. Soc. Lond. 143: 553-568.
- Pepper, R.L. and J. Simmons. 1973. In-air visual acuity of the bottlenose dolphin. Exp. Neurol. 41: 271-276.
- Pike, G. 1962. Migration and feeding of the gray whale (<u>Eschrichtius</u> <u>gibbosus</u>). J. Fish. Res. Board Can. 19: 815-838.
- Pivorunas, A. 1976. A mathematical consideration on the function of baleen plates and hair fringes. Whales Res. Inst., Sci. Report No. 28: 37-55.
- Pivorunas, A. 1979. The feeding mechanisms of baleen whales. Amer. Sci. 67 (4): 432-440.
- Prieur, D. and E. Hussenot. 1978. Marine mammals stranded during the <u>Amoco</u> <u>Cadiz</u> oil spill. Penn ar Bard 11 (94): 361-364.
- Purves, P.E. and G.E. Pilleri. (eds.). 1983. Echolocation in Whales and Dolphins. Academic Press, London, U.K. 261 pp.
- Rice, D.W. 1961. Sei whales with rudimentary baleen. Norsk Hvalfangst-Tidende 5: 189-193.
- Rice, D.W. and A.A. Wolman. 1971. The life history and ecology of the gray whale, <u>Eschrichtius robustus</u>. Am. Soc. Mammal., Spec. Publ. No. 3.

- Ridgway, S.H. (ed.). 1972. Homeostasis in the aquatic environment. pp. 632. In Mammals of the Sea: Biology and Medicine. Charles C. Thomas Publ., Springfield, IL. 812 pp.
- Rowe, L.D., J.W. Dollahite and B.J. Camp. 1973. Toxicity of two crude oils and of kerosine to cattle. J. Am. Vet. Med. Assoc. 162 (1): 61-66.
- St. Aubin, D.J., J.R. Geraci, T.G. Smith and T.G. Friesen. 1985. How do bottlenose dolphins, <u>Tursiops truncatus</u>, react to oil films under different light conditions? Can. J. Fish. Aquat. Sci. 42 (3): 430-436.
- St. Aubin, D.J., R.H. Stinson and J.R. Geraci. 1984. Aspects of the structure and composition of baleen, and the effects of exposure to petroleum hydrocarbons. Can. J. Zool. 62: 193-198.
- Schmidt, R.F. (ed.). 1977. Somatovisceral sensibility. pp. 81-175. In Fundamentals of Sensory Physiology. Springer-Verlag, New York, NY.
- Sergeant, D.E. 1970. Sea mammals and man: a look at the future. Fish. Res. Board Can., Arctic Biol. Station, Ste. Anne de Bellevue, P.Q. Unpublished manuscript. 6 pp.
- Shane, S.H. and D.J. Schmidly. 1978. The population biology of the Atlantic bottlenose dolphin, <u>Tursiops</u> <u>truncatus</u>, in the Arkansas Pass area of Texas. U.S. Marine Mammal Commission, Washington, DC. Report No. MMC-76/11.
- Slijper, E.J. 1979. Whales. Second Edition. R.J. Harrison (ed.). Hutchinson, London, U.K. 511 pp.
- Smith, T.G., J.R. Geraci and D.J. St. Aubin. 1983. The reaction of bottlenose dolphins, <u>Tursiops truncatus</u>, to a controlled oil spill. Can. J. Fish. Aquat. Sci. 40 (9): 1522-1527.
- Sorensen, P.W., R.J. Medved, M.A.M. Hyman and H.E. Winn. 1984. Distribution and abundance of cetaceans in the vicinity of human activities along the continental shelf of the northwestern Atlantic. Mar. Environ. Res. 12: 69-81.
- Spong, P. and E. White. 1971. Visual acuity and discrimination learning in the dolphin (Lagenorhynchus obliquidens). Exp. Neurol. 31: 431-436.
- Straughan, D. 1972. Biological effects of oil pollution in the Santa Barbara Channel. pp. 355-359. In Marine Pollution and Sea Life. M. Ruivo (ed.). Fishing News Ltd., London, U.K.
- Thomson, C.A. and J.R. Geraci. 1986. Cortisol, aldosterone and leucocytes in the stress response of bottlenose dolphins, <u>Tursiops truncatus</u>. Can. J. Fish. Aquat. Sci. 43 (5): 1010-1016.
- U.S. Dept. Health and Welfare. 1978a. Tabulations of 1976 case reports. Publ. Health Serv./FDA. Bull. Nat. Clearinghouse Poison Control Centers, Bethesda, MD.
- U.S. Dept. Health and Welfare. 1978b. Phencyclidine overdose management. Publ. Health Serv./FDA. Bull. Nat. Clearinghouse Poison Control Centers, Bethesda, MD.
- Valpey, R., S.M. Sumi, M.K. Copass and G.J. Goble. 1978. Acute and chronic progressive encephalopathy due to gasoline sniffing. Neurol. 28: 507-510.
- Waller, G.N.H. 1984. The ocular anatomy of cetacea an historical perspective. Invest. Cetacea: 136-148.
- Walls, G.L. 1963. The Vertebrate Eye and its Adaptive Radiation. Hafner, New York, NY.

- Walsh, W.A., F.J. Scarpa, R.S. Brown, K.W. Ashcraft, V.A. Green, T.M. Holder and R.A. Amoury. 1974. Gasoline immersion burn. The New Engl. J. Med. 291: 830.
- Wang, C.C. and G.U. Irons. 1961. Acute gasoline intoxication. Arch. Environ. Health 2: 714-716.
- Wolfram, M.A., N.F. Wolejsza and K. Laden. 1972. Biomechanical properties of delipidized stratum corneum. J. Invest. Dermat. 59 (6): 421-426.
- Wursig, B., C.W. Clark, E.M. Dorsey, M.A. Fraker and R.S. Payne. 1982. Normal behavior of bowheads. pp. 33-143. In Behavior, Disturbance Responses and Feeding of Bowhead Whales, <u>Balaena mysticetus</u> in the Beaufort Sea, 1980-1981. LGL Ecol. Res. Assoc., Inc. Bryan, TX. U.S. Bureau of Land Management, Washington, DC.
- Yablokov, A.V., V.M. Bel'kovich and V.I. Borisov. 1974. Whales and dolphins. Transl. Kity I Del'finy, 1972, Izd-vo Nauka, Moscow, U.S.S.R. Joint Publ. Res. Serv., Arlington, VA.
- Zieserl, E. 1979. Hydrocarbon ingestion and poisoning. Comprehen. Therapy 5/6: 35-42.

CHAPTER 6

SEA OTTERS AND OIL:

ECOLOGIC PERSPECTIVES

Katherine Ralls

Department of Zoological Research National Zoo Smithsonian Institution Washington, DC 20008

and

Donald B. Siniff

Department of Ecology and Behavioral Biology University of Minnesota Minneapolis, MN 55455

Introduction

Otters comprise the subfamily Lutrinae of the family Mustelidae, order Carnivora. Most are associated with fresh water; only two species occur at sea. The marine otter, <u>Lutra felina</u>, which ranges along the west coast of South America, is somewhat smaller than its more extensively studied counterpart in the North Pacific, the sea otter (Mason and MacDonald 1986). Much of the ensuing discussion will focus on the latter species.

Sea otters exploited the marine environment more recently than other mammals, and are consequently less specialized for life in the ocean. The dense fur, streamlined shape and amphibious habits are shared with its more terrestrial relatives, the river otters. However, it possesses many aquatic adaptations (Estes 1980), such as hind flippers, loss of the clavicle, allowing great flexibility of the pectoral girdle, and large kidneys. As a predator of marine invertebrates in the nearshore community, the sea otter possesses a modified dentition with flattened premolars and molars which are well-suited to crushing its hard-shelled prey (Kenyon 1969, Reidman and Estes 1988).

The sea otter is the largest lutrinid (Mason and MacDonald 1986) yet is the smallest marine mammal. An adult male can weigh up to 45 kg; females are considerably smaller (Estes 1980).

Distribution

The sea otter originally inhabited a large area in the North Pacific, ranging from the northern islands of Japan northward along the eastern coast of Kamchatka, through the Commander and Aleutian Islands to the Alaskan peninsula, and south along North America as far as central Baja California (Kenyon 1969, Estes 1980) (Figure 6.1). However, the species was heavily exploited for its fur and was reduced to a few remnant populations by the beginning of the twentieth century. Some of these populations subsequently became extinct but others increased once sea otters were legally protected under a number of statutes, beginning with the International Fur Seal Treaty in 1911 (Kenyon 1969, Estes 1980).

Sea otters have now reoccupied most of their historical range across the North Pacific, from the southern end of the Kurile Islands, eastward to Prince William Sound in the northeastern Gulf of Alaska (Reidman and Estes 1988). In the 1960's and 1970's, Alaskan sea otters were translocated to southeast Alaska, British Columbia, Washington, and Oregon (Jameson *et al.* 1982). The Oregon population died out but the others became established and appear to be increasing.

The remnant population in California, which is classified as "threatened" by the U.S. Fish and Wildlife Service (Ladd 1986a), also increased and is currently distributed along the coast between approximately Point Ano Neuvo in the north and the Santa Maria River in the south, although some individuals

Figure 6.1

Distribution of the sea otter (after Kenyon 1969).



wander beyond these limits (Leatherwood *et al.* 1978). The central part of the California range is inhabited primarily by adult females and pups, along with juveniles and some territorial males; the most northern and southern areas are inhabited largely by males (Estes and Jameson 1983). In 1987, the U.S. Fish and Wildlife Service translocated sea otters to another part of their historical range, San Nicolas Island off southern California (Ladd 1986 a&b, Brownell 1988).

Preferred Habitat

Sea otters are primarily a coastal species. However, in areas where the water is relatively shallow, large numbers of individuals sometimes occur far from shore. They are frequently found over 8 km from shore in the Copper River delta area in the Gulf of Alaska (Monnett 1987) and over 30 km from shore around Unimak Island in the Bering Sea (Kenyon 1969). Sea otters prefer to rest in kelp if it is available, as it helps keep them from drifting and perhaps affords some protection from white sharks (<u>Carcharodon carcharias</u>). In California, sea otters are most commonly observed inshore of the outer limit of the giant kelp (<u>Macrocystis pyrifera</u>) canopy (Reidman and Estes 1988). However, juvenile males spend much of their time in open water beyond the limits of the kelp (Siniff and Ralls 1987) and otters are abundant in many areas, such as Prince William Sound, Alaska, where very little kelp is present.

Sea otters occur over a variety of substrate types and nearshore communities. In California, areas with rocky bottoms support higher densities of otters (approximately 5 individuals/km²) than those with sandy bottoms (0.8 individuals/km²) (CDFG 1976). This is probably because rocky bottom areas are characterized by very productive communities that include a variety of invertebrate prey species taken by sea otters (Reidman and Estes 1988).

Site Fidelity and Movement Patterns

Individual sea otters typically remain within a small area from day to day. In California, the average distance between successive daily locations, determined by radio-tracking, ranged from 0.7 km for adult males to 2.4 km for juvenile males (Siniff and Ralls 1987). Movements of over 10 km per day are infrequent, but in both California and Alaska, otters sometimes move over distances of 100 km or more within a few days. Thus, home ranges tend to consist of extensively used areas connected by travel corridors. Individuals can also range over etended ares (Ribic 1982a, Garshelis and Garshelis 1984, Monnett and Rotterman 1987, Siniff and Ralls 1987). In one two-year study in California, adult females visited an average of 24 km of coastline, juvenile females 47 km, adult males 98 km and juvenile males 128 km (Siniff and Ralls 1987).
In Alaska, sea otters often make long-distance seasonal movements between breeding and wintering areas (Garshelis and Garshelis 1984, Monnett and Rotterman 1987). In California, males may (Estes and Jameson 1983) or may not (Loughlin 1980a, Siniff and Ralls 1987) show similar behavior; females in California do not move on a seasonal basis.

Strong preference for specific kelp beds and feeding areas appears to govern an otter's movement (Loughlin 1977). Otters of all age and sex classes, including territorial males, sometimes travel for long distances and then return to the same area (Loughlin 1977, Garshelis and Garshelis 1984, Garshelis *et al.* 1984, Estes and Jameson 1983, Siniff and Ralls 1987). At least five of 17 male California sea otters that were tagged and moved a distance of 72 km returned to the vicinity of their capture location within nine months (Odemar and Wilson 1969, Wild and Ames 1974). We observed two males in California that were moved approximately 150 km. One returned within a week and the other in about one month.

Reproduction

Sea otters can mate and pup throughout the year; reproductive activities are more seasonal in Alaska than in California. In Prince William Sound, mating generally occurs in fall and most pups are born in May (Garshelis *et al.* 1984). The same pattern probably exists throughout Alaska, although the pupping peak may extend into summer in some areas, with mating activity common as late as December (Kenyon 1969, Schneider 1973). In the western Pacific, there may be two reproductive peaks, one in June-July and the other in September-October (Barabash-Nikiforov *et al.* 1968). In California, pupping peaks in spring and a smaller, secondary peak appears to occur in fall (Siniff and Ralls 1987).

In California, the period from copulation to birth is about six months (Estes and Jameson 1983), and is thought to include a variable period of delayed implantation (Kenyon 1981). Kenyon (1969) estimated the gestation period in Alaska to be about 120 days. Birth may occur on land (Jameson 1983) but aquatic births are thought to be more common, at least in California. Although twins are born occasionally, they are apparently never successfully raised (Jameson and Bodkin 1986). Most pups are weaned within five to eight months (Garshelis *et al.* 1984, Payne and Jameson 1984, Wendell *et al.* 1984, Monnett 1987). After about four months of age, the pup's diet consists mostly of prey captured by its mother, although the pup continues to suckle until they separate (Payne and Jameson 1984).

Female sea otters reach sexual maturity at three to five years of age in Alaska (Kenyon 1969, Garshelis *et al.* 1984). There are no comparable data for California, except for the single observation of a pup produced by a fouryear-old female (Wendell *et al.* 1984). Males are thought to reach sexual maturity at five or six years of age (Green 1978, Schneider 1978) but generally begin breeding at a somewhat older age. Garshelis (1984) found that none of the breeding males sampled from Prince William Sound was younger than six.

Earlier studies, based on examination of reproductive tracts from animals collected in the U.S.S.R. and Alaska, suggested that sea otters generally give birth only once every two years (Barabash-Nikiforov 1947, Kenyon 1969, Schneider 1973). However, subsequent observations of tagged individuals showed that most females pup more frequently (Jameson and Johnson 1979, Loughlin *et al.* 1981, Estes and Jameson 1983, Garshelis *et al.* 1984, Wendell *et al.* 1984). Two methods of estimating the annual reproductive rate in California gave comparable values of 0.87 and 0.90 pups per female per year (Siniff and Ralls 1987), or a pupping interval of about 420 days (Siniff and Ralls 1987).

Some sea otter populations in Alaska have increased at rates as high as 16% per year (Kenyon 1969, Estes 1981). Annual increment of the California population is not as high. For many decades, the population grew at about 5% per year (Ralls *et al.* 1983, Brody 1987) but it has not increased since the early 1970's (Estes and Jameson 1983, Wendell *et al.* 1986, Brody 1987). The population dynamics of sea otters are not well understood. However, a recently developed computor model may provide some insights (Brody 1987), and its relevance to predicting recovery rates after oil spills is addressed in Chapter 11.

Social Organization and Reproductive Behavior

Sea otters are polygynous. Breeding males defend territories seasonally or year-round in areas occupied by reproductive females and their young ("female areas") (Kenyon 1969, Calkins and Lent 1975, Loughlin 1980, Estes and Jameson 1983, Garshelis *et al.* 1984). A male usually forms a temporary consortship, lasting one to four days with an estrous female (Kenyon 1969, Vandevere 1970, Garshelis *et al.* 1984). The pair remains close together during this period. Males may tend females with large pups and even some with small pups, although it appears that copulation is rarely successful until after the nursing period is over (Kenyon 1969, Calkins and Lent 1975, Garshelis *et al.* 1984). Adult females do not always remain in the territory of a single male.

Large numbers of males congregate in areas where few reproductive females are present ("male areas"). The groups include individuals that are too young to breed and older males at a time that they are not maintaining seasonal territories. Male otters are usually the first to colonize new habitat, so "male areas" tend to be located at the edge of the range, where food is abundant (Benech 1981, Estes and Jameson 1983, Garshelis *et al.* 1984, Garshelis *et al.* 1986). Otters tend to rest in groups called "rafts". The composition of these groups is fluid. Those consisting primarily of females are usually small in California and Prince William Sound, although aggregations of more than 100 females have been observed in parts of Alaska (Monnett and Rotterman 1987). Throughout this range, males may rest in very large rafts consisting of hundreds of individuals (Kenyon 1969, Garshelis *et al.* 1984). Otters sometimes emerge from the water to rest on ice or land; they do this more frequently, and in larger groups, in Alaska and the U.S.S.R. than in California (Kenyon 1969, Faurot 1985), perhaps because of the more severe climate and reduced probability of human disturbance.

Mothers and pups have strong social bonds, and remain together until the pup is weaned (Payne and Jameson 1984); however, mothers that are ill or in poor physical condition may abandon pups (Garshelis and Garshelis 1987). Weaning appears to be abrupt. In Prince William Sound, most male weanlings move long distances soon after separation from their mother and establish new home ranges in "male areas"; females tend not to travel as far and remain within the natal "female area" (Monnett and Rotterman 1987). Adult females sometimes reassociate with weaned pups (Garshelis and Garshelis 1987); nothing is known about the frequency of this behavior or the extent to which female otters might associate with older related individuals.

Behaviors associated with reproduction can lead to injuries that sometimes prove fatal (Garshelis *et al.* 1984). While copulating, or attempting to, the male secures a bite-hold onto the female's nose or face (Kenyon 1969, Vandevere 1970). Females emerge with bloody noses (Brosseau *et al.* 1975) and lasting scars (Foott 1971). Territorial males occasionally fight (Fisher 1939, Vandevere 1970, Loughlin 1977) but the frequency and extent of injuries are unknown.

Trophic Levels and Feeding Habits

Feeding otters alternately dive to obtain prey items and float at the surface to consume their catch. Pups less than about six weeks old are unable to dive and must remain on the surface while their mothers search for food (Payne and Jameson 1984). The use of rocks as tools to dislodge or break open hard-shelled prey is more common in California (Hall and Schaller 1984) than in Alaska (Kenyon 1969).

Most sea otter populations feed almost entirely on macroinvertebrates, although a few in Alaska and the U.S.S.R. also feed on epibenthic fish (Estes *et al.* 1981, Maminov and Shitkov 1970). At the population level, the diet tends to become more varied after sea otters have occupied an area for several years (Estes *et al.* 1981, Garshelis *et al.* 1986, Reidman and Estes 1988). Typically, after colonizing a new area, most of the population consumes large calorically rich prey items. As such prey become less plentiful, the diet begins to include smaller items and less preferred species. Individual otters show marked variation in food preference; one individual may feed largely on clams and another on mussels and turban snails (Estes *et al.* 1981, Lyons and Estes 1985, Siniff and Ralls 1987). These differences persist over long periods of time (Lyons 1987). Individuals also differ with respect to average dive length, surface interval, feeding bout length, and the interval between feeding bouts (Siniff and Ralls 1987).

In the wild, otters can feed as much as 12 hours each day (Garshelis *et al.* 1986). Observations on otters in California suggest that juvenile females spend more time feeding during times of the day when other otters are resting (Siniff and Ralls 1987). As a group, otters show no particular preference for daytime or nightime feeding, though much of the activity occurs during late afternoon, arly evening, and early morning. Individuals differ in their diurnal feeding pattersn, perhaps associated with the activity of their prey. The interval between feeding bouts, is roughly equivalent to the transit time in the gut, about three hours (Stulken and Kirkpatrick 1955, Costa 1978, Ribic 1982b, Siniff and Ralls 1987).

Metabolism and Thermoregulation

The otter's rapt attention to feeding directly reflects its need to fuel a metabolic rate which is over twice that of a terrestrial mammal of comparable size (Morrison *et al.* 1974, Costa and Kooyman 1982, Davis *et al.* 1986). Captive animals consume 190 to 250 kcal/kg/day (Estes 1980). There are no comparable values for wild otters, but Costa (1978) estimated that they must consume the equivalent of 23-33% of their body weight per day. These features describe an animal that is locked into a feeding mode which cannot be interrupted.

Unlike most marine mammals, the sea otter has little subcutaneous fat to aid in reducing heat loss, and must depend on its dense pelage for insulation. The pelage consists of an outer layer of guard hairs and an extremely dense underfur with over 100,000 hairs per square cm (Kenyon 1969). The hairs are arranged in bundles, each containing approximately one guard hair and 70 underfur hairs. Bundle density varies over the body, ranging from about 2,400 per square cm on the forearm to 851 on the dorsal surface. Air is trapped within the fur, adding to its insulative value (Kenyon 1969, Costa and Kooyman 1982, Davis *et al.* 1986).

The pelage must be actively maintained to be effective. Consequently, sea otters groom intensively. Loughlin (1977) described a somewhat stereotyped sequence of grooming. After an initial period of vigorous rolling and somersaulting, the otter rubs various parts of its body with the forepaws. It then licks and rubs its tail, hindquarters, chest, and forepaws. Sea otters typically groom themselves rather than each other. However, young pups are unable to groom themselves and a female may spend up to 20% of the daylight hours grooming her pup (Sandegren *et al.* 1973).

Summarizing the Risk

Many features of an otter's life history may predispose it to exposure to spilled oil. They show strong site fidelity within a well-defined range. Circumstances often bring them together to form loose associations, or rafts, sometimes numbering a hundred or more otters. Thus there exists the possibility that a relatively large group of animals might be exposed simultaneously. The effect on the population as a whole would not necessarily be irreversible, in as much as such rafts are composed mostly of non-breeding males. However, breeding males and females which congregate in smaller groups show even greater attachment to a defined territory. Such animals, while vulnerable, are also crucial to the viability of the population.

Particularly vulnerable is the newborn otter which is entirely dependent on its mother during the first few months of its life. It is left unattended and virtually helpless at the surface while the mother dives in search of food. The prey that she seeks and may retrieve for her pup are those that accumulate and store hydrocarbon residues from contaminated sediments (Neff, Chapter 1). In typical otter fashion, the mother may surface some distance from where she submerged, perhaps in a kelp bed which has entrapped oil. Once contaminated, an otter's normal preoccupation with grooming may become obsessive, displacing other behaviors, including feeding and resting. Despite the effort, the otter has only a small chance of restoring the insulative value of its coat.

Literature Cited

Barabash-Nikiforov, I.I., S.V. Marakov and A.M. Nikolaev. 1968. Otters. Izd-vo Nauka, Leningrad. 184 pp.

Benech, S.V. 1981. Observations of the sea otter <u>Enhydra lutris</u> population between Point Buchon and Rattlesnake Creek, San Luis Obispo, California, January through December 1980. ECOMAR, INC. VII-6-81. 41 pp.

Brody, A. 1987. A spatially explicit simulation model of the California sea otter population. In Population Status of California Sea Otters. D.B. Siniff and K. Ralls (eds.). Final Report. Minerals Management Serv. Contract No. 14-12-001-3003.

Brosseau, C., M.L. Johnson, A.M. Johnson and K.W. Kenyon. 1975. Breeding the sea otter at Tacoma Aquarium. Int. Zoo Yearbook 15: 144-147.

Brownell, R.L., Jr. 1988. California sea otter translocation. Mar. Mamm. Sci. 4: 85.

California Department of Fish and Game. 1976. A proposal for sea otter protection and research, and request for return of management to the state of California. Unpubl. Report. January 1976. 2 Vols.

Calkins, D.G. and P.C. Lent. 1975. Territoriality and mating behavior in Prince William Sound sea otters. J. Mamm. 56: 528-529.

