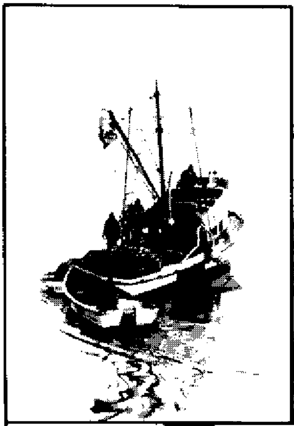
Proceedings of the workshop on Biological Interactions Among Marine Mammals and Commercial Fisheries in the Southeastern Bering Sea

October 18-21, 1983
Anchorage, Alaska, U.S.A.



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Alaska Sea Grant Report 84-1
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Introduction

The Alaska Department of Fish and Game, under contract to the North Pacific Fishery Management Council, conducted a study on the status of information on the feeding habits of Bering Sea marine mammals in 1982. One of the study's recommendations was to hold a workshop to discuss the biological interactions among marine mammals and commercial fisheries in the Bering Sea.

The North Pacific Fishery Management Council and the Marine Mammals Commission asked the University of Alaska Sea Grant Program to coordinate and conduct the workshop.

The workshop on the Biological Interactions Among Marine Mammals and Commercial Fisheries in the Southeastern Bering Sea was held October 18-21, 1984 in Anchorage, Alaska. This document is the proceedings volume from that workshop.

Executive Summary

The Bering Sea, lying between Alaska and Siberia, is a highly productive region and hence not surprisingly supports very large commercial fisheries and the largest populations of marine mammals in the United States. The marine mammals and fisheries interact in many ways.

Presently, both the marine mammals and the fisheries from three miles to 200 miles offshore are managed by the federal government. The marine mammals are managed under the Marine Mammal Protection Act of 1972, which placed a moratorium on taking mammals, with a number of important exceptions. The act also permits management to be returned to the state (in this case Alaska) under certain conditions. Marine mammal populations that reach "optimum sustainable populations" (OSP), could be subject to some exploitation.

The fisheries in this 200-mile Fishery Conservation Zone (FCZ) are managed according to the provisions of the (Magnuson) Fisheries Conservation and Management Act (FCMA) of 1976. This act established eight regional councils which develop, for the approval of the Secretary of Commerce, the plans that regulate the primary domestic fisheries and any foreign fisheries.

The North Pacific Fishery Management Council is the operating agency for fisheries management of the Bering Sea, and has prepared a number of plans for Bering Sea and other North Pacific fisheries. The fisheries councils are mandated by the FCMA to achieve "optimum yield" in the fisheries managed. Optimum yield is the number of fish to be taken in order to provide the greatest benefit to the nation, especially in terms of food production and recreational opportunity. It is based on the maximum sustainable yield, augmented by relevant economic, social, and environmental factors. Maximum sustainable yield is an average, figured over a reasonable length of time, of the largest number of fish that can be taken in a fishery under current environmental conditions.

In contrast, the primary objective of the Marine Mammal Protection Act is to maintain the health and stability of the marine ecosystem and, whenever consistent with this primary objective, to obtain and maintain optimum sustainable populations (OSP) of marine mammals. The statutory definition of OSP has been interpreted in regulations as follows:

> Optimum sustainable population is a population size which falls within a range from the population level of a given species or stock which is the largest supportable within the ecosystem to the population level that results in maximum net productivity. Maximum net productivity is the greatest net annual increment in population numbers or biomass resulting from additions to the population due to reproduction and/or growth less losses due to natural mortality. It is thus observed that from the definition, OSP is a range of population sizes from approximately the MSY level (if the population were harvested) to the carrying capacity level.

The carrying capacity may well be a function of the fisheries operating in the region since the marine mammals may depend on the same fish taken by the fishery. Alternatively, the marine mammals may compete with fish that are the targets of the commercial fishery. There are therefore complex interactions between fisheries and marine mammals at the ecosystem level. In addition there are more direct interactions when marine mammals take fish from gear, damage fishing gear, or are killed or injured by fisheries operations.

This workshop was to focus primarily on the ecosystem-level of interactions. In particular, it was to identify research needed to quantify these interactions. It is important to quantify these interactions even though given the current state of knowledge, we might not yet be able to formulate the interactions into ecosystem models. However, it is certainly possible to identify what research is needed, and to rank it in terms of that which will best help answer questions that arise when preparing fisheries management plans or discussing issues involving marine mammal populations. It is to such research identification that the four groups within this workshop addressed themselves.

Each group was established to consider a major fishery or related group of fisheries (salmon, groundfish, shellfish, and herring) and marine mammals that substantially interact with them. The fisheries involved are usually unique for type of gear used and species targeted. Some of the fisheries are projected to have minor importance, for example, the pandalid shrimp fishery. Others are very large and important, such as the salmon or Alaska pollock fisheries. The levels of available information on the ecology, behavior and dynamics of the several fish and marine mammal populations vary substantially. Nevertheless the primary thrust of the research recommendations of the four groups is that more information is needed on the marine mammals, particularly their numbers, diet and distribution in the areas where the fishery interactions do or may occur.

The four working groups also addressed research required to study marine mammal-fisheries interaction, but did not prioritize the research proposals. This will depend on evaluation of the degrees of interaction, the importance or economic value of the fishery, and the status of the marine mammal.

The groups discussed, in varying degrees, the steps that might be taken to evaluate marine mammal-fisheries interactions and in planning future research. One suggestion is to focus on one or two of the major "problem interactions" by convening small workshops to work on only one interaction. Such a workshop should be a hands-on operation, with data provided or prepared in advance, and would be able to both achieve what is possible given the present state of information availability, and to pinpoint more specifically the current data gaps and research needs for the interaction chosen. Two candidates for such intensive workshops might be the fur seal-pollock interaction or the sea lion-salmon interaction.

Douglas G. Chapman
January 1984

Overview Papers

Background: Why Marine Mammal-Fishery Interactions in the Bering Sea (and elsewhere) are of Interest

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Marine mammal-fishery interactions are of interest because marine mammals affect and are affected by fisheries. They are disturbed, harassed, injured and killed, either incidentally or deliberately, during fishing operations; they take or damage bait and fish caught on lines or in traps and nets; they damage fishing gear during these encounters or when they accidentially become entangled; they are entangled and drown in lost or discarded fishing gear; and, in some areas, they compete with fishermen for the same fish and shellfish resources. The potential adverse effects of these interactions on both marine mammals and fisheries are generally recognized and have been considered, in part, by previous workshops sponsored by the Marine Mammal Commission (Mate, 1980; Contos, 1982) and the International Union for the Conservation of Nature and Natural Resources (Beverton, 1982).

The genesis of the present workshop can be traced to two things: the Marine Mammal Commission's January 1979 comments on the Fishery Management Plan and Draft Environmental Impact Statement for the Groundfish Fishery in the Bering Sea/Aleutian Islands Area; and the development of the basic ecological approach to management that is reflected in both the Marine Mammal Protection Act (P.L. 92-522, 21 October 1972) and the Magnuson Fishery Conservation and Management Act (P.L. 94-265, 13 April 1976).

The Commission's comments on the FMP and the DEIS for the Bering Sea Groundfish Fishery noted that the Magnuson Fishery Conservation and Management Act (MFCMA) and the Marine Mammal Protection Act (MMPA) call for an integrated ecosystem approach to the management of marine mammal and fish populations, and questioned: (1) whether the best available data and theory concerning marine mammal-fishery interactions had been utilized in developing the FMP; and (2) whether the FMP adequately identified and considered uncertainties concerning the reliability of available data and theory. The North Pacific Fishery Management Council recognized that there were weaknesses in the FMP and a steering group, consisting of representatives of the North Pacific Fishery Management Council, the Marine Mammal Commission, and the National Marine Fisheries Service, was constituted to discuss and develop a plan for better defining and correcting weaknesses in this and other Fishery Management Plans.

The first meeting of the steering group was held in Seattle, Washington in August 1979. At this meeting, it was agreed that: (1) the ultimate goal was to develop standard procedures and models for assessing the interrelationships between target and non-target fish populations, marine mammal populations, bird populations, and other components of marine ecosystems; (2) efforts should be focused, at least initially, on the Bering Sea ecosystem; (3) a contract study should be undertaken to compile available information on the species' composition, status, food habits, and food requirements of marine mammals that occur in the Bering Sea; and (4) a symposium or workshop should be held to assess the adequacy of existing data, procedures, and models being used to develop Fishery Management Plans, with particular emphasis on the Bering Sea ecosystem.

In response to the agreements reached by the steering group, the National Marine Fisheries Service organized and convened a workshop on ecosystem simulation models. In addition, the North Pacific Fishery Management Council, with partial support from the Marine Mammal Commission, contracted with the Alaska Department of Fish and Game to compile and evaluate available information concerning the feeding habits, food requirements, and status of marine mammals in the Bering Sea. The workshop was held at the Northwest and Alaska Fisheries Center in Seattle, Washington, from 29 April through 1 May 1980; the Workshop results are summarized in an unpublished manuscript entitled "Report of the Workshop on Ecosystem Simulation Models and Their Applications to Fishery Management" (Anon., 1980). The ADF&G contract study was completed in 1982 and, among other things, the contract report (Lowry, et al., 1982) suggests (p. 398) that a workshop be held "to consider possible integration of recently gathered information and to investigate the most productive directions for future work . . ."

This workshop (i.e., the present workshop) is a direct product of that suggestion.

General Background

As indicated above, the Marine Mammal Protection Act and the Magnuson Fishery Conservation and Management Act share a common heritage - namely the growing awareness that exploitation may affect and be affected by non-exploited, as well as exploited components of both terrestrial and marine ecosystems. This awareness also is reflected in the recent scientific literature (e.g., Holt and Talbot, 1978) and in international agreements, such as the Convention on the Conservation of Antarctic Marine Living Resources.

New Principles for the Conservation of Wild Living Resources

Workshops were held at Airlie House, Virginia in February and April 1975 to critically examine the basis for management of wildlife resources and "to prepare appropriate recommendations for improvement in their management". The report of these workshops (Holt and Talbot, op. cit.) recognizes that wildlife resources have both consumptive and non-consumptive values and notes (p. 5) that: past attempts to manage wildlife resources have allowed gross depletion of many resources; the absence of rational management policy or the application of a policy that results in overutilization or the abuse of a resource results in loss of the full range of benefits to both present and future generations; the primary goal of conservation policy should be to maintain resource systems (ecosystems) in desirable states; and "a resource system in a desirable state would have the capacity to accommodate changing human values and to persist in the face of changing environmental conditions". The report proposed (pp. 14-15) the following four general principles for the conservation of wild living resources:

"1. The ecosystem [of which the resource(s) are a part] should be maintained in a desirable state such that

   a. consumptive and non-consumptive values could [can] be maximized on a continuing basis;

   b. present and future options are ensured;

    c. risk of irreversible change or long-term adverse effects as a result of use is minimized.

2. Management decisions should include a safety factor to allow for the facts that knowledge is limited and institutions are imperfect.

3. Measures to conserve a wild living resource should be formulated and applied so as to avoid wasteful use of other resources.

4. Survey or monitoring, analysis, and assessment should precede planned use and accompany actual use of wild living resources. The results should be made available promptly for critical public review."

The report also noted (p. 8) that some of the failures in management for maximum sustainable yield "must be ascribed more to failures in application than to weaknesses in the concept".

The Marine Mammal Protection Act

Although the Marine Mammal Protection Act preceded the Airlie House Workshops, it recognizes the deficiencies in past management efforts and reflects the "new conservation principles". Prior to passage of the Marine Mammal Protection Act, conservation and protection of marine mammals were the responsibilities of coastal states, such as Alaska, Washington, Oregon, California, etc., and/or international authorities, such as the International Whaling Commission, the North Pacific Fur Seal Commission, and the International Commission on North Atlantic Fisheries. Management by some of these authorities was not very effective and, by the late 1960's, the American public and the Congress, as well as the scientific community, were expressing concern that certain species and populations of marine mammals were in danger of extinction or depletion as a result of human activities. The regulation of commercial whaling by the International Whaling Commission, the incidental take of porpoise by the U.S. tuna purse seine fleet, and the clubbing of "baby" harp seals in the North Atlantic were of particular concern (see, for example, H.R. Report No. 92-707 (1972), H.R. Report No. 92-1488 (1972), and S. Report No. 92-863 (1972)).

The Marine Mammal Protection Act established a moratorium on the taking of marine mammals in U.S. waters and the importation of marine mammals and marine mammal products into the U.S. "Take" is defined in the Act as harassing, hunting, capturing, killing, or attempting to harass, hunt, capture, or kill any marine mammal. The Act provides for waiver of the moratorium and return of management to the states. It also provides for issuing permits to take marine mammals for purposes of public display and scientific research, and for permits or exemptions to allow limited taking of marine mammals incidentally during commercial fishing operations. Under the Act, the Secretary of Commerce is responsible for cetaceans and pinnipeds other than walrus, while the Secretary of the Interior is responsible for all other marine mammals (walrus, manatees, dugongs, sea otters, and polar bears). The Secretaries of Commerce and Interior have delegated responsibilities to the National Marine Fisheries Service and the Fish and Wildlife Service, respectively.

The primary objective of the Marine Mammal Protection Act is to maintain the health and stability of the marine ecosystem and, whenever consistent with this primary objective, to obtain and maintain optimum sustainable populations of marine mammals. The Act, as amended, defines "optimum sustainable population" (OSP), with respect to any population stock, as --

> "the number of animals which will result in the maximum productivity of the population or the species, keeping in mind the carrying capacity of the habitat and the health of the ecosystem of which they form a constituent element".

This statutory definition has been interpreted by the National Marine Fisheries Service and the Fish and Wildlife Service for application in the management context as follows:

> "Optimum sustainable population is a population size which falls within a range from the population level of a given species or stock which is the largest supportable within the ecosystem to the population level that results in maximum net productivity.

> Maximum net productivity is the greatest net annual increment in population numbers or biomass resulting from additions to the population due to reproduction and/or growth less losses due to natural mortality" (50 CFR 216.3).

This interpretive definition of OSP has been used as the basis for decisions concerning the status of porpoise stocks impacted by the yellowfin tuna purse seine fishery in the eastern tropical Pacific and a number of other issues requiring OSP determinations (see Smith, 1979, for example).

Section 103 of the Act requires that regulations concerning the taking and importation of marine mammals be prescribed by the Secretaries of Commerce and Interior on the basis of the best scientific evidence available and in consultation with the Marine Mammal Commission. In prescribing such regulations, the Secretaries are directed to give full consideration to all factors which may affect the numbers and species of marine mammals that may be taken or imported, including but not limited to the effect of such regulations on -

"(1) existing and future levels of marine mammal species and population stocks;

(2) existing international treaty and agreement obligations of the United States;

(3) the marine ecosystem and related environmental considerations;

(4) <u>the conservation, development, and utilization of fishery resources</u>; and

(5) the economic and technological feasibility of implementation" (emphasis added).

The Magnuson Fishery Conservation and Management Act

The Magnuson Fishery Conservation and Management Act, like the Marine Mammal Protection Act, is a product, in part, of deficiencies in past management efforts and reflects the "new conservation principles" proposed in the report of the Airlie House Workshops. Before passage of the Magnuson Fishery Conservation and Management Act, there was little effective regulation of fisheries outside the three mile U.S. territorial sea. International fishery agreements had not been effective in preventing or terminating overfishing, and heavy foreign fishing on the U.S. continental shelves had seriously depleted some fish stocks and interfered with domestic fisheries.

The MFCMA established a Fishery Conservation Zone (FCZ) extending 200 nautical miles off the U.S. coast and asserted exclusive jurisdiction over: all fish within the FCZ; all anadromous fish species throughout their range, except when such species occur in the territorial sea or FCZ of another nation; and all Continental Shelf fishery resources beyond the FCZ. The MFCMA created eight regional fishery management councils, charged the councils with developing Fishery Management Plans (FMPs) according to National Standards set out in the Act, and assigned authority and responsibility for administering the Act to the Secretary of Commerce.

The National Standards, set out in Section 301 of the Act, constitute statutory criteria for judging consistency of FMPs and are as follows:

"(1) Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery.

(2) Conservation and management shall be based upon the best scientific information available.

(3) To the extent practicable, an individual stock of fish shall be managed as a unit throughout its range, and interrelated stocks of fish shall be managed as a unit or in close coordination.

(4) Conservation and management measures shall not discriminate between residents of different states. If it becomes necessary to allocate or assign fishing privileges among various United States fishermen, such allocation shall be (A) fair and equitable to all such fishermen; (B) reasonably calculated to promote conservation; and (C) carried out in

> such manner that no particular individual, corporation, or other entity acquires an excessive share of such privileges.
>
> (5) Conservation and management measures shall, where practicable, promote efficiency in the utilization of fishery resources, except that no such measures shall have economic allocation as its sole purpose.
>
> (6) Conservation and management measures shall take into account and allow for variations among, and contingencies in, fisheries, fishery resources, and catches.
>
> (7) Conservation and management measures shall, where practicable, minimize cost and avoid unnecessary duplication" (emphasis added).

The Act defines "conservation and management" as "all of the rules, regulations, conditions, methods, and other measures (A) which are required to rebuild, restore, or maintain, and which are useful in rebuilding, restoring, or maintaining, any fishery resource and the marine environment; and (B) which are designed to assure that -

> (i) a supply of food and other products may be taken, and that recreational benefits may be obtained, on a continuing basis;
>
> (ii) irreversible or long-term adverse effects on fishery resources and the marine environment are avoided; and
>
> (iii) there will be a multiplicity of options available with respect to future uses of these resources" (emphasis added).

The term "optimum", with respect to the yield from a fishery, is defined as -

> "the amount of fish - (A) which will provide the greatest overall benefit to the nation, with particular reference to food production and recreational opportunities; and (B) which is prescribed as such on the basis of the maximum sustainable yield from such fishery, as modified by any relevant economic, social, or ecological factor" (emphasis added).

Section 303 of the Act requires that Fishery Management Plans be consistent with the National Standards, the other provisions of the Act, and "any other applicable law". It also requires that FMPs assess and specify the present and probable future condition of, and the maximum sustainable yield and optimum yield from, the fishery for which the FMP is developed. Section 301(B) of the Act directs that the Secretary of Commerce "shall establish advisory guidelines (which shall not have the force and effect of law), based on the National Standards, to assist in the development of Fishery Management Plans".

Guidelines for Fishery Management Plans

In July 1977, the National Oceanic and Atmospheric Administration (NOAA) issued Guidelines for Fishery Management Plans (50 CFR 602.2) as required by Section 301(B) of the MFCMA. In October 1979, the Environmental Defense Fund (EDF) petitioned the National Marine Fisheries Service (NMFS) to initiate review and revision of the Guidelines. The National Marine Fisheries Service granted this petition, solicited comments from outside NOAA (40 FR 8686), and, by Federal Register Notice of 23 June 1982, proposed revision of the Guidelines (final rule-making was announced in February 1983 (48 FR 7402)). In its proposed revision, NOAA rejected (p. 27229) an EDF proposal which would have included "significant adverse impacts on other species or stocks not included in the management unit" as one of the criteria for defining "overfishing". In its explanation of the rejection, NOAA stated that:

> "While these considerations [impacts on non-target species and stocks] are listed as examples of ecological factors in specifying OY and in Standard 6, the data and sophisticated techniques needed for ecosystem management are probably not yet at the stage of practical application".

In the referenced examples (pp. 27236-7) of ecological factors to be considered in specifying OY, the Notice indicates that:

> "Examples are the nature of a mixed-species fishery, predator/prey relationships, and dependence of marine mammals and birds or endangered species on a stock of fish. Equally important are environmental conditions

> that stress marine organisms, such as natural and man-made changes in wetlands or nursery grounds, and effects on habitat of pollutants".

NOAA also rejected an EDF proposal to revise the definition of MSY and, in its explanation of the rejection, stated that:

> "The minimum population argument [made by EDF] is similar in concept to that underlying the Marine Mammal Protection Act (MMPA), but it is clear that the Magnuson Act's emphasis on achieving OY precludes the exclusively protectionist point of view that forms the basis of the MMPA."

NOAA accepted, in part (p. 27231), an EDF proposal to require that FMPs identify serious inadequacies in the existing biological data base and incorporate measures designed to generate the needed information.

Workshop Objectives

The previous points provide the background for defining the objectives of this workshop. It follows from the preceding, for example, that the primary workshop objectives should be:

- to determine whether or not existing data, theory, models, management techniques, and research/monitoring programs are at the stage of practical application needed for ecosystem management, and, if not, to determine the critical deficiencies and what could be done to overcome them; and

- to determine whether existing FMPs, particularly those for Bering Sea fisheries, reflect the best available data and theory concerning possible interactions between fisheries, fish stocks and other ecosystem components, particularly marine mammal populations, and, if not, to identify the apparent weaknesses and steps, including further research, that could be taken to overcome them.

In particular, the Workshop should consider the following questions:

1. How might fisheries in the Bering Sea (and elsewhere as appropriate) affect and be affected by marine mammals?

2. What marine mammals and fisheries are most likely to be affected in detectable ways?

3. Is there any evidence that either marine mammal populations or fisheries in the Bering Sea have been adversely affected by one or the other? If so, what is the evidence and the significance of the effect(s)? If not, is there any need to consider the subject further?

4. How, if at all, have the possible effects of fisheries on marine mammals been considered in determining MSY, OY, or conservation measures included in existing or proposed FMPs -- e.g., is mortality due to marine mammal predation assumed to be part of natural fish mortality such that marine mammal food requirements automatically are met when MSY is estimated?

5. How, if at all, have the possible effects of marine mammals on fish stocks and fisheries been considered in determining MSY, OY or conservation measures included in existing or proposed FMPs and marine mammal management programs or plans?

6. Are the data, theory, models, and procedures being used to assess possible interactions among fisheries, fish stocks, marine mammals and other ecosystem components sufficient to identify the likely consequences (costs and benefits) of possible alternative management strategies? If not, what are the problems and how might they be overcome?

7. Are there any particular marine mammal or fish species or populations that are likely to be particularly sensitive to, and sensitive indicators of, harvest-caused changes in the Bering Sea ecosystem? If so, how might these species or populations be monitored or otherwise used to detect and assess the significance of harvest-caused changes?

8. Are catch, effort and related biological data currently being collected, and research/monitoring programs currently being conducted or planned, likely to be sufficient to detect and monitor the possible impacts of fisheries on fish and marine mammal populations, and/or the effects of marine mammals on fisheries and fish populations? If not, why not, and what additional data collection and monitoring seem necessary?

9. Are experiments necessary to determine the probable functional and numerical relationship between various fish and marine mammal populations? If so, what types of experiments seem necessary and how would they contribute to developing and implementing ecosystem-oriented management strategies for fish and/or marine mammal populations in the Bering Sea and elsewhere?

Summary Comments

In summary, this workshop is a product of continuing efforts to facilitate effective integration and implementation of the Marine Mammal Protection Act and the Magnuson Fishery Conservation and Management Act. It is intended, among other things, to determine whether or not existing data, theory, models, management techniques, and research/monitoring programs are at the stage of application needed to assess the relative costs and benefits of alternative management strategies and, if not, to determine the critical deficiencies and what can be done to overcome them. In this context, the participants should keep in mind that:

1. marine mammals, fish and other components of the Bering Sea and other marine ecosystems have non-consumptive as well as consumptive values;

2. although stated somewhat differently, the principal goals of both the Marine Mammal Protection Act and the Magnuson Fishery Conservation and Management Act are to restore and maintain marine ecosystems in a desirable state;

3. a "desirable state" can be defined as that in which: (a) consumptive and non-consumptive values can be optimized on a continuing basis, (b) near and long-term options are maximized, and (c) the risk of irreversible change or long-term adverse effects as a result of use is minimized;

4. the MFCMA provides that OY determinations include consideration of ecological factors such as the dependence of marine mammals on target fish populations;

5. the MFCMA requires that FMPs be consistent with other applicable law, which presumably includes the MMPA;

6. the NMFS/FWS interpretive definition of "optimum sustainable population" arguably would allow marine mammal populations to be reduced to their MNP (MSY) levels, if necessary, among other things, to facilitate conservation, development and utilization of fishery resources;

7. given the preceding, there can be little if any doubt that the general goals and objectives of the MFCMA and the MMPA are fully consistent (see also K.A. Green-Hammond, 1980), but that estimates of OY for fish populations and maximum allowable take for marine mammal populations -- i.e. the optimal strategy for maximizing the combined consumptive and non-consumptive value of both marine mammal and fish populations -- very well would be different depending upon the relative value that the manager or decision maker attributes to fishery yield versus marine mammal protection; and

8. the purpose of this Workshop is to determine whether and, if so, how the consequences of alternative management strategies can be determined more reliably, not to make value judgments concerning the relative desirability of alternative management strategies.

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Relevancy of Southeast Bering Sea Oceanographic Studies to Fisheries and Marine Mammals

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Introduction

Factors which cause variation in fish stocks are important considerations in the management of marine resources. Such variation determines the size of the total "pie" to be partitioned among preditors such as man and marine mammals. A variety of factors influence the stocks of commercially valuable fish in the ocean. Purely biological factors such as predation and feeding conditions have been frequently studied fisheries interactions. The nature of these influences is complex, since they differ among age classes and are often density dependent (Sissinwine *et al.*, 1982). During postlarval stages of fish development, predation is often the dominant removal mechanism.

Additionally, factors which are not biological in nature can significantly impact fish stocks. These factors are usually physical environmental processes (Bakun *et al.*, 1982). Further, this type of endogenous variation is stochastic and is not theoretically tractable in present predictive models of fish stock abundance. These nonbiological factors can influence fish growth directly through temperature effects, or bring about variation indirectly by influencing for example, the extent of "safe sites" for larval fish development (Frank and Leggett, 1982). The time of first feeding for larval fish has been identified as a "critical period" in their life history (Lasker, 1975). The physical environment encountered during this time could conceivably significantly influence the number of fish surviving beyond this point.

A direct association between physical environmental processes and fish abundance was found in the very productive coastal area off Peru. Plankton productivity there decreases sharply during periods of warm equatorial water intrusion. This change is believed to be climatically induced, and results in a significant decrease in the commercial catch of anchovy (Cushing, 1981). Interannual variability in plankton production has also been documented in the upwelling area off the Oregon coast (Peterson and Miller, 1975). Although weather patterns are recognized as important in such low frequency biological variability, the specific mechanisms by which meteorological variability affects higher trophic levels are not well understood.

On the broad, high latitude southeast Bering Sea shelf, physical processes such as coastal upwelling or sharp gradients in horizontal advection are not available to supply surface nutrients for plankton growth. Deep water nutrients, therefore are largely dependent on vertical mixing due to local wind activity to reach surface waters (Coachman and Walsh, 1981). Sambrotto *et al.* (submitted) show that wind induced mixing of the upper water column controls phytoplankton growth by influencing both the nutrient availability and light conditions across much of this shelf. Further, meteorologically controlled wind mixing was observed to vary significantly between years, and with it the amount and pattern of primary production.

In this communication, oceanographic data is used in an inductive approach to the question of higher trophic level production in the eastern Bering Sea. We consider the initial steps of the food chain and evaluate the environmental factors affecting plankton which may manifest themselves in the stocks of fish and marine mammals. Such a mechanistic approach raises a variety of difficult questions and forming definitive answers to them is not a reasonable goal of this study. The question of mechanisms can however, be examined in light of specific hypotheses from the oceanographic data collected in the eastern Bering Sea.

The methodology used to generate data discussed in this report have been detailed elsewhere. Interested readers are referred to the publications of Coachman and Walsh (1981), Cooney and Coyle (1982), Dagg *et al.* (1982), Sambrotto *et al.* (submitted), Smith and Vidal (submitted), and Stoker (1981).

Physics and Planktonology of the Southeastern Bering Sea

During the last five years the National Science Foundation sponsored PROBES (Processes and Resources of the Bering Sea Shelf) project has collected oceanographic data in the Southeast Bering Sea (Figure 1). These data document the development of intense diatom-dominated spring blooms of this subarctic shelf (Iverson *et al.*, 1979). Most of the important environmental influences in spring bloom development have been evaluated during the PROBES project. Therefore, the southeast Bering Sea shelf presented an unusually good "laboratory" in which an improved quantitative analysis of plankton growth could be attempted. Iverson *et al.* (1979) reported observations supporting the hypothesis that major food webs leading to large stocks of pelagic and benthic fauna on the eastern Bering Sea shelf are separated in space by their relationships to a complex physical system of oceanic/shelf fronts separated by inter-front regions (Figure 2). The fronts arise from changes in the mixing energy balance between tides (shearing up from bottom) and winds (mixing down from surface) (Coachman and Walsh, 1981). In the coastal domain the two mixing energies overlap leading to vertically homogeneous water. At the depths found in the middle shelf

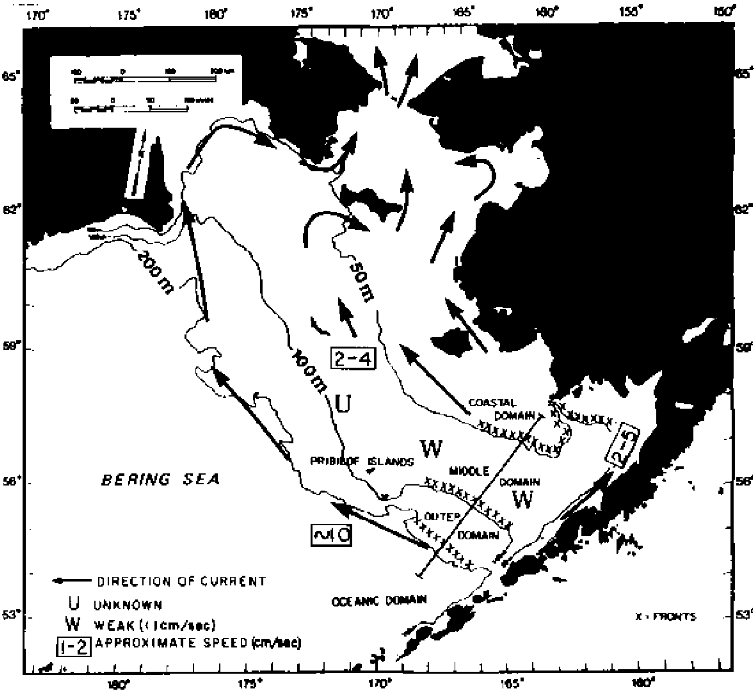

Figure 1. Estimated mean circulation, approximate location of fronts and main cross shelf PROBES line on the eastern Bering Sea shelf (modified from Kinder and Schumacher, 1981 with current data from Coachman *et al.*, 1975 added).

domain the two mixing energy sources are separated and under conditions of sufficient surface buoyant energy input, a separate, lighter surface layer develops (Figure 2). The transition from this two layered water column to the vertically mixed coastal water has been identified as a structural front caused by the changing balance between buoyant energy content and tidal mixing (Schumacher *et al.*, 1979).

This cross shelf physical structure results in each domain exhibiting distinct temperature, salinity and stratification properties as well as different circulation features (Coachman *et al.*, 1980). The shelf break front is within ± 50 km of the shelf break (ca. 170 m isobath), about 500 km from shore; the middle front lies over the 80-100 m isobaths, 350-400 km from shore, and the inner front is centered over the 50 m isobath, 80-150 km from shore. Proceeding landward from the shelf break front, the hydrographic domains which these fronts define are called outer, middle and coastal.

Long term mean currents on the shelf are small (ca. 1-2 cm/sec drift to the Northwest, Figure 1). Subtidal flow is weak (1-5 cm/sec^{-1}) and parallel to the fronts in the vicinity of the shelf break and inner fronts, while flow in the middle domain is insignificant (Coachman,

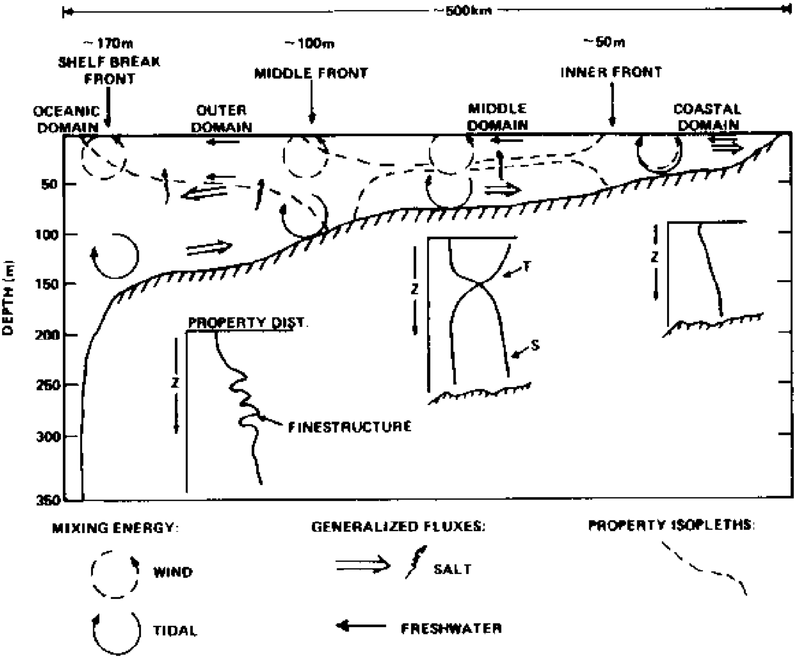

Figure 2. Schematic summarization of vertical property distributions and fluxes on the southeastern Bering Sea shelf (from Coachman *et al.*, 1980).

1982; Figure 2). The distributions of properties are governed largely by a diffusion defined to include the tidal scales (Coachman and Charnell, 1979). Due to the lack of other mixing forces besides the predictable influence of tides over large areas of the shelf, wind mixing periodically contributes most of the water column mixing energy (Schumacher and Kinder, 1983).

Historically, mean storm tracks pass over the middle shelf domain of the southeastern Bering Sea from February through April (Bower *et al.*, 1977). During an average year, about 14 storms pass over the region during these months with 25-36% of the associated winds greater than 22 knots. The lack of temperature and salinity structure in the water during winter allow these early spring winds to easily mix the water column to the bottom on the middle shelf. Usually, by May, storm tracks move out of the eastern Bering Sea and mean wind speeds drop to 13-14 knots. Storms occasionally pass through the region after May, however (Brower *et al.*, 1977).

The mean position of the maximum upper air winds (which tend to guide or "steer" the surface lows) is approximately parallel to the 40° latitude, some 1600 km south of the eastern Bering Sea shelf. Niebauer (1980, 1983) has suggested that the mean winter atmospheric circulation is the driving force behind large year-to-year temperature variations in this area. The region has been under the influence of a general warming trend since 1976; 1979 and 1981 were especially warm years. Monthly mean sea surface temperatures for a 300 km square centered on the Pribilof Islands for May 1979-1981 were 4.66°C, 2.89°C and 4.13°C respectively, or 2.41°C, 0.64°C and 1.88°C above normal. Inspection of monthly mean 700 mb (approximately 3000 m above sea level) flow patterns of "steering winds" indicate that the mean late winter and spring air flow was from the south leading to the above normal temperatures in 1979-1981 (Niebauer, 1983). Conversely, predominantly northerly winds produce colder middle shelf water temperatures (McLain and Favorite, 1976).

Such short term climatic fluctuations play a large role in conditioning the water of the middle shelf domain (Niebauer, 1980). In cold years this region is ice covered (e.g., 1976), in warm years it is not (e.g., 1978-1982). The spring bottom water temperature distribution reflects the severity of the previous winter. As evidence of the paucity of cross shelf exchange occurring in this region, in any one year, bottom temperature varies little from spring to fall (Coachman and Charnell, 1979). The bottom temperature range is approximately -1 to 4° depending on the previous winter (Coachman and Charnell, 1979). The formation of a stable upper layer in spring may first be initiated by ice melt in cold years, whereas in warm years changes in salinity seem to play a small role in controlling density. Seasonally, surface temperatures vary from below freezing in winter, to 10° in summer.

The eastern Bering Sea has long been a biologically productive region to man. This shelf covers only 0.33% of world's ocean area yet provides approximately 5% of the total world fishery catch (Goering and McRoy, 1981). The catch per unit area is comparable to the shelves off Nova Scotia and in the northern North Sea (Coachman and Walsh, 1981). This suggests that the larger fish yields may be the result of the extensive shelf area. Attempts at building a mechanistic model capable of accurately predicting variations in the "maximum sustainable yield" of these resources has already begun (Laevastu and Favorite, 1977). Such work is significant since apparent pollock densities over the past 20 years have varied by up to 50% (Smith, 1981).

Grazing studies suggest that copepod feeding activities have a significantly greater impact on outer shelf and oceanic areas than on the middle shelf (Dagg *et al.*, 1982, Figure 1). Shoreward of the middle front, most of the spring bloom production is not consumed by the pelagic fauna. Much of this phytoplankton biomass reaches the bottom intact and supports a large benthic standing stock on the eastern Bering shelf (Stoker, 1981). The bypassing of the pelagic food web occurs in the middle shelf domain because the phytoplankton community is geographically isolated from the large and effective grazers of the outer shelf region (Cooney and Coyle, 1982). In the southeast Bering Sea, maximum spring Chl *a* values were about four times greater at middle shelf stations than at those near the heavily grazed shelf break (Goering and Iverson, 1979). The middle shelf grazers, therefore, do not appear to be "food limited" during the bloom period.

The Relationship Between Vertical Mixing and Phytoplankton Growth

Spring in high latitude shelf waters of moderate depth is characterized by the transition from deeply mixed surface layers to less turbulent, more shallow layers. The suppression of vertical turbulence by a density discontinuity improves light conditions for the mixed layer phytoplankton community and ultimately restricts the exchange of properties between deeper water and the upper euphotic zone. This leads to conditions in which phytoplankton production can be limited by the availability of nutrients (Dugdale and Goering, 1967), among which nitrogen is generally in shortest supply relative to its utilization in the marine environment (Ryther and Dunston, 1971).

In the middle shelf area of the southeastern Bering Sea, the amount of mixing between the upper and lower parts of the water column assumes a dominant role in controlling the temporal development of the spring diatom bloom. Due to nitrate's simultaneous nutritive importance and dependence on vertical mixing processes to reach the trophogenic zone, rates of nitrate uptake are a sensitive indicator of the physical - biological development taking place during the spring bloom period. Also of importance in the analysis of higher trophic levels, nitrate uptake is proportional to the total amount of primary production taking place.

Most of the data presented are from Station 12 (depth 77 m) located ca. 25 km inshore from the middle front on the main PROBES line (Figure 1). For clarity the results of these time series can be organized by developmental periods demarcated by the physical and biological conditions in the water column. Prebloom periods are considered those in which little or no vertical structure is present in the profiles of temperature, Chl *a*, and nitrate. Peakbloom conditions are the relatively short lived periods which exhibit a surface (0-20 m) maximum in Chl *a*. The postbloom period follows after the exhaustion of mixed layer nitrate.

This sequence is responsible for the "pulsed" production observed on high latitude shelves (Figure 3). At the end of winter and throughout most of April, the mixed layer was relatively deep, often encompassing the entire water column which displayed little density structure and low Chl *a* levels (Figure 3). The lack of upper water stability at this time was also reflected by the usually homogeneous vertical distribution in temperature, Chl *a*, and nitrate.

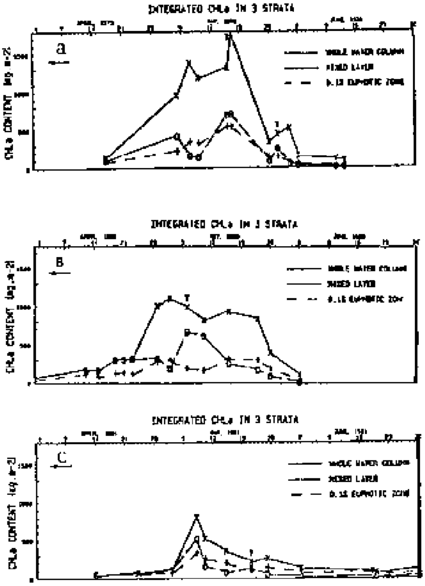

Figure 3. Time series of phytoplankton standing crop in three water column strata in A) 1979, B) 1980, and C) 1981.

In 1981, the observed path of low pressure centers coincided with the mean (along 40°N), keeping many storms out of the Bering Sea. In 1979 and 1980 these low pressure centers passed approximately 1000 km farther north than usual, driving more storms over the region. This resulted in generally greater wind speeds throughout the 1980 bloom period relative to 1981. Interannual variability was also recorded in the April water temperatures of this area. Mid April 1980 temperatures were significantly cooler than the other years. On a larger time and space scale, the May density structure variations observed here are related to short term (ca. years) climatic fluctuations that strongly affect the eastern Bering Sea. May is the transition period during which the water column changes from homogeneous to strongly stratified.

Throughout the deeply mixed prebloom period nitrate uptake rates and phytoplankton standing crop remain low. In Figure 3 the prebloom period is characterized by the mixed layer containing more Chl *a* than (i.e., being deeper than) the euphotic zone. Theoretically, net water column production begins when the ratio of the mixed layer depth to that of the critical depth (Sverdrup, 1952) becomes less than one, a development which preceded middle shelf sampling in all three years.

Peakbloom periods were brought on by the shoaling of the mixed layer above the bottom of the euphotic zone and coincided with a doubling of the upper water Chl *a* concentrations to maximum bloom values of $\sim$1000 mg m^{-2} (Figure 3). It is necessary in the following discussion to distinguish this high growth rate period from the preceding prebloom period in which net water column phytoplankton growth has taken place, but at a lower rate. The specific timing of the phytoplankton bloom periods was controlled by a hiatus in wind mixing events associated with low pressure systems moving through the area such as 29 April-2 May 1980 and 14-17 May 1980.

The requirement of mixed layer shallowing for optimal growth conditions is identical to the prerequisite identified for bloom initiation in the deeper areas of the Baltic (Kaiser and Schulz, 1978) and the North Sea (Williams and Lindley, 1980). It is also consistent with generally held concepts of water column stability and light interactions in the sea (Ryther, 1963).

The end of May marked the transition to post bloom water column conditions and after 1 June, surface bloom conditions ceased. Chl *a* values returned to early April levels (Figure 3), and nitrate was not observed in the mixed layer after June. After nitrate is exhausted in the mixed layer during the peak bloom period, continued new productivity depends on the supply of nutrients from deeper water. This supply is hampered, however, by the intensifying pycnocline, a situation which develops by late May in the middle shelf area.

The calm 1981 conditions may have been responsible for the shallow nitrate nutricline found in early June. For example, the 2 mg-at m^{-3} isopleth in early June 1981 was at 18 m, while in 1979 and 1980 it was at 25 and 26 m respectively. The favorable light level at which this 1981 middle shelf nitracline existed may have played a role in the occurrence of a pronounced subsurface Chl *a* maximum found at 20 to 30 m throughout June. A similar June Chl *a* layer was not found in postbloom 1980 stations although sampling was not continued as long as in 1981.

Spring Production as a Continuous Function of Upper Water Mixing

Nutrient effects have been treated quantitatively using nutrient limitation factors in models of phytoplankton growth (Steele and Menzel, 1962). Also the dependence of productivity of a vertical diffusive nutrient flux in water columns containing a pycnocline has been investigated (Eppley *et al.*, 1979). The latter approach was based on the stability of the upper water column and suggests diminished mixing not only minimizes respirational losses, but restricts nutrient supply. Nitrate uptake, therefore, should follow the development of upper water buoyancy from respiration limited through nutrient limited bloom phases.

A schematic interpretation of the dependence of nitrate uptake on upper water mixing is shown in Figure 4. Nitrate uptake can be effected positively or negatively by increased mixing. For example, a mixing event during the respiration limited phase would decrease nitrate uptake (arrow A indicates the actual change during the early May 1980 storm). Mixing during nutrient limitation, on the other hand, would restore higher nitrate uptake (arrow B indicates the estimated changes during the mid-May 1979 storm). The solid arrowhead indicates the point of nitrate depletion from the mixed layer which separates the respiration limited from the nutrient limited phases and marks the termination of peak bloom conditions. The postbloom restriction of nitrate uptake in the mixed layer is pictured as an exponential decay function (arrow C indicates the net change from 10 May to 2 June 1981).

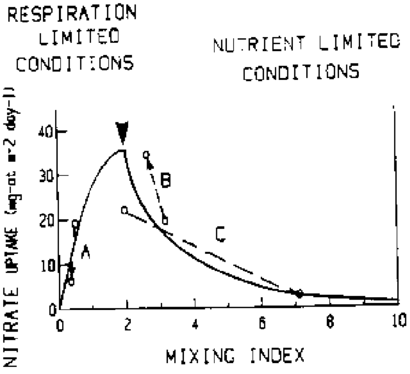

Figure 4. Schematic interpretation of the developmental relationship between mixing and nitrate uptake.