Costa, D.P. 1978. The ecological energetics, water, and electrolyte balance of the California sea otter, <u>Enhydra lutris</u>. Ph.D. Thesis, Univ. of California, Santa Cruz, CA.

Costa, D.P. and G.L. Kooyman. 1982. Oxygen consumption, thermoregulation, and the effect of fur oiling and washing on the sea otter, <u>Enhydra</u> <u>lutris</u>. Can. J. Zool. 60: 2761-2767.

Davis, R.W., T.M. Williams, R. Kastelein, J.A. Thomas, L.H. Cornell, T. Williams and E.R. Yohe. 1986. Sea Otter Oil Spill Mitigation Study. Final Report. Hubbs Mar. Res. Inst., San Diego, CA. Minerals Management Service, Contract No. 14-12-0001-30157. 219 pp.

Estes, J.A. 1980. Enhydra lutris. Mammalian Species No. 133: 1-8.

Estes, J.A. and R.J. Jameson. 1983. Summary of available population information on California sea otters. POCS Technical Paper No. 83-11. Minerals Management Serv. Interagency Agreement No. 14-12-001. 29 pp.

Estes, J.A., R.J. Jameson and A.M. Johnson. 1981. Food selections and some foraging tactics of sea otters. pp. 606-641. In Proc. Worldwide Furbearer Conf. (1980). J.A. Chapman and D. Pursley (eds.). Frostburg, MD.

Faurot, E. 1985. Haulout behavior of California sea otters, <u>Enhydra lutris</u>. Mar. Mammal Sci. 1: 337-340.

Fisher, E.M. 1939. Habits of the southern sea otter. J. Mammal. 20: 21-36.
Foott, J.O. 1971. Nose scars in female sea otters. J. Mammal. 51: 621-622.
Garshelis, D.L. and J.A. Garshelis. 1984. Movements and management of sea otters in Alaska. J. Wildl. Manage. 48: 665-678.

Garshelis, D.L., J.A. Garshelis and A.T. Kimker. 1986. Sea otter time budgets and prey relationships in Alaska. J. Wildl. Manage. 50: 637-647.

Garshelis, D.L., J.A. Garshelis and D.B. Siniff. 1987. Activity patterns of sea otters in Prince William Sound, Alaska. (in press).

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Hall, E.R. and G.B. Schaller. 1964. Tool-using behavior of the California sea otter. J. Mamm. 45: 287-298.

Jameson, R.J. 1983. Evidence of birth of sea otter on land in central California. Calif. Fish and Game 69: 122-123.

Jameson, R.J. and J.L. Bodkin. 1986. An incidence of twinning in the sea otter (<u>Enhydra lutris</u>). Mar. Mammal Sci. 2: 305-309.

Jameson, R.J. and A.M. Johnson. 1979. Evidence of annual reproduction among sea otters. Abstract, 3rd Biennial Conf. Biol. Mar. Mamm., Seattle, WA.

Jameson, R.J., K.W. Kenyon, A. M. Johnson and H.M. Wight. 1982. History and status of translocated sea otter populations in North America. Wildl. Soc. Bull. 10: 100-107.

Kenyon, K.W. 1969. The sea otter in the eastern Pacific Ocean. N. Amer. Fauna 68: 1-352.

Kenyon, K.W. 1981. Sea otter, <u>Enhydra lutris</u>. pp. 209-223. In Handbook of Marine Mammals. S.H. Ridgway and R.J. Harrison (eds.). Academic Press, New York, NY. 235 pp.

Ladd, W. 1986a. New hope for the Southern sea otter, part 1. End. Spec. Tech. Bull. 11 (8 & 9): 12-14.

Ladd, W. 1986b. New hope for the Southern sea otter, part 2. End. Spec. Tech. Bull. 11 (10 & 11): 5-7.

Leatherwood, S., L.J. Harrington-Coulombe and C.L. Hubbs. 1978. Relict survival of the sea otter in central California and evidence of its recent redispersal south of Point Conception. Bull. Southern Calif. Acad. Sci. 77: 109-115.

Loughlin, T.R. 1977. Activity patterns, habitat partitioning, and grooming behavior of the sea otter, <u>Enhydra lutris</u>, in California. Ph.D. Thesis, Univ. Calif., Los Angeles, CA. 110 pp.

Loughlin, T.R. 1980. Radio telemetric determination of the 24-hour feeding activities of sea otters, <u>Enhydra lutris</u>. pp. 717-724. In A Handbook on Biotelemetry and Radio Tracking. C.J. Amlaner, Jr. and D.W. MacDonald (eds.). Pergamon Press. Oxford, U.K.

Loughlin, T.R., J.A. Ames and J.E. Vandevere. 1981. Annual reproduction, dependency period and apparent gestation period in two California U.S.A. sea otters <u>Enhydra lutris</u>. Fish. Bull. 79: 347-349.

Lyons, K.J. and J.A. Estes. 1985. Individual variation in diet and foraging strategy in the female California sea otter, <u>Enhydra lutris</u>. Abstract. Western Soc. Naturalists 66th Annual Meeting, Monterey, CA.

Lyons, K. 1987. Individual variation in the diet and foraging strategy in the female California sea otter, <u>Enhydra lutris</u>. Abstracts, Animal Behavior Society, 16-21 June 1987, Williamstown, MA.

Maminov, M.K. and A.M. Shitkov. 1970. On the food of the sea otter on Paramushir Island. Proc. Pac. Res. Inst. Fish Ocean. (TINRO) 70: 176-179.

Mason, C.F. and S.M. MacDonald. 1986. Otters: Ecology and Conservation. Cambridge Univ. Press. 236 pp.

Monnett, C. 1987. Movement, developmental and mortality patterns of sea otters in Alaska. Ph.D. Thesis. Univ. Minnesota, MN. Monnett, C. and L. Rotterman. 1987. Movement patterns of adult female and

Monnett, C. and L. Rotterman. 1987. Movement patterns of adult female and weanling sea otters in Prince William Sound, Alaska. pp. 193-235. In Population Status of California Sea Otters. D.B. Siniff and K. Ralls (eds.). Final Report. Minerals Management Service, Contract No. 14-12-001-3003. Los Angeles, CA. Morrison, P.M., M. Rosenmann and J.A. Estes. 1974. Metabolism and thermoregulation in the sea otter. Physiol. Zool. 47: 218-229.

Odemar, M.W. and K.C. Wilson. 1969. Results of sea otter capture, tagging and transporting operations by the California Department of Fish and Game. pp. 73-79. In Proc. 6th Annual Conf. Biol. Sonar and Diving Mammals. Stanford Res. Inst., Menlo Park, CA.

Payne, S.F. and R.J. Jameson. 1984. Early behavioral development of the sea otter, <u>Enhydra lutris</u>. J. Mamm. 65: 527-531.

- Ralls, K., J. Ballou and R.L. Brownell, Jr. 1983. Genetic diversity in California sea otters: theoretical considerations and management implications. Biol. Cons. 25: 209-232.
- Reidman, M. and J. Estes. 1988. A review of the history, distribution and foraging ecology of sea otters. pp. 4-21. In The Community Ecology of Sea Otters. G.R. Van Blaricom and J.A. Estes (Eds.). Springer-Verlag, Berlin.
- Ribic, C.A. 1982a. Autumn movement and home range of sea otters in California. J. Wildl. Manage. 46 795-801.
- Ribic, C.A. 1982b. Autumn activity of sea otters in California. J. Mamm. 63: 702-706.
- Sandegren, F.E., E.W. Chu and J.E. Vandevere. 1973. Maternal behavior in the sea otter. J. Mamm. 54: 668-679.
- Schneider, K. 1973. Reproduction in the female sea otter. Progress Report. Federal Aid in Wildl. Restoration Project W-17-4 and W-17-5, Alaska Dept. Fish and Game. 13 pp.
- Schneider, K. 1978. Reproduction in the female sea otter in the Aleutian Islands. Unpubl. Report. Alaska Dept. Fish and Game. 44 pp.
- Siniff, D.B. and K. Ralls (eds.). 1987. Population Status of California Sea Otters. Final Report. Minerals Management Serv. Contract No. 14-12-001-3003.
- Stulken, D.E. and C.M. Kirkpatrick. 1955. Physiological investigation of captive mortality in the sea otter (<u>Enhydra lutris</u>). Trans. 20th N. Amer. Wildl. Conf.: 476-494.
- Vandevere, J.E. 1970. Reproduction in the southern sea otter. pp. 221-227. In Proc. 7th Annual Conf. Biol. Sonar and Diving Mammals. Stanford Res. Inst., Melo Park, CA.
- Wendell, F.E., J.A. Ames and R.A. Hardy. 1984. Pup dependency period and length of reproductive cycle: estimates from observations of tagged sea otters, <u>Enhydra lutris</u>, in California. Calif. Dept. Fish and Game 70: 89-100.
- Wendell, F.E., R.A. Hardy and J.A. Ames. 1986. An assessment of the accidental take of sea otters, <u>Enhydra lutris</u>, in gill and trammel nets. California Dept. Fish and Game, Marine Resources Tech. Rept. No. 54. 31 pp.
- Wild, P.W. and J.A. Ames. 1974. A report on the sea otter, <u>Enhydra lutris</u> L., in California. Calif. Dept. Fish and Game, Marine Resources Tech. Report No. 20. 93 pp.

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CHAPTER 7

PHYSIOLOGIC AND TOXICOLOGIC EFFECTS

ON SEA OTTERS

J.R. Geraci

Department of Pathology Ontario Veterinary College University of Guelph Guelph, Ontario N1G 2W1

Historical Perspective

Oil spills are headline news wherever they occur, and in recent years there have been numerous attempts to search each incident for a biological effect. These can be so subtle as to escape detection; other effects unfold as a drama larger than the spill itself. This is true of course for waterfowl, which may be fatally drawn to a tranquil oil sheen, and the sea otter, whose need for an impeccable coat drives it to consummate grooming.

The otter is the marine mammal most likely to be harmed by oil, with effects both immediate and long-term. Kenyon (1969) offered the first relevant account when noting that the population of otters in the southern Shumagin Islands, Alaska, mid-way along the Aleutian chain, had been estimated at 4000 in 1920, and was reduced after a tanker and a freighter were wrecked and spilled oil in the area during World War II. He furthermore cites Marakov's (1963 cited in Kenyon 1969) belief that human activities, including spills of petroleum products, have prevented recovery of the otter population of the Commander Islands in the Bering Sea. Van Blaricom and Jameson (1982) cited Barabash-Nikiforov's *et al.* (1968) account of a spill of gasoline and diesel fuel in the nearby Kurile Islands, which spread through 40 km of the coastline and killed over 100 sea otters. The event occurred in 1964 (Howe 1983).

Other accounts have followed, showing greater or lesser effects of oil on these animals. There is glancing mention of an occasional carcass with evidence of fouling, along the shores of Alaska (Anon. 1971, Hess and Trobaugh 1971) and California (Anon. 1980, 1982, Kooyman *et al.* 1976, Jameson 1986). On the other hand, there is an exceptional story of a spill affecting not the sea otter, but the related European otter, <u>Lutra lutra</u>, whose habitat includes nearshore waters along the western British Isles.

Less than two months after becoming operational, the oil terminal at Sullom Voe in Shetland experienced its first significant mishap when on December 30, 1978, about 1200 tonnes of Bunker C fuel spilled from the tanker Esso Bernicia and eventually spread along 110 km of weaving shoreline (Richardson 1979). After learning that river otters had been oiled, a team of investigators visited the area to assess the effect of the spill on the population, and collect carcasses for necropsy examination (Baker et al. 1981). One animal with a patchy coating of oil was taken for rehabilitation. It was cleaned, fed and kept warm, and although it ate offerings of fish, it died two days later. Another was rescued, but died the next day. By February 22, 1979, 11 other river otters had been found dead and variably coated with Necropsy examinations were performed on five carcasses. oil. Two had tracheitis and all had congested lungs and blood in the stomach; the intestines of four had blood mixed with oil. A limited examination of another otter revealed, in the intestines, bloody fluid which was shown by chromatographic analysis to contain oil.

The investigators commented on other river otters that might have died in natural lairs and hiding places and so would not have been found. Later casualties, not so heavily oiled, were discovered up to 150 m from the sea, where they had apparently been seeking shelter. Conclusion? At least 15%, and possibly as much as 50% of the local river otter population had been killed in the incident.

Detection and Avoidance

The <u>Esso Bernicia</u> event provides a clear description of the fate of an otter that has encountered a substantial spill of oil. How could an animal that depends so critically on the integrity of its fur find itself in such an obviously life-threatening situation? Might it have unwittingly entered oiled waters or climbed onto the contaminated shore? Would they under most circumstances avoid such a hazardous environment? Evidence from studies and anecdotal reports offers some insight into the behavior of otters that made them victims of the <u>Esso Bernicia</u> spill.

In 1977, Siniff and his colleagues (1982) conducted an experiment on the sea otter's response to oil. They observed behavioral reactions of two otters in a pool partially covered with Prudoe Bay crude oil. Immediately after the oil was added, the otters became "nervous and curious", even though the oil was contained on the opposite side of a surface divider. Occasionally they would rear up and stare at the oil. They made determined efforts to escape. When swimming underwater around the perimeter of the pool, the otters would occasionally surface on the oiled side, but would remain for only a few seconds. They spent less than one minute of each hour on the oiled side, but eventually both became covered with oil. One would emerge from the water to the level of its shoulders and shake vigorously in an apparent attempt to rid itself of oil.

The study provides a clear impression that otters given a choice, would avoid oil. Obviously they had detected it, using vision perhaps, though the strength of that sense is debatable (Limbaugh 1961, Gentry and Peterson 1967, Nachtigall 1986), and quite likely through their undisputed sense of smell (Elliot 1875, Coues 1877, Kenyon 1969). With reference to the latter ability, Barabash-Nikiforov (1947) noted that the otter must react fairly vigorously to odors since it usually orients itself by its sense of smell, and offered as example the relevant story of Japanese poachers who once fouled shore rocks with kerosene to frighten otters toward the sea, where they were easier prey.

Why then did the river otters not avoid the <u>Esso Bernicia</u> spill? Perhaps because of an overriding determination to remain in the area. There is also some indication, from events surrounding the incident itself, that once fouled, an otter's preoccupation with grooming may make it inattentive to the threat of additional or repeated contact. Baker *et al.* (1981) had noted that following the spill, the otters initially did not recognize oil as a danger. One otter dove and emerged in a patch of floating oil. Another walked along the rocky shore, making no apparent attempt to avoid regions with oil. Two more were seen on the shore; "one of these, rather atypically, did not appear to notice the observer, in full view, as he approached to within a metre. It was moderately oiled and intent on grooming ...". The determination to groom is an otter's key to survival, and at the same time, a predictable weakness after it confronts oil. Siniff *et al.* (1982) brushed a coating of oil over a small area of the abdomen of four sea otters, then released them and followed their behavior using radio-transmitters. Grooming was the principal activity during the first few days. Williams (1978) in an earlier version of the Siniff *et al.* (1982) report had observed that after two otters contacted oil in a holding pool, they spent 75% of their time under water trying to clean themselves. These observations were confirmed in subsequent studies (Costa and Kooyman 1982, Davis *et al.* 1986), leading Climberg and Costa (1985) to conclude that otters are susceptible to slicks because they spend much time on the surface feeding, grooming, resting and swimming.

It may be possible to design experiments to test the relative contribution of each of these behaviors to an otter's overall response to oil. For practical, and perhaps humane, purposes it may be enough to project that otters are probably able to detect oil. Once contaminated, they are driven to distraction by compulsive grooming which overpowers what might have been an avoidance response.

Surface Fouling

Studies on muskrats (Ondatra zibethicus) (Wragg 1954, McEwan et al. 1974) forshadowed the probable effects of surface fouling on sea otters. By destroying the insulative quality of the coat, oil disrupted the animals' sensitive energetic balance. Later experiments on sea otters confirmed this Kooyman et al. (1977), in a study to determine thermal effect of oil. conductance of pelts from selected marine mammals, found that of the sea otter to be the best insulator; that is, it was least able to conduct heat. The same pelt, after it had been drenched with oil and rinsed, showed a 2-fold increase in thermal conductivity, or loss of insulative value. Koovman *et al*. (1977) concluded from their study that oil fouling seriously degrades the fur, and that an animal unable to reverse the effect, by grooming for example, could not endure water immersion long.

Davis et al. (1986) approached the same question using a larger sampling and a slightly different protocol. They found that pelts layered with fresh oil showed a 3-fold increase in thermal conductance. Weathered oil had less effect presumably because it was more viscous and tended to remain on the tips of the guard hairs, thereby preserving the integrity of the underfur.

Costa and Kooyman (1982) were the first to record the consequences of fouling to a live otter in a captive setting. They brushed low-viscosity crude oil over the back, covering about 18% of an animal's body surface. Three otters fouled in this way were then permitted to swim in a clean pool of water for 30 minutes. When tested thereafter, their metabolic rates were found to have increased 40% over that before oiling. One animal left oiled had nearly a 2-fold increase in metabolic rate on the sixth day. Apparently,

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the otter had groomed thereby spreading oil over the fur, further reducing its insulative value. The loss of insulation might have been partially offset by peripheral vasoconstruction beneath the oiled area, but, concluded the investigators, an animal would probably not be able to endure the effects of fouling the entire body.

The same conclusion was drawn from the study by Siniff *et al.* (1982) on radio-tagged otters in Prince William Sound, Alaska. The activity of the animals increased dramatically during the first week following treatment; most of it was associated with grooming; feeding patterns did not change. The otters survived the experiment because, the authors suggested, only a small portion of the pelage had been fouled, and food resources in the area were abundant.

A later study by Davis *et al.* (1986) identified, and for the first time graded under controlled conditions, each element of an otter's metabolic and behavioral responses to oil. The investigators measured metabolic rate before and after fouling 20% of the fur with fresh crude oil. The result was a 2fold increase in metabolic rate. This was slightly more than Costa and Kooyman (1982) had found, and by reason of technique, was a more accurate reflection of the impact of fouling on energy balance. More important however, was their observation that after fouling, grooming activity increased from 35% to 61%, swimming increased from 10% to 17%, and the time spent resting on the surface decreased from 49% to 12%. They also found that grooming activity, contrary to its intent, made matters worse by spreading oil onto clean areas and rubbing it deep into the fur.

Grooming emerges as the common behavior driven by oil, whether in the natural setting following the <u>Esso Bernicia</u> spill, or after deliberate fouling. It can be debated whether such an activity would be all consuming as suggested by the studies of Williams (1978) and to a lesser extent Davis *et al.* (1986), or whether animals under less confined, more natural conditions might continue their normal feeding patterns and ultimately recover from the experience (Siniff *et al.* 1982).

It is a matter of degree. A more extensive coating of oil would likely have tipped the balance and delivered the otters in the Siniff *et al.* (1982) study into a tightening metabolic spiral: oil fouls the fur, reduces its insulative properties, and thereby promotes heat loss; the animal compensates by increasing metabolic rate which in turn it must fuel by consuming more food; but eating gives way to vigorous grooming, and that energy, squandered on spreading the oil, is not restored; body mass decreases and more heat is lost.

One can suppose that not all otters that contact oil will be affected to the same extent. Pups, by virtue of their size and the characteristically high density of their fur, would be most sensitive. So would animals foraging in marginal feeding areas, as they might have to expend greater energy to gather food needed to offset heat loss. Fresh oil penetrates and spreads quickly, and readily dissolves natural lipids. Weathered oil has less tendency to foul. Consequently otters that contact a fresh spill would be more vulnerable than late-comers. And otters with strong homing tendencies that leave the site of a fresh spill might return to a less threatening scene. There are other complications, of course - sea temperatures affect the fate both of oil and otters, contaminated kelp beds may prolong the time of contact, grooming of pups may transfer oil, and so on. In the broader sense, these all help to underscore the inarguable fact that the sea otter's committment to grooming predetermines its fate once it has contacted oil.

Cleaning Fouled Otters: Some attempts have been made to reverse the effects of fouling by cleaning an otter's pelt, in the same way birds have been treated after becoming coated with oil. Three studies have addressed the question. After measuring the metabolic rate of otters fouled with oil, Costa and Kooyman (1982) washed two animals with a 1 to 8% solution of Amber Lux (Lever Brothers), an anionic surfactant-type detergent, then returned them to a holding pool with a water temperature of 20° C. The otters resumed their normal behavior and appearance. They were oiled, washed again, and this time were placed in a holding area with water at 10° C, and an air temperature at 25 to 30° C. Both shivered vigorously; one groomed and recovered, the other died of pneumonia 11 days after oiling. Meanwhile, metabolic studies had shown that washing the otters had decreased the insulative value of the pelt by about 2 to 5 times. It was transitory, and by about 8 days, the fur's thermal conductance had returned to normal.

Siniff et al. (1982) also washed an oiled otter, but with uncertain results. After encountering crude oil in a small pool, an otter was cleaned with Polycomplex-11 (Guardian Chemical). The fur was wet with the cleaning agent, rinsed in water, and rubbed thoroughly with towels. The animal was then allowed to dry and groom for 8 hours before being placed in water. The fur immediately became saturated, whereupon the animal had to be removed, redried, and left overnight in a dry pen. It was released into the wild the following day and tracked for 24 hours before technical difficulties precluded further observations.

Davis et al. (1986) made a concerted effort to develop a safe and effective procedure to clean and rehabilitate sea otters. After being fouled, mildly sedated otters were cleaned with 4 to 8 L of a 1:16 solution of $\underline{\text{Dawn}}^{\text{TM}}$ detergent (Proctor and Gamble), which in a previous study had been shown to be the most effective of six cleansers tested. DawnTM met two important criteria; it not only removed the contaminating oil, but if used correctly, it would restore loft to the pelt, and thus the insulating air layer within the fur. Otters were washed for 40 minutes, then for 40 minutes rinsed with a shower head under moderate water pressure; air entrained in the water helped to restore the pelt. The animals were then dried with towels. Judging from observations and results of clinical and physiological tests, the investigators concluded that "sea otters that have had 20% of their body surface area oiled can be successfully cleaned and rehabilitated in 1 to 2 weeks However normal grooming by the cleaned otter is essential for the full restoration of the fur. One or two additional weeks may be required for a complete recovery from the stress of oiling and cleaning "

The critical factor it seems, and one that had frustrated previous attempts, is the need to adequately rinse the detergent from the pelt. Otherwise even small quantities act as a wetting agent and allow water to penetrate the fur. The investigators also pointed out the need to provide both water and haul-out space during recovery. This affords an animal the opportunity to enter the water to cool, and to leave it when attempting to reduce heat loss. The choice to do so is individual. Otters in the study hauled out for various lengths of time after they had been cleaned. This excellent study by Davis *et al.* (1986) should serve as a reference for any program designed to rehabilitate fouled sea otters.

Other Effects

A sea otter amid fresh oil may inhale volatile vapors leading to pulmonary and other systemic injuries, in the same way as pinnipeds (St. Aubin, Chapter 3) and cetaceans (Geraci, Chapter 5). That close to oil, the otter would not likely escape the more certain consequences of fouling. Consequent grooming, a survival strategy of questionable value under such circumstances, may cause the animal to ingest oil. More important to the population, perhaps, is the undefinable effect of ingesting prev items. largely molluscs, which have little or no capacity to metabolize petroleum hydrocarbons and may shuttle them unchanged along to an otter (Neff, Chapter 1). We expect, without direct evidence, that otters have the same detoxifying enzyme system which has been identified in pinnipeds, cetaceans, and mammals generally; the subject deserves further study. The net effect of consuming hydrocarbons in this way would, over the long term, impose additional stress to an animal or population that might have escaped or survived the initial impact of a spill.