Conditions of peak productivity occur in a physically defined "window" between the large respirational losses which occur in the low-stability, pre-bloom water column and the more stable nutrient-limited conditions of the post-bloom water column. The window restricts the bloom to a brief time period by the relatively rapid transition from a respiration limited to a nutrient limited water column. Surface bloom conditions represent the temporal interface between these two types of limitation to growth, both of which are dependent on the degree of upper water column stability. This "window" is largely defined by the wind mixing conditions during the bloom period (May in the middle shelf area).

Several examples of the effect of wind mixing on nitrate productivity were observed during the PROBES project. A 24 hr. station occupied on 16-17 May 1979 documented a wind mixing event caused by the 20 knot winds associated with this mid-May storm. The prestorm conditions are depicted in Figure 5. Just prior to the storm, postbloom conditions prevailed, and most of the Chl *a* had accumulated in a subsurface layer. The subsequent storm was neither long lived or extremely intense but wind mixing was sufficient to deepen the mixed layer to 23 m on 17 May

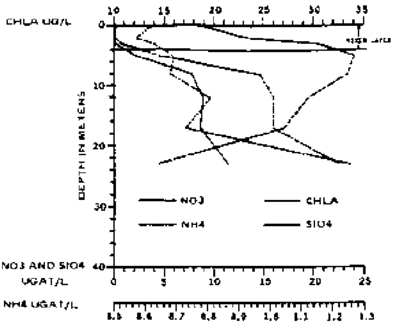

Figure 5. Vertical structure of Chl *a* and nutrients at a post-bloom station just before a storm.

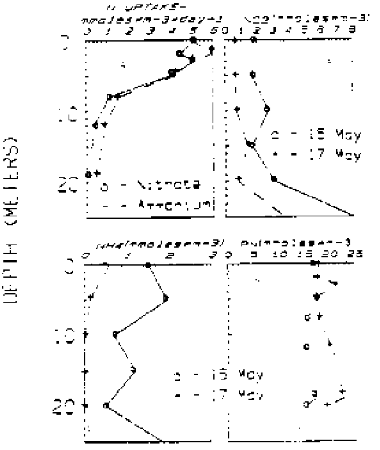

Figure 6. Predicted nitrogen uptake and observed changes in dissolved and particulate nitrogen during 24 hr. period of active mixing.

1979 and bring about significant changes in phytoplankton growth (Figure 6).

During this entrainment event, the measured decreases in nitrate and ammonium content of the upper 25 m corresponded to the ^{15}N measured rates of uptake of these nitrogen compounds (ΔNO_3^- = 38.3 mg-at m^{-2} day^{-1}, ρNO_3^- = 36.4 mg-at m^{-2} day^{-1}). Also, the total ^{15}N measured transport rates approached the observed 24 hr. change in particulate nitrogen (90 mg-at m^{-2}). The nitrate uptake rates measured at this time were the highest observed during 1979. The stimulatory effect of this wind mixing on phytoplankton growth is also supported by the time series of integrated water column Chl *a* (Figure 3) which reached the highest amount recorded over the three year study period. In Figure 3a the mixing event stands out as the point at which the mixed layer Chl *a* content surpassed that of the euphotic zone; a situation indicative of prebloom conditions.

Yearly Variation in Production

Table 1 organizes the various methods used to estimate primary productivity during this study by shelf domain. Station 12 represents the middle domain and Station 5 the outer. Nitrate productivity is estimated from the time and depth integrated $\rho^{15}NO_3^-$ measurements and the net water column change in nitrate content. For comparison, carbon productivity from the ^{14}C technique is included from data collected by Dr. Richard Iverson (personal communication).

The two estimates of nitrate productivity agree closely in each year on the middle shelf (Station 12) and suggest 690 mg-at m^{-2} is the average nitrate consumption during the spring bloom period on the middle shelf. The time integrated ^{14}C estimates of spring bloom production display the greatest interannual variability, but on average during the spring bloom period, carbon productivity is 100 g m^{-2} (R. Iverson, personal communication).

Table 1. Comparison among years and methods of measuring productivity in the middle and outer shelves during the spring bloom[a].

		$\int_{\rho}{}^{15}NO_3^-$	$\Delta\int NO_3^-$	Ave.	Estimated Net Production (P_N) g C m^{-2}		
Station	Year	mg at m^{-2}		$\frac{C}{N}$	Carbon budget	^{15}N	^{14}C
12	1979	920	830	5	-	109.8	74.9
	1980	670	710	7	98.7	105.8	134.2
	1981	484	500	8.8	83.2	105.6	48.2
$\bar{X}$ ± S.D.		691±219	680±167		91±11	107±2	86±44
5	1979	-	600	6.6[b]	-	91[c]	-
	1980	-	990	10.6	89	250[c]	99
	1981	-	390	6.7	91	71[c]	73
$\bar{X}$ ± S.D.			660±304		90±1	137±48	86±18

[a] All estimates applied to 25 April-2 June of each year.
[b] Assumed.
[c] Based on $\Delta\int NO_3^-$.

The courser sampling done at the outer shelf Station 5 may be largely responsible for the greater spread in the productivity estimates here (Table 1). The frequency of productivity estimates at Station 5, for example, averaged 19 days, compared to 5 days at Station 12. It is better to judge cross shelf patterns in nitrate uptake, therefore, from changes in mixed layer nitrate concentrations which were more frequently sampled. Based on these measurements, there is no significant difference between middle and outer shelf productivity during the spring bloom.

October productivity data are available from 1980, and chemical and Chl *a* data exist from NOAA cruises at other times of the year. Estimates of yearly production can therefore also be made. Nitrogen productivity data were extrapolated from the June postbloom conditions on the middle shelf to the cessation of phytoplankton activity in November. The result when converted to carbon (188 g C m^{-2} yr^{-1}), is in good agreement with the ^{14}C derived estimate of 166 g C m^{-2} yr^{-1} (R. Iverson, personal communication). Judging from observed cross shelf and temporal patterns of productivity, these yearly productivity values are applicable from approximately the 60 m depth out to 130 m, or almost 60% of the shelf area.

Estimates of spring bloom nitrate uptake indicate that nitrate uptake in 1981 was far less than during May 1980 in both the middle and outer shelf reference stations (Table 1). A similar discrepancy between 1980 and 1981 exists in the cross shelf intensity and persistence of the phytoplankton standing crop. It appears that differences in the amount of wind generated entrainment during May are responsible for the interannual variability of shelf nitrogen productivity. The mixing conditions in May 1980 were also associated with much higher ^{14}C productivities than were the calmer 1981 conditions.

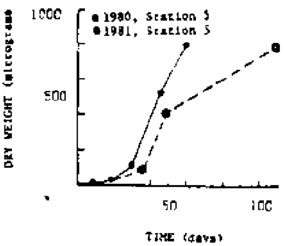

Figure 7. Growth rate of *Neocalanus plumchrus* at outer shelf Station 5 in 1980 and 1981. (From Smith and Vidal, in press).

The extensive zooplankton data collected by the PROBES project also reveals interannual variation (Dagg *et al.*, 1982; Smith and Vidal, submitted; Vidal and Smith, submitted). Selected zooplankton distributions presented by Smith and Vidal (1982) appear to be closely associated with the bio-physical relationships observed in the cross shelf patterns of primary production. For example, the mean abundance and growth rate of the larger outer shelf taxa such as *Neocalanus plumchrus* and *Neocalanus cristatus* was greater in 1980 than in 1981 (Figure 7). Interannual temperature variations probably are not responsible since water temperatures were actually slightly cooler in 1980 and this would slow growth rates. However, food abundance and/or food quality may have played an important role in regulating population size and growth.

The larger standing crops supported by the more extensive nitrate resupply in 1980 may have provided a greater abundance of food for the large bodied outer shelf herbivores. This is a possible explanation for the greater growth rates observed in 1980. Also, higher concentrations of phaeophytin were observed in outer domain waters during May of 1980 than in 1981. This suggests an interannual difference in zooplankton food processing since phaeopigments have been shown to be a useful index of zooplankton grazing activity (Therriault and Platt, 1978).

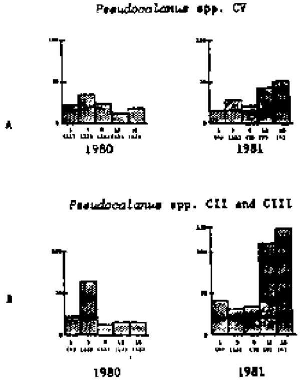

Figure 8. Mean abundance (number/m^{-3}) over the upper 120 m for *Pseudocalanus* spp. on the shelf of the southeastern Bering Sea in 1980 and 1981 (20 April-7 June). Data from Smith and Vidal (in press).

The amount of primary production reaching the benthos would similarly be dependent on prolonged mixing. In any year much of the primary production on this shelf reaches the bottom. The amount of organic matter reaching the benthos, therefore, varies among years in direct proportion to surface production. Caution, however, must be used in the generalization of the above relationships. For example, the mean abundance of *Pseudocalanus* spp. during spring and summer was on average much greater over the middle shelf domain Stations 12 and 16 in 1981 than 1980 (Figure 8). The difference in abundance was particularly large for copepodid stages II and III which were present in much higher numbers during the calm 1981 conditions. This relationship may be due to the association of *Pseudocalanus* spp. with the subsurface Chl *a* layers which were much more pronounced and extensive in 1981 than they were in 1980 (Figure 9). The water stratum just above such layers is commonly associated with relative maxima in zooplankton abundance (Herman, 1983). In the southeast Bering Sea, these layers are the basis for an extremely active layer of pelagic trophic transfer which includes the larvae of the walleye pollock (Nishiyama and Hirano, 1982) and perhaps crab larvae as well. The dependence of larval fish survival with such layers has also been documented in other areas (Lasker, 1975).

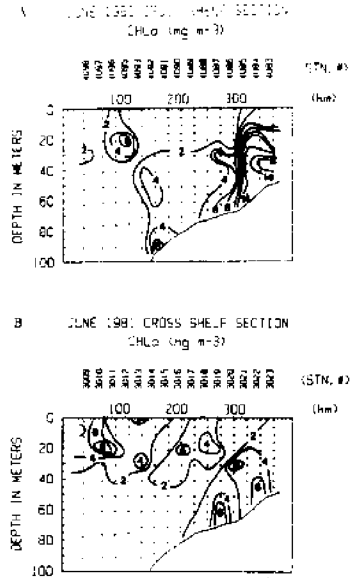

Figure 9. Comparison of early June cross shelf Chl *a* in (A) 1980 and B) 1981.

Interannual differences in wind mixing, therefore, may impact selected food chains in quite different ways. Years in which frequent storms pass over the southeast Bering Sea in May and June, such as in 1980, generate relatively high production and may increase the total organic matter flux to the benthos and the growth rates of water column grazers such as *N. plumchrus*. In the absence of these storms, as in 1981, calm conditions promote the development of sub-surface Chl *a* maxima and their associated food chains as typified by *Pseudocalanus* spp.

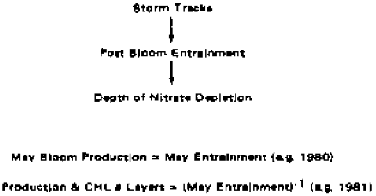

Figure 10. Proposed hierarchy of meteorology over the intensity and pattern of spring primary production.

The hypothesized hierarchy of environmental influences on shelf biology is diagrammed in Figure 10. The intensity and spatial and temporal extent of storm activity may play an important role in interannual differences in pollock year classes. This suggests that biological production on a high latitude shelf such as the eastern Bering Sea responds to large scale (e.g., North Pacific) climatic variations, and that these interannual variations may effect food chains of interest to man.

The Production Regime of the Northern Part of the Eastern Bering Sea Shelf: A Second Example of Oceanographic Bio-Physical Interaction

The analysis of bio-physical interactions can be extended to other ocean areas as well. In this respect it is informative to contrast the dominant physical features influencing the southeastern shelf with those dominating the production patterns observed in the Bering Strait

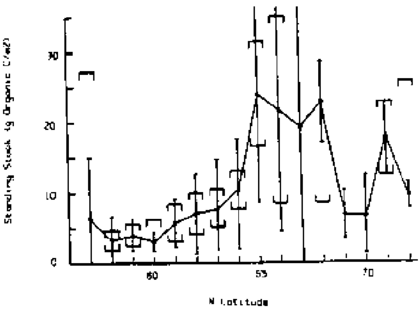

Figure 11. Relationship of benthic biomass (g organic C m^{-2}) to latitude (°N) on the Bering/Chukchi shelf (after Stoker, 1981).

area. Previous work suggests that there is a significant difference between the two areas. Figure 11 is a reproduction from Stoker (1981) which indicates that the benthic standing stock is much greater in the area of the strait than it is farther south. Presumably the production pattern in the overlying water also reflects this difference.

Figure 1 indicates that unlike the middle domain of the southeastern shelf, advection is a much more significant feature of the northern shelf area. Current measurements in the area suggest the average flow for the year through Bering Strait is approximately 0.8 Sverdrups and is somewhat higher in summer (Coachman and Aagaard, 1981). The water passing through the strait has three major components (Coachman *et al.*, 1975). In the west, the flow is dominated by relatively cold, high salinity water from the Gulf of Anadyr. This flow appears to be a continuation of the shelf break current which has turned north at Cape Navarin (Figure 1). In the east, warmer coastal water dominated by Yukon river discharge flows out of Norton Sound.

These two flows show up clearly on a temperature enhanced image of the area (Figure 12). In this July, 1977 photograph, the surface "Gulf of Anadyr water" in the western strait was recorded at 3-4°, while the warmer eastern flow was 9-12°. Actually salinity is a more reliable criterion for distinguishing the water masses since the Gulf of Anadyr water has a higher salinity due to its slope water origin. Also recorded in Figure 12 is the flow of water north around the eastern end of St. Lawrence Island. This may originate from "modified shelf water" south of St. Lawrence, which is the third water mass moving through the strait identified by Coachman *et al.*, (1975). However there is evidence that much of this flow is also composed of Gulf of Anadyr water.

An important characteristic of the Gulf of Anadyr water is its high nutrient content. Data from Husby and Hufford (1969), Kinney *et al.*, (1970), and Coyle (1981) indicate that this flow is associated with much higher nitrate levels than the Yukon river influenced water in the east. This western flow, therefore, represents a continuous supply of nutrients to the shallow Bering Strait area throughout the summer.

The advective nutrient supply to the western Bering Strait was associated with markedly greater production on a recent NSF sponsored cruise (15-21 August 1983) in the area (Figure 13). The coverage (which unfortunately did not include the entire western side) indicates that total standing crop increased as the colder, more saline and nutrient rich Gulf of Anadyr water was encountered. Unlike much of the southern shelf in which a lack of vertical turbulence fosters nutrient limitation after an initial spring bloom, the nutrient rich flow in the

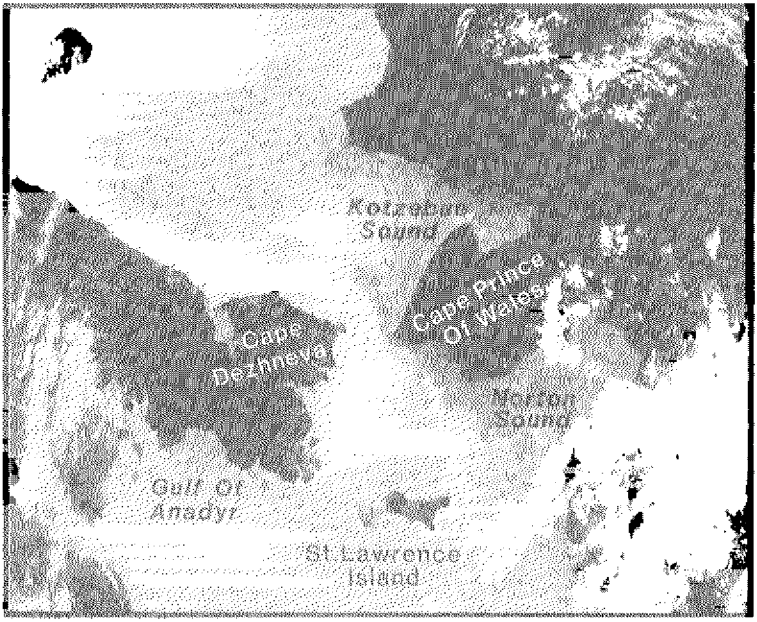

Figure 12. Temperature enhanced satellite image of Bering Strait area in July. The whitish plume passing near Cape Dezhneva was ∿3.3°C while the coastal water near Cape Prince of Wales (which appears darker in this image) was 11.7°C.

western Bering Strait appears to support substantial phytoplankton growth throughout the summer.

The remaining limitation to total yearly phytoplankton growth in the western strait area is the length of time suitable water column light conditions prevail (this is analogous to a terrestrial growing season). The seasonal extent of suitable conditions can be estimated from the "respiration index" which integrates mixing conditions, daily light, and a photosynthetic parameter. Figure 14 depicts the changes in the respiration index and daily light during the year in the vicinity of Bering Strait. Due to the relatively shallow water depth over most of the area (∿40-50 m) changes in daily light are responsible for most of the variation in this index of growth conditions. Values of the respiration index below 0.3 indicate extremely favorable growth conditions and prevail from April to September. The ice typically leaves the strait by June and does not return until December. This "ice reduced growing season" from June to September therefore, would be the period actually available for active water column phytoplankton growth.

In the presence of favorable light conditions, the "upshelf" flow of the nutrient rich Gulf of Anadyr water creates a situation analogous to a laboratory "continuous culture" of algae. This analogy is useful since it permits the relationships derived from continuous culture studies to be applied to the production system in this area. The analogy serves as a conceptual model only and it is recognized that the

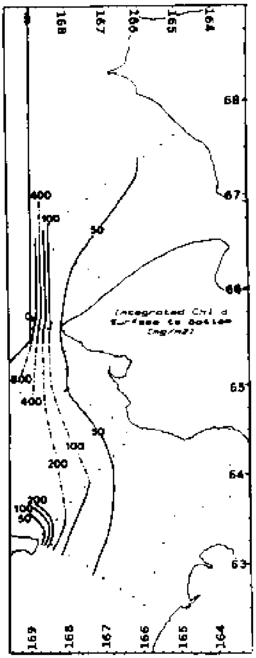

Figure 13. Integrated water column Chl *a* content in eastern Bering Strait area during August, 1983.

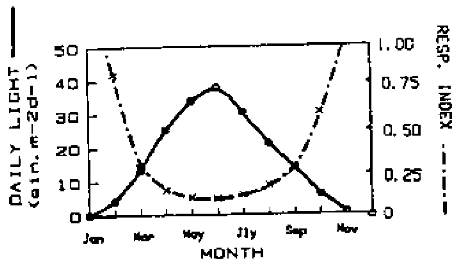

Figure 14. Seasonal variation in daily light and respiration index (an indicator of phytoplankton growth conditions) in Bering Strait.

natural system is much more complex than the carefully defined conditions existing in a laboratory continuous culture (Jannasch, 1974). However, such a model has been applied to systems outside the laboratory before (Gaudy and Gaudy, 1966).

Essentially, a continuous culture consists of microorganisms in a reaction vessel which are maintained at some selected growth rate by the continuous addition of nutrients and removal of cell yield. We suspect the cold plume of water exiting the Gulf of Anadyr through the western Bering Strait (Figure 12) functions much like a reaction vessel for phytoplankton growth over the summer months. It is most convenient to use nitrate utilization in the plume to follow phytoplankton activity. The simplifying assumption is made that all the nitrate used comes from the Gulf of Anadyr flow and is in some part consumed during the northward movement of this water mass. A mass balance relationship can then be formulated:

$$\rho NO_3^- = \Delta NO_3^- \frac{\text{Flow}}{\text{Area}} \qquad (1)$$

In which ρNO_3^- is the areal nitrate utilization rate (mg-at m^{-2} d^{-1}), and ΔNO_3^- is the decrease in average water column nitrate concentration from the Anadyr Strait to latitude 66°42'N (∿6 mg-at m^{-3}). The latter parameter was obtained from the data of Husby and Hufford (1969). The flow was derived from the summer transport rates through the Bering Strait given by Coachman and Aagaard (1981) (∿1.3 Sv). It was assumed that the Gulf of Anadyr flow comprised ∿60% of this transport while the remaining flow was Alaskan coastal and modified shelf water (Coachman *et al.*, 1975) which was not considered in the calculation. The area used was the typical extent of the Gulf of Anadyr water in the area of Bering Strait as interpreted from the available oceanographic data.

The resulting areal nitrate utilization rate for the area ($\sim$19 mg-at m^{-2} d^{-1}) is moderately large relative to the range of values recorded throughout the bloom in the southeastern shelf (Figure 4). Assuming nitrate supplies half of the nitrogen demand of the phytoplankton (the rest being derived from regenerated sources) this figure can be converted to an equivalent carbon productivity of $\sim$ 3.2 g C m^{-2} d^{-1}. This is in the range of ^{14}C productivity values of 2.05 g C m^{-2} d^{-1} measured in this water mass during the August NSF sponsored cruise and 4.0 g C m^{-2} d^{-1} measured by McRoy and Goering (1976) in this area.

If this level of production (3.2 g C m^{-2} d^{-1}) is maintained over the April-September period, the yearly production in this area would be approximately 380 g C m^{-2}, significantly higher than the southeastern shelf. Also, since most of the biomass produced reaches the bottom in such shallow water, the "cell yield" of this continuous culture system would largely end up in benthic food chains. The unusual oceanographic features found in this area therefore, can account for the large increase in benthic standing stock in Bering Strait (Figure 11).

A comparison among several shelf areas in which the production regime has been studied is presented in Table 2. Table 2 indicates that the yearly production varies a great deal among these shelves. The large yearly production of the western Bering Strait region is unusual considering the latitude at which it takes place. The production in both Bering Strait and the Georges Bank area is linked directly to physical oceanographic processes which keep the euphotic zone supplied with nutrients. This point can be illustrated by computing the "vertical mixing index" for each area. This index is defined as:

$$\frac{\rho NO_3^- - \text{winter } NO_3^- \text{ store}}{\text{growing season} * [NO_3^-]_{\text{bottom water}}} \qquad (2)$$

In equation 2 ρNO_3^- is the yearly amount of nitrate utilization (mg-at m^{-2}). The winter store of nitrate is the amount present in the upper water ($\sim$40 m; mg-at m^{-2}) at the end of winter at high latitudes.

Table 2. Comparison of the production regimes of several shelf areas.

Shelf area	Yearly Prod. (g C m^{-2})	F Factor	Growing Season[a] (days)	Vert. Mix. Index (m d^{-1})	Benthic flux (g C m^{-2})
Georges Bank	375[b]	0.50	240	0.93	200[c]
New York Bight	250[d]	0.44	240	0.45	115[c]
Western Bering St.	380	0.50	120	0.80	340
Southeast Bering Sea (middle shelf)	170	0.40	160	0.17	150[e]
Peru	1000	0.50	365	1.24	-

[a] The length of time a stable, ice free water column exists.
[b] Cohen *et al.*, 1982.
[c] Dagg and Turner, 1982
[d] P. Falkowski, personal communication cited in c.
[e] Dagg *et al.*, 1982.