Summary

Oil poses the greatest threat to marine mammals with hair or fur; of those the otter is clearly the most vulnerable. They are small, highly energetic and cannot tolerate interruptions in feeding. The dense hair coat, an ideal matrix for retaining oil, must be kept groomed, and therefore free of oil. One that might escape the consequences of ingesting oil while grooming a fouled coat, might later be exposed to systemic effects of eating contaminated prey.

Their vulnerability is compounded by their behavior as a group, which tends to fix them in an area, whether or not it contains oil. And displacement, whether by their own response, or through well-meaning intervention, does not necessarily guarantee survival.

Literature Cited

Anon. 1971. Alaska Peninsula oil spill. Smithsonian Inst. Cntr. Short-lived Phenomena. Annual Report (1970). Event No. 36-70. pp. 154-157.

Anon. 1980. Dead oiled sea otter. Smithsonian Inst. Sci. Event Alert Network (SEAN) Bull. 5 (11): 34.

Anon. 1982. Dead sea otter with tar patch on fur. Smithsonian Inst. Sci. Event Alert Network (SEAN) Bull. 7: 33.

Baker, J.R., A.M. Jones, T.P. Jones and H.C. Watson. 1981. Otter, <u>Lutra</u> <u>lutra</u> L. mortality and marine oil pollution. Biol. Conserv. 20: 311-321.

Barabash-Nikiforov, I.I., V.V. Reshetkin and N.K. Shidlovskaya. 1947. The sea otter (Kalan). Report No. OTS 61-31057. Nat. Tech. Info. Serv., Springfield, VA. 227 pp. (Translated by Israel Prog. Sci. Transl.).

Climberg, R.L. and D.P. Costa. 1985. North Aleutian shelf sea otters and their vulnerability to oil. pp. 211-217. In Proc. 1985 Oil Spill Conf.: Prevention, Behavior, Control, Cleanup. Los Angeles, CA. Amer. Petrol. Inst., Washington, DC.

Costa, D.P. and G.L. Kooyman. 1982. Oxygen consumption, thermoregulation, and the effect of fur oiling and washing on the sea otter, <u>Enhydra</u> <u>lutris</u>. Can. J. Zool. 60: 2761-2767.

Coues, E. 1877. Fur-bearing animals. pp. 294-348. In Audubon and His Journals I. (1898). M.R. Audubon and E. Coues (eds.). London, U.K.

Davis, R.W., T.M. Williams, R. Kastelein, J.A. Thomas, L.H. Cornell, T. Williams and E.R. Yohe. 1986. Sea otter oil spill mitigation study. Unpubl. Final Report. Hubbs Mar. Res. Inst., San Diego, CA. Minerals Management Serv., Contract No. 30157. 220 pp.

Elliot, H.W. 1875. A report upon the condition of affairs in the territory of Alaska. Govern. Printing Office, Washington, DC. 277 pp.

Gentry, R.L. and R.S. Peterson. 1967. Underwater vision of the sea otter. Nature 216: 435-436.

Hess, R. and L. Trobaugh. 1971. Kodiak Island oil pollution. Smithsonian Inst. Cntr. Short-lived Phenomena. Annual Report (1970). Event 26-70. pp. 150-153.

Howe, J.R. 1983. The sea otter puzzle. Audubon 85 (1): 34-39.

Jameson, G.L. 1986. Trial systematic salvage of beach-cast sea otter, <u>Enhydra lutris</u>, carcasses in the central and southern portion of the sea `otter range in California. Report. U.S. Mar. Mammal Comm., Washington, DC. Contract No. MM2629849-8. 60 pp.

Kenyon, K.W. 1969. The sea otter in the eastern Pacific Ocean. Dover Publ. Inc., New York, NY. 352 pp.

- Kooyman, G.L., R.L. Gentry and W.B. McAllister. 1976. Physiological impact of oil on pinnipeds. Report. Northwest Fish. Cntr., Nat. Mar. Fish. Serv., Nat. Oceanic and Atmospheric Admin. 23 pp.
- 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. pp. 151-157. In Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D.A. Wolfe (ed.). Pergamon Press, New York, NY.

Limbaugh, C. 1961. Observations on the California sea otter. J. Mammal. 42: 271-272.

McEwen, E.H., N. Aitchison and P.E. Whitehead. 1974. Energy metabolism of oiled muskrats. Can. J. Zool. 52: 1057-1062.

Nachtigall, P.E. 1986. Vision, audition, and chemoreception in dolphins and other marine mammals. pp. 79-113. In Dolphin Cognition and Behavior: A Comparative Approach. R.J. Schusterman, J.A. Thomas and F.G. Wood (eds.). Lawrence Erlbaum Assoc., Publ., Hillsdale, NJ. 393 pp.

Richardson, M.G. ESSO BERNICIA incident, Shetland, December/January. Mar. Pollut. Bull. 10 (4): 97.

- Siniff, D.B., T.D. Williams, A.M. Johnson and D.L. Garshelis. 1982. Experiments on the response of sea otters, <u>Enhydra lutris</u> to oil contamination. Biol. Conserv. 23: 261-272.
- Van Blaricom, G.R. and R.J. Jameson. 1982. Lumber spill in central California waters: implications for oil spills and sea otters. Science 215: 1503-1505.
- Williams, T.D. 1978. Chemical immobilization, baseline hematological parameters and oil contamination in the sea otter. U.S. Mar. Mammal Comm. Report No. MMC-77/06. Nat. Tech. Info. Serv., Springfield, VA. 27 pp.
- Wragg, L.E. 1954. The effect of DDT and oil on muskrats. Can. Field Natural. 68: 11-13.

CHAPTER 8

POLAR BEARS AND OIL: ECOLOGIC PERSPECTIVES

I. Stirling

Canadian Wildlife Service, 5320 122 Street, Edmonton, Alberta T6H 3S5

and

Zoology Department, University of Alberta Edmonton, Alberta T6G 2E9

Introduction

Bears are found on all the continents of the world except Australia and Antarctica, yet only one species, the polar bear (Ursus maritimus), evolved to take advantage of the marine ecosystem. The ice along the coast of the polar basin provided a platform upon which the ancestral polar bear could move from the safety of land onto the surface of the sea to hunt seals. This change in life style set the stage for the polar bear to diverge from its brown bear ancestors only a quarter of a million years or so ago. The polar bear quickly evolved its white coat, elongated skull, small ears, and large feet in response to the selection pressures of life in its new environment. Although its outward appearance is now quite different from its relatives, the fact that it readily interbreeds with brown bears in captivity, and their offspring are also capable of interbreeding, indicates that the evolution of the polar bear is indeed a recent event. Unlike the seals or whales, polar bears have not evolved the ability to stay underwater for prolonged periods. Nor have they developed webbing between their toes like sea otters, or other morphological adaptations typical of pinnipeds or cetaceans. Yet polar bears spend as much of the year as possible on sea ice, and are completely dependent on the sea for their existence; they are true marine mammals in an ecological sense.

Distribution

Polar bears presently range throughout the ice covered waters of the Arctic (Figure 8.1), and occur as local subpopulations of a few hundred to a Their seasonal distribution and movements vary considerably few thousand. between areas, depending on the local annual pattern of ice formation, distribution, and breakup. During the winter and spring, polar bears are distributed offshore from the mainland and various Arctic archipelagos. As the sea ice breaks up in the spring and early summer, bears follow the receding ice edge, which harbors their preferred prey, ringed seals and, to a lesser extent, bearded seals. In regions where the ice melts completely, polar bears are forced onto the land and either walk to another area where the sea is still covered with ice, or wait for freeze-up, as they do along the shores of There, the bears must spend about four months on land living on Hudson Bay. stored fat. Toward the end of this annual fast, some bears, notably subadults and females with cubs, deplete most of their stored reserves, become hungry and explore alternative food sources, such as the dump at Churchill (Lunn and Stirling 1985).

Individual polar bears show a high degree of seasonal fidelity to particular areas within their home ranges, yet are not fixed to restricted locations. Unlike terrestrial bears which defend territories containing the best feeding areas, polar bears must move in response to annual variation in seal distribution. In good hunting areas, densities of polar bears may increase greatly as long as seals are abundant. More often, polar bears are widely distributed on the sea ice at fairly low densities as solitary animals of family groups, and during the spring, as breeding pairs.

Figure 8.1

General distribution of prime polar bear habitat in the Beaufort, Bering, and Chuckchi seas so far as it is known, approximate distribution and seasonal movement patterns of different subpopulations of polar bears, a sample of offshore drilling sites, and the direction of major ocean currents.



Life History

Polar bears mate in April and May. Following a period of delayed implantation, the fertilized egg begins to develop in September or October. In early November, pregnant females dig maternity dens in snowdrifts on land near the coast, or offshore in the multi-year pack ice in the Beaufort Sea (Amstrup 1986). Cubs are born in December and early January, weighing only a kilogram. By the time they weigh 10-15 kg, they are able, with their mothers, to hunt seals on sea ice. In most areas of the Arctic, cubs remain with their mothers for two and one-half years before they are weaned, although in southern Hudson Bay, some females wean their cubs at one and one-half years Consequently, the reproductive interval for most females is three of age. This long period of weaning is necessary for cubs to learn hunting vears. methods and seasonal movements. It also means that polar bears have a very low reproductive rate so that populations will recover slowly from declines caused by overhunting or environmental disruption. When fully grown, adult male polar bears weigh from 450 to 600 kg and females between 150 and 300 kg, although pregnant females can weigh up to about 500 kg. Maximum recorded age for females in the wild is 32 years and 28 yeras for males, although only a small proportion of the population lives longer than 20 years. Intense competition for mates results in wounds and broken canine teeth in males, which accounts for their shorter life expectancy (Ramsay and Stirling 1986).

Migration: Seasonal movements of polar bears in the Beaufort, Bering, and Chukchi Seas are influenced primarily by the state of the sea ice and its consequent effect on the distribution of prey. In summer, open water prevails along the coastlines and the polar bears move north to remain with the pack ice where they can still hunt seals (Figure 8.1); a few bears may be stranded on land. In fall, the polar pack begins to drift south again and young ice forms between it and the land (Lindsay 1975, 1977). The number of polar bears and the timing of their arrival along the coast is closely correlated with the density and southward advance of polar pack ice (Lentfer 1972, Stirling 1974b). During winter and early spring, polar bears congregate to hunt along the leads that parallel the coast (Figure 8.1). In the Beaufort Sea, individual bears may move up to several hundred kilometers back and forth along these leads (Amstrup 1986). Consequently, a significant portion of the local population is liable to pass near any particular point in the transition zone during the course of a winter.

During the late spring and summer in the High Arctic, polar bears, especially subadults, sometimes swim for several hours among the ice floes. Up to 4% of their time can be spent in the water. Tagged bears have been recorded swimming across bays and wide leads, and even larger bodies of water. In eastern Barrow Strait, they have been tracked moving distances of a hundred kilometers or so. Habitat Preference: The most important single factor influencing the potential vulnerability of polar bears to oil is their habitat preference. Although polar bears occur throughout the Arctic, their distribution within that vast and variable habitat is determined by that of their principal prey species, the ringed seal and the bearded seal, which in turn are largely influenced by ice conditions and water depth (Stirling *et al.* 1982, Kingsley *et al.* 1985).

Stirling *et al.* (1981) determined the habitat preference and distribution of polar bears in the eastern Beaufort Sea and Amundsen Gulf based on sightings of polar bears and their tracks, recorded during approximately 74,500 km of survey done from 1971 through 1979. They identified seven broad categories of sea ice habitat of which only the following three were important to polar bears: 1) <u>stable fast ice</u> with deep snowdrifts along the pressure ridges suitable for ringed seal birth lairs (Smith and Stirling 1975), usually occurring in mouths of bays and as land-fast ice out from coastlines; 2) the <u>floe edge</u> where leads are wide (> 1 km), usually with small open and refrozen leads parallel or emanating from it; and, 3) areas of <u>moving ice</u> with 7/8 or more cover, where wind and currents cause much movement of ice followed by refreezing that creates intermittent lanes or patches of refrozen young ice.

Adult male polar bears show a strong preference for the floe edge and moving ice over areas of extensive stable ice. Subadult males had similar though slightly less marked preferences. In contrast, adult females with first-year cubs preferred areas of stable fast ice, probably because there were fewer bears there, especially adult males which might take their killed seals or attack their cubs. The distribution of subadult females was similar to that of adult females with young cubs. Lone adult females and females with older cubs showed no statistically significant preference for any of the three preferred habitat types, athough more were caught along the floe edge and active ice areas.

The most likely reason for the greater number of polar bears in the floe edge and active ice habitats is that seals are more abundant there, and probably more accessible. Some knowledge of how seals are distributed facilitates an understanding of habitat preference and distribution of the bears. As freeze-up progresses during autumn, ringed and bearded seals maintain breathing holes by abrading young ice with the heavy claws of their foreflippers (Smith and Stirling 1975). Breeding adult ringed seals tend to concentrate in areas of fast ice which remains frozen through most if not all of the winter. Here, pregnant females scoop out subnivean birth lairs in deep drifts which develop over their breathing holes. The snow cover provides protection from predators. This protection is lacking along the floe edge or in the areas of active ice where there may be little or no snow cover. Seal pups in these areas are more vulnerable to predation.

The location of leads clearly influences the distribution of hunting polar bears during winter. This was observed in a study survey conducted in March 1983 (Stirling *et al.* unpublished ms.). During the first 16 hours of an aerial survey, representing some 2500 km of searching for bears over completely frozen ice, only six bears were seen. After a week of strong

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winds opened a fresh lead about 150 km offshore, 90 sightings of bears were made in the next six days. Few tracks were seen outside a corridor of about 1 kilometer on either side of the lead and no bear was sighted during the 250 km return flights made daily between shore and the lead.

The most important floe edge and moving-ice habitats are distributed in a band of varying width which overlaps the shoreleads along the west coast of Banks Island, through the Bathurst Polynya at the entrance to Amundsen Gulf, and west parallel to the north coast of Canada and Alaska (Figure 8.1) (Smith and Rigby 1981). This intermediate zone of fractured, unconsolidated, annual ice lies over relatively shallow water between the annual landfast ice along the coast and the multi-year polar pack ice further offshore. In Canada, it is usually referred to as the transition zone, and in the United States as the seasonal pack ice zone (Dickens et al. 1987). Along the mainland coast of the eastern Beaufort Sea, the location of the seaward edge of landfast ice is generally predictable and roughly follows the 20 m depth contour (Cooper 1974). Its position in the western Beaufort Sea is similar. The most important stable ice habitat in most areas tends to lie between the coastline and the floe edge and in deep bays.

Exploration and Production Activities in Prime Habitats

In the eastern Beaufort Sea, offshore drilling has taken place along the mainland coast north of the Mackenzie Delta and Tuktoyaktuk Peninsula. Because of technical limitations on equipment available (Croasdale 1986), most of the activity has been in shallower areas (< 50 m). Thus, there is overlap between the most important polar bear feeding habitat and offshore drilling activities (Stirling 1988).

Large-scale spills or blow-outs from these wells could affect prime habitat for polar bears in the Beaufort Sea. The problem would be magnified by a predominant east-west current (Wilson 1974) that could carry escaped oil into the transition zone in the floe edge and moving ice habitats. In fall, oil incorporated into newly forming ice would be similarly transported, but not released until spring (Neff, Chapter 1). Ice in the Beaufort Sea moves from east to west at speeds that vary from about 4 km/day in March and April up to 15 km/day in September and October (H. Melling, pers. comm.). Consequently, oil entrapped in ice would also reach the floe edge and moving ice habitats in the transition zone where polar bears of all age classes and both sexes are most abundant.

Oil production activities are also situated in the path of the polar bears' annual migration across the southern Beaufort Sea (Figure 8.1). Thus, bears might potentially move through a polluted area. The number that might be affected would vary with season, location, and the number of leads. In most years, migration along leads peaks in spring and fall. Spills from tankers and, to a lesser degree, support vessels, represent another threat, particularly since their routes could pass through prime polar bear habitat in the Beaufort Sea. For example, oil from wells in the Mackenzie Delta northwest of Tuktoyaktuk could be shuttled to a supertanker stationed west of Point Barrow, Alaska. To do so would require several trips by a smaller ice-reinforced tanker. The supertanker would then head for southern ports via the Chukchi and Bering Seas. It is clear that the risk to polar bears will increase with extent and frequency of such activities.

Habitat Modification

In recent years, a variety of ingenious techniques have been developed to facilitate offshore drilling for an extended period after freeze-up and, in some cases, through the entire winter (Croasdale 1986, Stirling 1988). These include artificial islands, ice islands, the floating Conical Drilling Unit, the Single Steel Drilling Caisson which is ballasted to a subsea berm and, possibly most relevant of all to this discussion, the Mobile Arctic Caisson called the Molikpaq (Figure 8.2). The Molikpaq was designed for drilling to depths of up to 6000 m in 20 to 40 m of water and appears to be the prototype for future development. It is intended to operate in a depth range that overlaps much of the best floe edge and active ice habitat in the transition zone.

Polar bears have been observed in the vicinity of the Molikpaq throughout the winter. Most bears do not remain in the area for long, but under certain circumstances, such platforms and artificial islands can influence their distribution and movement. During periods of calm, cold weather, particularly in late March and early April when sea ice is thickest, most of the cracks where polar bears can hunt freeze over. However, the currentinduced movement of ice from east to west causes leads to form "downstream" from the installations (Figure 8.2). These leads are used routinely by small numbers of seals; as many as 30 or 40 have been observed. Polar bears, including adult females and their cubs, are attracted to these leads when others are unavailable (Stirling 1988). Some bears stay for several days and possibly even for a few weeks, eventually dispersing as other leads appear later in spring. In the event of a spill or blowout from a well, it is likely that bears hunting around the rigs would be among the first exposed to oil.

Behavior

Hunting: The hunting strategy of a polar bear can promote contact with oil. They typically lie motionless beside an open or snow-covered breathing hole, or at the edge of a lead, and strike at seals that surface there. In doing so, the bear reaches into the water with its jaws, often submersing its head and occasionally diving into the lead. Another strategy, used during late spring and summer after the snow has melted, is to stalk basking seals by

Figure 8.2

The Molikpaq drilling offshore in the Beaufort Sea, northeast of Tuktoyaktuk in March. Note the cracks in the ice formed in the lee of the drilling platform as the annual ice drifts past.



Figure 5.6

Amount of oil, as a percentage of initial coating, on fouled baleen preparations rinsed for up to 32 hours. Data are shown for one sample each from fin (\triangle) , sei (\blacktriangle) and gray (\blacksquare) whales. Over 70% of the oil was lost within 30 minutes. In 8 of 11 trials, over 95% was cleared after 24 hours.



Ingestion and Accumulation

Consumed petroleum hydrocarbons are toxic to a wide variety of mammals. The subject evokes considerable interest because of the prevalence and devastating effects of accidental hydrocarbon ingestion by young children (U.S. Dept. Health and Welfare 1978 a&b). The compounds are systemically harmful, the degree depending on their chemical composition. Those with low viscosity and surface tension irritate the gastrointestinal tract, and induce vomiting which leads to aspiration of the material into the lungs causing pneumonia and death (Zieserl 1979). Larger quantities, as much as 140 times the aspirated dose (Gerarde 1964) can be tolerated if the substance remains in the gastrointestinal tract, but that is harmful as well. Hydrocarbons can be directly toxic to the mucosal epithelium (Rowe *et al.* 1973), and when absorbed distribute throughout the body and produce their greatest effects on the central nervous system.

There has been some speculation that cetaceans could consume oil while Fraker et al. (1978) suggested that bowheads, because of their feeding. feeding behavior, could ingest damaging quantities of oil. Hansen (1985) affirmed that baleen whales that skim the surface and water column are more likely to ingest oil than gulp-feeders or toothed whales. Gray whales, because of their versatile feeding habits could conceivably consume floating tar balls (Calkins 1979) or contaminated bottom sediments (Hansen 1985). Virtually any species might ingest oil by feeding on contaminated prey. The assumptions are logical, and one could fairly believe that of the vast quantities of oil discharged at sea (Neff, Chapter 1), at least a gulp or two must find its way into the gullet of a hungry whale. Yet these animals bear no evidence obvious enough to have drawn attention. As far as we know, the literature consists of only a threadbare notation that "hydrocarbons" were found in the intestines of two bottlenose dolphins along the coast of France (Duguy and Toussaint 1977).

There has also been a study to determine how small quantities of refined petroleum oil consumed over a fairly long period of time would affect the health of <u>Tursiops</u> (Caldwell and Caldwell 1982). It was an attempt to establish whether machine oil accidentally seeping into a pool might have been responsible for an unprecedented increase in mortality of captive dolphins. The only notable clinical finding had been elevated circulating levels of the enzyme glutamic pyruvic transaminase, suggesting that the liver might have been injured.

In the experiment, one dolphin was given the same machine oil in capsule form, at a rate of 5 mL/day, 5 days/week, for a total of 335 mL in 14 weeks. Another dolphin, used as a control was given mineral oil under the same conditions, for a total of 225 mL in 10 weeks. The animals were examined for clinical, hematological and blood chemical changes during the study. None was found, nor was there evidence of any relevant effects on necropsy examination of the test dolphin when it was euthanized one month later for reasons unrelated to the study. The results are not surprising. The quantity of oil consumed by the dolphin was substantially lower than the toxic dose for other mammals. Seals had also shown no effect after ingesting similar quantities (Geraci and Smith 1976). In fact, the amount of substance considered to be critical is higher than one would reasonably wish to administer to a cetacean. In mice, it is in the order of 5 to 25 mL/kg for heavy fuel oils, and 14 to 20 mL/kg for ligher fuel oils (Elars 1979 a,b; 1980 a-d). Let us assume that a cetacean would be at risk after taking a quantity of fuel oil at a mid-range concentration of 15 mL/kg. To achieve that, an adult harbor porpoise would have to consume one liter, a bottlenose dolphin three to four liters, and a pilot whale thirty liters. A forty-ton whale would require an estimated 600 L or roughly 150 U.S. gallons.

Could a cetacean realistically ingest such quantities of oil? It would be impossible to predict the behavior of an excited animal unavoidably confronting a spill. It may swallow oil accidentally, or as we observe in terminally stressed odontocetes, drink seawater liberally, and with that, consume oil. Otherwise, it would seem unlikely, that in the normal course of events, that a whale or dolphin would ingest much floating oil. A dolphin may drink 500 to 1500 mL of seawater daily (Ridgway 1972 p. 632). If contaminated, only a small portion of that would be oil. Odontocetes are predators that normally would not scavenge oil-killed fish, except perhaps for some Tursiops that have learned to forage behind fishing boats for a netspilled meal. And lessons from captivity suggest that they would probably disregard it if tainted. Mysticetes in the area of a spill are more likely to ingest oil-contaminated food, particularly zooplankters which actively consume oil particles. Assuming toxic oils to comprise 10% of the estimated 1600 kg of food consumed in a day by a forty-ton fin whale, the total quantity of ingested oil would be 160 kg. This approaches the critical dose calculated for highly toxic fuel oils. The question is, would fin whales feed around a spill of fresh volatile oil long enough to accumulate such quantities? There is no evidence from observational studies or stranding records to suggest that they do.

Petroleum hydrocarbons persist in the food chain, particularly in species that have a low capacity to detoxify. Molluscs and other benthic invertebrates can accumulate residues from bottom sediments and remain contaminated for many years (Gilfillan and Vandermeulen 1978). Gray whales and other bottom-feeding cetaceans might therefore ingest petroleum long after a spill has dissipated.