Assuming there is no lateral advection of nitrate the difference must come from vertical mixing. The numerator therefore is normalized to the length of the growing season (days) and the nitrate concentration of the source water being mixed into the euphotic zone (mg-at m^{-3}) to yield a rate of mixing in m day^{-1}. Yearly nitrate utilization can be estimated from carbon productivity if the f factor (the ratio of nitrate to total productivity) is known. On this basis, it is clear that the physics controlling deep water supply also control production, even though these shelves are not influenced by the classic upwelling mechanisms of lower latitude shelves such as that off Peru.

Also significant in Table 2 is the large percentage of production we estimate reaches the bottom in the shallow western Bering Strait area. We suspect that, as in the middle shelf domain of the southeastern Bering shelf, zooplankton grazing is a negligible sink for primary production in Bering Strait. The large standing stock of benthic organisms in the Strait is a manifestation of these specific production conditions.

Summary

The overriding importance of physical oceanographic factors on the production regimes of high latitude shelves is responsible for much of the spatial-temporal variation in production. Approaching higher trophic level production from this aspect offers a means of elucidating the underlying mechanisms responsible for the observed correlation of climatic factors and variations in commercially important fish stocks. Since the physical oceanography of the southeast Bering Sea is so strongly influenced by storms for example, special attention should be given to the analysis of meteorological-fisheries interactions. Atmospheric pressure patterns also influence the flow of water through the Bering Strait causing episodic flow reversals (Coachman and Aagaard, 1981). The food webs in this area are less well known, but some effect of these reversals on higher trophic levels could be expected.

These proposed interactions can be summarized in the form of questions which need to be addressed:

1) Do the yearly meteorological conditions (number of storms, their direction and intensity) have a significant direct impact on selected fish stocks?

2) If a relationship can be found in question #1, what mechanisms underlie the observed correlation?

3) What is the greatest fluctuation in fish stocks which could be expected due to environmental variability?

The response of population growth and recruitment to climatic variation would be useful information in fisheries management. Ideally catch quotas should accurately reflect and anticipate the actual variations in stock size instead of being based on some average value. Alternatively, if no clear impact of climatic variation on pollock or herring stocks for example, can be discerned, useful information will have been generated. The lack of fish stock response would suggest that density dependent effects such as predation are more important in determining recruitment strength than are direct environmental forces during the larval stage.

It would be significant if given meteorological conditions were found to impact discrete food webs differently. Presumably the response of the benthos would differ from that of pelagic food chains in response to variations in the quantity and pattern of plankton production.

Acknowledgments

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Research and Commercial Fisheries Data Bases for Eastern Bering Sea Groundfish

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Abstract

Commercial groundfish fisheries of a substantial nature began in the eastern Bering Sea in 1954. Catches peaked at 2.5 million metric tons (t) in 1972, but declined to 1.3 million t in 1981 due to restrictions placed on the fishery as evidence of declining stock abundances became available. As the fishery grew to major proportions, systematic research vessel surveys were conducted to monitor the condition of the groundfish resources.

Resource assessment surveys were initially small-scale efforts conducted by research agencies from the United States and Japan. In 1975 and in most subsequent years, the Northwest and Alaska Fisheries Center expanded their surveys to sample a major portion of the distribution of species on the eastern Bering Sea continental shelf. Since 1979, most of these annual surveys have been coordinated efforts with the Fishery Agency of Japan which has provided sampling of resources on the continental slope. The incorporation of hydroacoustic-midwater trawl techniques into the surveys in 1979 and 1982 have also provided overall assessments of the walleye pollock (Theragra chalcogramma) gramma) population.

Japan began to report detailed catch and effort data for their groundfish fishery in the Bering Sea in 1964. Following implementation of the Magnuson Fishery Conservation and Management Act in 1977, other fishing nations have also been required to report similar data. Since the mid-1970s, the U.S. Observer Program has provided excellent biological data on principal species of groundfish taken in the foreign fisheries.

Existing resource assessment and fisheries data bases have revealed dramatic changes in the groundfish complex since the early 1970s.

The abundance of walleye pollock, which is the single most abundant species in the complex, has shown remarkable stability through most of this period. However, recent data suggest the population may be entering a period of major fluctuations in year-class strength. The data base has also shown a more than 10-fold increase in abundance of Pacific cod (Gadus macrocephalus) and a more than 4-fold increase in yellowfin sole (Limanda aspera) and Alaska plaice (Pleuronectes quadrituberculatus) in this period. Most of the resources appear to be in good condition with the exception of Pacific ocean perch (Sebastes alutus) and sablefish (Anoplopoma fimbria). The abundance of the sampled groundfish complex showed an apparent increase in biomass from 4.4 million t in 1975 to 7.1 million t in 1979 and has remained at the higher level.

Current research on the groundfish complex involves continued development and study of the fishery and survey data bases to monitor the condition of the resources and study population dynamics. Special studies are directed at understanding the stock structure of principal species through tagging and genetic studies, trophic and species assemblege studies to define interrelationships between species, and studies to examine the relationship between the physical environment and the distribution of groundfish as well as the success of recruitment.

Introduction

Existing data bases available at the Northwest and Alaska Fisheries Center (NWAFC) on eastern Bering Sea groundfish consist of two types; those from samples of the commercial catch and those from research vessel surveys. Time series of catch, effort, and biological data have been collected by foreign governments from their fisheries and submitted to the United States and, in recent years, these data have also been collected in the fisheries by the U.S. Observer Program. Research vessel data bases exist from a number of government agencies that have operated research vessels in the eastern Bering Sea. For many years, these agencies operated independently but recently there has been greater coordination of survey activities that have provided more comprehensive assessments of the groundfish resources in this region.

This report describes the research and commercial fisheries data bases available for eastern Bering Sea groundfish on the computer system at the NWAFC. The report will also describe findings from the data bases in terms of magnitude of the groundfish resources in the eastern Bering Sea and observed changes in the resources over the period 1975-82 and and current research that is being conducted on the resources.

Commercial Fisheries Data Bases

History of groundfish fisheries

The commercial fishery for groundfish in the eastern Bering Sea is about 100 years old. A handline fishery for Pacific cod (Gadus macrocephalus) began on a regular annual basis in 1882 (Cobb, 1927). This fishery continued until 1950 but throughout its history was a relatively small-scale effort with a peak annual catch of about 14,000 metric tons (t).

The next fishery to develop in the eastern Bering Sea was a setline fishery for Pacific halibut (Hippoglossus stenolepis). This fishery has continued to the present time and has also represented a rather minor fishery with peak catches of 4,900 t in 1963 (Myhre et al., 1977).

The first trawl fishery for groundfish in the eastern Bering Sea was a Japanese effort which operated during the 1930s (Forrester et al., 1978). Following an exploratory effort by two trawlers in 1930, a mothership-catcher boat operation began in waters off Bristol Bay in 1933 and returned each year until 1937. This fishery targeted walleye pollock (Theragra chalcogramma) and flounders for fish meal with a peak annual catch during this period of 43,400 t. In 1940-41, the Japanese conducted a second mothership operation targeting yellowfin sole (Limanda aspera) for human consumption. Catches were about 10,000 t each year.

Groundfish trawl fisheries were resumed in the eastern Bering Sea following World War II. Japan initiated these fisheries in 1954 but was soon followed by commercial vessels from the U.S.S.R. in 1958 and later by vessels from the Republic of Korea (ROK) in 1967, Taiwan in 1974, Poland in 1979, and the Federal Republic of Germany (West Germany) in 1980. U.S. trawlers entered the fisheries in 1977 and have delivered catches to both domestic processers and foreign processing vessels in joint venture operations. Japanese and U.S.S.R. fisheries initially targeted on yellowfin sole but later diversified into a number of components targeting various species.

Trends in catches of groundfish in the eastern Bering Sea during the history of the modern day fisheries (1954-82) are illustrated in Figure 1. Total catches of groundfish have reached two peaks. The first and smaller peak occurred during 1960-62 when Japan and the U.S.S.R. were intensively exploiting yellowfin sole and other flounders for fish meal. Total estimated catches of yellowfin sole and other species reached a peak of 715,000 t in 1961. Following the development of shipboard methods of producing surimi (minced fish) in 1964, the Japanese fishery for walleye pollock developed rapidly and groundfish catches rose to a second, much higher peak of over 2.0 million t per year in 1971-73. Since then, catches have declined to an average of about 1.2 million t because of restrictions stemming from evidence of declining stock abundance of pollock and other species.

Japan has taken the major share of the groundfish catches in the eastern Bering Sea, usually accounting for 80 to 90% of the total catches each year (Fig. 1).

Data reported by fishing nations

Catch data from the early years of eastern Bering Sea groundfish fisheries are reported by Forrester et al. (1978). It was not until 1964 that detailed catch and effort and biological data were first reported, and then only from Japanese fisheries. Japanese fisheries have accounted for a high proportion of the groundfish catch, however, and this 19-year time series of data has proven extremely valuable in assessing the condition of walleye pollock and other target species of the fishery.

The data base consists of catch and effort and length-frequency data.

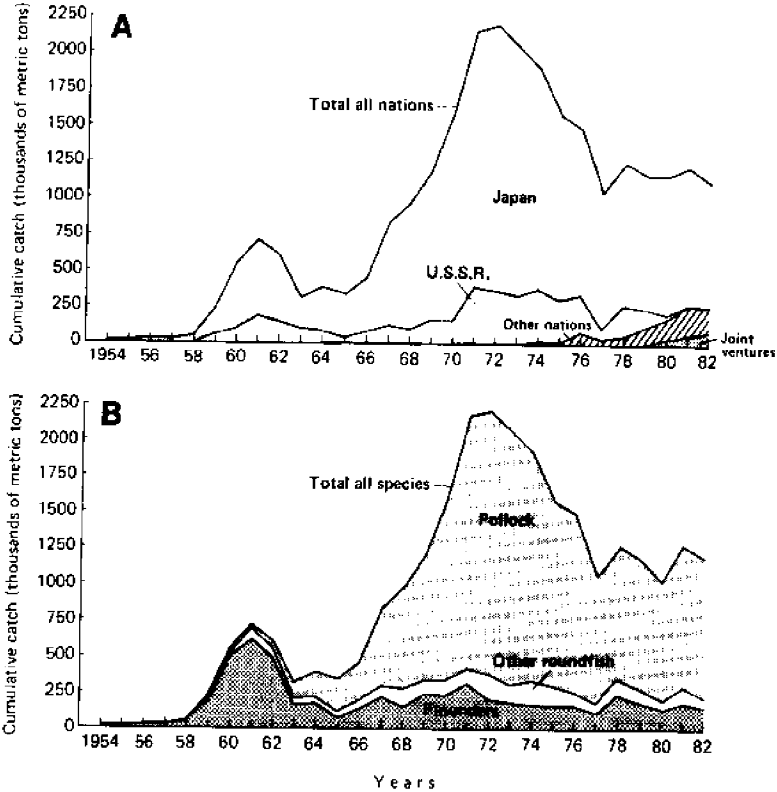


Figure 1.--Catches of groundfish in the eastern Bering Sea by nation and species, 1954-82.

The catch and effort data is detailed. It is reported by species, type of fishing gear, vessel size, month, 1/2° of latitude, and 1° of longitude. Figure 2 illustrates the degree of detail available from the data base. The figure illustrates total annual catches of Pacific cod in each 1/2° latitude and 1° longitude block, but the data base can be used to determine the monthly species composition and relative abundance of individual species within each of these statistical blocks. Size composition of principal species in the catches is also available (Table 1).

Data Collected by U.S. Observers

The National Marine Fisheries Service (NMFS) began to place U.S. observers aboard foreign groundfish vessels in 1973. The primary purpose of this program was to obtain data on the incidental catch of species of particular interest to U.S. fisheries such as Pacific halibut, salmon (Oncorhynchus sp.), and crab (Paralithodes sp., Chionoecetes sp., and others) (Nelson et al., 1981). Since the program's inception, however, observers have also collected catch and effort, species composition, and biological data on species taken in the commercial catch. This program has grown into a major source of data for groundfish and provides a convenient method of obtaining special data and specimen samples.

The proportion of the fishery covered by the U.S. Observer Program is shown in Table 2. Figures are not available for years prior to 1977 but the coverage was less than 5% annually in that period. In 1977, 5.6% of the vessel months were covered by observers and coverage was increased to range between 8.3 and 12.3% in 1978-81. Coverage increased significantly to 29.3% in 1982 and is scheduled to be 100% by 1984.

Numbers of fish measured and age structures collected by observers each year in 1973-82 are listed in Table 3. In the early years of the program, these collections were relatively substantial for some of the major species such as pollock and yellowfin sole, but for other species the collections were often small and taken irregularly.

Following implementation of the Magnuson Fishery Conservation and Management Act in 1977, the magnitude of the collection increased markedly and all of the principal, commercially important species taken were consistently sampled each year. By 1982, over a million fish were measured and 26,000 age structures collected by the observers. Thus, the commercial catch in the eastern Bering Sea is extremely well monitored by the Observer Program and provides an excellent source of data for assessing the condition of the exploited stocks.

Research vessel data bases

Research vessel investigations in the eastern Bering Sea date back to 1880 when the U. S. Fish Commission's steamer Albatross explored this region for commercial concentrations of Pacific cod (Rathbun, 1894). Like this first exploratory effort, objectives of research surveys prior to the 1950s were primarily directed toward assisting the development of commercial fisheries. With the development and intensification of commercial fisheries in the eastern Bering Sea in the 1950s

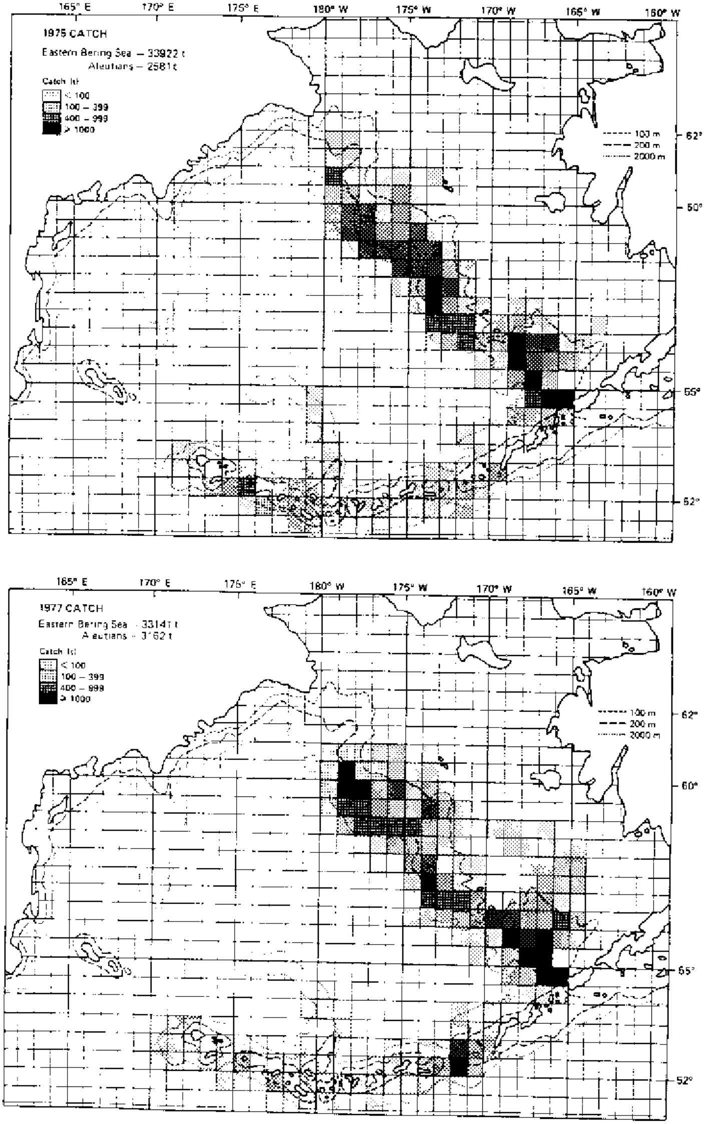


Figure 2.--Distribution of catches of Pacific cod by Japanese fisheries in 1975 and 1977.

Table 1.--Numbers of length measurements by year and species taken by Japan and other nations from samples of their commercial catches in the eastern Bering Sea.

	Species											
Year	Walleye pollock	Pacific cod	Sablefish	Pacific ocean perch	Herring	Yellowfin sole	Rock sole	Flathead sole	Alaska plaice	Turbot	Pacific cod	Total
1964	17,434	3,100	4,703	8,902		26,898	1,462	4,593	896	5,454	768	74,210
1965	46,642	3,031	7,577	4,813	463	4,323	416	1,031		24,313	632	93,241
1966	22,689	12,832	8,325	14,029		17,491	10,087	5,320	644	36,412	464	128,293
1967	44,255	15,217	14,367	6,486		17,392	7,186	6,329	2,054	4,783		118,069
1968	64,902	8,881		8,125	13,832	6,068	4,047	8,088		1,735	511	116,189
1969	77,391	1,549	3,720	4,270		7,991	2,352	1,985		772		100,030
1970	144,775	390	3,946	5,261		9,320	6,370	646				170,708
1971	174,072	3,537	1,532	431	7,737	23,366	5,864	3,153				219,692
1972	149,124	267	750		6,094	9,501	10,407	872				177,015
1973	209,529	1,823	98	5,516		14,431	1,664	4,631				237,692
1974	232,843	43				3,959	6,211	658	203			243,917
1975	207,797	793		3,296		13,323	2,580	3,697				231,486
1976	267,255	244				11,876	1,100	1,059				281,534
1977	176,414					11,194	3,690	911				192,209
1978	152,632	465	353	620		13,668			33			167,771
1979	132,518	1,157	4,790	6,378		8,046						152,889
1980	144,817	1,683	12,472	533		1,705						161,210
1981	133,923	1,170				20,674		1,706				157,473

Table 2.--Percentage U.S. observer coverage of foreign groundfish vessels in the eastern Bering Sea and Aleutian Islands region, 1977-82.

Year	Nation	Observer months	Vessel months	Percent coverage
1977	Japan	41.1	914.1	4.5
	U.S.S.R.	14.0	114.5	12.2
	R.O.K[a]	4.2	23.8	17.6
	Taiwan	0	2.9	0
	All nations	59.3	1,055.3	5.6
1978	Japan	96.6	1,068.5	9.0
	U.S.S.R.	15.8	207.2	7.6
	R.O.K.	5.3	63.4	8.4
	Taiwan	0	7.5	0
	All nations	117.7	1,346.6	8.7
1979	Japan	112.6	960.8	11.7
	U.S.S.R.	20.8	138.7	15.0
	R.O.K.	13.3	96.8	13.7
	Taiwan	0	7.3	0
	Poland	4.0	20.2	19.8
	All nations	150.7	1,223.8	12.3
1980	Japan	74.2	998.4	7.4
	U.S.S.R.	0.2	3.9	5.1
	R.O.K.	12.8	142.6	9.0
	Taiwan	0	10.9	0
	Poland	7.6	60.6	12.5
	West Germany	0.8	3.8	21.1
	Joint ventures[b]	8.7	29.9	29.1
	All nations	104.3	1,250.1	8.3
1981	Japan	76.2	913.8	8.3
	R.O.K.	19.4	119.8	16.2
	Taiwan	0	11.2	0
	Poland	11.5	62.0	18.5
	West Germany	0.9	9.6	9.4
	Joint ventures	10.4	47.7	21.8
	All nations	118.4	1,164.1	10.2
1982	Japan	235.7	875.2	26.9
	R.O.K.	42.0	129.9	32.3
	Taiwan	3.3	14.8	22.3
	West Germany	5.3	7.1	74.6
	Joint ventures	28.8	46.6	61.8
	All nations	315.1	1,073.6	29.3

[a] Republic of Korea.

[b] Joint ventures involving U.S. catcher boats delivering catches to foreign vessels.

Table 3.--Numbers of length measurements and age structures collected by the U.S. Observer Program in the eastern Bering Sea, 1973-82.

Species	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
	Number of length measurements									
Walleye pollock	22,973	35,241	17,058	31,420	125,197	170,324	261,555	184,249	234,510	523,035
Pacific cod		132		334	2,695	12,363	17,222	19,603	24,795	73,473
Sablefish					376	1,120	9,475	13,946	9,144	46,756
Pacific ocean perch		84	1		1,059	7,926	1,061		1,502	
Shortraker rockfish						935	508			
Shortspine thornyhead						756	26	490	16	390
Yellowfin sole	2,306	1,876	3,223	5,723	12,025	46,734	41,410	41,811	43,789	132,655
Rock sole	1,057	354	330	122	2,007	5,994	7,558	3,737	2,985	3,343
Flathead sole	32		2,014	124	9,117	10,473	17,791	5,828	8,930	2,779
Alaska plaice	575	139	981	490		5,687	584	9,550	3,141	7,100
Greenland turbot			1,116		10,734	49,521	64,129	30,841	59,655	266,103
Arrowtooth flounder	28				1,429	12,185	5,792	9,790	6,269	27,436
Pacific halibut	548	5,378	868	3,239	5,407	11,478	18,359	23,181	24,271	53,375
Total	27,519	43,204	25,591	41,452	170,046	335,496	445,470	343,026	419,007	1,136,445
	Number of age structures									
Walleye pollock	3,212	2,348	2,189	4,622	6,430	10,897	13,845	10,437	10,057	11,722
Pacific cod		159	311	362	1,033	803	1,559	1,803	1,872	964
Sablefish					274	274	1,155	1,868	982	2,509
Pacific ocean perch		84	20		135	655	281		171	
Shortraker rockfish						138	10			
Shortspine thornyhead					2	138		150		
Yellowfin sole	486	227	223	401	689	1,620	2,392	2,086	1,660	2,731
Rock sole	139	109	117	9	430	460	391	292	121	230
Flathead sole		8	464	128	791	662	1,012	614	490	
Alaska plaice	59	80	172	2		564	7,522	487	209	253
Greenland turbot			275		1,118	3,552	4,503	2,935	4,254	5,962
Arrowtooth flounder		126			230	878	608	2,089	845	1,726
Pacific halibut										
Total	3,896	3,141	3,771	5,524	11,132	20,641	33,278	22,761	20,661	26,097

and 1960s, research surveys began to be conducted in a more systematic manner to provide better information on the biological characteristics and abundance of the resources. Extensive investigations by the Soviet Union in 1957-63, although primarily directed toward determining the extent and potential of groundfish for commercial exploitation, provided the first important biological information on the resources (Moiseev, 1963-65, 1970). The U.S.S.R. continued to collect data on groundfish in subsequent years and annual surveys were initiated by the Japan Fisheries Agency (JFA) and the International Pacific Halibut Commission (IPHC) in the early 1960s and by the NWAFC in the early 1970s. These agencies operated independently, surveying only portions of the eastern Bering Sea, and frequently different portions of the region each year; therefore, an overall understanding of the resources was not easily developed from these data. In 1975, through joint funding by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) and the NWAFC, research vessel effort of sufficient magnitude was made available to survey the major portion of the eastern Bering Sea continental shelf (Pereyra et al., 1976). This and later surveys of similar or greater magnitude conducted by the NWAFC and cooperating foreign vessels have increased knowledge of eastern Bering Sea groundfish very substantially since the mid-1970s and provided comprehensive data bases on the resources.

Listed in Table 4 are data bases from surveys by the NWAFC and other agencies available on the NWAFC computer system. A brief description of these data bases is given below.

International Pacific Halibut Commission (IPHC) surveys

The IPHC was the first research agency to initiate systematic surveys of groundfish in the eastern Bering Sea starting in 1963. These surveys continued annually except for 1964 until 1982 (Best, 1969a, 1969b, 1974; Best and Hardman, 1982). The target species for these surveys was Pacific halibut but catch data were also collected for other species of fish taken during the surveys.

Figure 3 illustrates the station patterns of the IPHC surveys annually through 1978. In some early years of the surveys, sampling was relatively extensive covering broad areas of the eastern Bering Sea continental shelf north to Nunivak Island and beyond. Since the early 1970s, however, the surveys have been limited to a relatively small area along the north side of the Alaska Peninsula for the purpose of indexing the abundance of juvenile halibut.

The IPHC data base contains station data including position, date, depth, duration of tows, and bottom, surface, and air temperature. The catch data consist of weights but not numbers of groundfish and commercially important species of invertebrates taken at each station. No biological data were taken for species other than Pacific halibut.

Japan Fishery Agency (JFA) data bases

Research vessels from Japan began to conduct demersal trawl groundfish surveys in the eastern Bering Sea in 1966. These surveys continued annually until 1978 except for 1972. (Chikuni, 1971, 1975; Sasaki, 1977; Takahashi, 1971; Wakabayashi, 1972a, 1972b, 1977; Wakabayashi et

Table 4.--Research vessel survey data from the eastern Bering Sea available on the Northwest and Alaska Fisheries Center computer system.

Year	Agency[a]	Dates	Target species	Number of stations	Number catch records	Number of fish measured[b]	Number of specimen records[b,c]
1963	IPHC	5/19-8/12	Halibut	99	1,107	--	--
1965	IPHC	6/12-8/27	Halibut	204	1,914	--	--
1966	IPHC	6/2-8/19	Halibut	105	865	--	--
	JFA	5/18-7/18	Groundfish	134	1,166	2,775	--
1967	IPHC	5/31-7/29	Halibut	147	1,117	--	--
	JFA	7/2-9/5	Groundfish	106	1,023	3,059	--
1968	IPHC	6/1-7/10	Halibut	83	683	--	--
	JFA	6/21-7/20	Groundfish	148	1,335	4,980	--
1969	IPHC	6/1-6/25	Halibut	62	532	--	--
	JFA	6/30-9/6	Groundfish	224	2,524	8,162	--
1970	IPHC	5/31-6/29	Halibut	104	860	--	--
	JFA	7/2-8/2	Groundfish	124	1,381	7,042	--
1971	IPHC	6/6-8/9	Halibut	147	1,327	--	--
	JFA	5/30-6/30	Groundfish	152	1,717	9,599	--
	NWAFC	7/23-8/31	Groundfish	52	1,162	2,041	1,458
1972	IPHC	6/6-6/27	Halibut	69	496	--	0
	NWAFC	5/28-7/24	Groundfish	103	2,203	7,500	1,466
1973	IPHC	6/18-6/29	Halibut	38	307	--	--
	JFA	5/2-6/24	Groundfish	117	1,306	6,335	--
	NWAFC	6/26-8/12	Groundfish	157	3,436	5,686	1,301
1974	IPHC	6/2-6/10	Halibut	44	360	--	--
	JFA	5/5-6/11	Groundfish	64	958	1,458	--
	NWAFC	6/14-8/1	Groundfish	198	4,359	12,470	2,070
1975	IPHC	6/2-6/14	Halibut	53	354	--	--
	JFA	5/4-7/3	Groundfish	123	1,298	2,926	--
	NWAFC	6/1-10/20	Groundfish	809	16,436	46,240	13,687
1976	IPHC	6/4-6/19	Halibut	77	379	--	--
	JFA	5/13-7/4	Groundfish	104	984	3,515	--
	NWAFC	4/1-8/9	Groundfish	683	13,719	37,247	15,149
1977	IPHC	6/6-6/19	Halibut	48	551	1,727	566
	JFA	6/3-7/25	Groundfish	60	576	2,942	--
	NWAFC	6/4-8/5	Groundfish	173	3,784	8,311	2,031
1978	IPHC	6/6-6/17	Halibut	236	1,842	--	--
	JFA	5/4-7/15	Groundfish	168	2,470	49,959	--
	NWAFC	2/11-3/9	Herring	41	462	1,654	728
	NWAFC	5/20-8/16	Groundfish	316	7,758	28,014	3,951
1979	NWAFC-JFA	5/22-8/24	Groundfish	1,101	21,827	123,297	17,519
1980	NWAFC	1/25-2/13	Herring	17	90	395	--
	NWAFC	5/23-7/30	Groundfish	386	8,499	32,305	5,401
1981	NWAFC	2/11-2/24	Groundfish	70	984	6,990	515
	NWAFC-JFA	5/22-8/11	Groundfish	678	12,501	76,676	3,580
	NWAFC	9/21-10/6	Herring	93	822	3,165	--
	NWAFC	10/14-11/4	Groundfish-mammal	41	807	3,811	1,034
1982	NWAFC	4/22-5/6	Spawning pollock	25	93	793	2,631
	NWAFC-JFA-USSR	5/29-11/9	Groundfish	1,075	17,129	108,784	9,978
	NWAFC	9/11-9/18	Ocean front-groundfish	31	595	2,623	--
	NWAFC	9/22-10/3	Cod-pollock tagging	85	207	--	--
	NWAFC		Groundfish-mammal	54	1,180	5,592	291

[a] Agencies are: International Pacific Halibut Commission (IPHC), Japan Fisheries Agency (JFA), and Northwest and Alaska Fisheries Center (NWAFC).

[b] Dash indicates no data taken or not on the NWAFC computer system.

[c] Mainly age readings.

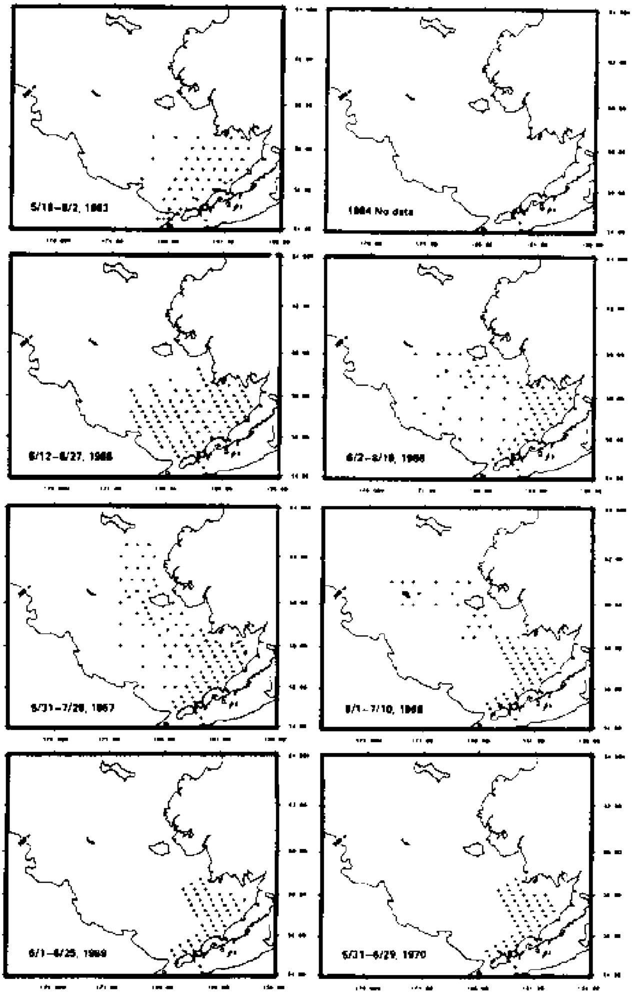


Figure 3.--Station pattern of demersal trawl surveys by the International Pacific Halibut Commission, 1963-78.

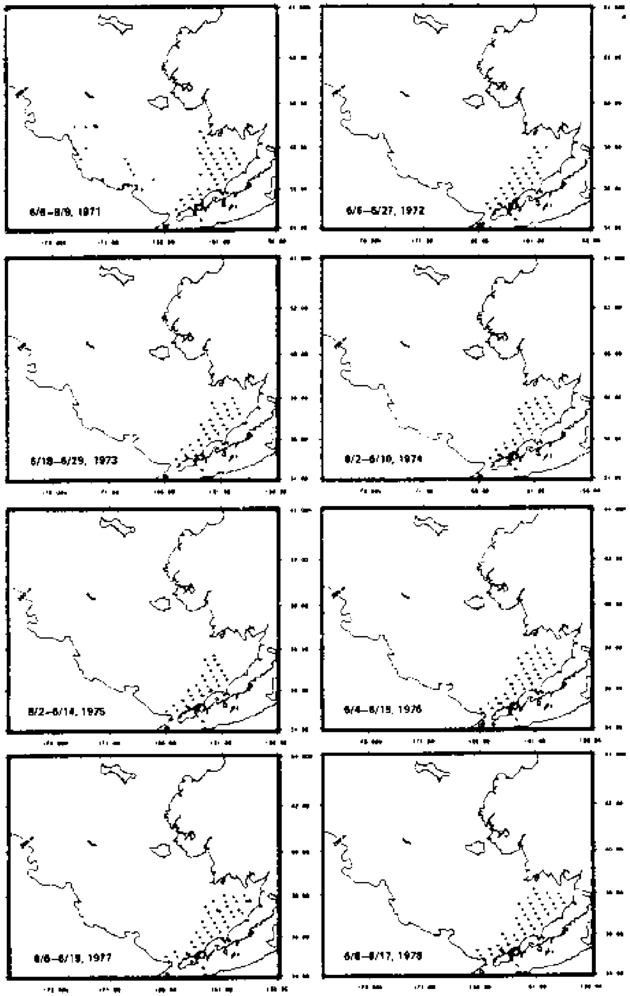


Figure 3.--Cont'd.

al., 1977; Wakabayashi and Yabe, 1981; Yamaguchi, 1972, 1975, Yamaguchi and Kihara, 1978). Thereafter, the Fishery Agency and the NWAFC conducted cooperative surveys which are discussed later in this report. Station patterns of the Japanese surveys in 1966-78 are illustrated in Figure 4. Like the IPHC surveys, the JFA sampling areas in the eastern Bering Sea were variable but generally more extensive than sampling by the IPHC vessels. In some years, the Japanese concentrated effort on the inner shelf (1967-70), and in other years on the outer shelf (1973-74); but sampling of groundfish in the southeast Bering Sea was fairly comprehensive in 1966, 1971, 1974-76, and 1978.

Data collected during the Japanese surveys were comprehensive. The station data consist of starting position, date, time, duration, direction, and depth of the tow. Surface to bottom temperature profiles were also taken at some stations by Expendable Bathythermograph (XBT) casts and surface temperatures were recorded at every station.

Catch weights are given for all principal species and species groups of fish but not numbers of fish. Catch data are also given for octopus, squid, and shrimp by weight, and for species of crab in numbers of individuals. Extensive size-composition data are also available for major commercially important species of demersal fish.

U.S.S.R. data bases

Data collected by Soviet research vessels are generally not available on the NWAFC computer system. Only 1982 data are available when a U.S.S.R. research vessel cooperated with U.S. and Japanese vessels in a joint survey. The 1982 Soviet data are mainly from west of the U.S.-U.S.S.R convention line extending to Soviet coastal waters of the Gulf of Anadyr and west of Cape Navarin. As previously mentioned, the Soviets conducted extensive demersal trawl surveys in the period 1957-62, but the exact nature of these surveys is not clear from reported results (Moiseev, 1963-65, 1970). Any survey work conducted between the early 1960s and the late 1970s has not been reported to the best of our knowledge.

During recent years, U.S.S.R scientists have presented results of their surveys in the eastern Bering Sea in reports submitted during U.S.-U.S.S.R. bilateral meetings. These reports mainly present results of hydroacoustic and ichthyoplankton surveys of spawning pollock but some results of demersal trawl surveys are also reported (Bulatov, 1979, 1981, 1982; Moiseev and Bulatov, 1979; Fadeev et al., 1983).

Northwest and Alaska Fisheries Center data bases

The NWAFC began the collection of catch and biological data for groundfish in 1971. The 1971 and 1972 survey areas were limited in scope (Fig. 5). In 1973, a broader area of the southeastern Bering Sea was surveyed extending from inner Bristol Bay to the shelf edge including waters surrounding the Pribilof Islands (Fig. 6). The area was established as an index area and has been consistently sampled every year since 1973 to provide a 10-year time series of data on the fish and invertebrate resources in this region. Although this comparative fishing area has proven valuable in assessing the abundance and biological condition of a number of species, it has been inadequate for assessing other species, notably walleye pollock which range widely

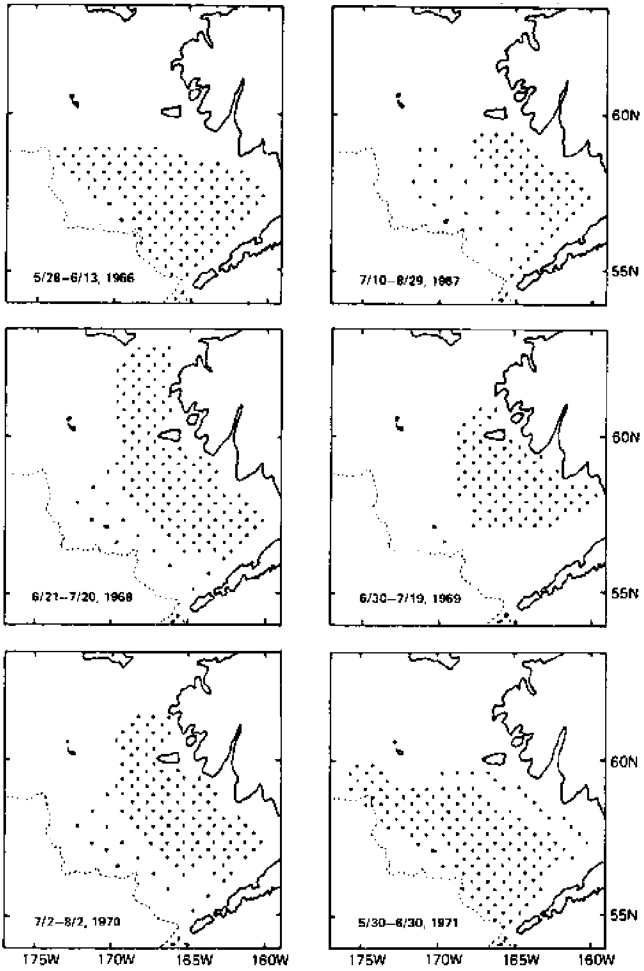
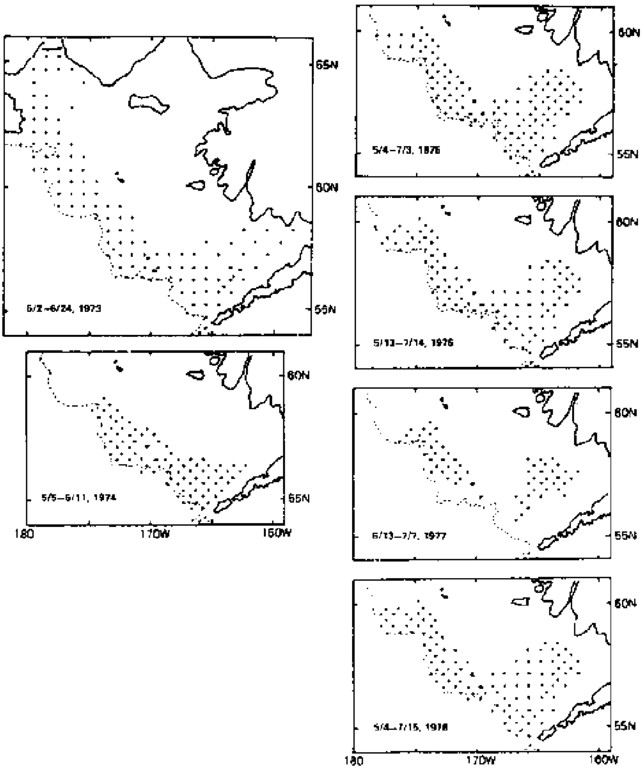


Figure 4.--Station pattern of demersal trawl surveys by the Fishery Agency of Japan, 1966-78.



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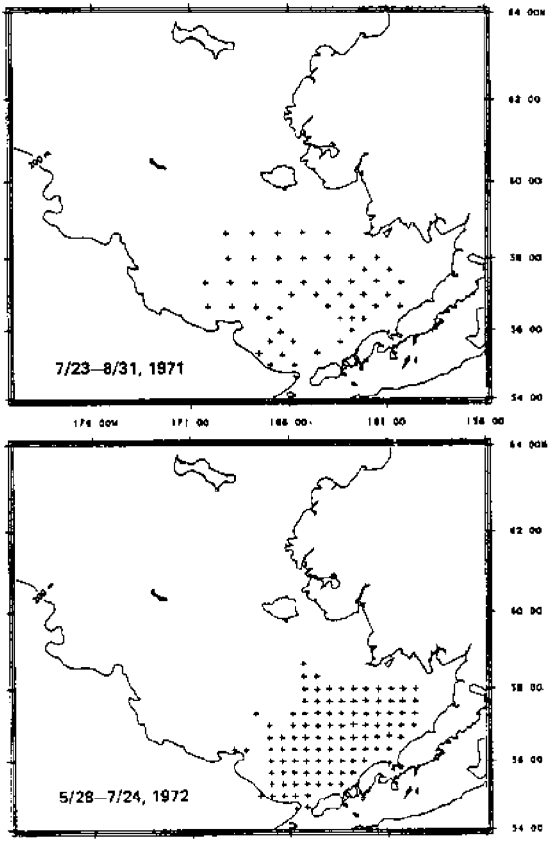

Figure 5.--Station pattern of demersal trawl surveys by the Northwest and Alaska Fisheries Center in 1971 and 1972.

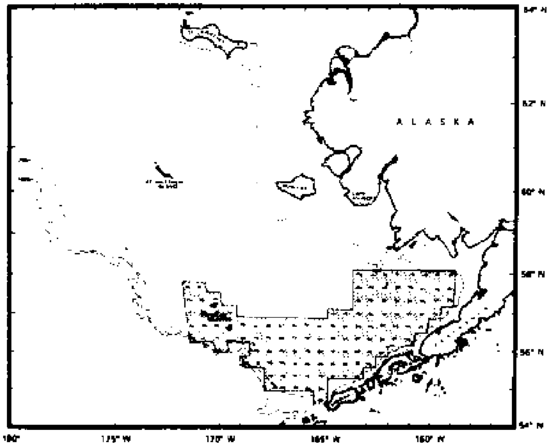

Figure 6.--Comparative fishing area sampled annually during Northwest and Alaska Fisheries Center demersal trawl surveys in 1973-82.

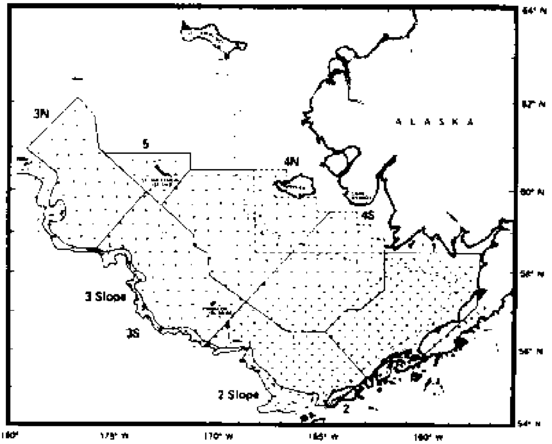

Figure 7.--Area of the eastern Bering Sea generally sampled during large-scale surveys by the Northwest and Alaska Fisheries Center in 1975 and 1979-82. Area within the dashed lines was not sampled during the 1981 survey.

throughout the eastern Bering Sea.

In 1975, as a result of OCSEAP's need for information on the fisheries resources throughout the eastern Bering Sea, the NWAFC survey area was expanded to the approximate area shown in Figure 7. Data from the 1975 survey demonstrated the inadequacy of the comparative fishing area in the southeast Bering Sea for assessing certain species and led to the sampling of the larger survey area shown in Figure 7 in most subsequent years. Smaller areas were surveyed in 1976, 1977, and 1978 (Fig. 8).

Survey activity was further expanded in 1979 through the cooperation of Japanese research vessels and the incorporation of hydroacoustic-midwater trawling techniques (Bakkala and Wakabayashi, 1983). Beside the sampling of the major portion of the eastern Bering Sea continental shelf, resources occupying the region between the latitudes of St. Matthew and St. Lawrence Islands were surveyed for the first time, as were the demersal resource of the continental slope through the efforts of the Japanese research vessels. In addition, the first hydroacoustic assessment of midwater concentrations of pollock were carried out over the outer continental shelf and slope.

Comprehensive surveys like the 1979 survey are planned every 3 years in the eastern Bering Sea. The second of these triennial surveys was carried out in 1982. The 1982 survey represented the broadest sampling effort yet carried out in this region (Fig. 9). U.S. research vessels sampled continental shelf waters from the Alaska Peninsula north to Norton Sound. A Japanese research vessel intensively sampled continental slope waters and a cooperating U.S.S.R. research vessel sampled waters west of the U.S.-U.S.S.R. Convention Line to coastal waters of Siberia.

The data bases resulting from the independent NWAFC and cooperative surveys contain standard station data including date, time, depth, duration, distance towed, positions in terms of both latitude and longitude, and Loran coordinates. Catches aboard U.S. vessels were processed and numbers and weights of each species in the catch determined. Also available are length-frequency data and age-length keys for all major, commercially important species (Table 4).