To predict the consequences of chronic ingestion of sub-lethal quantities of oil, we should know whether a cetacean can detoxify petroleum compounds, or metabolites that persist in tissues of fish and other prey (McCain *et al.* 1978). Cytochrome P450, an iron-containing protein in liver cells, is part of a dynamic enzyme system involved in that metabolic process. It has been identified in liver from the bottlenose dolphin, white-sided dolphin, harbor porpoise and minke whale (Geraci and St. Aubin 1982, Goksoyr *et al.* 1986), and is probably common to cetaceans generally. A pilot study on rats has shown that oil is a potent inducer of P450 (Geraci and St. Aubin 1982), and we would expect it to have a comparable effect in a cetacean. These findings call for expanded studies on detoxifying systems in cetaceans. At present, an animal suspected to have been exposed to oil should be analyzed for cytochrome P450.

It is also possible to examine tissues for metabolites of petroleum hydrocarbons. We undertook a search for naphthalene in samples of liver and blubber from 15 species of whales which either had stranded, been taken as part of a fishery, or died in captivity. The analytical procedure was not particularly sensitive owing to limitations on methods for extracting naphthalene from tissue homogenates. Nevertheless, certain trends were Highest levels were found in the blubber of small odontocetes; evident. The pattern of accumulation values in mysticetes were considerably lower. seemed to be consistent with the habitat of the animals. Beluga whales and narwhals, which had the highest concentrations, live in a cold environment which retards hydrocarbon metabolism in fish (Collier et al. 1978), potentially leaving more available to be consumed. Mysticetes generally feed on organisms that accumulate and depurate relatively rapidly (Neff et al. 1976). Alternatively, the difference in the levels of naphthalene residues in odontocetes and mysticetes could reflect specific hydrocarbon detoxification capabilities in the two groups. These possibilites should be tested, and to do so, it will be necessary to develop a sensitive method for analyzing naphthalene and its metabolites in marine mammal tissue, correlate levels with controlled ingestion of petroleum compounds, then analyze tissues from animals available through strandings or other opportunities. Data from these studies will provide the means to test the hypothesis that a cetacean may ingest oil, and perhaps be harmed by it.

Summary

An oil spill at sea would add an element of risk to the environment of a whale or dolphin. Fresh crude oil or volatile distillates release toxic vapors that can damage sensitive tissues, harmful fractions may be swallowed or consumed through contaminated prey, and thicker tarry substances with entrapped debris linger at the surface, threatening to plug the vital baleen and digestive apparatus of whales that engulf them.

In spite of numerous spills in which cetaceans have been observed at sea, none of these effects has been detected, or recorded at least with any certainty. Experimental evidence shows that dolphins can see oil at the surface; they can also feel it, and prefer to avoid it. Other cetaceans seem to be comparably equipped to detect oil, yet in the wild, whales and dolphins have been observed swimming and feeding in its presence, without apparent ill effect. Not a strong enough adverse stimulus perhaps, or maybe they disregard oil for more consuming matters. Unlike furbearers, there is no avenue for uncontrolled heat loss through fouling of the skin. Furthermore, cetacean epidermis is nearly unpenetrable even to the highly volatile compounds in oil, and when skin is breached, realistic exposure to these fractions does not impede the progress of healing. Though encounters are likely, there is no evidence that oil or tar balls foul the feeding apparatus of baleen whales, and laboratory studies suggest such an effect would be transient.

Current technology provides the means to probe deeper in search of effects, to the molecular level, if necessary. That may serve our scientific curiosity, but would not bring us closer to an understanding of the central question. On the whole, it is quite improbable that a species or population of cetaceans will be disabled by a spill at sea, whatever the likelihood that one or a few animals might be affected or even killed. Yet, some habitats and, therefore, their residents, are more vulnerable than others. The iceedge, refuge for bowheads, narwhals and beluga whales, is a riskier trap than pelagic waters. And coastal areas with bustling oil production activity might see dolphins as the unwitting sentinals of a deteriorating environment. The stage is now set for decisions to identify, wisely utilize, and monitor such habitats.

Literature Cited

- Agarkov, G.B., B.G. Khomenko, V.G. Khadzhinskiy. 1974. Morphology of Delphinidae. Moscow: Naukova-Dumka (available JPRS 66036).
- Albert, T.F. 1981. Some thoughts regarding the effect of oil contamination on bowhead whales, <u>Balaena mysticetus</u>. pp. 945-953. In Tissue Structural Studies and other Investigations on the Biology of Endangered Whales in the Beaufort Sea. T.F. Albert (ed.). Appendix No. 9. Report to U.S. Bureau of Land Management, Washington, DC.
- Anon. 1970. Santa Barbara oil spill. Smithsonian Inst. Cntr. Short-lived Phenomena. Annual Report (1969). Event No. 9-69. pp. 88-97.
- Anon. 1971. Alaska Peninsula oil spill. Smithsonian Inst. Cntr. Short-lived Phenomena. Annual Report (1970). Event No. 36-70. pp. 154-157.
- Anon. 1981. Oil spills off N.C. Boston Globe, May 9.
- Anon. 1982. Stranded, tarred pilot whale. Smithsonian Inst. Sci. Event Alert Network (SEAN) Bull. 7 (3): 26.
- Bass, M. 1986. Sniffing gasoline. J. Amer. Med. Assoc. 255 (19): 2604-2605.
- Battelle Memorial Institute. 1969. Review of Santa Barbara channel oil pollution incident. Res. Report Dept. of the Interior, Fed. Water Pollut. Control Admin. and Dept. of Trans., U.S. Coast Guard. Contract No. 14-12-530. 157 pp.
- Bergey, M. 1979. The <u>Ixtoc</u> oil spill effects on marine mammals and turtles. Report by author aboard Res. Vessel Oregon II on 22-day shrimp tagging expedition. 49 pp.
- Braithwaite, L.F. 1981. The effects of oil on the feeding mechanism of the bowhead whale. Final Report. Contract No. AA851CT055. Bringham Young Univ., Provo, UT. 43 pp.
- Braithwaite, L.F. 1983. The effects of oil on the feeding mechanism of the bowhead whale. Final Report. U.S. Dept. of the Interior, Washington, DC. Contract No. AA 851-CT0-55. 45 pp.
- Brown, W.R., J.R. Geraci, B.D. Hicks, D.J. St. Aubin and J.P. Schroeder. 1983. Epidermal cell proliferation in the bottlenose dolphin (<u>Tursiops</u> <u>truncatus</u>). Can. J. Zool. 61 (7): 1587-1590.
- Brownell, R.L., Jr. 1971. Whales, dolphins and oil pollution. pp. 255-276.
 In Biological and Oceanographic Survey of the Santa Barbara Channel Oil Spill 1969-1970. Volume 1. Biology and Bacteriology. D. Straughan (ed.). Allan Hancock Foundation, Sea Grant Publ. No. 2.
- Butler, M.J.A., F. Berkes and H. Pawles. 1974. Biological aspects of oil pollution in the marine environment: a review. Mar. Sci. Cntr., McGill Univ., Montreal, P.Q. Manuscript Report No. 22. 133 pp.
- Caldwell, M.C. and D.K. Caldwell. 1982. A study of the effects of oil ingestion on a bottlenose dolphin, <u>Tursiops truncatus</u>. pp. 224-237. In Study of Effects of Oil on Cetaceans. J.R. Geraci and D.J. St. Aubin (eds.). Final Report. U.S. Dept. Interior, Bureau of Land

Management, Washington, DC. Contract No. AA 551-CT9-29. 274 pp.

Calkins, D.G. 1979. Marine mammals of Lower Cook Inlet and the potential for impact from outer continental shelf oil and gas exploration, development and transport. Final Report. Outer Continental Shelf Environ. Assess. Program. Research Unit 243. pp. 171-264.

- Carpenter, C.P., D.L. Geary, Jr., R.C. Myers, D.J. Nachreiner, L.J. Sullivan and J.M. King. 1977. Petroleum hydrocarbon toxicity studies. XIV. Animals and human response to vapors of high aromatic solvent. Toxicol. Appl. Pharmacol. 41 (2): 235-249.
- Collier, T.K., L.C. Thomas and D.C. Malins. 1978. Influence of environmental temperature on disposition of dietary naphthalene in coho salmon (<u>Oncorhynchus kisutch</u>): isolation and identification of individual metabolites. Comp. Biochem. Physiol. 61C: 23-28.
- Cornish, H.H. 1980. Solvents and vapors. pp. 468-496. In Toxicology. 2nd Edition. Casarett and Doull (eds.). MacMillan Publ. Co. Inc., New York, NY.
- Cowles, C.J., D.J. Hansen and J.D. Hubbard. 1981. Types of potential effects of offshore oil and gas development on marine mammals and endangered species of the northern Bering Sea and Arctic Ocean. Tech. Paper No. 9, Bureau of Land Management, Alaska OCS Office, Anchorage, AK. 23 pp.
- Cummings, W.C. and P.O. Thompson. 1971. Gray whales, <u>Eschrichtius</u> robustus, avoid the underwater sounds of killer whales, <u>Orcinus</u> orca. Fish. Bull. 69: 525-530.
- Dawson, W.W. 1980. The cetacean eye. pp. 53-100. In Cetacean Behavior: Mechanisms and Functions. L.M. Herman (ed). John Wiley & Sons Inc., New York, NY.
- Duguy, R. and P. Toussaint. 1977. Recherches sur les facteurs de mortalite des cetaces sur les cote de France. Conseil Intern. L'Explor. de la Mer, Comite de Mammiferes Marins. Report C.M. 1975/N:5.

Dutton, W.F. 1934. Petroleum dermatitis. Med. Rec. 140: 550-552.

- Eberhardt, R.L. and W.E. Evans. 1962. Sound activity of the California gray whale, <u>Eschrichtius glaucus</u>. J. Aud. Eng. Soc. 10: 324-328.
- Easton, R. (ed.). 1972. Black Tide: The Santa Barbara Oil Spill and Its Consequences. Delcorte Press, New York, NY. 336 pp.
- Elars Bioresearch Laboratories, Inc. 1979a. Acute toxicity tests of API178-3 No. 2 home heating oil (10% Cat). Project No. 1443. API Med. Res. Publ. 2732773. 52 pp.
- Elars Bioresearch Laboratories, Inc. 1979b. Acute toxicity tests of AP178-4 No. 2 home heating oil (50% Cat). Project No. 1443. API Med. Res. Publ. 2732772.
- Elars Bioresearch Laboratories, Inc. 1980a. Acute toxicity tests of API 78-2 No. 2 home heating oil (30% Cat). Project 1443. Amer. Petro. Inst. Med. Res. Publ. 2732771. 48 pp.
- Elars Bioresearch Laboratories, Inc. 1980b. Acute toxicity tests of API 78-7 No. 6 heavy fuel oil (API gravity 17.1/0.8% S). Project 1443. Amer. Petro. Inst. Med. Res. Publ. 2732774. 45 pp.
- Elars Bioresearch Laboratories, Inc. 1980c. Acute toxicity tests of API 79-2 No. 6 heavy fuel oil (API gravity 5.2/1.2% S). Project 1443. Amer. Petro. Inst. Med. Res. Publ. 2732813. 52 pp.
- Elars Bioresearch Laboratories, Inc. 1980d. Acute toxicity tests of API 78-6 No. 6 heavy fuel oil (API gravity 11.7/2.7% S). Project 1443. Amer. Petro. Inst. Med. Res. Publ. 2732814. 47 pp.
- Evans, W.E. 1982. A study to determine if gray whales detect oil. pp. 47-61. In Study of the Effects of Oil on Cetaceans. J.R. Geraci and D.J. St. Aubin (eds.). Final Report. U.S. Dept. of the Interior, Bureau of Land Management, Washington, DC. Contract No. AA 551-CT9-29.

Fraker, M.A., D.E. Sergeant and W. Hoek. 1978. Bowhead and white whales in the southern Beaufort Sea. Beaufort Sea Project Technical Report No. 4: 114 pp.

Fritts, T.H., A.B. Irvine, R.D. Jennings, L.A. Collum, W. Hoffman and M.A. McGehee. 1983. Turtles, birds, and mammals in the northern Gulf of Mexico and nearby Atlantic waters. Report U.S. Fish Wildl. Serv., Office of Biol. Sci. Publ. FWS/OBS-82/65.

Geraci, J.R. and D.J. St. Aubin. 1980. Offshore petroleum resource development and marine mammals: a review and research recommendations. Mar. Fish. Rev. 42: 1-12.

Geraci, J.R. and D.J. St. Aubin. 1982. Study of the effects of oil on cetaceans. Final Report. U.S. Dept. of the Interior, Bureau of Land Management, Washington, DC. 274 pp.

Geraci, J.R. and D.J. St. Aubin. 1985. Expanded studies of the effects of oil on cetaceans.. Final Report. Part I. U.S. Dept. of the Interior, Minerals Management Serv., Washington, DC. 144 pp.

Geraci, J.R., D.J. St. Aubin and R.J. Reisman. 1983. Bottlenose dolphins, <u>Tursiops truncatus</u>, can detect oil. Can. J. Fish. Aquat. Sci. 40 (9): 1515-1522.

Geraci, J.R. and T.G. Smith. 1976. Direct and indirect effects of oil on ringed seals (<u>Phoca hispida</u>) of the Beaufort Sea. J. Fish. Res. Board Can. 33 (9): 1976-1984.

Gerarde, H.W. 1964. Kerosine - experimental and clinical toxicology. Occup. Health Rev. 16: 17-21.

Giacometti, L. 1967. The skin of the whale (<u>Balaenoptera physalus</u>). Anat. Rec. 159: 69-76.

Gilfillan, E.S. and J.H. Vandermeulen. 1978. Alterations in growth and physiology of soft-shell clams, <u>Mya arenaria</u>, chronically oiled with Bunker C from Chedabucto Bay, Nova Scotia, 1970-76. J. Fish. Res. Board Can. 35: 630-636.

Goksoyr, A., J.E. Solbakken, J. Tarlebo and J. Klungsoyr. 1986. Initial characterization of the hepatic microsomal P-450-system of the piked whale (minke) <u>Balaenoptera</u> <u>acutorostrata</u>. Mar. Env. Res. 19: 185-203.

Goodale, D.R., M.A. Hyman and H.E. Winn. 1981. Cetacean responses in association with the <u>Regal Sword</u> oil spill. Cetacean and Turtle Assess. Program, Univ. Rhode Island. Annual Report (1979). U.S. Dept. of the Interior, Washington, DC. pp. XI-1 - XI-6.

Grose, P.L. and J.S. Mattson (eds.). 1977. The Argo Merchant spill: a preliminary scientific report. NOAA Environ. Res. Lab., Boulder, CO. 133 pp.

Gruber, J.A. 1981. Ecology of the Atlantic bottle-nosed dolphin (<u>Tursiops</u> <u>truncatus</u>) in the Pass Cavallo area of Matagorda Bay, Texas. M.Sc. Thesis, Texas A&M Univ., College Station, TX. 182 pp.

Haldiman, J.T., W.G. Henk, R.W. Henry, T.F. Albert, Y.Z. Abdelbaki and D.W. Duffield. 1985. Epidermal and papillary dermal characteristics of the bowhead whale (<u>Balaena mysticetus</u>). Anat. Rec. 211: 391-402.

Hansbrough, J.F., R. Zapata-Sirvent, W. Dominic *et al.* 1985. Hydrocarbon contact injuries. J. Trauma 25 (3): 250-252.

Hansen, D.J. 1985. The potential effects of oil spills andother chemical pollutants on marine mammals occurring in Alaskan waters. U.S. Dept. of the Interior, Minerals Management Serv., Alaska OCS Region, Anchorage, AK. Report MMS 85-0031.
Herman, L.M. and W.N. Tavolga. 1980. The communication system of cetaceans. pp. 149-209. In Cetacean Behavior: Mechanisms and Functions. L.M. Herman (ed.). John Wiley & Sons Publ., New York, NY.

Hunter, G.A. 1968. Chemical burns of the skin after contact with petroleum. Br. J. Plast. Surg. 21: 337-341.

- Ljungblad, D.K., S.E. Moore and D.R. Van Schoik. 1983. Aerial surveys of endangered whales in the Beaufort, eastern Chukchi, and northern Bering Seas, 1982. Alaska OCS Office, Minerals Management Serv., Report No. NOSC TR1046. 382 pp.
- Madsen, C.J. and L.M. Herman. 1980. Social and ecological correlates of cetacean vision and visual appearance. pp. 101-148. In Cetacean Behavior: Mechanisms and Functions. L.M. Herman (ed.). John Wiley & Sons, Inc., New York, NY.
- Mann, G. 1946. Oyo y vision de las ballenas. Biologica 4: 23-71.
- 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 oils from experimentally oiled sediments to English sole, <u>Parophrys vetulus</u> and pathological consequences. J. Fish. Res. Board Can. 35: 657-664.
- Neff, J.M., B.A. Cox, D. Dixit and J.W. Anderson. 1976. Accumulation and release of petroleum-derived aromatic hydrocarbons by four species of marine animals. Mar. Biol. 38: 279-289.
- Nicol, C.W. 1976. The Mizushima oil spill a tragedy for Japan and a lesson for Canada. Environ. Canada. Environ. Protection Serv. Report No. EPS-8-EC-76-2.
- Ogawa, T. and T. Shida. 1950. On the sensory tubercles of lips and of oral cavity in the sei and fin whale. Sci. Rep. Whales Res. Inst., Tokyo 3: 1-16.
- Owen, R.E. 1984. Oil spill from the British tanker <u>Alvenas</u>. Nat. Mar. Fish. Serv., Southeast Fish. Cntr., Miami, FL. Unpublished Report. 3 pp.
- Palmer, E. and G. Weddell. 1964. The relationship between structure, innervation, and function of the skin of the bottlenose dolphin, <u>Tursiops</u> <u>truncatus</u>. Proc. Zool. Soc. Lond. 143: 553-568.
- Pepper, R.L. and J. Simmons. 1973. In-air visual acuity of the bottlenose dolphin. Exp. Neurol. 41: 271-276.
- Pike, G. 1962. Migration and feeding of the gray whale (<u>Eschrichtius</u> <u>gibbosus</u>). J. Fish. Res. Board Can. 19: 815-838.
- Pivorunas, A. 1976. A mathematical consideration on the function of baleen plates and hair fringes. Whales Res. Inst., Sci. Report No. 28: 37-55.
- Pivorunas, A. 1979. The feeding mechanisms of baleen whales. Amer. Sci. 67 (4): 432-440.

Prieur, D. and E. Hussenot. 1978. Marine mammals stranded during the <u>Amoco</u> <u>Cadiz</u> oil spill. Penn ar Bard 11 (94): 361-364.

Purves, P.E. and G.E. Pilleri. (eds.). 1983. Echolocation in Whales and Dolphins. Academic Press, London, U.K. 261 pp.

- Rice, D.W. 1961. Sei whales with rudimentary baleen. Norsk Hvalfangst-Tidende 5: 189-193.
- Rice, D.W. and A.A. Wolman. 1971. The life history and ecology of the gray whale, <u>Eschrichtius robustus</u>. Am. Soc. Mammal., Spec. Publ. No. 3.

Ridgway, S.H. (ed.). 1972. Homeostasis in the aquatic environment. pp. 632. In Mammals of the Sea: Biology and Medicine. Charles C. Thomas Publ., Springfield, IL. 812 pp.

- Rowe, L.D., J.W. Dollahite and B.J. Camp. 1973. Toxicity of two crude oils and of kerosine to cattle. J. Am. Vet. Med. Assoc. 162 (1): 61-66.
- St. Aubin, D.J., J.R. Geraci, T.G. Smith and T.G. Friesen. 1985. How do bottlenose dolphins, <u>Tursiops</u> <u>truncatus</u>, react to oil films under different light conditions? Can. J. Fish. Aquat. Sci. 42 (3): 430-436.
- St. Aubin, D.J., R.H. Stinson and J.R. Geraci. 1984. Aspects of the structure and composition of baleen, and the effects of exposure to petroleum hydrocarbons. Can. J. Zool. 62: 193-198.
- Schmidt, R.F. (ed.). 1977. Somatovisceral sensibility. pp. 81-175. In Fundamentals of Sensory Physiology. Springer-Verlag, New York, NY.
- Sergeant, D.E. 1970. Sea mammals and man: a look at the future. Fish. Res. Board Can., Arctic Biol. Station, Ste. Anne de Bellevue, P.Q. Unpublished manuscript. 6 pp.
- Shane, S.H. and D.J. Schmidly. 1978. The population biology of the Atlantic bottlenose dolphin, <u>Tursiops truncatus</u>, in the Arkansas Pass area of Texas. U.S. Marine Mammal Commission, Washington, DC. Report No. MMC-76/11.
- Slijper, E.J. 1979. Whales. Second Edition. R.J. Harrison (ed.). Hutchinson, London, U.K. 511 pp.
- Smith, T.G., J.R. Geraci and D.J. St. Aubin. 1983. The reaction of bottlenose dolphins, <u>Tursiops truncatus</u>, to a controlled oil spill. Can. J. Fish. Aquat. Sci. 40 (9): 1522-1527.
- Sorensen, P.W., R.J. Medved, M.A.M. Hyman and H.E. Winn. 1984. Distribution and abundance of cetaceans in the vicinity of human activities along the continental shelf of the northwestern Atlantic. Mar. Environ. Res. 12: 69-81.
- Spong, P. and E. White. 1971. Visual acuity and discrimination learning in the dolphin (<u>Lagenorhynchus obliquidens</u>). Exp. Neurol. 31: 431-436.
- Straughan, D. 1972. Biological effects of oil pollution in the Santa Barbara Channel. pp. 355-359. In Marine Pollution and Sea Life. M. Ruivo (ed.). Fishing News Ltd., London, U.K.
- Thomson, C.A. and J.R. Geraci. 1986. Cortisol, aldosterone and leucocytes in the stress response of bottlenose dolphins, <u>Tursiops truncatus</u>. Can. J. Fish. Aquat. Sci. 43 (5): 1010-1016.
- U.S. Dept. Health and Welfare. 1978a. Tabulations of 1976 case reports. Publ. Health Serv./FDA. Bull. Nat. Clearinghouse Poison Control Centers, Bethesda, MD.
- U.S. Dept. Health and Welfare. 1978b. Phencyclidine overdose management. Publ. Health Serv./FDA. Bull. Nat. Clearinghouse Poison Control Centers, Bethesda, MD.
- Valpey, R., S.M. Sumi, M.K. Copass and G.J. Goble. 1978. Acute and chronic progressive encephalopathy due to gasoline sniffing. Neurol. 28: 507-510.
- Waller, G.N.H. 1984. The ocular anatomy of cetacea an historical perspective. Invest. Cetacea: 136-148.
- Walls, G.L. 1963. The Vertebrate Eye and its Adaptive Radiation. Hafner, New York, NY.

- Walsh, W.A., F.J. Scarpa, R.S. Brown, K.W. Ashcraft, V.A. Green, T.M. Holder and R.A. Amoury. 1974. Gasoline immersion burn. The New Engl. J. Med. 291: 830.
- Wang, C.C. and G.U. Irons. 1961. Acute gasoline intoxication. Arch. Environ. Health 2: 714-716.
- Wolfram, M.A., N.F. Wolejsza and K. Laden. 1972. Biomechanical properties of delipidized stratum corneum. J. Invest. Dermat. 59 (6): 421-426.
- Wursig, B., C.W. Clark, E.M. Dorsey, M.A. Fraker and R.S. Payne. 1982. Normal behavior of bowheads. pp. 33-143. In Behavior, Disturbance Responses and Feeding of Bowhead Whales, <u>Balaena mysticetus</u> in the Beaufort Sea, 1980-1981. LGL Ecol. Res. Assoc., Inc. Bryan, TX. U.S. Bureau of Land Management, Washington, DC.
- Yablokov, A.V., V.M. Bel'kovich and V.I. Borisov. 1974. Whales and dolphins. Transl. Kity I Del'finy, 1972, Izd-vo Nauka, Moscow, U.S.S.R. Joint Publ. Res. Serv., Arlington, VA.
- Zieserl, E. 1979. Hydrocarbon ingestion and poisoning. Comprehen. Therapy 5/6: 35-42.



swimming along the edge of the ice. A bear may dive and swim underwater between natural holes in the ice, surfacing quietly to breathe, until it arrives next to its prey, at which point it suddenly surfaces to attack. Bears also obtain food by scavenging remains left by other bears.