Applications of data bases

Data bases available from the commercial fishery since 1964 have proven valuable for assessing the condition of target species of the fishery such as walleye pollock, yellowfin sole, Pacific ocean perch, and sablefish (Bakkala and Low, 1983). They have not proven reliable for estimating abundance of nontarget species. The value of fishery data for assessing the abundance of Pacific ocean perch and sablefish has declined because these species have become mainly nontarget species as a result of their low abundance. Research vessel surveys have provided assessment data for nontarget species of the fishery as well as independent assessments of target species. Although survey data is available since the early 1960s, the variability and limited scope of the survey activity and data collections in the 1960s and early 1970s restricted the usefulness of these data.

It was not until the NWAFC began to conduct large-scale surveys and sample major portions of the eastern Bering Sea in 1975 and later years

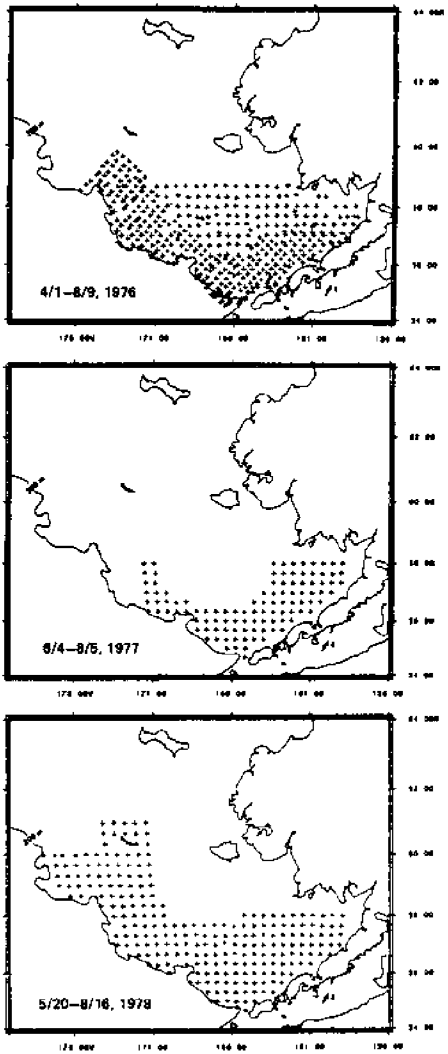

Figure 8.--Area of the eastern Bering Sea surveyed with demersal trawls by the Northwest and Alaska Fisheries Center in 1976-78.

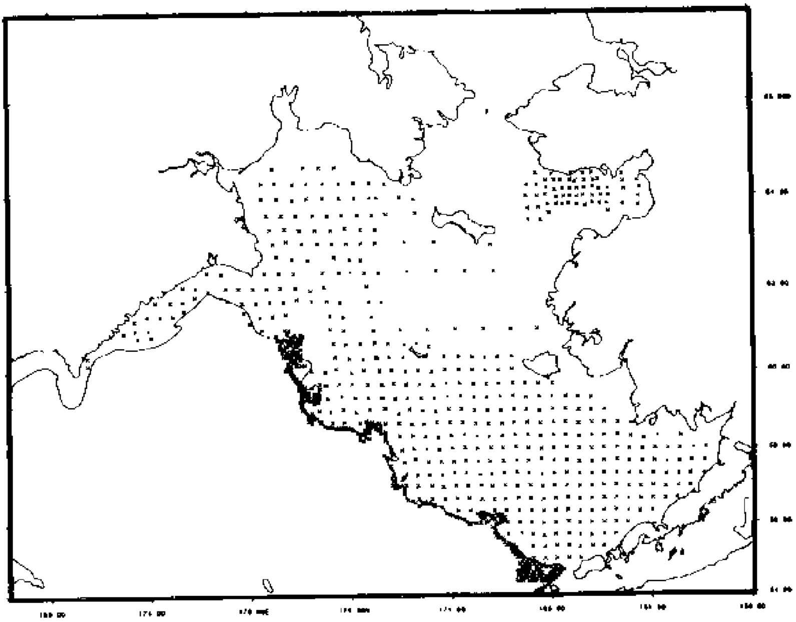

Figure 9.--Areas of the Bering Sea sampled in 1982 by cooperating vessels from the United States, Japan, and the U.S.S.R.

that a more comprehensive understanding of the resources began to be realized. The distribution, biology, and population dynamics of principal species have become more clearly understood though the cooperation of Japanese research vessels which have provided good assessment of the continental slope resources and the use of hydroacoustic-midwater trawling techniques for overall assessments of the pollock resource.

In recent years, the data collected aboard research vessels and in the commercial fishery by foreign governments and the U.S. Observer Program have produced comprehensive data bases on the resources each year. These survey and fishery data are analyzed to prepare annual status of stock documents that are used by the North Pacific Fisheries Management Council to manage the stocks. The data are also used to provide the U.S. fishing industry with information on the distribution and abundance of species of interest and for various scientific studies.

Composition and dynamics of the demersal fish community as shown by research vessel data bases

Listed in Table 5 are biomass estimates for principal species and species groups of groundfish in the eastern Bering Sea as shown by large-scale NWAFC surveys in the years 1975 and 1979-82. It should be noted that the demersal trawl data do not provide true biomass estimates for semidemersal species such as walleye pollock and herring. For example, a combined demersal trawl-hydroacoustic survey indicated that the total biomass of pollock in the eastern Bering Sea in 1979 was approximately 11 million t while the NWAFC demersal trawl survey estimate was only 2.9 million t. The demersal trawl estimates are more representative of the true biomass for other species, particularly the flatfishes. Even in the case of these species, younger age groups are not fully recruited to the trawls and all fish in the path of the trawl may not be caught.

Of the various groundfish groups the biomass estimates for the sampled portion of the populations show that in the period 1975-81, the cods (Gadidae) dominated survey catches representing from 49 to 56% of the total sampled biomass; but by 1982, this family only represented 40% of the biomass estimated from the survey. The flatfish family (Pleuronectidae) was the second most important group in 1975-81 constituting 36-45% of groundfish catches, and in 1982 was the predominate group, accounting for 60% of the demersal fish catch. The cods and flatfishes combined usually accounted for over 90% of the total fish biomass. A third group, consisting of all other species, represented 6-11% of the total fish catches.

Walleye pollock was the single most abundant species of fish in the eastern Bering Sea although this was not always reflected by the demersal trawl data. In 1979, based on combined hydroacoustic and demersal trawl data, pollock represented 11 million t, or 67% of the total estimated fish biomass of 16 million t (Okada and Wakabayashi, 1983). Yellowfin sole has been the second most abundant species with biomass estimates ranging from about 1 million t in 1975 to over 3 million t in 1982. Other species were usually much less abundant, although the abundance of Pacific cod had increased to 1.0 million t in 1982 and the estimated biomass of rock sole (Lepidopsetta bilineata) and Alaska

Table 5.--Species composition and biomass estimates of groundfish in the eastern Bering Sea as shown by NWAFC survey data, 1975-82.

Species	1975		1979		1981		1982	
	Biomass	Proportion of total	Biomass	Proportion of total	Biomass	Proportion of total	Biomass	Proportion of total
Walleye Pollock	2,426,400	0.536	2,876,537	0.393	2,627,854	0.367	2,725,500	0.290
Pacific cod	64,500	0.014	733,797	0.100	860,168	0.120	1,013,714	0.108
Other cod	19,100	0.004	79,628	0.011	1,564	<0.001	1,921	<0.001
Total cods	2,510,000	0.555	3,689,962	0.504	3,489,586	0.487	3,741,135	0.399
Yellowfin sole	1,038,600	0.229	1,907,685	0.261	2,063,434	0.288	3,330,932	0.355
Rock sole	170,300	0.038	182,846	0.025	280,047	0.039	601,032	0.064
Flathead sole	113,000	0.025	101,830	0.014	161,102	0.022	200,999	0.021
Alaska plaice	127,300	0.028	282,952	0.039	438,899	0.061	643,252	0.069
Greenland turbot	126,700	0.028	143,283	0.020	78,652	0.011	37,142	0.004
Arrowtooth flounder	28,000	0.006	41,984	0.006	53,450	0.007	70,168	0.007
Pacific halibut	30,600	0.007	64,155	0.009	48,060	0.007	60,526	0.006
Other flatfish	11,100	0.002	72,087	0.010	72,952	0.010	152,305	0.016
Total flatfish	1,645,600	0.364	2,796,822	0.382	3,196,596	0.446	5,096,356	0.543
Sablefish	-[a]		42,743	0.006	8,736	0.001	6,891	0.001
Rockfish	-		5,278	0.001	634	<0.001	5,325	<0.001
Herring	-		11,957	0.002	1,690	<0.001	3,592	<0.001
Sculpins	122,548	0.027	269,206	0.037	154,214	0.022	223,489	0.024
Eelpouts	98,574	0.022	360,833	0.049	130,812	0.018	108,601	0.012
Skates	42,001	0.009	74,012	0.010	155,206	0.022	169,307	0.018
Poachers	12,842	0.003	28,182	0.004	11,455	0.002	13,742	0.001
Miscellaneous species	94,969	0.021	43,915	0.006	13,987	0.002	9,823	0.002
Total other roundfish	370,934	0.082	836,126	0.114	476,734	0.067	540,770	0.058
Total All Species	4,526,534	1.000	7,322,910	1.000	7,162,916	1.000	9,378,261	1.000

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[a] Dash indicates values not available for these species and biomass estimates if any are included in other species.

plaice had each increased to over 0.6 million t in 1982.

The biomass estimates from the demersal trawl surveys show marked changes in the composition of the groundfish complex over the period 1975-82. For the overall complex, biomass estimates approximately doubled from 4.5 million to 9.4 million t. Part of this increase is believed to have been caused by a change in trawl rigging prior to the 1982 survey which caused the trawls to fish harder on bottom than the previously rigged trawls (Bakkala and Low, 1983). This was evidenced by observations of greater amounts of bottom debris in catches in the newly rigged trawl than in trawls with the original rigging. More important evidence of the greater efficiency of the modified rigging was the substantial increase in abundance of flatfishes between the 1981 and 1982 surveys. The increases cannot be accounted for by recruitment and growth of the species alone. These observations indicate that trawls used in earlier years may not have been as efficient for flatfish as the 1982 trawls and therefore underestimated the biomass of these species in 1982. Thus, the increases in abundance shown by the survey data between 1975 and 1982 are probably not as large as they would appear, although large increases for some species have occurred. Catches of roundfish such as walleye pollock did not appear to be affected by the change in rigging.

The survey data in 1975 and 1981 can be used to illustrate changes in composition and abundance of the groundfish complex because the efficiency of trawls used in that period are believed to be approximately the same. The sampled biomass of all fish increased by about 2.6 million t in this period. Higher abundance of yellowfin sole accounted for about 1.0 million t of this increase while Pacific cod contributed about 0.8 million t. There were also substantial increases in some of the other flatfishes, particularly rock sole and Alaska plaice.

The abundance of pollock remained relatively stable between 1975 and 1982. This stability has also been reflected by measures of relative abundance obtained from commercial fishery data (Bakkala and Wespestad, 1983). However, abundance of pollock may decline in immediate future years because of the recruitment of three consecutive year-classes having lower than average abundance. These are the 1979, 1980, and 1981 year-classes. In 1983, these year-classes were 2-4 years old, ages which normally account for the principal portion of the commercial catch.

Current and Future Research Projects

The main focus of research by the NWAFC in the eastern Bering Sea in the immediate future will be the continued monitoring of demersal fishery resources through annual resource assessment surveys and data collection by the U.S. Observer Program. These annual assessments are required to provide current information on the resources for management purposes. The developing time series of survey data also provides information on the dynamics of the populations and changes in distribution resulting from variation in environmental conditions. The annual surveys and the U.S. Observer Program are also a source of data and samples for special research projects.

A special research project nearing completion is a food habits study on Pacific cod. Food habits studies are being continued through the collection of stomachs from a variety of species to study trophic relationships among demersal species in the eastern Bering Sea.

Another objective of current research is the study of stock structure of species in the region. These studies are presently targeting on Pacific cod and walleye pollock. In 1982, tagging studies were initiated on these two species. Tagging of cod proved to be successful and good results are being obtained from this study. Pollock proved difficult to tag and special studies are needed to develop techniques of tagging this species. Growth and genetic studies (using electrophoretic techniques) are other methods being used to study the stock structure of pollock in the eastern Bering Sea.

Electrophoretic techniques are also being used to determine whether specimens identified as arrowtooth flounder (Atheresthes stomias) actually consist of two species, arrowtooth flounder and Kamchatka flounder (Atheresthes evermanni). Similarly, electrophoretic techniques are being used to determine if specimens identified as flathead sole (Hippoglossoides elassodon) may include another species, Bering flounder (Hippoglosoides robustus).

The NWAFC is also beginning to investigate interrelationships of the environment and distribution of demersal fish. In 1982, a short, 2-week survey investigated the distribution of groundfish in relation to one of the ocean fronts located near the 100 m isobath in the southeast Bering Sea. The front was identified using a CTD (conductivity-temperature-depth) instrument and trawling was conducted on either side of the front. Some interesting observations were made. Species that are principally concentrated on the outer shelf, such as walleye pollock, had significantly lower catch rates on the inner side of the front, and species mainly distributed on the inner shelf, such as yellowfin sole, had significantly lower catch rates on the outer side of the front. These studies were continued in 1983 by making CTD casts throughout the survey from one of the two survey vessels. This will be the first broad-scale collection of temperature-salinity profiles in the eastern Bering Sea.

The future direction of research in the eastern Bering Sea is anticipated to be directed toward an understanding of the trophic relationship among species and of the influence of the environment on the resources. Efforts will also be directed toward predictions of yields one or more years in advance of species recruitment to the fisheries.

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Review of Existing Fisheries Management Programs in the Bering Sea, Including Utilization of Current Data Bases

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Abstract

This paper gives a brief perspective of the historical and existing system of fisheries management in the Bering Sea. The fisheries resources are managed by four main bodies. The International North Pacific Fisheries Commission manages the Japanese High Seas Mothership Fishery in the western Bering Sea. The International Pacific Halibut Commission sets regulations for the Halibut Set-line Fishery. The State of Alaska has continued to manage the Herring, Inshore Salmon, and King and Tanner Crab Fisheries with some coordination with the North Pacific Fishery Management Council. It is the Council, however, that has the dominant role in fisheries management under the authority granted by the Magnuson Fishery Conservation and Management Act. The Council manages the Groundfish Trawl Fishery which has far-reaching impacts on all the other resources, including marine mammals. Therefore, there is a special need to study marine mammal-fisheries interactions which is the main purpose of this workshop.

Introduction

The Bering Sea supports a rich array of marine life which are of great commercial, esthetic, and ecological value. Over 50 species of marine mammals are found here. Large numbers of sea birds from over 150 species breed and inhabit the area year-round; while others are transient in residence. Equally important are the abundant fish and shellfish resources, especially those in the south eastern Bering Sea. Salmon use the area as a feeding ground; Pacific halibut (*Hippoglossus stenolepis*) nurse here; and massive volumes of groundfish, herring (*Clupea harengus pallasi*), king crab, tanner crab, squid, and sea snails inhabit the area year-round. Together, they support some rather active commercial fisheries.

The fisheries presently catch more than 1 million tons of fish and shellfish annually. Historically catches have exceeded 2 million t. Their catch and fishing activities, therefore, require management. This paper will summarize the type of management programs designed to regulate the fisheries for different species at different times and some of their interactions. The roles of state, federal, and international bodies in their management will be noted, as well as the utility of data bases for decision making.

Resources and Fishing Areas

There are hundreds of species of fish and shellfish that are of reasonable abundance and occurrence in the eastern Bering Sea. They are all part of an intricate ecological network which is too complicated to track. The fish and shellfish resources that are of commercial importance, however, make up the bulk of the biota that appear to have the most direct and significant links to marine mammal and sea bird populations. These resources can be classified for discussion under the following categories--groundfish, pelagic fish, salmon, and crab and other shellfish.

Groundfish. The groundfish complex is the most abundant group of fisheries resource in the eastern Bering Sea. It supports a lucrative fishery capable of sustaining catches in excess of 2 million t per year. The dominant species are walleye pollock (*Theragra chalcogramma*), yellowfin sole (*Limanda aspera*), Pacific halibut (*Hippoglossus stenolepis*), Pacific cod (*Gadus macrocephalus*), sablefish (*Anoplopoma fimbria*), Pacific ocean perch (*Sebastes alutus*), and many other species of rockfish and flatfishes.

Although the groundfish resources are harvested as multispecies groups, the fisheries may be classified as follows:

(a) A Pacific halibut fishery conducted by U.S. setline vessels north of Unimak Island and the continental shelf and along the Aleutian Islands;

(b) A pollock fishery conducted by foreign motherships and large independent stern trawlers on the outer continental shelf and along the continental slope;

(c) A yellowfin sole fishery conducted by foreign motherships and large independent stern trawlers on the continental shelf;

(d) A Pacific cod and sablefish fishery conducted by foreign longline vessels over the continental slope and along the Aleutian Islands;

(e) A rockfish fishery conducted by foreign medium-size and small-size stern trawlers over the continental slope and along the Aleutian Islands;

(f) A general groundfish fishery for pollock, cod, rockfish, and flatfishes by foreign medium-size and small-size trawlers throughout the eastern Bering Sea;

(g) A yellowfin sole fishery conducted by domestic trawlers on the continental shelf north of the Alaska Peninsula; and

(h) A pollock-Pacific cod fishery conducted by domestic trawlers along the Aleutian chain and in the Bering Sea in the vicinity of Unimak Island.

The groundfish resources, in general, are harvested year-round in the eastern Bering Sea. Fishing activities, however, are more extensive and intensive in the warmer months from May to October. The setline fishery for halibut has definite short open fishing seasons, generally in the summer months.

Pelagic Fish. Herring (Clupea harengus pallasi) and Atka mackerel (Pleurogrammus monopterygius) are the only two pelagic species that support commercial fisheries in the eastern Bering Sea. Atka mackerel are taken in conjunction with the foreign trawl fisheries, mainly along the Aleutian Islands. Herring conduct definite seasonal migrations from the feeding grounds in open waters of the eastern Bering Sea to spawning grounds along the Alaskan coasts. As such, they can be harvested either at the time of spawning along the coastline or intercepted in the open seas. At present, herring are harvested inshore at the time of spawning by U.S. fishermen only; whereas, in the past, they were subject to exploitation by foreign vessels in the open seas.

Crabs and Shellfish. The major species subjected to commercial exploitation are king crab (mainly Paralithodes sp., and Tanner crab (Chionoecetes bairdi and C. opilio). Korean horse hair crabs (Erimacrus isenbeckii) are harvested on an experimental basis around the Pribilof Islands. Pink shrimp (Pandalus borealis) was an important commercial resource around the Pribilofs, but it is now low in abundance and does not support a fishery. Several species of sea snails, including Neptunia lyrata, are harvested by Japanese vessels in the continental shelf, primarily around the Pribilof Islands.

Red king crab (Paralithodes camtschatica) are harvested over the continental shelf north of the Alaska Peninsula, especially around the Pribilof islands, and in Norton Sound. Blue king crab (P. platypus) are lower in abundance and found in the same general vicinity as red king crab. Golden king crab (Lithodes aequispina) are sometimes harvested, but they are the least abundant and occur mainly in deeper waters where U.S. fishermen do not generally operate.

The distribution and fishery for Tanner crab overlap that of king crab. C. bairdi is more southerly in distribution than C. opilio The C. bairdi crab are of larger and preferred commercial size and are, therefore, harvested in greater quantities.

Salmon. Salmon are anadromous species that undertake long and definite migrations through the eastern Bering Sea. They spawn in bodies of fresh water in North America and the Asian continent. The offsprings migrate out into the open sea where they grow to adult size before returning to home streams for spawning. By virtue of their definite migratory pattern, the salmon may be harvested near shore as the fish return to spawn or they can be intercepted in the high seas. Such a high seas salmon fishery is conducted by Japan in the western Bering Sea (Figure 1). The catch are primarily Asiatic salmon, but some salmon of North American origin are intercepted there as well. The fishing season and area of the Japanese High Seas

Salmon Fishery are delineated by regulation under INPFC and bilateral arrangements between the U.S.S.R. and Japan.

The domestic fishery for salmon is conducted inshore when the salmon returns to spawn. It is the biggest fishing industry off Alaska and catches are closely regulated by the State of Alaska.

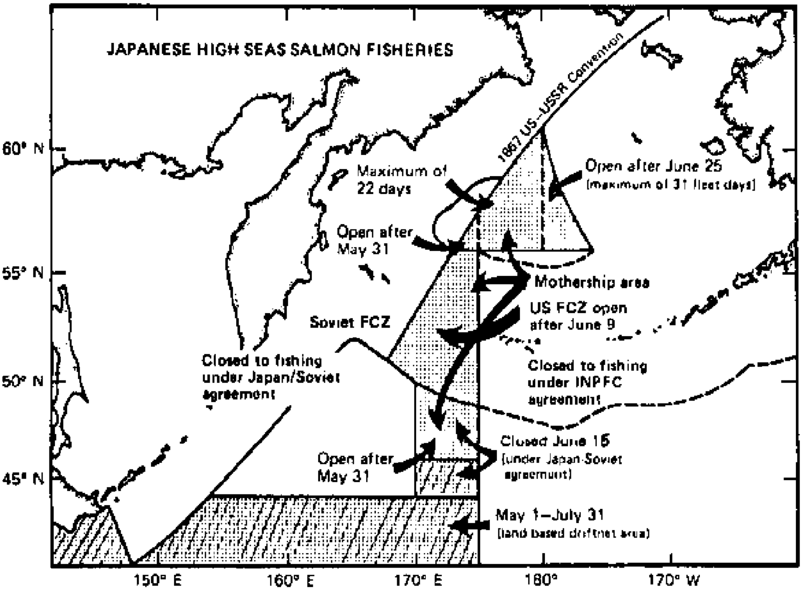

Figure 1. Areas of operation for the Japanese high seas salmon fishery.

Historical Perspective of Management Programs

Pacific Halibut Fisheries. Commercial fisheries on halibut commenced in the eastern Bering Sea in the late 1920's (Thompson and Freeman, 1930). Fishing activities were sporadic until 1952, when U.S. and Canadian vessels began regular fisheries there. Catches were generally less than 1,000 t and low by comparison to catches in the Gulf of Alaska and waters off British Columbia. At the time the halibut fishery became regular, foreign setline and trawl fisheries were undergoing rapid developments in the Bering Sea as well. Records of halibut catches by these fisheries were not clear, although halibut were later prohibited from retention for commercial use.