Polar bears spend more time hunting than in any other activity. During the spring, adult females with cubs, and adult males can spend 19 to 25% of their time hunting, whereas in the summer they hunt for 30 to 50% of the time (Stirling 1974a, Stirling and Latour 1978). Hunting success varies considerably seasonally and between individuals. In early summer, the best time for hunting seals, adult femals with cubs catch one every four to five days. During winter, the interval between successful hunts is likely much longer, judging from the observation that bears of all ages and both sexes are lighter in March or April than in July. Seals are less available in winer, causing bears to explore alternative foods and leading more frequently to fatal encounters with humans at that time of year.

Reproduction: To a degree, behaviors associated with polar bear reproduction isolate them from potential interaction with oil. From mid-April to late May, breeding pairs are found along the floe edge and active ice areas that predominate along the transition zone and around polynyas such as those near Cape Bathurst or Point Barrow. Males accompany females for a week or more, apparently to induce ovulation, and may lead them away from areas where competing males are abundant (Ramsay and Stirling 1986). Thus, for relatively short periods, breeding polar bears may be distributed away from areas where risk of contact with oil might be greatest.

In fall, pregnant females move away from areas frequented by other bears. In the Beaufort Sea region, most maternity denning on land occurs on the west and south coasts of Banks Island. Few dens have been reported in recent years along the mainland coast of Alaska and Canada, possibly because excessive hunting pressure prior to the early 1960's eliminated those individuals showing some fidelity to the area (Stirling *et al.* 1975). Amstrup (1986) has shown that 80% or more of maternity denning along the mainland coast of northern Alaska and Canada takes place in multi-year pack ice up to about 300 km offshore. Bears in those dens are likely too far removed to contact oil during the winter.

The risk of exposure would be greater for polar bears in dens along the mainland coast in the vicinity of Herschel Island through the Alaskan north slope. After leaving the dens in spring, these females appear hunt seal pups in stable fast ice on the landward side of the transition zone. Eventually, they must cross it to reach the retreating pack ice where they spend the summer. A lead fouled by a spill might obstruct their path, or contaminate bears that continue their migration.

Grooming: Polar bears are clean animals. Over the years, we have caught several thousand and very few have been greasy or dirty. Grooming is necessary to maintain thermal efficiency of their pelt, which is often soiled after feeding. Polar bears feed on seals by tearing pieces of skin and blubber away from the carcass; fat is eaten preferentially. After feeding for 20 to 30 minutes, bears wash their paws and faces in a nearby lead or melt pond on the ice (Stirling 1974a). A bear may repeat this behavior several times while eating, and again after it is done. During colder weather when water is not available, bears clean themselves by licking their paws and rolling or pushing their face and neck against the snow. Mutual grooming has also been observed among females and cubs of all ages. Thus, it is likely that polar bears will attempt to remove any substance, including oil, from their fur.

Investigative Behavior: To survive in an extreme environment, such as the Arctic sea ice, a predator must be opportunistic and innately investigative. It is not surprising that polar bears are extremely curious and explore anything novel in their environment. They are also scavengers that will eat an extraordinary variety of unnatural food, some so obviously lacking in nutrition that the reason for eating them is unclear. For example, styrofoam, pieces of plastic, and even parts of a car battery (which apparently killed the animal) have all been found in the stomachs or scats of polar bears (Russell 1975, Lunn and Stirling 1985). Similarly, Inuk hunters have observed polar bears biting cans of snowmobile oil, and there are instances of bears biting and causing leaks in fuel bladders. These anecdotes raise a number of questions: does the smell of refined or crude oil attract polar bears? Would one scavenge a dead oil-covered sea bird or seal, thereby ingesting toxic materials? Might a bear actively avoid an oil-covered lead if it could or would it simply swim through it?

Summarizing the Risk

The way in which a bear gathers food, the characteristics of its environment, and its migratory behavior are all potentially capable of bringing it in contact with spilled oil. The animal is closely associated with ice floes - the same type of environment which entrains, concentrates, and moves surface oil, and retards its degradation and elimination. Polar bears share with sea otters, the need to maintain a pristeen hair coat as protection against heat loss. Consequently, exposure under any of these conditions is likely to be deliterious.

Literature Cited

- Amstrup, S.C. 1986. Research on polar bears in Alaska, 1983-85. pp. 85-112, In Proc. 9th Working Mtg. IUCN Polar Bear Specialist Group (1985), Edmonton, Alta. Int. Union Conserv. Nature and Nat Resources Publ., 1196 Gland, Switzerland.
- Cooper, P.F. Jr. 1974. Landfast ice in the southeastern part of the Beaufort Sea. pp. 235-242. In The Coast and Shelf of the Beaufort Sea. J.C. Reed and J.E. Sater (eds.). Arctic Inst. North America, Arlington, VA.
- Croasdale, K.R. 1986. Arctic offshore technology and its relevance to the Antarctic. pp. 245-264. In Antarctic Treaty System, An Assessment. Polar Research Board (ed.). National Academy Press, Washington, DC.
- DeMaster D.P. and I. Stirling. 1981. <u>Ursus maritimus</u>. Mammalian Species 45:1-7.
- Dickens, D., L. Martin, I. Bjerkelund, S. Potter, D. Erickson, J. Harper, P. Norton, S. Johnson and P. Vonk. 1987. Environmental Atlas for Beaufort Sea Oil Spill Response. D. Dickens Assoc. Ltd., Vancouver, B.C. 182 pp.
- Kingsley, M.S.K., I. Stirling and W. Calvert. 1985. The distribution and abundance of seals in the Canadian High Arctic, 1980-82. Can. J. Fish. Aquat. Sci. 42: 1189-1210.
- Lentfer, J.W. 1972. Polar bear sea ice relationships. pp. 165-171. In Bears - Their Biology and Management. S. Herrero (ed.). IUCN New Series No. 23.
- Lindsay, D.G. 1975. Sea Ice Atlas of Arctic Canada, 1961-1968. Report. Dept. Energy, Mines and Resources, Ottawa. 213 pp.
- Lindsay, D.G. 1977. Sea Ice Atlas of Arctic Canada, 1969-1974. Report. Dept. Energy, Mines and Resources, Ottawa. 219 pp.
- Lunn, N.J. and I. Stirling. 1985. The ecological significance of supplemental food to polar bears during the ice-free period of western Hudson Bay. Can. J. Zool. 63: 2291-2297.
- Ramsay, M.A. and I. Stirling. 1986. On the mating system of polar bears. Can. J. Zool. 64: 2142-2151.
- Russell, R.H. 1975. The food habits of polar bears of James Bay and Southwest Hudson Bay in summer and autumn. Arctic 28: 117-129.

Smith, M., and B. Rigby. 1981. Distribution of polynyas in the Canadian Arctic. pp. 7-28. In Polynyas in the Canadian Arctic. I. Stirling and H. Cleator (eds.). Can. Wildl. Serv. Occ. Paper No. 45.

- Smith, T.G. and I. Stirling. 1975. The breeding habitat of the ringed seal (<u>Phoca hispida</u>): the birth lair and associated structures. Can. J. Zool. 53: 1297-1305.
- Stirling, I. 1974a. Midsummer observations on the behavior of wild polar bears (<u>Ursus maritimus</u>). Can. J. Zool. 52: 1191-1198.
- Stirling, I. 1974b. Polar bear research in the Beaufort Sea. pp. 721-733. In The Coast and Shelf of the Beaufort Sea. J.C. Reed and J.E. Slater (eds.). Arctic Inst. North Amer., Arlington, VA.
- Stirling, I. 1988. Attraction of polar bears to offshore drilling sites in the eastern Beaufort Sea. Polar Record 25: (in press).

Stirling, I., D. Andriashek and W. Calvert. 1981. Habitat preferences and distribution of polar bears in the western Canadian Arctic. Report. Can. Wildl. Serv., Edmonton, to Dome Petrolum, Calgary, Alta.

Stirling, I., D. Andriashek and W. Calvert. The polar bear in the western Canadian Arctic, 1971-1979. Unpubl. Manuscript. Can. Wildl. Serv. 146 pp.

Stirling, I., M.C.S. Kingsley and W. Calvert. 1982. The distribution and abundance of seals in the eastern Beaufort Sea, 1974-79. Can. Wildl. Serv. Occ. Paper 47. 23 pp.

Stirling, I. and P.B. Latour. 1978. Comparative hunting abilities of polar bear cubs of different ages. Can. J. Zool. 56: 1768-1772.

Wilson, H.P. 1974. Wind and currents in the Beaufort Sea. pp. 13-17. In The Coast and Shelf of the Beaufort Sea. J.C. Reed and J.E. Sater (eds.). Arctic Inst. North Amer., Arlington, VA.

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CHAPTER 9

PHYSIOLOGIC AND TOXICOLOGIC EFFECTS

ON POLAR BEARS

D.J. St. Aubin

Department of Pathology Ontario Veterinary College University of Guelph Guelph, Ontario N1G 2W1

Historical Notes

There have been relatively few major spills in the polar bear's natural range, and no reports of bears having been critically fouled by oil. Anecdotal accounts show that bears occasionally come into contact with it. Stirling (Chapter 8) has learned of bears biting cans of motor oil and fuel storage bladders, without evidence of immediate harm. Adding to these scant data are findings from a single laboratory study (Oritsland *et al.* 1981). The effects of oil on bears can be predicted more from what we know about their physiology and life history, than from these limited observations.

Detection and Avoidance

Stirling (Chapter 8) has vividly described the way in which a polar bear gathers food. It hunts prey using obviously keen eyesight and by detecting the odor of a ringed seal through the domed roof of a subnivean birth layer. These sensory modalities are common to carnivores, and would seem to provide a bear with the means to detect spilled oil.

Some indication of their ability to do so can be gleaned from the laboratory study on three captive bears. The animals were coaxed individually along a passageway leading to a small pool containing 7000 L of seawater covered with a 1-cm surface slick of crude oil. None entered the pool voluntarily, but all three investigated its oil-covered surface. As the bears stretched out over the pool to reach seal blubber suspended inaccessibly from the top of the cage, the door was closed behind them forcing them into the The bears made deliberate attempts to escape, and were able to do so water. to some extent by supporting themselves on the cage bars which encircled the pool; they continued their attempts to obtain the bait. When the cage door was opened after 15 to 50 minutes, the bears left the pool immediately. These brief observations make it clear that bears can detect oil and seem determined to avoid it. Their reaction to it under those circumstances offers clues that hint at how a free-ranging bear might behave in a wild setting.

The bear's annual cycle includes seasonal migrations across open leads as it follows the edge of the pack ice. Confronted by an oil-covered lead, it might investigate and avoid the contaminated water. But would it nevertheless enter the lead, bent on continuing its migration through an area that offered no clean alternative? Would it resist the lure of a seal emerging, perhaps disoriented, in the slick? In the captive setting, it was their desire to obtain food which caused the bears to lean precariously out over the oiled pool. Their appetites were enhanced by limited food availabilty during the pre-experimental period, yet natural cycles in prey abundance could place similar demands on free-ranging bears. Ready access to seals confined to limited open water areas during the winter might in fact draw polar bears to contaminated areas.

Surface Contact

To protect them from extreme thermal demands of their environment, polar bears rely principally on a thick coat of hair, though subcutaneous fat contributes somewhat to their insulation (Scholander *et al.* 1950, Oritsland 1970). The effect of fouling on thermoregulation in these animals is thus a major concern which has been addressed by measuring thermal conductance through oiled pelts <u>in vitro</u>. Four samples collected during fall months from young bears were cleaned of underlying flesh, mounted over a constant temperature heat flow disc, and subjected to variable wind. Heat flux through dry pelts averaged 1.75 W/m²/°C, a value intermediate to previous measurements for winter (Scholander <u>et al</u>. 1950) and summer (Oritsland 1970) samples.

The specimens were then placed in a water bath at 15 to 20°C, that was covered by a 1-cm layer of oil. Three types of oil, representing a range of viscosities, were used. Each sample was agitated for five minutes in the oilwater mixture, and soaked for an additional 25 minutes. Heat flux was determined immediately after oiling, and again on each of two successive days. Initially, there was a 5 to 6 fold increase in conductivity in wet, oiled pelts, when compared with dry controls; unfortunately no wet controls were performed to provide some indication of the change in conductivity due to On subsequent days, the average increment seawater alone (Figure 9.1). The sample treated with low-viscosity crude oil decreased to 2 to 4 fold. showed the most rapid recovery, and extrapolation of the data suggests that pre-exposure values would have been restored after 3 or 4 days. A much more prolonged recovery, in the order of 2 to 3 weeks, might be expected following exposure to weathered fractions or viscous oil at low temperatures.

Oiled pelts exposed to winds of up to 5 m/second showed further reduction in insulative properties; the effect was most pronounced in the sample treated with high viscosity oil. Thermal stress imposed by wind chill would thus be particularly severe in oiled polar bears.

Another consequence of oiling was a 28% increase in the pelts' absorption of solar energy. Similar findings have been reported for phocid seal pelts (Oritsland 1975). At low ambient temperatures, this effect might reduce overall thermal stress, though not enough to overcome large increases in conductance. During warm summer months, however, active polar bears are susceptible to overheating, a problem that would be compounded by the additional heat absorbed through its pelt.

These in vitro studies provided a clear indication that surface fouling will have a significant impact on energy metabolism of polar bears. The investigation complemented a study in which live bears were exposed to oil. They had been captive for 3-4 months before being placed in the oil-covered pool. Basal metabolic rate, determined 5 to 8 days after surgical implantation of temperature transmitters, was somewhat higher than expected, then rose 10-fold while the animals exercised (Hurst *et al.* 1982). Rigorous exposure to wind at -16 to -24°C caused skin temperatures to fall as much as 7°C, but had little effect on core temperatures. After the bears had been in the oiled pool for 15 to 50 minutes, they were again exposed to alternating periods of





wind and calm air. Two still showed no change in core temperature, whereas that of the third bear decreased steadily when it was exposed to wind, and rose again to pre-oil values when the air was calm. One day after oiling, metabolic rate of the bears was 27% to 86% higher. The studies confirm the expected finding that an animal that depends on its coat for insulation will be metabolically effected by oiling (Kooyman *et al.* 1977). However, the magnitude of the impact on polar bears cannot be established from the study, because of the inexplicably high metabolic rates determined prior to oil exposure.

Oil Ingestion

Stirling's (Chapter 8) description of grooming behavior in polar bears sets the stage for understanding how the problem of oil-coating can be transformed into one of ingestion. The experimental study confirmed the association. During the first few hours after oiling, all three bears groomed their paws and forelegs intensively. One rubbed its coat along the cage bars, another attempted to use snow that was provided. The snow became fouled and the bears consumed that too.

Grooming activity subsided over the next five days, though the bears were still covered with oil. Ingested oil caused vomiting and diarrhea. Hydrocarbons were absorbed into the circulation, distributed to various tissues, and excreted by bile and urine. During the four weeks after oiling, there was biochemical evidence that the bears were developing liver and kidney failure, and a disorder of red blood cell formation. Twenty six days after oiling, one of the bears died, and three days later, another was euthanized.

The principal findings on necropsy examination were degeneration of kidney tubules, low-grade liver lesions, suppression of lymphoid activity, and fungus-containing ulcers in the gastrointestinal tract. This pattern of pathologic change suggests that the toxic effects of oil were compounded by the stresses associated with the experiment. The bears were confined for metabolic studies, their diet was inadequate, water was limited for a critical time after oiling, and surgical incisions and injection sites had become infected. Lymphoid suppression and widespread mycotic lesions draw attention to the degree to which the animals were stressed. Could the stress of oiling alone produce these kinds of changes in a free-ranging bear? Perhaps so, when seals are scarce, temperatures are extreme, and energy stores are reduced.

Balancing the Effects

The dramatic consequences of oil exposure, albeit intensified by the experimental protocol, highlight the vulnerability of polar bears. There is no reason to expect that they would somehow avoid such effects in the wild.

For the sake of the story, let us place a polar bear on the edge of a lead fouled with oil. A single plunge into it while chasing a seal, or emerging through it on its return, would likely affect the bear in a way comparable to a sea otter, forcing it to groom compulsively at the expense of other behaviors. In a futile effort to restore the insulative quality of its coat, the bear will ingest oil, adding to its metabolic stress. And the bear may become increasingly less aware of the source of oil.

More than any other marine mammal, bears scavenge food, and are likely to manipulate and consume an oil-soaked seal or bird carcass. They show no particular aversion to the taste of oil, judging from anecdotes of their behavior in the wild. This is further supported by the reaction of two of the study bears when placed in a holding cage previously occupied by an oilfouled bear. Both became preoccupied with cleaning their lightly soiled paws, then turned their attention to the cage itself, actively licking oil residues from the bars and floor. For polar bears, the problems associated with ingesting fresh oil far outweigh the risks of consuming trace amounts of petroleum hydrocarbons in the tissues of their prey.

Perhaps the most important lesson from the oiling study relates to the role of stress in determining the ultimate effects of oil exposure. Taken alone, it is conceivable that a 500 kg bear might ingest a liter or more of oil without serious consequences. Yet, the same quantity in an animal stressed by inadequate diet or other unusual environmental conditions could be fatal. Seasonal and annual fluctuations in prey abundance might greatly alter the condition of free-ranging bears, making them more likely to seek contaminated prey, and predisposing them at such times to the most severe consequences of oil exposure.

Literature Cited

- Hurst, R.J., N.A. Oritsland and P.D. Watts. 1982. Body mass, temperature and cost of walking in polar bears. Acta Physiol. Scand. 115: 391-395.
- 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. pp. 151-157. In Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D.A. Wolfe (ed.). Pergammon Press, New York, NY. 478 pp.
- Oritsland, N.A. 1970. Temperature regulation of the polar bear (<u>Thalarctos</u> <u>maritimus</u>). Comp. Biochem. Physiol. 37: 225-233.
- Oritsland, N.A. 1975. Insulation in marine mammals: the effect of crude oil on ringed seal pelts. pp. 48-67. In The Effect of Contact and Ingestion of Crude Oil on Ringed Seals of the Beaufort Sea. T.G. Smith and J.R. Geraci (eds.). Beaufort Sea Project. Inst. of Ocean Sci., Sidney, British Columbia. Technical Report No. 5.
- Oritsland, N.A., F.R. Engelhardt, F.A. Juck, R.A. Hurst and P.D. Watts. 1981. Effects of Crude Oil on Polar Bears. Environ. Studies Report No. 24. Northern Affairs Program, Dept. Indian Affairs and Northern Development, Ottawa, Ont. 268 pp.
- Scholander, P.R., V. Walters, R. Hock and L. Irving. 1950. Heat regulation in some arctic and tropical mammals and birds. Biol. Bull. 99: 225-236.

CHAPTER 10

OIL EFFECTS ON MANATEES:

EVALUATING THE RISKS

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D.J. St. Aubin and V. Lounsbury

Department of Pathology Ontario Veterinary College University of Guelph Guelph, Ontario N1G 2W1

Introduction

The Order Sirenia consists of two families: the Trichechidae (manatees), which is comprised of three species belonging to the genus <u>Trichechus</u>, and the Dugongidae (dugongs), represented by a single species. Their ancestral relationships are unclear, though likely they are descended from a terrestrial herbivore (Domning 1982); perhaps their closest living terrestrial relatives are elephants and hyraxes. Unique anatomical and physiological traits distinguish them from other marine mammals, as does their herbivorous diet. Like cetaceans, they are considered to be wholly aquatic, though they may emerge from water to browse on vegetation just above the shoreline.

The present discussion will focus on the West Indian manatee, the only sirenian in U.S. waters. Observations on the Amazonian manatee, African manatee, and dugong will be included to fill gaps in data or provide important comparative information. Detailed accounts of manatee ecology and life history, beyond the scope of this review, have been compiled by Bertram and Bertram (1973), Hartman (1979), and Caldwell and Caldwell (1985).

Distribution and Abundance

In the broadest sense, the West Indian manatee ranges from Virginia to central Brazil, including the shores of the Gulf of Mexico and the islands of the Caribbean Sea (Figure 10.1). Their distribution is discontinuous, and it seems more convenient to assign them to four principal locations: the Atlantic and Gulf coasts of Florida; the Yucutan south to Honduras; between the Orinoco and Amazon Rivers on the coast of Guyana; and the Greater Antilles, including Cuba, Puerto Rico, Hispaniola and Jamaica. These populations are considered to be more or less distinct; seasonal movements and occasional strays provide only limited opportunities for mixing and recruitment.

The population of West Indian manatees is estimated to range between 8000 and 17000 animals, most of which are found in Guyana (FAO 1976). In Florida waters, estimates vary between 800 and 1200; most reports set the population at 1000 (Brownell *et al.* 1978). In view of its restricted range and relatively low numbers, the West Indian manatee has been listed as vulnerable to extinction, by the International Union for the Conservation of Natural Resources. It has been reduced from historical levels of several thousands, largely because of exploitation for its highly palatable meat (Bertram and Bertram 1973), and more recent accidental encounters with human activities (Irvine *et al.* 1978, Hartman 1979, Odell and Reynolds 1979).

Figure 10.1

Distribution of the West Indian manatee. Favored wintering sites in Florida waters and the location of some power plants that attract manatees are indicated.



Life History

Breeding activity in manatees continues throughout the year in Florida, though analysis of calf mortality indicates minor peaks in reproduction during spring and fall (Brownell *et al.* 1978). Only the Amazonian manatee appears to be a truly seasonal breeder, having reproductive peaks that coincide with annual cycles in water level (Best 1982). Copulation is preceded by vigorous courtship activity, which belies the manatee's reputation for sluggish behavior. Bulls may escort a cow for a month or more, then engage in frantic pursuit through mud and vegetation before mating (Hartman 1979).

Gestation lasts roughly a year, and cows apparently seek sheltered waters to give birth to their single calves (Hartman 1979). The young may nurse for a year or more, but may begin grazing after two to three months (Hartman 1979). The association between cow and calf lasts up to 18 months (Powell and Waldron 1978); minimum reproductive interval is therefore 2-2.5 years (Hartman 1979), though some suggest that 3-4 (Powell and Waldron 1978) or even 5 years (Brownell *et al.* 1978) is more common.

Estimates of age at sexual maturity for female manatees vary from 3-5 years (Hartman 1979) to 7-9 years (Odell 1977); males mature at 9-10 years (Odell 1977). Though there are no reliable estimates for average lifespan in the wild, captive animals have been maintained for 25-30 years (Brownell *et al.* 1978, Hartman 1979). By contrast, dugongs mature later, and have a life expectancy of 50-60 years (Marsh *et al.* 1984).

Preferred Habitat, Seasonal Movements and Migration

Manatees dwell in protected, low salinity waters where vegetation is abundant. They range extensively into freshwater systems, including the St. Johns River in northern Florida where they may congregate over 250 km from the sea (Powell and Waldron 1978). As a rule, they only venture into open oceanic waters to move from one favorable feeding area to another (Hartman 1979). Such movements are generally confined to waters less than 5 m deep close to shore, though extensive shallows off Florida's west coast can force animals many kilometers from land. Rare offshore sightings near the Dry Tortugas, FL, are thought to represent sporadic movements from other regional concentrations in the Caribbean Islands or Mexico (Reynolds and Ferguson 1984).

Seasonal movements are governed by the manatee's apparent intolerance to cold. Historically, manatees retreated during the winter months to the southernmost areas of Florida, or sought natural warm springs such as those in Citrus County or the upper reaches of the St. Johns River (Campbell and Irvine 1978). The advent of electric power plants which discharge warm water has provided manatees with new alternative wintering sites. Their preference for this habitat does not limit their movements entirely. Manatees also undertake reasonably lenghty excursions into the cold sea during winter, judging from the growth of marine algae and barnacles on the skin of animals returning to warm springs (Hartman 1979).

With the return of warm weather, manatees disperse along the coast. Some return to the same summer feeding grounds (Shane 1984), though their attraction to a specific area is not particularly strong (Hartman 1979). In general, their movements during summer are unpredictable, ranging along several hundred kilometers of coastline as they explore alternative feeding areas (Hartman 1979). Individuals may remain in the same area for several months, or simply move on after only a few days.

Habitat Use and Physiology

Sirenian behavior and distribution are influenced by two important aspects of their physiology: nutrition and metabolism. As the only herbivorous marine mammals, they occupy a unique ecological niche, which limits their distribution to low-energy, inshore habitats supporting the growth of sea-grasses. Their attraction to springs and river systems seems less a requirement for freshwater than a preference for the type of vegetation there.

Manatees consume a wide variety of aquatic and semi-aquatic plants, and show a mild preference for submerged succulent vegetation (Reynolds 1978, Hartman 1979). Their selection appears to change seasonally with availability of specific forms (Hartman 1979). When preferred underwater types are depleted, they turn to floating mats of vegetation, algae, roots or detritus, and at times will emerge from the water to consume overhanging vegetation (Reynolds 1978, Powell and Waldron 1978, Hartman 1979, Reynolds 1981). While grazing, they ingest considerable quantities of encrusting organisms such as diatoms, molluscs and crustaceans (Best 1981). Foreign objects, such as plastic bags, pieces of rope and cloth, and artificial sponges may also be ingested (Reynolds 1980).

Manatees must feed for 6 to 8 hours each day (Hartman 1979, Best 1981) to compensate for the low energy content of the diet and their relatively low digestive efficiency, which in the Amazonian manatee ranges from 44-68% (Best 1981). On average, they consume 10-15% of their body weight daily (Best 1981). They are not ruminants, and rely instead on hind-gut fermentation to digest cellulose (Reynolds 1980). The digestive process is relatively long; transit time for the Amazonian manatee ranges up to 140 hours (Best 1981).

A rather low-yield diet and quiet manner faithfully serve the manatee's extraordinarily low metabolic rate. Scholander and Irving (1941) first demonstrated that its metabolism was far below that predicted on the basis of body size. Subsequent studies on the West Indian and the Amazonian manatees confirmed that the rate is approximately 15-35% that of other mammals of comparable size (Gallivan and Best 1981, Irvine 1983, Gallivan *et al.* 1983).

Slow metabolism accounts in part for the manatee's tropical range. Their ability to tolerate cold water is limited also by high thermal conductance of their skin, which has only sparse sensory hairs and virtually no blubber (Irvine 1983). Only the Amazonian manatee develops seasonal reserves of subcutaneous fat, not for purposes of thermoregulation, but to offset annual fluctuations in food abundance and not for purposes of thermoregulation (Gallivan *et al.* 1983). In water below 20°C, manatees may increase their metabolic rate (Hartman 1979), and also allow core temperature to decrease, in effect decreasing the temperature gradient between the body and the environment (Gallivan *et al.* 1983). These strategies provide limited benefit. Unseasonably cold temperatures, such as occurred durng the winter of 1976-77 in Florida, are thought to be responsible for increased mortality in the more northerly wintering sites (Campbell and Irvine 1978).

Historical Notes on the Effects of Oil

Information on the effects of oil on other marine mammal groups is patchy in some respects, yet is voluminous when compared with the scant data available for sirenians. There has been no experimental study, and only a handful of observations suggesting oil as a factor contributing to mortality.

No major spill has occurred in Florida waters occupied by manatees. To glean some understanding of the effects of oil on these animals, we can draw on observations from the Persian Gulf, where an apparent increase in dugong mortality coincided with the uncontrolled release of large quantities of oil from platforms damaged during the Iran-Iraq war. Between February and August, 1983, an estimated 30 million gallons of crude oil spilled from eight wells in offshore Iranian oil fields (Miller 1983). Continued fighting interfered with attempts to cap the wells or clean up the oil. An estimated 40-50% of the oil was presumed to have evaporated, leaving a mat of heavier fractions floating just under the surface (Miller 1983). By July, 53 dugong carcasses had been recovered, in addition to an "unusual number" of fish, turtles, dolphins, snakes and birds (Anon 1983). So little was known of the dugong population in the area that the loss of at least 50 of them was thought to represent a major proportion of the local stock. The findings are difficult to interpret in the absence of systematic monitoring programs to establish In addition, detailed examinations were not normal mortality patterns. performed, and we are left with an association between oil and mortality as ephemeral as the vapors that dissipated into the atmosphere.

Closer to home, the relationship between oil and sirenian mortality is as obscure. During the winter of 1981 and 1982, three dead manatees were recovered near Jacksonville, FL, and one along the Little Manatee River which empties into Tampa Bay, FL (Table 10.1). The decomposed carcasses had tarlike material in the lower digestive tract (Anon 1981a, 1981b, 1981c, 1982). Additional findings included plastic in the stomach in one animal (Anon 1981c), and broken ribs associated with a superficial wound on the back of another (Anon 1981a). No laboratory analyses were performed to confirm the Table 10.1: Reports of manatees and dugongs associated with oil.

DATE	LOCATION & SOURCE	OIL TYPE & QUANTITY	SPECIES	ІМРАСТ	REFERENCE
		W -1 	· · · · · · · · · · · · · · · · · · ·		
Jan. 1981	San Carlos Creek Jacksonville, FL Unknown Source	Tar-like petroleum substance	West Indian manatee	Male found freshly dead; broken ribs, tar-like substance in caecum and large intestine.	Anon. 1981a
Feb. 1981	Jacksonville, FL Unknown Source	Tar-like petroleum substance	West Indian manatee	Body badly decomposed; tar-like substance in caecum and upper large intestine.	Anon. 1981)
March 1981	Jacksonville, FL Unknown Source	Tar-like petroleum substance	West Indian manatee	Badly decomposed; plastic and tar-like substance in stomach.	Anon. 1981c
Feb. 1982	Little Manatee River, FL	Tar-like petroleum	West Indian manatee	Contents of caecum and upper colon were black and smelled like tar.	Anon. 1982
Feb. 1983	Persian Gulf Well blowout	Crude oil est. 30x10 ⁶ gallons	Dugong	53 carcasses recovered over a 5 month period.	Anon. 1983

composition of the substance presumed to be petroleum. It would be frivolous to imply an association between oil and the deaths of these manatees.

Presumed Effects of Oil

With no real information, the analysis of potential risks is therefore limited to speculation based on an understanding of their life history and ecology. First, how would manatees react to oil? Would they be able to detect it, and if so, avoid it? Anatomical studies suggest that they have reasonable visual acuity (Cohen et al. 1982), though it is of little value to them in the murky waters they often inhabit. Their depth perception at close range is apparently poor, and they may bump their heads and eyes against objects in the water (Hartman 1979). They show no reluctance to surface and breathe in the midst of thick mats of floating vegetation (Hartman 1979), and perhaps would do so if the surface were covered with oil as well. They may have a reasonably good sense of smell, judging by the development of the olfactory bulb (Murie 1872, Chapman 1875, cited in Ronald et al. 1978). For reasons more basic than to understand the effects of oil, we need to improve our knowledge of sensory perception in sirenians.

Manatees concentrate their activities in relatively shallow water, and often rest at or just below the surface, behaviors that would bring them into contact with spilled oil. As in other marine mammal groups, we might presume that exposure to petroleum would irritate eyes and sensitive mucus membranes. Beyond this, we expect no unusual reactions in epidermis. Their pelage is limited to sparse sinus hairs which may have some role in cutaneous perception. Coating of these structures with oil would not likely result in significant impairment, to a degree that would overshadow the more realistic threat of irritated eyes and lungs.

Judging from their relatively non-selective feeding habits, it is not inconceivable that manatees might consume tar balls along with their normal diet. Despite the many opportunities for manatees to encounter tar, such occurrences are reported rarely (Anon. 1981a-c, 1982). From 1974 to 1978, at least 175 dead manatees were examined in Florida waters (Beck *et al.* 1978, Campbell and Irvine 1978, Odell and Reynolds 1979). Human activities, including those associated with motor boats and flood control dams, were frequently cited as causes of death, yet no mention was made of petroleum.

A manatee might also ingest fresh petroleum which some have suggested (Geraci and St. Aubin 1980, Reynolds 1980), might interfere with the secretory activity of their unique gastric glands or harm intestinal flora vital to digestion. Whether the long retention time of ingested vegetation in the gut would increase the extent of hydrocarbon absorption is another matter for speculation. Most of the volatile toxic fractions would be assimilated within a relatively short time, leaving the high molecular weight substances to pass in the feces. Perhaps these compounds would be degraded to more absorbable forms by a manatee's intestinal bacteria, thereby enhancing hydrocarbon uptake. The question is academic. There is no evidence that manatees would be peculiarly sensitive to small quantities of incidentally ingested petroleum.

Bartz and Verinder (1980) evaluated the potential threat of oil development activities to manatees along the Gulf of Mexico coast of Florida. They predicted no adverse effects, on the presumption that oil spilled offshore would not likely reach critical estuaries and embayments frequented by manatees. The authors voiced a greater concern over the projected increase in vessel traffic, which has a recognized impact. They and Brownell *et al.* (1978) mentioned the possibility that spilled oil might affect the quality or availability of aquatic vegetation, but offered that the effect would be too brief and localized to represent a significant threat (Bartz and Verinder 1980).

The need for manatees to occupy somewhat restricted habitats, places them in a potentially vulnerable position, particularly during winter. Oil spills or any other environmental perturbation within the confines of preferred river systems and canals would likely endanger the local population. Those able to escape such an area might be forced into colder waters, where thermal stress could complicate the effects of even brief exposure to oil. During summer, displacement would be less detrimental since manatees are accustomed to exploiting alternative feeding areas as they deplete local vegetation. This scenario is not one likely to be associated with offshore production or transportation of petroleum. The greater risk is from coastal accidents involving fuel barges or marina storage tanks. Yet their impact would be localized, and therefore could not endanger a large segment of the population.

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Literature Cited

Anon. 1981a. Manatee mortality. Smithsonian Inst. Sci. Event Alert Network (SEAN) Bull. 6 (1): 26.

Anon. 1981b. Dead manatee with ingested tar found. Smithsonian Inst. Sci. Event Alert Network (SEAN) Bull. 6 (2): 31.

Anon. 1981c. Dead manatee found with ingested tar and plastic. Smithsonian Inst. Sci. Event Alert Network (SEAN) Bull. 6 (3): 33.

Anon. 1982. Dead manatee with tar-like substance in caecum and upper colon. Smithsonian Inst. Sci. Event Alert Network (SEAN) Bull. 7 (3): 37.

Anon. 1983. Dugongs, other marine life victims of Gulf oil spill. World Wildl. Fund News No. 24 (July/Aug.).

- Bartz, M.R. and S.H. Verinder. 1980. OCS oil and gas proposed 1981 sales A66 and 66: draft environmental impact statement. Bureau of Land Management, New Orleans Outer Continental Shelf Office, New Orleans, LA. 169 pp.
- Beck, C., R.K. Bonde and D.K. odell. 1978. Manatee mortality in Florida during 1978. pp. 76-85. In The West Indian Manatee in Florida. R.L. Brownell, Jr. and K. Ralls (eds.). Proc. Workshop FL Audubon Soc., FL Dept. Nat. Res., Natl. Fish. Wildl. Lab., U.S. Fish Wildl. Serv., Sea World of Florida, Orlando, FL. 154 pp.
- Bertram, G.C.L. and C.K.R. Bertram. 1973. The modern Sirenia: their distribution and status. Biol. J. Linnean Soc. 5: 297-338.
- Best, R.C. 1981. Foods and feeding habits of wild and captive Sirenia. Mammal Rev. 11 (1): 3-29.
- Best, R.C. 1982. Seasonal breeding in the Amazonian manatee, <u>Trichechus</u> <u>inunguis</u> (Mammalia: Sirenia). Biotropica 14 (1): 76-78.
- Brownell, R.L., Jr., K. Ralls and R. Reeves. 1978. Report of the West Indian manatee workshop. pp. 3-16. In The West Indian Manatee in Florida. R.L. Brownell, Jr. and K. Ralls (eds.). Proc. Workshop FL Audubon Soc., FL Dept. Nat. Res., Natl. Fish Wildl. Lab., U.S. Fish Wildl. Serv., Sea World of Florida, Orlando, FL. 154 pp.
- Caldwell, D.K. and M.C. Caldwell. 1985. Manatees <u>Trichechus manatus</u>, <u>Trichechus senegalensis</u>, and <u>Trichechus inunguis</u>. pp. 33-66. In Handbook of Marine Mammals. Volume 3. Sirenians and Baleen Whales. S.H. Ridgway and R. Harrison (eds.). Academic Press, London, U.K.
- Campbell, H.W. and A.B. Irvine. 1978. Manatee mortality during the unusually cold winter of 1976-77. pp. 86-91. In The West Indian Manatee in Florida. R.L. Brownell, Jr. and K. Ralls (eds.). Proc. Workshop FL Audubon Soc., FL Dept. Nat. Res., Natl. Fish Wildl. Lab., U.S. Fish Wildl. Serv., Sea World of Florida, Orlando, FL. 154 pp.
- Cohen, J.L., G.S. Tucker and D.K. Odell. 1982. The photoreceptors of the West Indian manatee. J. Morphol. 173 (2): 197-202.
- Domning, D.P. 1982. Evolution of manatees: a speculative history. J. Paleontol. 56: 599-619.
- Food and Agriculture Organization (FAO). 1976. Mammals in the Seas. Small Cetaceans and Sirenians. Report of the Advisory Committee on Marine Resources Research. ACMRR/MM/SC/3. 96 pp.
- Gallivan, G.J. and R.C. Best. 1981. Metabolismo e respiracao do peixe-boi da Amazonia (<u>Trichechus</u> inunguis). Acta Amazonica 11 (4): 679-687.

Gallivan, G.J., R.C. Best and J.W. Kanwisher. 1983. Temperature regulation in the Amazonian manatee, <u>Trichechus</u> inunguis. Physiol. Zool. 56 (2): 255-262.

Geraci, J.R. and D.J. St. Aubin. 1980. Offshore petroleum resource development and marine mammals: a review and research recommendations. Mar. Fish. Rev. 42: 1-12.

Hartman, D.S. 1979. Ecology and behavior of the manatee (<u>Trichechus manatus</u>) in Florida. Spec. Publ. No. 5. Amer. Soc. Mammalogists. 153 pp.

Irvine, A.B. 1983. Manatee metabolism and its influence on distribution in Florida. Biol. Conserv. 25: 315-334.

Irvine, A.B. and H.W. Campbell. 1978. Aerial census of the West Indian manatee, <u>Trichechus manatus</u>, in the southeastern United States. pp. 17-21. In The West Indian Manatee in Florida. R.L. Brownell, Jr. and K. Ralls (eds.). Proc. Workshop FL Audubon Soc., FL Dept. Nat. Res., Natl. Fish Wildl. Lab., U.S. Fish Wildl. Serv., Sea World of Florida, Orlando, FL. 154 pp.

Irvine, A.B., D.K. Odell and H.W. Campbell. 1978. Manatee mortality in the southeastern United States from 1974 through 1977. pp. 67-75. In The West Indian Manatee in Florida. R.L. Brownell, Jr. and K. Ralls (eds.). Proc. Workshop FL Audubon Soc., FL Dept. Nat. Res., Natl., Fish Wildl. Lab., U.S. Fish Wildl. Serv., Sea World of Florida, Orlando, FL. 154 pp.

Marsh, H., G.E. Heinsohn and L.M. Marsh. 1984. Breeding cycle, life history and population dynamics of the dugong, <u>Dugong dugon</u> (Sirenia: Dugongidae). Aust. J. Zool. 32: 767-788.

- Miller, J. 1983. Persian Gulf nations worry as oil spill goes on unchecked. New York Times, Aug. 10.
- National Science Research Council, Guyana. 1974. An international centre for manatee research. Report. Workshop, Georgetown, Guyana. 34 pp.
- Odell, D.K. 1977. Age determination and biology of the manatee. Final Report. U.S. Fish Wildl. Serv., Washington, DC. Contract No. 14-16-0008-930. 124 pp.

Odell, D.K. and J.E. Reynolds. 1979. Observations on manatee mortality in south Florida. J. Wildl. Management 43 (2): 573-577.

Powell, J.A. and J.C. Waldron. 1978. The manatee population in Blue Spring, Volusia County, Florida. pp. 41-51. In The West Indian Manatee in Florida. R.L. Brownell, Jr. and K. Ralls (eds.). Proc. Workshop FL Audubon Soc., FL Dept. Nat. Res., Natl. Fish Wildl. Lab., U.S. Fish Wildl. Serv., Sea World of Florida, Orlando, FL. 154 pp.

Reynolds, J.E., III. 1978. Manatees of Blue Lagoon Lake, Miami, Florida: biology and effects of man's activities. pp. 25-32. In The West Indian Manatee in Florida. R.L. Brownell, Jr. and K. Ralls (eds.). Proc. Workshop FL Audubon Soc., FL Dept. Nat. Res., Natl. Fish Wildl. Lab., U.S. Fish Wildl. Serv., Sea World of Florida, Orlando, FL. 154 pp.

Reynolds, J.E., III. 1980. Aspects of the structural and functional anatomy of the gastrointestinal tract of the West Indian manatee, <u>Trichechus</u> <u>manatus</u>. Ph.D. Thesis, Univ. Miami, FL. 110 pp.

Reynolds, J.E., III. 1981. Behavior patterns in the West Indian manatee, with emphasis on feeding and diving. Florida Scientist 44 (4): 233-241.
Reynolds, J.E., III and J.C. Ferguson. 1984. Implications of the presence of manatees (<u>Trichechus manatus</u>) near the Dry Tortugas Islands. Florida Scientist 47 (3): 187-189. Ronald, K. L.J. Selley and E.C. Amoroso. 1978. Biological synopsis of the manatee. Int. Dev. Res. Center, Ottawa, Ont. 112 pp.

Rose, P.M. 1978. A preliminary report on the aerial census of the West Indian manatee, <u>Trichechus manatus</u>, in and around several "once-through cooling" power plant effluents; December-March 1977-78. pp. 22-. In The West Indian Manatee in Florida. R.L. Brownell, Jr. and K. Ralls (eds.). Proc. Workshop FL Audubon Soc., FL Dept. Nat. Res., Nat. Fish Wildl. Lab., U.S. Fish Wildl. Serv., Sea World of Florida, Orlando, FL. 154 pp.

Scholander, P.F. and L. Irving. 1941. Experimental investigations on the respiration and diving of the Florida manatee. J. Cellular Comp. Physiol. 17: 169-191.

Shane, S.H. 1984. Manatee use of power plant effluents in Brevard County, Florida. Florida Scientist 47 (3): 180-187.

CHAPTER 11

EFFECTS OF OIL

ON MARINE MAMMAL POPULATIONS:

RESULTS OF MODEL SIMULATIONS

J.M. Neff

Battelle Ocean Sciences 397 Washington Street Duxbury, Massachusetts 02332

Introduction

Over the last several years, a large number of computer models have been developed and evaluated to predict the trajectory and fate of oil spilled in the marine environment (Samuels *et al.* 1983). There have been many attempts to model the population dynamics and behavior of marine mammals (Swartzman 1984). Some attempts have been made to combine these two types of models to predict the risks and effects of oil-exposure to these species. Three examples of these oil spill/marine mammal risk analysis models will be discussed here. These are:

- "A Risk Analysis Model for Marine Mammals and Seabirds: A Southern California Bight Scenario" (Ford 1985);
- "Simulation Modeling of the Effects of Oil Spills on Population Dynamics of Northern Fur Seals" (Reed et al. 1986);
- "Computer Simulation of the Probability that Endangered Whales Will Interact with Oil Spills" (Reed et al. 1987).

Impact models are used to make quantitative predictions of the numbers of animals that might be adversely affected by a given spill incident. Such predictions are required by the National Environmental Policy Act (NEPA) as part of environmental impact statements. Impacts can be predicted by using laboratory and field observations of known responses or from extrapolation and regression analysis of historic data. These two approaches require extensive data on toxicity and behavior of oil spilled under different environmental conditions and on the natural history of the relevant species (Eberhardt 1987). Sufficient data usually are not available to make reliable predictions of impact by these means.

Therefore, a third method, involving simulation models, often is used. The apparent advantage of computer models compared to the other approaches is that the models always can produce output (predictions of impact). A variety of input parameters are required to make the model run. When the actual values are incompletely known or the processes being modeled are very complex, simplifying assumptions are made. Sensitivity analyses and comparisons of predictions with field data may be performed to evaluate these assumptions. However, the model always represents a greatly simplified approximation of the real world. When models include elements that are naturally highly variable and difficult to predict precisely (e.g. wind and temperature regimes, or small-scale whale movements), the models will generate plausible predictions even if some of the simplifying assumptions are inaccurate or incomplete. The problems of reliability of model predictions are compounded when several different models are linked together so that output of one model is used as input to another, and so forth. Errors in the first model will be propagated and perhaps magnified in subsequent models.

Oil spill/marine mammal impact models are intended to make predictions of the impact of oil spills at different times and places on populations of marine mammals, and the time required for recovery of the affected populations following a spill. Such "information" may be used as part of cost/benefit and risk analyses related to proposed offshore oil and gas activities. It may be used to make management decisions about exploration and production practices and spill cleanup strategies. Such uses of model predictions must be done with great caution and with an understanding of the limitations of the models.

Modeling can and should play a major role in identifying data gaps (Eberhardt 1987). In developing a model, it is necessary to look closely at available data and to determine the need for additional data. Steps can then be taken to obtain those data.

Risk Analysis for Marine Mammals in the Southern California Bight

Three computer simulation models were linked to provide a method to describe quantitatively the risks of oil spills to marine mammals and birds (Ford 1985). These models are the Oil Spill Risk Assessment Model (OSRAM), the Short Term Oil Response Model (STORM), and the Oil Spill Population Response Model (OSPREY) (Figure 11.1).

OSRAM is an oil spill trajectory model maintained by the Minerals Management Service. It is used in part to estimate the probability that a spill will occur at a given location and that it will contact a specified target region (Lanfear *et al.* 1979). In the context of this risk analysis, OSRAM was used to generate trajectories and sizes of oil slicks originating from groups of existing leases and potential crude oil transport routes in the Southern California Bight. STORM predicts the mortality incurred by a population of marine mammals as a result of an oil spill. Its primary purpose is to estimate the fraction of the population that would die as a result of a specified oil spill scenario. OSPREY was used to assess the potential longterm effects of oil-spill-mediated mortality on population size and recovery rate.

The marine mammal populations for which risk assessment was attempted were the northern fur seal, the northern elephant seal, the California sea lion, and the common dolphin. The study area for the analysis was the Southern California Bight, defined here as the body of water lying between the Southern California mainland to the east, the California Current to the west, Point Conception to the north, and the Mexican border to the south (Figure 11.2).

Model Structure

Detailed descriptions of OSRAM are provided by Lanfear *et al.* (1979), Lanfear and Samuels (1981), and Smith *et al.* (1982); only a brief description is given here. OSRAM uses wind and current data to simulate the possible



Figure 11.1

Flow diagram showing the relationship among the three models used in the analysis of risks to marine mammals of oil spills in the Southern California Bight.



FIGURE 11.2.