Retention for commercial use was first prohibited for Japan under provisions of the International Convention for the High Seas Fisheries of the North Pacific Ocean. This Convention set up the International North Pacific Fisheries Commission in 1951. Member nations have remained Canada, Japan, and the United States. For other nations, halibut was prohibited by bilateral arrangements or through common understanding.

Although Pacific halibut remains a prohibited species in foreign and domestic trawl fisheries, the magnitude of incidental catches remains a controversial management issue. This issue is especially important to the International Pacific Halibut Commission which manages the halibut resource under a U.S.-Canada Treaty and to the North Pacific Fishery Management Council which manages all the fishery resources within the 3-200 mile fishery conservation zone (FCZ) under the Magnuson Fishery Conservation and Management Act (FCMA).

Groundfish and Pelagic Fisheries. Groundfish fisheries were essentially developed on the eastern continental shelf and along the continental slope by foreign nations, primarily by Japan and the U.S.S.R. In 1933, Japan initiated a mothership-catcher boat operation for fish meal. This fishery terminated in 1937 when prices for meal dropped (Forrester et al., 1978). In 1940-41, the Japanese fishery resumed as a frozen fish operation but was interrupted by World War II. During these two periods, there was no need for management.

Japan resumed fishing in the Bering Sea in 1954. Development was rapid and Japan became the dominant fishing nation in the region. The fisheries developed into four principal components: the Mothership Fishery, the North Pacific Trawl Fishery, the North Pacific Longline-Gillnet Fishery, and the Land-based Trawl Fishery. These components are distinguished here because their organization made it easier for negotiations of fishing regulations with Japan prior to implementation of the FCMA.

Prior to implementation of the FCMA, catches of groundfish by Japan could only be controlled by Japanese-imposed regulations, always urged by the U.S. and negotiated on a bilateral basis. These bilateral arrangements generally addressed gear conflicts, areas and ports of access, catch restrictions, research activities, and vessel boardings. There were a series of such bilateral arrangements with Japan in the 1970-1975 period. In general, the arrangements served to restrain, partially, the unchecked expansion of the Japanese pollock fishery.

Since Japan was also a member of th INPFC, some regulations on the area of operation of the groundfish fleet and the taking of Pacific halibut were also imposed through deliberations of the INPFC. The INPFC allowed the issue of abstention from fishing to be addressed if two or more member nations exploit a stock and the stock is considered to be fully utilized. Pacific halibut fall in this category and Japan was prohibited from taking halibut and restricted in groundfish operations from selected areas, for example, in a winter halibut savings area of the eastern Bering Sea at certain times of the year.

The first commercial groundfish fishery in the eastern Bering Sea by the U.S.S.R. started in 1958. Like the Japanese, the Soviets expanded their fisheries in terms of effort, target species, and area. Unlike Japan, however, any management provision had to be established by bilateral arrangements. Some bilateral meetings were conducted which led to general agreements on area restrictions and self control of catch levels. In general, however, this type of management was not very effective.

The two other foreign nations that fished in the eastern Bering Sea during 1954-1977 were the Republic of Korea and Taiwan. The Korean fishery started in 1968, while that of Taiwan started in 1974. Catches by these two nations, especially Taiwan were small, and any amount of regulation was arranged through bilateral understandings as in the case of the U.S.S.R. These arrangements, again, were not effective.

After implementation of the FCMA in 1977, all the groundfish fisheries became more closely regulated under U.S. directions. Aspects of their regulation will be discussed later.

Commercial exploitation of herring in the eastern Bering Sea was started on a regular basis in 1960, first by the U.S.S.R. and then by Japan in 1967. Together with Atka mackerel, they were harvested in conjunction with foreign trawls and gillnet fisheries. Both of them were virtually unregulated prior to the FCMA except through bilateral arrangements made with foreign nations covering groundfish in general.

Crab and Shellfish. The king crab fishery in the Bering Sea was started in 1948 by domestic fishermen. Japan entered the fishery in 1953 and the U.S.S.R. in 1959. In the case of Tanner crab, the resource was harvested as incidental catches in the king crab fishery until 1964, when both Japan and the U.S.S.R. increased their fishing effort on the resource. The shift to Tanner crab was due largely to restrictions by the U.S. on foreign king crab catches in 1964.

Prior to 1964, there were no U.S. regulations for the foreign and domestic crab fisheries. In 1964, the U.S. ratified the 1958 Continental Shelf Convention and declared the crab resources as "creatures of the Continental Shelf", thereby establishing management control over the resources. To regulate the foreign catch of crabs, bilateral arrangements were concluded with Japan and the U.S.S.R. that year and in subsequent years. Catch quotas and a minimum size limit was applied to king crab as early as 1964. It was not until 1969 that catch quotas were negotiated and applied to the foreign Tanner crab fisheries. In later years, the use of tangle nets was outlawed.

With each succeeding bilateral arrangement with Japan and the U.S.S.R., the U.S. was able to impose greater restrictions on their crab catches. By 1972, the U.S.S.R. was phased out of the king and Tanner crab fisheries. Japan was phased out of the king crab fishery after 1974, but it was not until after 1980 that Japan was phased out of the Tanner crab fishery.

Regulation of the domestic crab fisheries was instituted essentially in the late 1960's by the State of Alaska. The State of Alaska, through the Alaska Board of Fisheries and the Alaska Department of Fish and Game, established the seasons, fishing areas, minimum size, and the regulation to harvest male crabs only. After implementation of the FCMA, the Federal Government found itself having overlapping authorities to regulate the crab resources with the State of Alaska Discussions on this contemporary management issue will be included later.

Pink shrimp resources were exploited in fairly large quantities by Japan around the Pribilof Islands in the late 1950's but were quickly depleted (Kasahara, 1964). The fishery was not regulated at all and since depletion, has not recovered to support a fishery again.

The fishery for sea snails in the eastern Bering Sea was initiated by Japan in 1973. Although 21 vessels were licensed by Japan to fish for snails using snail pots, the fishery was largely experimental in nature. Since 1977, their management has come under the FCMA and the fishery is conducted on a small scale by a few Japanese vessels.

Present Fisheries Management Programs

There are four main legal bases for management of fisheries resources in the Bering Sea. These are:

(a) The International Convention for the High Sea Fisheries of the North Pacific Ocean which established the INPFC;

(b) The Pacific Halibut Fishery Convention, which established the International Pacific Halibut Commission;

(c) The Magnuson FCMA which established the North Pacific Fishery Management Council; and

(d) State of Alaska statutes which established the Alaska Board of Fisheries and the Alaska Department of Fish and Game.

High Seas Salmon Fisheries. The Convention that established the INPFC was first signed by Japan, Canada, and the U.S. in 1952 and was amended by protocol in 1978. In terms of fisheries management, the Convention only addresses the Japanese High Seas Salmon Mothership Fishery in the western Pacific. The Japanese salmon fishery within the U.S.S.R. 200-mile zone is addressed by Japan-Soviet arrangements. Except for the eastern limit (175° E longitude) and northern limit (46° N latitude), the Japanese land-based salmon driftnet fishery is regulated entirely by Japan.

The Convention is very specific in delineating the area, fishing dates, and amount of mothership fleet days that the Japanese fishery can conduct in the western Pacific. These regulations are summarized in Figure 1. The figure shows opening and closing dates by subareas for the mothership fishery. In the northeast subarea, the season opens after June 25 for 31 mothership fleet days. A mothership fleet day is defined as one mothership with no more than 41 catcher-boats. The central northern subarea opens the same time for 22 mothership days. The northwest subarea opens after May 31. There are two other subareas for the mothership fishery, one outside and the other inside the U.S. FCZ. The outside subarea opens after May 31, while the inside subarea opens after June 9.

The Convention also specifies the amount and nature of research that may be conducted on Dall porpoise (Phocoenoides dalli) that are affected by the operation of the salmon mothership fishery. Beyond these issues, the Convention also addresses the exchange of fisheries data and coordination of fisheries research among the member nations within the INPFC Convention area. These include groundfish and crab resources as well.

One might say that the INPFC is an administrative body whose major purpose is to provide a common forum for 1) discussion of specific items dealing with salmonids and Dall porpoise, and 2) coordination of scientific studies on these and other fishery resources. It is up to the contracting parties to carry out the research.

Although the high seas salmon fishery is conducted in the western Pacific, this topic is mentioned here because it affects salmon of North America origin. The interception of North American fish is not simple to resolve despite the Convention and the U.S. claim over its salmon beyond the U.S. 200-mile zone under the FCMA. In practice, restraints on interception of North American salmonids require voluntary action by Japan, of course with much prodding from the U.S.

Pacific Halibut Setline Fishery. The Halibut Commission was established in 1923 by a Convention between Canada and the U.S. for preservation of the halibut fishery in the north Pacific Ocean and Bering Sea. The Convention was amended several times and the latest amendment by protocol was made in 1979. Unlike INPFC, the Halibut Commission has a scientific staff to conduct research on halibut and make recommendations on management of the resource and its fishery to the Governments of Canada and the U.S. for implementation.

In terms of management of the halibut resource in the eastern Bering Sea, the Halibut Commission addresses the condition and abundance of the stocks, the interrelationship of Bering Sea stocks to other regions, the impact of incidental catches by other fisheries, and make recommendations on its management to the Governments. By the latest Protocol, a directed fishery for halibut in the eastern Bering Sea can be conducted only by the U.S. The Halibut Commission has made recommendations on the annual catch quota, fishing season, and other administrative requirements for that fishery for implementation by the U.S.

The main management objective is to achieve maximum sustainable yield (MSY). Therefore, the Halibut Commission makes careful assessments of condition of stocks and recommends catch quotas commensurate with stock productivity by subareas. In the Bering Sea, the catch quota has been set at about 450 to 680 t the past two years. Two fishing seasons per year have generally been set for the halibut setline fishery, a May-June opening for 8-15 days and a later June-July opening for 19-27 days or until the quota is caught. In recent years (1983), there have been special considerations given to regulate the fishing season so that Alaskan natives in the Pribilofs can develop a viable commercial fishery to relieve them of their reliance on fur seal harvests.

Management recommendations are made by the 3 U.S. and 3 Canadian Commissioners appointed by their respective governments (IPHC, 1983). They, in turn, receive recommendations from the Halibut Commission staff, an industry advisory group (known as a conference board), and the public. All these management decisions are made over a period of a few days during the annual meeting of the Halibut Commission, when all interested parties are invited to attend. Their recommendations are then forwarded to the Governments for implementation.

Because the halibut resource is affected by fisheries for other resources, the Halibut Commission is usually represented at North Pacific Fishery Management Council (henceforth called the Council) meetings and in plan maintenance-development teams for the groundfish resources in the Bering Sea-Aleutians region to provide input for their management which may have direct or indirect effects on halibut.

Groundfish Fisheries. The FCMA provides the central legal basis upon which most fisheries resources are managed in the Bering Sea. The Act estabished the Council with 15 members in very specific terms (Alverson, 1977). The Council has an administrative staff, a Scientific and Statistical Committee (SSC), an Advisory Panel (AP), and has appointed ad hoc groups and plan maintenance-development teams to draft fishery management schemes or work on other problems.

Under the FCMA, all the fishery resources that occurs within the U.S. FCZ in the Bering Sea are to be managed either by preliminary management plans (PMP's) or fishery management plans (FMP's). The PMP's are prepared by the Secretary of Commerce as interim plans for management of the resources, while the Council finalizes its own plans. At present, only one fishery is still being managed by a PMP. This is the small-scale sea snail fishery conducted by one or two Japanese vessels. Two FMP's already have been implemented, one for the groundfish fishery and the other for the Tanner crab fishery. Draft FMP's have been prepared for the king crab fishery and herring fishery for sometime, but the Council has yet to approve them.

The FMP for groundfish in the Bering Sea and Aleutian Islands Region was first drafted in late 1978 and approved by the Council in November 1979. This FMP manages the major groundfish resources on a species-by-species basis--pollock, Pacific cod, yellowfin sole, turbots, other flatfish, Pacific Ocean perch, other rockfish, and sablefish. Squid and Atka mackerel, although not really groundfish, are included in the FMP because they are harvested by the same vessels. The FMP has four main management objectives (NPFMC, 1979):

(a) Promote conservation while providing for optimum yield from the region's groundfish resources in terms of:

    (1) Providing the greatest overall benefit to the nation with particular reference to food production and recreational opportunities;

    (2) Avoiding long-term or irreversible adverse effects on fishery resources and the marine environment; and

    (3) Insuring availability of a multiplicity of options with respect to future uses of these resources.

(b) Promote, where possible, efficient use of the fishery resources but not solely for economic purposes;

(c) Promote fair and equitable allocation of identified available resources in a manner that no particular group acquires an excessive share of the privileges;

(d) Base the plan on the best scientific information available.

Despite the complexity of the management objectives, the groundfish fishery is managed under a simple system. Optimum yields (OY's) are set for each groundfish species group according to their biological productive potential or acceptable biological catch (ABC). OY's are then allocated to user groups--first to domestic fisheries (known as domestic annual harvest, DAH) and then to foreign fisheries (known as total allowable level of foreign fishing, TALFF). Except for specific time and area closures for the foreign fleet, fishing is not tightly regulated by area or season. However, the retention of crab, salmon, and Pacific halibut are prohibited. Since the FMP was implemented, the OY's have been adjusted thrice--for 1981, 1982, and 1983--to reflect changes in condition of individual stocks. For these changes, lengthy administrative procedures must be followed before the amendments to the FMP can be made.

In order to improve on administrative requirements needed to amend the FMP each year and also to manage the groundfish resources more logically as interacting biota within the groundfish complex, an amendment (Amendment #1) was filed. This amendment calls for a more timely manner of setting species catch levels to reflect changes in stock conditions within the groundfish complex. It also considers the management and exploitation of the resources from a multispecies-ecosystem point of view, thereby including, as it should, a wider perspective of interactions. Amendment #1 will be applied for the 1984 fishing year for the first time and should allow a more flexible system of management to reflect the most current stock conditions. The fundamental basis of setting catch levels is still based on biological production.

Another significant amendment to the groundfish FMP is Amendment #3 which will progressively reduce the incidental catch rate of prohibited species in the foreign groundfish fisheries. A schedule of such reduction has been established to apply through 1986. This amendment was implemented to protect the traditional U.S. fisheries for crab, salmon, and halibut. The amendment, however, do not apply to domestic groundfish fisheries which is increasing at a very rapid rate and impacting more on the prohibited species. This problem will, no doubt, be an important issue to resolve in the near future as domestic fisheries continues to build.

King and Tanner Crab Fisheries

Since the draft FMP for king crab has not been approved and adopted by the Council, the fishery is currently managed by the State of Alaska, as it has been prior to FCMA, except that it is now done in consultation with the Council. Therefore, there are some sharing of Federal and State roles in king crab management.

Management of the king crab fishery has historically been made by the Alaska Board of Fisheries, a body appointed by the Governor of the State. Each year, the Board sets the regulations for the upcoming crab season. Regulations are set to control guideline harvest levels and fishing season. Since a cornerstone of king crab management is optimization of the reproductive potential of individual king crab stocks, only males of certain minimum size can be harvested. Guideline harvest levels are set commensurate with stock abundance and yield potential. Fishing seasons are set, not only, to protect crab during the mating, molting, and growing periods of their life cycle; but also to reflect weather conditions and timing of other fisheries, particularly salmon. Opening seasons are generally different by districts and closing dates are preset or ordered later. By regulation, crab can only be legally harvested by pot gear.

For Tanner crab fishery management, an FMP was implemented in May 1978. This FMP was drafted to conform with management regulations set by the Alaska Board of Fisheries, which like king crab, has been managing Tanner crab fisheries prior to FCMA. The management system for Tanner crab is also similar to that of king crab--establishment of harvest guideline levels and fishing season by district. The legal gear is again pots, and the catch is regulated for males only and by minimum size.

Harvest guideline levels are set according to stock abundance of legal sized male crabs and, therefore, yield potential. These levels had to be amended each year as condition of stocks change and the fact that the FMP is set up to operate one year at a time. These and other changes in regulations are determined each year prior to the crab season by the Alaska Board of Fisheries in joint meetings with the Council. Therefore, there is some form of cooperation between the two management bodies--one set up by a Federal law and the other by State statutes.

Utilization of Data Bases

Except for the Japanese High Seas Mothership Salmon Fishery, management of all fisheries in the Bering Sea are fundamentally based on abundance and status of the resources. The area and length of fishing season of the mothership salmon fishery are already set by treaty and cannot be changed easily from year to year. However, much scientific information on distribution of salmon stocks, their catches, and continent of origin of the fish have been collected. These sources of data have been used by the U.S. each year to persuade Japan to adopt voluntary measures to reduce their incidental catch of North American salmonids. When sufficient information is accumulated and when the proper political timing is right, the U.S. will no doubt attempt to renegotiate the Japan-Canada-U.S. Treaty to eliminate or further reduce the interception of North American fish.

For management of the other resources, mostly crab and groundfish, information on abundance and population dynamics of stocks are extremely important for decision making. The data required for these appraisals are collected from two main sources--from foreign fisheries, through the U.S. observer program or reported by foreign fisheries themselves, and from resource research surveys. These surveys are made by U.S. research vessels and by foreign research vessels, either in cooperation with the U.S. or independently by foreign scientists.

Both the two main sources of information are used to estimate stock abundance, condition of stocks, recruitment patterns, and their biological yield potential. Very specific details on population dynamics and composition of the stocks can be derived from available data and analytical techniques. Equilibrium or available yields are usually calculated to set the stage for management decisions.

By law, the optimum yield for the fishery or stocks must be based on bilogical condition of the stocks and the socio-economic needs of the users. The biological yield and condition of the stocks can be estimated for most of the resources in the Bering Sea, and the final catch levels are often determined through a public participation process where decisions are made in light of socio-economic data and testimonies from the public.

Discussion

It is intended that this review give a brief perspective of the historical and existing system of fisheries management in the Bering Sea. Since the present system of management involves INPFC, the Halibut Commission, the State of Alaska, and the Council, there is a need for coordination. The Council is the body that can perform this role. The Council membership and systems of public participation of its deliberations make it particularly effective to integrate management provisions of other fisheires into the Council's FMP's.

In the case of the Japanese high seas salmon fishery, however, the Council can do little to reduce the interception of North American fish. The State of Alaska can also do little to control the problem. It is clear that this problem can best be resolved by voluntary actions from Japan or by renegotiating the INPFC Treaty.

In the case of other fisheries, the Council plays a very important and dominant role in their management. The groundfish trawl fishery, for example, is so large in scale that it affects virtually all the other resources in the Bering Sea. Incidental catches of salmon, crab, and halibut are taken in trawls, the trawl gear competes for fishing grounds and pose a destructive threat to set-line and pot gear; and the removal of large volumes of groundfish affects the food supply for marine mammals and other species. Therefore, it is very important that the groundfish FMP be developed to take into account its impact on other resources.

Amendment #1 of the groundfish FMP does indeed have the intention to consider all the multispecies-ecosystem interactions. In reality, of course, the ability to do so depends on the state of scientific knowledge on these interactions. The state of knowledge, however, is not very advanced which is one of the purpose of this marine mammal fisheries interaction workshop.

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Review of Existing Data Base and of Research and Management Programs for Marine Mammals in the Bering Sea

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Abstract

The history of interaction between man and marine mammals in the Bering Sea began about 28,000 years ago and is characterized by four distinct periods: subsistence hunting , northern fur sealing, whaling, and commercial fishing. The commercial fishing period began in the mid-1900s and consists of two types of marine mammal-fisheries interactions: direct or operational, and indirect or biological. Our review of the data base on these interactions showed that inadequate data are available for most information categories. Even the data base for northern fur seals, which is the most complete, should be improved. Current and planned research addresses some direct interaction problems (such as the level of marine mammal incidental take and status of stocks), but more research is needed to assess the more subtle effects of the interaction problem. The impact of fish removal by commercial fisheries on marine mammal stocks (and vice versa) is an area needing more attention. Federal and state marine mammal management programs are essentially conservation oriented rather than manipulation oriented and are a reflection of current Federal laws and public opinion.

Introduction

The history of interactions between man and marine mammals in the Bering Sea probably began soon after man's arrival into the area and can easily be separated into four distinct periods (Table 1). The first, which we call the "subsistence period," dates to about 28,000 years ago when, as indicated by archeological and geological evidence, primitive hunting groups arrived by diffusion or migration in the Bering Sea region and crossed the emerging Bering land bridge into Alaska (Laughlin, 1967; Müller-Beck, 1967). The entire coastal area of the Bering Sea was occupied by Mongoloid peoples and their migration into North America was across either the coastal or interior portions of the land bridge, or both; none entered by way of the Commander and Aleutian Islands (Laughlin, 1967). The subsistence period persists today, evidenced by hunting of marine mammals--including seals, sea lions (Eumetopias jubatus), walrus (Odobenus rosmarus), some whales, and sea otters (Enhydra lutris)-- by Alaskan coastal and island natives. The number of animals taken has generally been considered low and minimal impact to local populations is assumed (see Simenstad et al., 1978, for differing opinion).

The second period, which we call the "fur seal period," began in 1786 with the discovery of the breeding grounds of the northern fur seal (Callorhinus ursinus) by the crew of the Russian ship St. George under command of Gerasim Pribilof on the islands that now bear his name. Fur seals have been commercially harvested for their fur on these islands since their discovery by the Russians. During the period of Russian ownership of the Pribilof Islands (1786-1867), it was estimated that more than 2.5 million skins were taken (Fiscus, 1978). The United States acquired the Pribilof Islands with the purchase of Alaska in 1867. From 1869 to 1911, fur seals were taken, with few restrictions, throughout their range. During the period of extensive pelagic sealing (1889-1909), over 600,000 seals were taken, most of which were females. By 1909 only 200,000 to 300,000 fur seals remained on the Pribilof Islands. Many years of negotiation between the U.S., U.S.S.R., Japan, and Great Britain (for Canada) produced the North Pacific Fur Seal Convention of 1911. In 1957, the four nations negotiated a new treaty called the "Interim Convention on Conservation of North Pacific Fur Seals" (Fiscus, 1978). The harvest continues today under control of the United States only on St. Paul Island where only immature males are taken (see Scheffer et al., in press, and Roppel, in press, for review of history of fur seal harvest, management and research on the Pribilof Islands).