MAP OF THE SOUTHERN CALIFORNIA BIGHT, SHOWING LOCATIONS OF PRINCIPAL FEATURES, PLATFORM SITES (P), AND TRANSPORT ROUTES (T) USED IN THE MODEL. trajectory of the center of an oil slick, given its source and the time of year. The model is stochastic, reflecting the extreme variability of typical wind patterns. Thus, no two simulated trajectories are identical. The standard version of OSRAM was extended to incorporate a submodel to simulate the radius of the slick and slick weathering. This modification was based on the model of Mackay *et al.* (1980). The volume of a spill was selected randomly from a lognormal distribution of spill volumes from oil production platforms, pipelines, and oil tankers, based on historic spill volume statistics (Lanfear and Armstrong 1983).

Spill trajectories were modeled for each of four seasons. Each spill was simulated from one of 14 production platform sites or from one of 14 segments of transportation (tanker or pipeline) routes in the study area Platform sites were considered to be points; transport (Figure 11.2). segments were considered to be lines with equal probability of a spill occurring at any location along the line. Locations of platform sites, pipelines, and transport routes were based on groups of existing leased tracts on the outer continental shelf off southern and central California (LaBelle et al. 1983a). For each of the 28 possible spill sites and each of the four seasons, 100 oil spill simulations were carried out. The output of each OSRAM simulation described the latitude and longitude of the center of the simulated oil slick and its radius at 3-hour time intervals. A simulation was terminated when (1) the center of the slick struck land, (2) the slick had weathered to 1 percent of its original volume, or (3) 30 days had elapsed from the time of the spill.

It was also necessary to estimate the probability of spills of different sizes occurring at a given location. These probabilities were based on the production at a given platform site, or the volume of oil transported along a particular tanker or pipeline route. Estimates of the volumes of oil produced, transported, and spilled were based on a preliminary version of the scenario of LaBelle *et al.* (1983a). It was assumed that the lifetime of a field will be 25 years and that spill rates would be the same as the historic rates of spills from platforms, tankers, and pipelines (Lanfear and Armstrong 1983).

The output of OSRAM for a large number of spill trajectories from a particular location was then plotted as a contour map of index values representing the time after the spill that oil was present in a given region of the southern California Bight. A region with a two-fold index will be twice as likely to contain a slick from the specified source, and therefore, animals utilizing that area will be twice as likely to encounter the slick.

Using this output from OSRAM, STORM estimates the number of animals that would contact the slick and subsequently die. Although it was recognized that the potential outcome of an encounter between a marine mammal and an oil slick is complex, for simplicity's sake, only two outcomes were modeled: animals either survived unimpaired or died. Their fate was determined by three factors. (1) Does the individual or group of individuals encounter a slick? (2) Avoid it? (3) If not, will the encounter prove fatal? In essence, it was assumed that if a marine mammal became oiled, it died. As discussed elsewhere in this volume, direct contact between most species of marine mammals and oil in the field only rarely leads to mortality. Certain species and life-stages are more vulnerable than others. Nevertheless, use of this worst-case contact/effects scenario does not greatly affect the outcome of the modeling. Sensitivity analysis of the model revealed that variation due to stochastic and time/trajectory variables were most important in determining the predicted portion of the population affected by the simulated spill. The most important factors in the model are the time of the year, the timing of the stages in the life cycle of the population being modeled, and the size and trajectory of the oil spill. In other words, the outcome of a model run depends primarily on whether the animals and oil happen to be in the same place at the same time.

The OSPREY model then predicts the long-term effects of the oil-related mortality (predicted by STORM) on the size of the affected population. OSPREY uses estimates of the mean and variance in age-specific annual fecundity and survival, including age-related mortality, to project population size and structure from year to year under natural conditions. Each OSPREY simulation consisted of three phases. First, the population was projected from current levels through to the life of the field, assuming no oil spill-related mortality. The population size and structure were then reset to the predevelopment values and projected for the life of the field, to include mortality due to oil spills. Finally, the population was projected further under natural conditions without additional spill-related mortality until recovery was achieved. That is, when the size of the population reached the level it would have attained at the end of the life of the field if there had been no spill-related mortality.

Model Results

Northern Fur Seals: There are two northern fur seal rookeries on San Miguel Island in the Southern California Bight: Castle Rock and Adams Cove. Strips of nearshore water 500 m wide adjacent to these two rookeries were treated as targets for oil spills. Pupping takes place in June and July, and females and pups remain in the rookeries for about 10 weeks. Fur seals are rarely encountered at sea in the Southern California Bight from May through December. Between January and April, northern fur seals are abundant in the eastern part of the Southern California Bight. Most are solitary during this time.

Northern fur seals in the study area are potentially vulnerable at sea during January through April and on the rookeries during May through December. The estimated probability of a spill resulting in greater than 1 percent mortality ranges from 26.9 percent for adult males to 32.7 percent for pups. The probability of a spill causing greater than 15 percent mortality is 7.7 percent for females and immature animals and 5.8 percent for adult males. There is a 5.8 percent chance that a spill during the life of the field will cause a 40-50 percent mortality of young of the year. Because of the seasonal nature of the distribution and behavior of northern fur seals in the Southern California Bight, oil spill impacts will vary strongly with time of year. For all three age/sex classes, the greatest mortality resulted when simulated spills in the Santa Maria Basin and western Santa Barbara Channel came ashore at the Castle Rock rookery in June. The estimated probability of a spill coming ashore at Castle Rock in June is 0.3 percent.

Three levels of probability of oil-spill-related mortality for the whole Southern California Bight population of northern fur seals were assessed. These three levels are (1) Conceivable but very unlikely. Worst case encountered. This was the maximum damage predicted by any model simulation. Its occurrence is highly unlikely. (2) Improbable, but likely enough to be considered seriously. The 95 percent worst case. This level of damage was predicted by the model only 5 percent of the time. (3) Likely to happen. The 50 percent worst case. This level of damage or less was predicted 50 percent of the time.

The results of these risk estimates are summarized in Table 11.1. There is a large difference between the worst case encountered and the 50 percent worst case for mortality of northern fur seals due to an oil spill. This difference is due to the slight possibility of a spill contacting a rookery during the pupping season.

Based on the most likely values of STORM input parameters, the predicted reduction in the size of the northern fur seal population in the Southern California Bight as a result of oil spills is 2.2 percent. With other STORM input parameters, the estimated reduction in population size ranges from 1.0 to 3.7 percent.

OSPREY analysis predicts that 1 year will be required for the northern fur seal population of the Southern California Bight to recover following the most likely spill scenarios. Under worst-case conditions, no more than 4 years would be required for recovery.

Northern Elephant Seals: While in the Southern California Bight, northern elephant seals spend at least 95 percent of the time on shore at their haulout grounds. The seasonal haul-out patterns differ for different age/sex classes. Because of this, the population was divided into three categories for the model: adult males, adult females and juveniles, and pups. As onshore oil spill targets, their rookeries on San Nicolas Island, the north shore coves of Santa Barbara Island, and Point Bennett, Adams Cove, and Tyler Bight on San Miguel Island were chosen. These targets applied only to the pups because it was considered highly unlikely that an adult or juvenile encountering an oil slick on the shore would die.

The predicted risk of oil spills to the elephant seals was very small. This was due to the fact that they spend a very small percent of their time in the Southern California Bight at sea, and they appear to be quite insensitive to oiling. The estimated probability was 0.0 percent that one or
Table 11.1: Largest simulated mortality (worst case mortality) due to a single spill during the life of the fiels for three levels of probability (Ford 1985).

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Species	50% Worst Case	95% Worst Case	Worst Case Encountered
Northern Fur Seal	0.9	18.9	23.0
Northern Elephant Seal	0.0	0.0	0.0
California Sea Lion	0.9	3.5	7.4

more spills would kill 1 percent or more of the population of immature animals or adult males and females. The pups are slightly vulnerable. There was a 1.2 percent chance that one or more spills would kill at least 1 percent of pups. Thus, the worst-case mortality predicted for the elephant seal population is 0.0 percent (Table 11.1). The population is growing at a rate of approximately 13 percent per year; oil spills were predicted to have no effect on this rate.

California Sea Lions: California sea lions are widely distributed and abundant (population size in excess of 70,000) for much of the year in inshore waters of the Southern California Bight. Rookeries are located on San Miguel, San Nicolas, Santa Barbara, and San Clemente Islands. Onshore targets for oil spills were specified for each of these rookeries. California sea lions are most common in the Bight during June through July when pupping occurs.

Three age/sex classes for the model were defined based on abundance and distribution patterns: females and immature animals, adult males, and pups. The risk of oil spills to California sea lions is not large. The chance of one or more spills resulting in greater than 1 percent mortality ranged from 11.7 percent for adult males to 35.6 percent for pups.

For females and immature animals, predicted highest mortality from a spill was 7.4 percent. This predicted mortality resulted when a transportation-related spill in the Santa Barbara Channel came ashore at the rookeries on San Miguel Island during the breeding season in June. The worst-case scenario for adult males was a transport-related January spill that persisted for a month on Cortez Banks. Such a spill resulted in a predicted mortality of 5.2 percent among adult males. The model predicted a 14.2 percent mortality of pups as a result of a transport-related spill south of Santa Cruz Island in July. The spill moved south and came ashore at the San Nicolas rookery within 9 days. The largest simulated spill-related mortality for the California sea lion population as a whole ranged from 0.9 percent for the 50 percent worst-case situation to 7.4 percent for the worst case encountered (Table 11.1). Oil spill risks to the California sea lion population in the Southern California Bight do not show strong seasonal or geographic components because the distribution of this species in the Bight is relatively uniform throughout the year.

An annual growth rate of 7.3 percent per year was used for estimating the recovery rate of the California sea lion population in the Southern California Bight. With the most likely values for STORM input parameters, the expected reduction in that population due to oil spills is 1.2 percent. Using different values for STORM input parameters, the maximum expected mortality ranged from 0.0 to 4.0 percent. The most likely time required for the sea lion population to recover from oil spills was 1 year. The highest estimate was 3 years. **Common Dolphin:** Common dolphins are most widespread in the Southern California Bight from June through September, when they extend from the southern boundary to the Channel islands. In the fall, the distribution is patchy, with concentrations of dolphins in the vicinity of San Nicolas and San Miguel Islands. In the winter and early spring, common dolphins are restricted to the southern portion of the Bight.

Because there are no data to indicate the level of contact with oil required to cause mortality, only the risk of contact with oil by common dolphins was modeled. There was a 27.2 percent chance that one or more oil spills during the life of the field would result in contact by more than 1 percent of the common dolphins in the Southern California Bight. The worstcase scenario resulted in 24.6 percent of the common dolphin population coming in contact with a spill. The spill originated from a platform located between Santa Catalina Island and Long Beach. The spill remained in the area for most of October without coming ashore. At its maximum extent, it covered an area of 52.8 km2 during a time when the number of common dolphins in the Bight was at a peak.

Common dolphins in summer were at greatest risk of contacting oil. Risk was lowest in winter. Areas where the greatest amount of contact is likely to occur are on the inner and outer banks.

Model of Effects of Oil Spills on Northern Fur Seals in the Bering Sea

Two models were linked to predict the possible effects of a large oil spill on the Pribilof Islands herd of northern fur seals (Reed *et al.* 1986) (Figure 11.3). The first model was a generic oil spill trajectory and weathering model. The second was a northern fur seal population dynamics model developed specifically for the project. This model was designed to simulate population dynamics and movement patterns of northern fur seals in the Bering Sea.

The simulation was of two hypothetical oil spills of 10,000 barrels each (1,590,000 L). The first was near Unimak Pass while seals were entering the Bering Sea from the Gulf of Alaska in the spring; the second was near the southern coast of Saint Paul Island in mid-July when the largest number of seals occupy rookeries (Figure 11.4). These spill simulations were selected to occur under temporal and spatial conditions that maximize the likelihood of contact between the seals and the spilled oil. Therefore, they should be considered extreme worst-case scenarios.

Model Structure

The oil spill trajectory and weathering model was based on one developed by Reed (1980) to simulate the interaction between spilled oil and fishery species (Spaulding *et al.* 1982, Applied Science Associates, Inc. 1986). The oil spill model was run independently of the seal population dynamics model



Figure 11.3

Schematic of linkages for fur seal - oil spill interaction model system.



FIGURE 11.4.

LOCATIONS OF HYPOTHETICAL SPILLS AFFECTING NORTHERN FUR SEALS (ARROWS) AND WHALES (NUMBERED THE SYMBOLS). NUMBERS REFER TO THE SITES OF SIMULATED SPILLS IN EACH OF FOUR OCS PLANNING AREAS.

and was used to generate simulations of spill size and movements at fixed time intervals. The output of the spill model then was used as input to the population dynamics model. As the seal migration proceeded, the position of each group of animals was monitored continuously. To determine the number of seal-oil interactions resulting from a specific spill, the new position of a seal group at the end of each time step was checked relative to the simulated oil distributions and movements.

Two hypothetical oil spill scenarios were used. The probability of these spills occurring at the times and locations specified while fur seals are present is less than 0.02. The simulated spills took place at Unimak Pass and south of Saint Paul Island in the southern Bering Sea. Each spill involved 10,000 barrels of Prudhoe Bay crude oil spilled over 12 hours and followed for a 10-day period. Each spill was divided into five smaller spills of 2000 barrels each.

The spill trajectory model took into consideration the rate of evaporation of oil based on wind speed, temperature, and slick area (Mackay *et al.* 1980, Payne *et al.* 1984). The spread of the slick and its dispersion into the water column were computed based on slick area and thickness, as well as wind speed (Mackay *et al.* 1980). The horizontal transport of oil was computed by the hydrodynamic and wind/weather models of Applied Science Associates, Inc. (1986).

The fur seal population dynamics model simulated patterns and movements of specific groups of seals in the southern Bering Sea. The groups were differentiated by sex, sexual status, and age, as they feed, reproduce, and migrate in space and time. Individual points, each representing a number of seals with similar characteristics, were used to track seal locations. The number of points used to represent the population was large enough that the modeled distribution was not significantly different from observations made in the wild. The status of a seal group (point) was defined by the following parameters: age in days, sex, reproductive status (immature, mature, pregnant, lactating, territory-holding, non-breeding), on land or at sea, oiled or not oiled. A location (latitude and longitude) was associated with each group of seals, and seals moved in accordance with a time-dependent migration model and feeding cycles within the Bering Sea that were dependent on age, and sexual and breeding status.

The fur seal population dynamics model was based on data on the natural history of the northern fur seals in the southern Bering Sea (Reed *et al.* 1986). The model assumed that if a pregnant or lactating seal died due to oiling, her pup died also. Because the fur seal population in the Bering Sea is not nutrient-limited, possible effects of oil spills on food availability were not considered.

There is no information on mortality rates of fur seals as a result of oiling. Therefore, a range of assumed mortality rates was simulated: 25, 50, 75, and 100 percent. Seals that were oiled but did not die were assumed to recover completely and to be no more or less sensitive to subsequent oilings.

Thus, if a 50 percent mortality rate was assumed and the seal group encountered a spill twice, the net mortality of that group would have been 75 percent (half the survivors of a 50 percent kill).

The simulated July oil spill impacting Saint Paul Island was divided into two components, one coming ashore within 48 hours of the spill, and the other coming ashore after about 60 hours of weathering. The June spill simulated near Unimak Pass did not come ashore.

Two population levels of fur seals were used in the simulations: an equilibrium population value of 1.16 million individuals, and a 1986 estimated population of 693 thousand animals. The equilibrium population size was based on the predictions of the population model in the absence of oiling and is similar to the estimated population size in 1979 (Lander 1980, 1981). The 1986 population size reflects primarily the decline in the fur seal population, apparently due to entanglement in fishing net fragments (Swartzman 1984, Fowler 1985).

Model Results

The Unimak Pass simulated oil spill resulted in oiling of 0.05 percent of the males and 3.7 percent of the females in the population. Because the simulated spill occurred during the peak migration of pregnant females to the rookeries, 94 percent of the seals oiled were females. Based on an equilibrium population size of 1.16 million, the mean total number of seals oiled in eight runs of the model was 29,364. Using the 1986 population size of 693 thousand, the number of seals oiled was proportionately less. In this spill scenario, seals were migrating through the pass, and so were assumed to be oiled only once.

Depending on the fraction of oiled seals assumed to die and the population size used, the total predicted seal mortality resulting from the simulated 10,000-barrel oil spill in Unimak Pass ranged from 4334 to 12,330 individuals (Table 11.2).

Two scenarios were considered for contact between seals and oil in the Saint Paul Island spill. In the first, seals on adjacent rookeries were oiled; in the second, seals on the rookeries were not oiled. The spill resulted in the oiling of a larger total number of seals than the Unimak Pass spill. In addition, the proportion of males and females oiled was similar (60 percent of oiled seals were females). If seals on the rookeries were oiled, then 6.2 percent of the females and 6.4 percent of the males in the population were oiled. If the seals on the rookeries were not oiled, 4.0 percent of the females and 5.3 percent of the males in the population were oiled.

In this simulated spill, some of the seal groups were assumed to be oiled more than once as they moved onto or off of the rookery. If seals on the rookery were oiled, the number of mortalities due to oiling varied from 24,610 to 73,948, depending on the simulated population size and the assumed Table 11.2. Numbers of seals oiled and subsequently dying as a result of oiling in simulated oil spills near Unimak Pass and Saint Paul Island assuming different percent mortalities for oiled seals (from Reed et al. 1986).

	% Mortality Once Oiled		St. Paul			
Initial Population		Unimak Pass	(Oiled on Rookeries)	(Not Oiled on Rookeries		
		Females Males	Females Males	Females Males		
	······································					
Equilibrium	100	27,354 1,976	43,440 30,508	29,530 22,123		
1.16 million	75	19,769 1,515	37,190 23,496	25,004 14,519		
	50	13,245 1,010	29,090 18,579	18,114 10,254		
	25	6,655 505	18,825 12,773	9,930 5,448		
· .						
1986 Population	100	16,859 868	26,237 18,905	19,906 12,973		
693 thousand	75	11,957 1,007	26,315 17,208	16,682 9,269		
	50	7,974 682	22,097 13,564	12,258 6,777		
	25	3,988 346	15,638 8972	6,821 3,782		
· · ·	5 5					

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percentage of oiled seals that died (Table 11.2). In the scenario in which sealson the rookery were not oiled, the corresponding range of mortalities was 10,603 to 51,653.

The number of seals oiled in the 1986 population simulations was approximately 63 percent of the number oiled in the equilibrium population simulations. Thus, the number of seals oiled by a given spill simulation is approximately proportional to the simulated population size.

The percentage of the equilibrium population of 1.16 million not affected by spilled oil that dies from natural causes each year is 16 and 29 percent for females and males, respectively. The estimated annual mortality rate of the 1986 population due to natural causes plus entanglement is 18 and 32 percent for females and males, respectively. By comparison, the simulated spills were predicted to kill up to 6 percent of the population, approximately one-sixth of which would have died anyway of natural causes by the end of the year.

Recovery time for the oil-impacted fur seal populations was also predicted, and was defined as the time from the spill until the difference in the size of the oil-impacted and non-affected seal populations became less than a specified percentage of the non-affected population size. The percent differences used were 0.1 and 1.0 percent, reflecting estimated complete recovery, and measurable recovery, respectively.

Recovery to the 0.1 percent level of the equilibrium population affected by oil required 40 to 50 years; recovery to the 1 percent level required about 20 years. The smallest predicted impact, involving death of about 12,000 seals, required about 5 years for recovery to the 1 percent difference level. In all cases, recovery was very rapid immediately after the spill, and then recovery rate slowed as the size of the affected population approached that of the unaffected population. In all simulations with the 1986 population, the effects of entanglement mortality were much greater than those of oilspill-mediated mortality on the fur seal population.

Model of Interaction of Oil Spills with Bowhead and Gray Whales in Alaskan Waters

An oil trajectory model, migration models, for bowhead and gray whales, and a diving-surfacing behavior model were linked (Figure 11.5) to simulate contact between potential oil spills and these species in Alaskan waters (Reed and Jayko 1986, Reed *et al.* 1987). The spill trajectory model was used to generate a number of possible trajectories for a given oil spill at different times and under different environmental conditions. Migrations of each species of whale were then simulated under the same environmental conditions as those used for the spill scenario, to predict the probable percent of the population that encountered oil and the amount of time spent in contact with the spill. The estimated time-in-oil was converted to the number of surfacings in oil for each whale by the diving-surfacing model. The final



Figure 11.5

Schematic of linkages for the whale - oil spill interaction model system

model output described the percentage of each population encountering oil spilled from a specific site, and the probable number of interactions with the oil for those whales passing through the oil slick.

Model Structure

The oil spill trajectory model is similar to that used by Reed et al. (1986) to simulate effects of oil spills on northern fur seals. Input parameters covered a wider range of times and environmental conditions than in the former application (Applied Science Associates 1985, Applied Science Associates and Hubbs Marine Research Institute 1985a). For each of five spill sites in the Navarin Basin, Saint George Basin, Chukchi Sea, and Beaufort Sea, 25 spill trajectories were generated for one or more seasons, varying the environmental conditions at the time of the spill for a total of 500 simulations. For each scenario, the release date was selected randomly and the wind field was selected from a different year of the historical wind record. Ice conditions were varied from heavy to light, with 25 percent of the scenarios run under heavy and 25 percent run under light ice conditions, and the remaining 50 percent run under average ice conditions. Predicted locations of the ice edge were taken from field observations of seasonal ice distribution under different ice conditions (LaBelle et al. 1983b).

Spill scenarios were run for 10 days after the last release of oil, allowing time for slick movement and weathering. When the model indicated that oil was trapped in or under ice, conditions slowing or preventing weathering, the spill was allowed to weather for a period of 10 ice-free days.

The whale migration models were based on whale sighting data for each species for all years for which sighting data were available. These data were used to define mean migration pathways. Mean speeds of migration were calculated by dividing the distances traveled in three to six months by the travel time. Simulated mean migration speeds and whale densities were compared to estimates from field observations at different times and locations, and values were adjusted to calibrate the model. The distribution of whales in space and time was represented by discrete points, each of which may represent one or more animals. The movement of a whale point was governed by a random walk algorithm that stochastically followed the migratory pathway. Bowhead and gray whale movements were simulated for each spill scenario to determine whether any whales encounter the oil, and if so, the amount of time spent in contact with it. Simulated whale migrations were begun on the first day of the month preceding the months in which the spill occurred. The migration model was run until the end of the oil spill, and spill statistics were entered into the model through the life of the spill. After 3 and 10 days of oil movement in ice-free water, the cumulative time-in-oil of each whale was recorded.

The diving-surfacing model then was used to convert the time-in-oil of each representative group of whales to an actual number of surfacings in an oil slick (Hubbs Marine Research Institute 1985). This was repeated for each group of whales and each spill scenario. No effects were inferred to result from encounters between whales and oil.

Five sites in the Saint George Basin, Navarin Basin, Chukchi Sea, and Beaufort Sea were chosen for simulated spill sites (Figure 11.4). Spill times were simulated in all months and spill volumes were 10,000 or 100,000 barrels. Twenty-five spill trajectories were generated for each spill site.

Model Results

For the spill sites in the Navarin Basin, period of each spill, and weather scenarios for which spills were simulated, only bowhead whales contacted spilled oil (Table 11.3). This species encountered oil following spills at two sites. Although whales were "present" at each of the other spill sites, simulated environmental conditions dispersed the oil before it contacted the whales. About 1 percent of the bowhead whale population overwintering near Saint Matthew Island encountered oil spilled from site No. 1 between February and May. Less than 0.1 percent of the bowhead whale population encountered oil spilled from site 4 over the same time period. During the simulated spills from Site No. 1, 0.7 percent of the bowhead whales surfaced between 1 and 100 times in oil and 0.3 percent of the population surfaced between 101 and 400 times in the oil. Only the portion of the bowhead whale population that wintered around Saint Matthew Island was at risk of coming in contact with the spill. Although the 25 simulations did not result in any contacts between gray whales and oil, this species does occur periodically in the Navarin Basin and could contact oil spilled there. These low estimates of encounters between whales and oil reflect the limited use of the Navarin Basin by these species.

Bowhead whales migrate through the Alaskan Beaufort Sea twice each year. During April through June, depending on ice conditions, they move east toward the summer feeding grounds off the MacKenzie River Delta; during September and October, they migrate back to the Bering Sea. Gray whales rarely move east of Point Barrow in the Beaufort Sea, but some feed during the summer in the eastern Chukchi Sea.

For each of the five spill sites modeled, between 0.1 and 1.9 percent of the bowhead whale population encountered oil (Table 11.3). Simulated spills during the spring at site No. 5 contacted fewer whales than spills at the other four sites in the spring and summer. Nearly all simulated encounters with oil were brief and only 0.2 and 0.3 percent of the population surfaced in oil more than 100 times during spills at Sites No. 1 and 4, respectively, during August through October.

There were a few encounters between gray whales and simulated oil spills in the Beaufort Sea (Table 11.3). The maximum number of encounters (0.2 percent of the population) occurred following a simulated spill at Site No. 5 (the westernmost site in the Beaufort Sea) in the late summer. The whales that encountered oil were in the eastern Chukchi Sea.

Table 11.3: Number of simulated spills (of 25 for each spill site) resulting in encounters between oil and whales and percent of the whole population encountering oil within ten days of the simulated spills on the Alaskan continental shelf.

Spill Site	Season	No. of (of 25 Sce Bowhead	Encounters enarios/Site) Gray	<pre>% of Population Encountering Oil Bowhead Gray</pre>	
Navarin Basin		·.		· · ·	
1	Febl - Mav31	19	0	1.0	0
2	Mayl - Nov30	0	Ō	0	0
3	Mayl - Nov30	0	0	0	0
4	Febl - May31	1	0	+	. 0
5	Mayl - Oct31	0	0	0	0
Beaufort Sea					
1	Augl - Oct31	15	0	1.9	0
2	Apr $1 - Jun 30$	10	· · · 1	0.4	+
2	Aug1 - Oct31	15	0	1.9	0
3	Augl - Oct31	11	0	1.3	0
4	Aug1 - Oct31	13	at 0	1.4	0
5	Apr1 - Jun30	5	1	0.1	+
5	Aug1 - Oct31	9	5	0.6	0.2
Chukchi Sea					
1	Apr1 - Jun1	5	0	0.1	0
1	Jun30 - Oct31	. 7	7	0.5	0.5
2	Augl - Oct31	3	0	0.1	0
3	Marl - Junl	9	3	0.4	0.1
3	Junl - Oct31	0	7	0	0.6
4	Jun1 - Oct31	4	12	0.1	0.5
5	Junl - Oct31	0	16	0	0.8
5	Oct2 - Jan30	1	6	+	0.2
St. George Ba	sin				•
1	Marl - Jun30	0	12	0	1.5
1	Augl - Dec31	· · · · · O	6	0	1.3
2	May1 - Oct31	0	0	0	0
3	May1 - Oct31	0	0	0	0
4	Mayl - Oct31	0	0	0	0
4	Novl - May31	0	0	0	0
5	Apr1 - Nov30	0	0	0	· 0

+, a value greater than 0.0 but less than 0.1 percent.

Bowhead whales are in the Chukchi Sea for a short time in the spring and autumn during their annual migrations between the Bering Sea and Canadian Beaufort Sea. Gray whales feed in the Chukchi Sea from July through October. The migration model predicted that approximately 20 percent of the gray whale population feed along the Alaskan coast of the Chukchi Sea during summer.

Approximately 0.5 percent of the bowhead whale population encountered oil during summer spills at Site No. 1 and spring spills at Site No. 3 in the Chukchi Sea (Table 11.3). Spills at the other three sites also resulted in some encounters; all were brief, with only a few instances of greater than 100 surfacings in oil by a whale.

All simulated oil spills in the Chukchi Sea, except a spring spill at Site No. 1 and a spill at Site No. 2 in the autumn, resulted in contacts between gray whales and oil (Table 11.3). Summer spills at Site No. 5 resulted in encounters with oil by 0.8 percent of the gray whale population. Summer spills at Sites No., 1, 3, and 4 resulted in oil encounters by 0.5 to 0.6 percent of the population.

The Saint George Basin is south of the normal distribution range of bowhead whales and this species is rarely encountered there, except possibly during heavy ice years. Virtually the entire gray whale population passes through Unimak Pass in April through early June during the northward migration and again in November and December during the southward migration.

There were no predicted encounters between bowhead whales and simulated oil spills in the Saint George Basin (Table 11.3). Gray whales encountered oil during simulated oil spills at Site No. 1 in the spring and late fall. A late fall/early winter spill in Unimak Pass (Site No. 1) resulted in a predicted encounter with oil by 1.3 percent of the gray whale population. An estimated 1.5 percent of the gray whale population encountered oil during a spring spill at Unimak Pass. A few of these encounters lasted long enough for the whales to surface more than 300 times in oil. No gray whales encountered oil during spills at the other four Saint George Basin sites.

If the results of the modeling of encounters between spilled oil and bowhead or gray whales are combined with estimates of the probability of oil spills in the Beaufort Sea from all sources, based on expected recoverable oil reserves in the area and typical spill rates (Minerals Management Service 1985), it is possible to estimate the total probability of whales encountering oil during the 30 to 40 year life of this oil field. There is a total probability of 51.8 percent that at least one bowhead whale will contact spilled oil due to oil development in the Beaufort Sea. There is a 6.3 percent probability that at least one gray whale will encounter oil resulting from a spill in the Bering Sea.

Summary

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These modeling efforts indicate the possible frequency with which marine mammals will encounter oil under different spill conditions. A fractional mortality of the oil-impacted pinnipeds, but not cetaceans, was inferred. These inferred mortalities provided the basis for predicting the impacts of oil on different pinniped populations, and the time required for the population to recover. Limited data from field observations (see St. Aubin, Chapter 3) indicate that the simulated mortalities due to contact with spilled oil probably are gross overestimatesThe models predict that pinniped mortalities due to encounters with oil spills range from 0 to 34 percent of the populations. If mortality is significant, time required for recovery ranges from 1 to about 50 years. Pinnipeds are most vulnerable when they are massed on rookeries for pupping. In the few simulations involving cetaceans, instances in which whales and dolphins encountered the oil were rare and restricted to small fractions of the populations. No effects of such encounters were inferred. Effects are likely to be minimal unless the contact with oil is extensive and repeated.

Literature Cited

- Applied Science Associates, Inc. 1985. Oil spill trajectory model description and example applications in the Bering, Chukchi, and Beaufort Seas. Interim Phase II Report. U.S. Dept. of the Interior, Minerals Management Serv., Alaska OCS Region, Anchorage, AK. Contract No. 14-12-001-30076.
- Applied Science Associates, Inc. 1986. Ocean circulation and oil spill trajectory simulations for Alaskan waters: Spill trajectory simulations for Shumagin oil and gas lease sale No. 86. NOAA/OAD Contract No. WASV 85-00099.
- Applied Science Associates, Inc. and Hubbs Marine Research Institute. 1985a. Linkage of bowhead and gray whale migration models and oil spill trajectory model. Interim Phase II Report. U.S. Dept. of the Interior, Minerals Management Serv., Alaska OCS Region, Anchorage, AK. Contract No. 14-12-0001-30076.
- Applied Science Associates, Inc. and Hubbs Marine Research Institute. 1985b. Bowhead and gray whale migration models. Interim Phase II Report. U.S. Dept. of the Interior, Minerals Management Serv., Alaska OCS Region, Anchorage, AK. Contract No. 14-12-0001-30076.
- Ford, R.G. 1985. A risk analysis model for marine mammals and seabirds: A Southern California Bight scenario. Report. U.S. Dept. of the Interior, Minerals Management Serv., Pacific OCS Region, Los Angeles, CA. OCS Study MMS 85-0104. 236 pp.
- Fowler, C.W. 1985. An evaluation of the role of entanglement in the population dynamics of northern fur seals on the Pribilof Islands. In Proc. Workshop on the Fate and Impact of Marine Debris. R.S. Shomura and H.O. Yoshida (eds). Nat. Oceanic and Atmospheric Admin. Technical Memo. Nat. Mar. Fish. Serv., NOAA-TM-NMFS-SWFC-54.
- Hubbs Marine Research Institute. 1985. An analysis and model for the surfacing behavior of gray and bowhead whales. Interim Phase II Report. U.S. Dept. of the Interior, Minerals Management Serv., Alaska OCS Region, Anchorage, AK. Contract No. 14-12-0001-30076.
- LaBelle, R.P., K.J. Lanfear, A.D. Banks and R.M. Karpas. 1983a. An oil spill risk analysis for the Southern California Lease Offering (February 1984). Minerals Management Serv. Environ. Modeling Group. U.S. Geological Survey. Open File Report 83-563. 115 pp.
- LaBelle, J.D., J.L. Wise, R.P. Voelkner, R.H. Schultze and G.M. Wohl. 1983b. Alaska Marine Ice Atlas. Arctic Environ. Info. and Data Center, Univ. Alaska, Anchorage, AK. 302 pp.
- Lander, R.H. 1980. A life table and biomass estimate for Alaskan fur seals. In Further Analysis of Pelagic Fur Seal Data Collected by the United States and Canada During 1958-1974. Parts 1 & 2. H. Kajimura, R.H. Lander, M.A. Perez and A.E. York (eds.). Reports. 23rd Annual Meeting of the Standing Scientific Committee, North Pacific Fur Seal Commission. NOAA/NMFS, Seattle, WA.
- Lander, R.H. 1981. A life table and biomass estimate for Alaskan fur seals. Fish. Res. 1: 55-70.

- Lanfear, K.J. and D.E. Armstrong. 1983. A reexamination of occurrence rates for accidental oilspills on the U.S. Outer Continental Shelf. pp. 355-359. In Proc. 1983 Oil Spill Conf.: Prevention, Behavior, Control, and Cleanup of Oilspills. Amer. Petrol. Inst., Washington, DC.
- Lanfear, K.J. and W.B. Samuels. 1981. Documentation and user's guide to the U.S. Geological Survey oilspill risk analysis model: Oilspill trajectories and the calculation of conditional probabilities. U.S. Geological Survey. Open File Report 81-316. 95 pp.
- Lanfear, K.J., R.A. Smith and J.R. Slack. 1979. An introduction to the oil spill risk analysis model. pp. 2173-2175. In Proc. 11th Offshore Tech. Conf., Houston, TX. OTC 3607.
- Mackay, D., S. Paterson and K. Trudel. 1980. A mathematical model of oil spill behavior. Environ. Protection Serv., Fish. and Environ., Canada.
- Minerals Management Service. 1985. Draft Environmental Impact Statement for the Proposed Five Year OCS Oil and Gas Lease Sale Schedule 19861991. U.S. Dept. of the Interior, Minerals Management Serv., Washington, D.C.
- Payne, J.R., B.E. Kirstein, G.D. McNabb, Jr., J.L. Lambach, R.T. Redding, R.E. Jordan, W. Hom, C. de Oliveira, G.S. Smith, D.M. Baxter and R. Goegel. 1984. Multivariate analysis of petroleum weathering in the marine environment Subarctic. In Environmental Assessment of the Alaskan Outer Continental Shelf Final Reports of Principal Investigators. Volumes 21 and 22. U.S. Dept. of Commerce, Nat. Oceanic and Atmospheric Amin., Outer Continental Shelf Environ. Assessment Program, Juneau, AK.
- Reed, M. 1980. An Oilspill Fishery Interaction Model Formulation and Application. Ph.D. Thesis. Univ. Rhode Island, Dept. of Ocean Engineering, Kingston, RI. 225 pp.
- Reed, M., D. French, J. Calambokidis and J. Cubbage. 1986. Simulation modeling of the effects of oil spills on population dynamics of northern fur seals. Report. U.S. Dept. of the Interior, Minerals Management Serv., Alaska OCS Region, Anchorage, AK. OCS Study MMS 86-0045. 139 pp.
- Reed, M. and K. Jayko. 1986. Computer simulation of the probability that endangered whales will interact with oil spilled in the Navarin Basin Planning Area. Report. U.S. Dept. of the Interior, Minerals Management Serv., Alaska OCS Region, Anchorage, AK. Contract No. 14-12-0001-30076.
- Reed, M., K. Jayko, A. Bowles, E. Anderson, S. Leatherwood and M. Spaulding. 1987. Computer simulation of the probability that endangered whales will interact with oil spills. Report. U.S. Dept. of the Interior, Minerals Management Serv., Alaska OCS Region, Anchorage, AK. OCS Study MMS 86-0044. 181 pp.
- Samuels, W.B., R.B. LaBelle and D.E. Amstutz. 1983. Applications of oilspill trajectory models to the Alaskan outer continental shelf. Ocean Manage. 8: 233-250.
- Smith, R.A., J.R. Slack, T. Wyant and K.J. Lanfear. 1982. The oilspill risk analysis model of the U.S. Geological Survey. U.S. Geological Survey Professional Paper 1227. 40 pp.
- Spaulding, M.L., S.B. Saila, M. Reed, L. Lorda, H. Walker, T. Isaji, J. Swanson and E. Anderson. 1982. Oil spill fishery impact assessment model: Application to selected Georges Bank fish species. Estuar. Cstl. Shelf Sci. 16: 511-541.

Swartzman, G. 1984. Present and future potential models for examining the effect of fisheries on marine mammal populations in the eastern Bering Sea. pp. 157-184. In Proc. Workshop on Biological Interaction Among Marine Mammals and Commercial Fisheries in the Southeastern Bering Sea. B.R. Melteff and D.H. Rosenburg (eds.). Alaska Sea Grant College Program. Univ. Alaska, Fairbanks, AK. Alaska Sea Grant Report 84-1.

Executive Summary

J.R. Geraci and D.J. St. Aubin

Department of Pathology Ontario Veterinary College University of Guelph Guelph, Ontario N1G 2W1

Oil spilled in the marine environment can have a devastating effect on a variety of species, particularly sea birds. Widespread concern over the conservation of marine mammals has compounded fears that these animals are also vulnerable to such effects, and has led to considerable speculation regarding the nature and severity of the impact of an oil spill. Marine mammals are a diverse group of animals ranging from sleek, speedy pelagic dolphins, to furbearing amphibious seals which hitch along clumsily on land. This analysis considers the effects of oil in relation to the differences among the major groups and between species of marine mammals. The vulnerability of pinnipeds, cetaceans, sea otters, polar bears, and manatees is viewed first from an ecologic perspective, considering aspects of life history, habitat use and preference, feeding habits, and behavior that might exaggerate or mitigate the possible impact of an oil spill. Against this background, the relatively sparse data from physiologic and toxicologic studies on marine mammals are discussed in relation to the much larger body of published information for humans, domestic and laboratory animals.

Pinnipeds are widely distributed along the Pacific, Arctic and northern North Atlantic coasts of North America. The three major groups include 34 species which share a common feature - they must come onto shore or ice for sustained periods to reproduce and molt. It is during such times that they are most vulnerable to contact with spilled oil. Their strong tendency to return annually to specific haul-out areas further compounds the risk of exposure in the event of a spill. Some species, particularly fur seals, rely on pelage for insulation and for them, surface coating with oil would compromise thermoregulation, with possible deleterious effects. Surface fouling in cold, Arctic waters presents an additional risk - thick, viscous petroleum can interfere with locomotion. Observations over the past 40 years indicate that oil-fouling can harm pinnipeds, though accounts of large-scale mortality are rare, even following major disasters near breeding colonies, such as occurred in the Santa Barbara Channel in 1969. The greater risk to pinniped populations lies more in chronic, sustained perturbations in survival and fertility, than from a single oil spill catastrophe.

The wholly aquatic nature of cetaceans protects them from exposure at the boundary between sea and land, yet offers them no avenue for escape from a spill other than to seek unspoiled waters. For pelagic species, such movements are relatively unrestricted, and consequently the risk of prolonged exposure to spilled oil is remote. Those inhabiting inshore waters, or confined to narrow open-water leads through pack ice, are considerably more vulnerable. Yet the documented cases of oil-associated mortality of cetaceans are so rare and equivocal as to suggest that concerns regarding their vulnerability may be more conjectural than real. The unique feeding apparatus of baleen whales would seem to represent a particularly sensitive tissue, and limited experimental evidence suggests that viscous oil in cold water can obstruct flow between the plates, at least temporarily. The consequences of such an effect would vary depending on timing relative to the annual feeding cycle of the fouled whale. Beyond this, it is unlikely that oil encountered by an itinerant dolphin or whale would represent a serious threat.

Among the most vulnerable marine mammals are sea otters, whose thick coat, compulsive grooming behavior, and precarious metabolic balance ensure that even casual encounters with oil can have deleterious effects. Compounding the concern is that their inshore distribution will increase the likelihood of exposure in the event of a spill. Attempts to rehabilitate oiled otters have met with variable success, providing little reassurance that such individuals can be spared from the consequences of fouling.

These concerns are shared for polar bears, with some qualification. While apparently sensitive to the metabolic effects of reduced insulation provided by an oil-fouled coat, polar bears are broadly distributed in offshore pack ice and it is not likely that a large number of animals would be affected by a localized spill. On the other hand, the polar bear's innate curiosity and opportunistic nature might lure individuals into potentially hazardous areas arond oil-rigs, to scavenge oil-contaminated seals.

Reduced population size and continued losses resulting from fatal encounters with human activity have sensitized us to the possible effects of oil on manatees. As herbivores, they risk incidental ingestion of oil coating their preferred diet of sea-grasses. Their relatively sedentary nature within restricted habitats offers little opportunity for escape. During winter months, displacement from warm embayments poses an additional threat. Beyond this, there is no evidence from field observations or stranding reports that manatees are peculiarly susceptible to incidental contact with spilled oil.

Marine mamals, except the manatee, are carnivores that rely on invertebrates or fish for sustenance. Their feeding strategies could lead to the ingestion of oil-contaminated food. The concern is not that an animal would risk acute intoxication by this source, but that long-term ingestion of contaminated organisms could affect its health.

Such risk would depend on the prey species. Planktonic crustaceans assimilate hydrocarbons during a spill, and retain unmetabolized and metabolized forms for a week to 10 days thereafter. These organisms would be a source of contamination to their consumers for a relatively short time after the spill. Similarly, marine fish process assimilated hydrocarbons, excrete them fairly quickly, and as such do not represent a long-term source of contamination.

On the other hand, bivalve molluscs have limited ability to metabolize and excrete these compounds, and therefore tend to accumulate greater concentrations with time, and through repeated exposure. Molluscs, therefore, impose an enduring threat to indulgent walruses, sea otters, and other benthic feeders. For a scouring gray whale, the risk of oil ingestion extends beyond tissue residues in food, to include direct exposure to raw and weathered petroleum in sediments.

Whatever the source of hydrocarbon uptake, indications are that marine mammals can metabolize and excrete these substances. This would limit the accumulation of residues in their own tissue, and minimize the probability of a residual effect following a spill event. There is no information with which to assess the effects on an animal feeding in persistently polluted waters, such as those associated with industrialized or urban areas. Under these conditions, it is impossible to distinguish the effects of hydrocarbons from those of the myriad of other substances present in such environments. Current technology may provide some answers, but at that level the issue becomes academic.

In recent years, computer models have been used as a tool to predict effects at the population level. Three such models were developed: for northern fur seals in the Bering Sea, gray and bowhead whales in Alaskan waters, and marine mammals of the Southern California Bight. This approach is attractive in yielding tangible probabilities for contact, and assessing rates of recovery and long-term impacts on productivity. However, in building models, many assumptions must be made, particularly when the data base is weak or incomplete. Herein lies the principal value of the modeling approach - data gaps are identified to help direct the necessary research effort.

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Appendix

Common and scientific names of marine mammal species referred to in text. Arranged alphabetically by common name within each Family.

ORDER PINNIPEDIA

FAMILY PHOCIDAE True seals, hair seals

Bearded seal Gray seal Harbor seal Harp seal Hooded seal Northern elephant seal Leopard seal Ribbon seal Ringed seal Saima ringed seal Spotted seal Weddell seal West Indian monk seal

Erignathus barbatus Halichoerus grypus Phoca vitulina Phoca groenlandica Cystophora cristata Mirounga angustirostris Hydrurga leptonyx Phoca fasciata Phoca hispida Phoca hispica saimensis Phoca largha Leptonychotes weddelli Monachus tropicalis

FAMILY OTARIIDAE ...

Zalophus californianus

... Sea lions, fur seals

California sea lion Cape fur seal Guadalupe fur seal Northern fur seal South American fur seal Steller's sea lion Southern sea lion

Arctocephalus pusillus pusillus Arctocephalus galapagoensis Callorhinus ursinus Arctocephalus australis Eumetopias jubatus Otaria byronia

FAMILY ODOBENIDAE Walruses

Atlantic walrus Pacific walrus

Odobenus rosmarus rosmarus Odobenus rosmarus divergens

ORDER CETACEA

SUBORDER MYSTICETI BALEEN WHALES

FAMILY BALAENIDAE Right whales

Bowhead whale Northern right whale Pygmy right whale Southern right whale

Balaena mysticetus Eubalaena glacialis Caperea marginata Eubalaena australis

FAMILY BALAENOPTERIDAE Rorqual whales

Blue whale Bryde's whale Fin whale Humpback whale Minke whale Sei whale

Balaenoptera musculus Balaenoptera edeni Balaenoptera physalus Megaptera novaeangliae Balaenoptera acutorostrata Balaenoptera borealis.

FAMILY ESCHRICHTIDAE Gray whale

Gray whale

Eschrichtius robustus

SUBORDER ODONTOCETI TOOTHED WHALES, DOLPHINS AND PORPOISES

FAMILY PHYSETERIDAE Sperm whales

Sperm whale

Beluga

Narwhal

Physeter catodon

FAMILY MONODONTIDAE Narwhal and beluga

Delphinapterus leucas Monodon monoceros

FAMILY ZIPHIIDAE ...

..... Beaked whales

Beaked whales

various species of the genera Mesoplodon, Berardius, Hyperoodon, Ziphius and Tasmacetus

FAMILY DELPHINIDAE

Atlantic white-sided dolphin Bottlenose dolphin Commerson's dolphin Common dolphin Dusky dolphin False killer whale Hawaiian spinner dolphin Hectors dolphin Hourglass dolphin Indo-Pacific humpbacked dolphin Killer whale Long-finned pilot whale Northern right whale dolphin Pacific white-sided dolphin Peale's dolphin Risso's dolphin Short-finned pilot whale Southern right whale dolphin Spotted dolphins

Striped dolphin White-beaked dolphin Lagenorhynchus acutus Tursiops truncatus Cephalorhynchus commersonii Delphinus delphis Lagenorhynchus obscurus Pseudorca crassidens Stenella longirostris Cephalorhynchus hectori Lagenorhynchus cruciger Sousa chinensis

Orcinus orca Globicephala melaena Lissodelphis borealis Lagenorhynchus obliquidens Lagenorhynchus australis Grampus griseus Globicephala macrorhynchus Lissodelphis peronii Stenella spp. (including S. attenuata, S. dubia, S. frontalis, S. plagiodon) Stenella coeruleoalba Lagenorhynchus albirostris

FAMILY PHOCOENIDAE True porpoises

Dall's porpoise Harbor porpoise Phocoenoides dalli Phocoena phocoena

FAMILY PLATANISTIDAE River dolphins

ORDER CARNIVORA

FAMILY MUSTELIDAE

Sea otter

Enhydra lutris

FAMILY URSIDAE

Polar bear

Ursus maritimus

ORDER SIRENIA

FAMILY TRICHECHIDAE Manatees

African manatee Amazonian manatee West Indian manatee Trichechus senegalensis Trichechus inunguis Trichechus manatus

FAMILY DUGONGIDAE Dugongs

Dugong

Dugong dugong