The harvest of northern fur seals (plus sea otters and some walruses) was the sole commercial activity between man and marine mammals in the Bering Sea until 1845 when Yankee whaling ships moved from whaling grounds near Kodiak Island and south of the Aleutian Islands into the Bering Sea area to hunt bowhead whales (Balaena mysticetus) and right whales (Eubaleana glacialis) (Hunt, 1975). The discovery of large numbers of harvestable whales touched off the third period which we call the "whaling period," when a rush of whaling vessels burst into the area, soon numbering as many as 250 vessels, and began the systematic elimination of these whales until their commercial extinction near the end of the century (Bockstoce, 1978). Pelagic whalers were also important in the historical reduction of the Pacific walrus population. During the period 1848 to 1914 it has been estimated that whalers killed approximately 140,000 walruses, or perhaps more if the number killed and lost was known (Bockstoce and Botkin, 1982). Currently, except for the controlled commercial harvest of fur seals on St. Paul Island, there is no directed killing of marine mammals for commercial purposes in the southeastern Bering Sea (or anywhere else in U.S. waters).

Table 1. Four periods of interaction between man and marine mammals in the Bering Sea including their duration and type of interaction.

Name of period	Duration	Type of interaction
Subsistence	ca. 28,000 years ago to present	Subsistence hunting of marine mammals by natives
Northern fur seal	1786 to present	Commercial harvest of northern fur seals
Whaling	1845 to ca. 1914	Commercial harvest of whales and walruses
Commercial fishing	ca. 1952 to present	Interactions between marine mammals and commercial fisheries

The fourth period in the history of interaction between man and Bering Sea marine mammals we term the "commercial fishing period" and suggest that it began in the mid-1900s when foreign commercial trawl fisheries started to exploit groundfish in the southeast Bering Sea soon after the end of World War II (Bakkala et al., 1979). This period, unlike the previous three which are characterized by the exploitation of marine mammals for subsistence or commercial gain, is characterized by the interrelationship between man's commercial fishing activities and marine mammals and the effect that each has on the other. The level of interaction between the two was described by Lowry (1982) as:

1. Direct or operational interactions, where
   a. marine mammals cause damage to a fisherman's gear and/or catch.
   b. marine mammals are injured or killed as a result of contact with fishing gear or fishermen.
2. Indirect or biological interactions, where
   a. predation by marine mammals reduces the quantity of a target species that is available to a fishery.
   b. harvests by a fishery reduce the amount of prey available to marine mammals.
   c. marine mammals function as hosts for parasites that may reduce marketability of commercial fish.

It is the fourth period in the history of interaction between man and marine mammals in the Bering Sea that is the subject of our paper and the reason for this volume. We will not here attempt to review or document occurrences of marine mammal-fisheries interactions as they relate to the above outline as this has been done numerous times in the past (e.g., Mate, 1980; Matkin and Fay, 1980; Lowry et al., 1982; Contos, 1982). Instead, our purpose is to present our appraisal of the existing marine mammal data relevant to assessing marine mammal-fisheries interactions in the Bering Sea. We will then review existing research programs addressing the issue either directly or indirectly and conclude with a discussion of the existing management programs pertaining to marine mammal-fisheries interactions.

Marine Mammal Data Base

Description of interactions

The distribution of marine mammals at sea often coincides with the fishery resource upon which they feed. For some marine mammal species those resources are also of commercial value (Table 2) and thus, it is not surprising that they would encounter commercial vessels and fishing gear seeking the same resource. Strombom (1981) presents an interesting review of marine mammal-fishery interactions in the northeast Pacific Ocean and southeast Bering Sea and concludes that interactions with the greatest potential significance to the largest number of fisheries is the predation of marine mammals and commercial fisheries on the same resource while depredation of caught fish by marine mammals and parasite host relationships were of lesser significance.

Interactions of significance to marine mammals include the subtle effects to populations by reducing the availability and quality of food, high levels of incidental catch (as in the Japanese high seas salmon, Oncorhynchus spp., gill-net fishery's catch of Dall's porpoise, Phocoenoides dalli), and mortality at sea caused by entanglement in debris. Fowler (1982) suggested that 5% or more of the northern fur seal population may die each year due to the direct effects of fisheries, principally by debris.

Marine mammals have been documented to interact with almost every commercial fishery in Alaska (Mate, 1980; Matkin and Fay, 1980; Strombom, 1981; Contos, 1982; Lowry, et al., 1982) and cause a variety of damage from fish loss to gear damage (Table 3). The severity of the interaction varies with the fishery and the perception of the evaluator. The number of incidentally caught marine mammals (principally northern sea lions) in the southeastern Bering Sea is highest in the foreign groundfish trawl net fisheries (Loughlin et al., 1983); the incidental catch of Dall's porpoise by the Japanese high seas salmon gill-net fishery is highest for the central Bering Sea (Jones, 1983). The level of damage by marine mammals to fisheries is equivocal. Our perception, however, is that the greatest dollar value damage occurs in the salmon gill-net and troll fisheries, although there are presently no substantiating data for the southeastern Bering Sea. Matkin and Fay (1980) showed that marine mammals

TABLE 2. Importance of present and potential commercial fishes and shellfishes in the diets of Bering Sea marine mammals (from Lowry et al. 1982).

	COMMERCIAL FISH SPECIES/GROUP											
	Present								Potential			
	Ground-fish	Herring	Salmon	Halibut	Squid	King crab	Tanner crab	Snails	Capelin	Saffron cod	Shrimp	Clams
MYSTICETE CETACEANS												
Gray whale	0	1	0	0	0	1	1	1	1	0	1	1
Fin whale	3	3	1	0	3	0	0	0	3	2	0	0
Minke whale	3	2	0	0	2	0	0	0	2	1	0	0
Blue whale	0	1	0	0	1	0	0	0	1	0	0	0
Sei whale	1	1	0	0	1	0	0	0	1	1	0	0
Humpback whale	3	3	1	0	1	0	0	0	3	3	1	0
Bowhead whale	0	0	0	0	0	0	0	0	0	0	0	0
Right whale	0	0	0	0	0	0	0	0	0	0	0	0
ODONTOCETE CETACEANS												
Sperm whale	2	1	1	1	3	1	1	0	1	0	0	0
Beluga	2	3	3	1	1	0	1	1	2	3	2	0
Beaked whales	1	0	1	0	3	0	0	0	0	1	0	0
Killer whale	2	2	2	1	1	0	0	0	1	1	1	0
Dall's porpoise	2	2	1	0	3	0	0	0	3	0	1	0
Harbor porpoise	2	2	1	0	1	0	0	0	2	3	1	0
PINNIPEDS												
Northern fur seal	3	2	1	0	3	0	0	0	3	0	0	0
Steller sea lion	3	2	1	1	1	0	0	0	2	1	1	0
Pacific walrus	0	0	0	0	0	1	1	2	0	0	1	3
Harbor seal	3	3	1	1	1	0	0	0	3	0	2	0
Spotted seal	3	3	1	0	1	0	0	0	3	3	2	0
Ribbon seal	3	1	0	1	2	0	0	0	2	2	3	0
Bearded seal	1	0	0	0	0	1	3	2	0	1	3	3
Ringed seal	1	1	0	0	1	0	1	0	1	3	3	0
CARNIVORES												
Polar bear	0	0	0	0	0	0	0	0	0	0	0	0
Sea otter	1	0	0	0	0	2	2	2	0	0	0	2

3 = Known major
2 = Potentially major
1 = Known or potentially minor
0 = Probably not eaten

caused damages amounting to about 4% of the gross potential value of the catch for salmon in the Copper River and Prince William Sound drift gill-net fisheries.

Table 3. Marine mammal interactions with commercial fisheries in Alaska and the type of damage caused by each (modified from Strombom, 1981)

Fishery	Principal marine mammal	Type of interaction
Groundfish trawl net	Northern sea lion Northern fur seal Harbor seal	Incidental take; minor catch loss and gear damage
Salmon gillnet	Northern sea lion	Catch loss, gear damage
	Harbor seal	Catch loss, some gear damage
	Spotted seal	Minor catch loss and gear damage
	Dall's and harbor porpoise	Incidental catch
	Cetaceans	Infrequent gear damage
	Sea otter	Minor gear damage
Salmon troll	Northern sea lion	Minor catch loss and gear damage
	Northern fur seal	Minor catch loss and gear damage
Salmon purse seine	Northern sea lion	Catch loss, gear damage
Halibut longline	Northern sea lion	Catch loss, gear damage
	Northern fur seal	Minor catch loss and gear damage
Sablefish longline	Northern sea lion	Catch loss, gear damage
	Killer whales	Catch loss, gear damage
King crab	Northern sea lion	Minor gear damage

Summary of existing data

In reviewing the current data for the southeastern Bering Sea, we found it important to first identify types of information needed. For our purposes we divided the needed information into categories by certain criteria and attempted to assess the type and quality of data available in each. This analysis was done for each marine mammal species that occurs in the southeastern Bering Sea. Our analysis relied heavily on a number of excellent and thorough reviews, including Mate (1980), McAlister (1981), Strombom (1981) Waring (1981), Contos (1982), Frost et al. (1982), and Lowry et al.

(1982). Seven information categories and the type of information in each were arranged in a somewhat loose order depicting our perception of their importance in assessing marine mammal-fishery interaction problems.

1. Direct fishery interaction - information on the damage to fishing gear and/or catch and marine mammals killed or injured in fisheries.
2. Food/energy/general ecology - information on the type and quantity of food eaten by each marine mammal species by age, sex and location; the energy and nutrient content of prey species; and the inter- and intrarelationships between predator and prey.
3. Distribution/abundance - the temporal and spatial distribution and abundance of marine mammals by species, age, and sex, and abundance trends.
4. Behavior - particularly at-sea behavior including feeding behavior, social behavior, migration or seasonal movements.
5. Reproduction/vital rates - information on reproductive rates, age-class distributions, natality and mortality, and other life history parameters.
6. Physiology/anatomy - information on metabolic rates, assimilation efficiencies, tooth and baleen morphology, gape size, and the like.
7. Parasitism/disease - type and quantity of parasite load and/or disease by sex and age class through time and in different locations.

Information for each of these categories is relevant to assessing marine mammal-fishery interaction problems, but only the first, direct fishery interactions, and fourth, behavior, pertain to the measurement or analysis of direct or operational interactions. The remaining five deal more with the indirect or biological interactions.

We evaluated current data by using information contained in the references mentioned above and our familiarity with some of the relevant information categories. Subjective values were assigned to each information category based on the amount of qualitative and quantitative data available for each (Table 4, footnote 1). The sum total (Data Base Total) of all categories represents a relative information level for each species, where the highest value implies a greater amount of information. One problem with this approach is that each information category is treated equally (e.g., feeding data versus parasitism data), but since each species is treated similarly, each Data Base Total (DBT) should be similarly biased.

Once we attained values for the DBTs, we compared them to values assigned to each species by Lowry (1982) and Lowry et al. (1982) based on the likelihood of the species interacting with commercial fisheries. Their evaluation was based on a number of feeding and population status parameters which were given relative values that summed to an assigned ranked value for each species (Table 4). The highest value possible was 15. Those species with a high ranked value, which indicated a higher likelihood of interaction with commercial species, included northern fur seals, northern sea lions, harbor seals, _Phoca vitulina_, spotted seals, _Phoca largha_,

Table 4. Assessment of the data base 1/ for different information categories for marine mammals in the Bering Sea and the Interaction Value for each. The list is ranked by Data Base Total.

Species	Information categories 2/							Data Base Total 3/	Interaction Value 4/
	Interaction	Food	Distr.	Behavior	Repro.	Physio.	Parasite		
Northern fur seal	3	4	4	4	5	3	4	27	13
Walrus	3	4	4	3	3	2	3	22	11
Sea Otter	3	3	4	3	2	3	2	20	12
Polar bear	2	3	3	3	3	3	2	19	9
Northern sea lion	3	2	4	3	3	2	2	19	13
Gray whale	2	2	4	3	4	3	1	19	11
Harbor seal	2	2	4	2	2	3	3	18	13
Bowhead whale	2	2	3	2	4	3	2	18	8
Dall's porpoise	3	3	3	1	3	1	2	16	10
Beluga whale	3	3	3	2	2	1	2	16	12
Ringed seal	2	3	3	3	2	1	2	15	9
Bearded seal	2	3	3	2	2	1	2	15	10
Spotted seal	2	2	3	2	2	2	1	14	12
Fin whale	1	1	3	1	3	2	3	14	8
Killer whale	2	2	3	2	2	2	1	14	9
Humpback whale	1	1	3	3	2	1	1	12	8
Minke whale	1	1	2	1	3	2	1	11	9
Harbor porpoise	1	2	3	1	2	1	1	11	12
Ribbon seal	1	2	3	1	1	1	1	10	10
Sei whale	1	1	2	1	2	2	1	10	8
Sperm whale	0	1	3	1	1	2	1	9	8
Blue whale	0	1	2	1	2	1	1	8	8
Beaked whales	0	1	2	1	2	1	0	7	10
Right whale	0	2	1	0	0	1	0	4	8

1/ Subjective appraisal of knowledge was based on:
0 - no data
1 - some qualitative data
2 - preliminary quantitative data
3 - some quantitative data
4 - adequate sample of quantitative data (i.e., sufficient to show trends)
5 - large data base (sufficient for use in models)

2/ See text for further description of the Information Categories.

3/ Data Base Total is the sum of the Information Categories.

4/ Based on Lowry et al. (1982) and Lowry (1982).

sea otters, harbor porpoises, Phocoena phocoena, and beluga whales, Delphinapterus leucas. Those with a low ranked value included most of the whales, ringed seal, Phoca hispida, and polar bears, Ursus maritimus (Table 4).

Northern fur seals had the highest DBT of 27 and one of the highest Interaction Values (IV) of 13. Based on our review, a large data base exists in the population dynamics category; adequate data are available for the food, distribution/abundance, and behavior categories (Table 4). Northern sea lions, which also have an IV of 13, have a DBT value of only 19. Adequate data are available only for the distribution/abundance category; all other areas have insufficient data bases to reasonably assess fisheries interactions. The few other species that have DBT values greater than that for sea lions have lower IVs, e.g., walruses have an DBT value of 23 and an IV of 11, sea otters have values of 20 and 12, and polar bears have values of 20 and 9, respectively. The data base for harbor seals is quite low in all areas except distribution/abundance, which is adequate. They have an IV of 13.

The DBT value for gray whales (Eschrichtius robustus) is 18, highest for any cetacean, but they have an IV of only 11. Beluga whales have a DBT value of 16 and an IV of 12; harbor porpoise also have an IV of 12 but a DBT value of only 11.

Clearly, the information level for all marine mammals is low, alarmingly so for those species with a high IV. Adequate data are only available in a few categories and only for a few species. The data base for the distribution/abundance category is best with a large data base for northern fur seals and walruses and adequate data for many others. But in most cases even these data are insufficient since they represent the distribution and abundance of the animals while onshore, not at sea. The interaction between marine mammals and commercial fisheries occurs at sea but the data needed to assess the number and distribution of marine mammals in and around the area of commercial activities is unsatisfactory. We believe that current data for most species is inadequate to assess the nature and magnitude of current or potential marine mammal-fishery interactions in the Bering Sea. The next section of this paper is our assessment of current and planned research pertaining to this issue.

Bering Sea Marine Mammal Research

Research pertaining to marine mammal-fisheries interactions in the southeastern Bering Sea is conducted by a variety of organizations in both the government and private sector. We reviewed the current and planned research based on inquiries to these different groups, including the Alaska Department of Fish and Game (ADF&G), U.S. Fish and Wildlife Service (USFWS), University of Alaska, University of Washington, and others. Our review consisted of an assessment of the emphasis of the research program, its proposed duration, and location (Table 5). We then analyzed the various research programs by marine mammal species (Table 6). We decided not to present a summary of each research program here, except for those at the

National Marine Mammal Laboratory (NMML) with which we are most familiar (Appendix I). If desired, the reader should consult each group for the specifics on their respective research efforts.

Research emphasis

The major emphasis of most research dealing with this subject is to increase understanding of the nature and magnitude of specific problem areas. Only a few studies address mitigation of specific problems or comprehension of the overall issue.

Research specifically addressing marine mammal-fishery interactions at the NMML includes 1) an assessment of the incidental catch of marine mammals by foreign groundfish trawl and longline vessels in the U.S fishery conservation zone (FCZ); 2) a large program on the incidental catch of Dall's porpoise in the Japanese mothership salmon gill-net fishery; 3) an estimate of the number of northern fur seals entangled in discarded net debris; 4) assessment of the incidental catch of northern sea lions in the Shelikof Strait walleye pollock (Theragra chalcogramma) joint venture fishery; and 5) various studies contracted to the Washington Department of Game (WDG) on the interaction of marine mammals and salmon fisheries in and around the Columbia River (Table 5, Appendix I).

There are many on-going or planned research programs at the NMML and other organizations that were designed for puposes other than investigating marine mammal-fishery interactions but that are relevant to the interaction issue. For instance, the NMML has had a long-term project on St. George Island designed to increase the understanding of northern fur seal biology. Portions of that project, particularly the depth-of-dive study, are directly applicable to the interaction issue by providing information on the duration, dive patterns, etc. of fur seal feeding. Current research by the ADF&G and funded by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) on beluga whale trophics and movement patterns, although designed to address oil and gas development issues, are directly applicable to interaction conflicts in Bristol Bay. Other projects at the NMML plus those funded by OCSEAP and other agencies address marine mammal distribution, abundance, and population dynamics. Data gathered in these studies contribute to the assessment of marine mammal-fishery interaction problems.

There are two current studies aimed at mitigation, reduction, or elimination of interaction of marine mammals with commercial fisheries. The first is a 1-year study to be completed in 1984 by the WDG to test various devices to deter pinnipeds from approaching net-caught fish or to frighten pinnipeds away from the fishing area. The second is part of the U.S.-Japan cooperative research project on Dall's porpoise. Since 1981, the Japanese Salmon Federation has been testing various devices to warn porpoise of the presence of the net. Studies are expected to continue to 1987 with implementation scheduled to begin in 1984 as required under the permit issued to the fishery under the Marine Mammal Protection Act of 1972 (MMPA).

Table 5. Current U.S. sponsored research dealing with marine mammal-fisheries interactions in the Bering Sea including the funding agency, research group, research emphasis, proposed duration, and location.

Funding agency 1/	Research group	Research emphasis	Proposed duration	Location 3/
NMFS	NMML	1. Foreign incidental kill	on-going	BS,GoA,NP
		2. Pelagic net debris	"	BS,PI
		3. Dall's porpoise incidental catch	1978-87	BS,NP
		4. Fur seal diving behavior	on-going	PI
		5. Pinniped population monitoring	"	most BS areas
		6. Shelikof Strait[2]/sea lion catch	1982-84	SS
	WA Dept of Game	1. Columbia River[2]/salmon fisheries	1980-83	OR,WA
OCSEAP	OCSEAP	1. Northern sea lion winter distribution	on-going	BS
	ADF&G	1. Beluga whale trophics movements and abundance	1982-84	Bristol Bay Pt. Barrow
	Envirosphere	1. Marine mammal distribution and abundance	1982-83	BS(Navarin Basin)
	Hubbs/Sea World	1. Marine mammal distribution and abundance	1982-83	BS
		2. Effect of boat traffic on beluga whales	1983	Bristol Bay
	LGL	1. Gray whale feeding ecology	1982	BS, Aleutian Is.
	Univ. Alask	1. Response of ring seals to disturbance	1982-84	Beafort Sea
NPFMC	ADF&G	1. Northern sea lion pup counts	1984	GoA
ADF&G	ADF&G	1. Walrus movements, distri.	1983-84	Bristol Bay
		2. Sea otter expansion	on-going	SE Alaska
AK St.	Univ. Alask	1. Under ice navigation by spotted seals	1983	Captive seals
NPS	Univ. Alask	1. Harbor seal ecology in ice	1980-83	Seward
MMC	UW	1. Effect of harvest on St. George I. fur seals	1982	PI
NSF	Moss Land.	1. Gray whale fdg. ecology	1983	BS
USFWS	USFWS	1. Polar bear dist., movements, general ecology	on-going	Barrow coast
		2. Walrus dist., abundance, behavior, pop. dyn.	on-going	E.BS, Chuckchi
		3. Sea otter dist., abundance, behavior, general ecology	on-going	SE AK, Prince William Sound

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1/ See Appendix II for a glossary of abbreviations.

2/ Not Bering Sea but information gathered relevant to issue.

3/ BS-Bering Sea, GoA-Gulf of Alaska, NP-North Pacific Ocean, OR-Oregon PI-Pribilof Islands, SS- Shelikof Strait, WA-Washington

Research on species

Aside from research dealing with particular topics or problem areas, it is also important to examine current and planned research in relation to each marine mammal species, particularly those with a high IV. Obviously, current and planned research programs dealing with marine mammal-fishery interaction issues should emphasize those species with a high likelihood of interaction (high IV) or those known to be involved in a particular conflict. The research effort should also concentrate on areas that are most likely to succeed and provide the most valuable and relevant information.

Northern fur seals, northern sea lions, and harbor seals each have an IV of 13 and there is either current or planned research dealing with interaction issues on those species (Table 6). For sea lions and harbor seals, the studies emphasize distribution, abundance, and feeding habits, although there is some direct fishery interaction research for sea lions caught in the foreign groundfish fishery and in the Shelikof Strait walleye pollock joint venture fishery. Extensive research is continuing for northern fur seals, primarily because of the federal government's obligations under the Interim Convention for the Conservation of North Pacific Fur Seals. The research relevant to marine mammal-fisheries interactions includes depth-of-dive studies on St. George Island, assessment of the nature and magnitute of the pelagic net debris issue, effect of a possible harvest on St. George Island, and pelagic studies on opportunistic feeding.

Research on walrus, particularly by Dr. Fay and his group at the University of Alaska and the USFWS, will continue. Their work emphasizes temporal and spatial distribution and abundance and the relationship to benthic food resources.

Dall's porpoise is the only cetacean species for which there is extensive on-going research (Table 6, Appendix I). The studies include distribution, abundance, incidental catch, and biology of Dall's porpoise, as well as the gear research mentioned earlier and studies of marine bird and fur seal entanglements in the North Pacific Ocean and Bering Sea. With the exception of this and studies on beluga whales mentioned previously, there are few studies dealing with cetacean interactions with fisheries. This is related to the low incidence of cetacean entanglements in commercial fishery operations in the Bering Sea.

Comments on research

Obviously, some types of information dealing with marine mammal-fishery interactions are easier to obtain than others due to problems with logistics, available funds, political climate, and existing laws. For instance, it is relatively easy to keep track of the incidental catch of marine mammals by foreign commercial fisheries in the FCZ because foreign nations are required by the Magnuson Fishery Conservation and Management Act (MFCMA) to allow U.S. fishery observers to board their vessels and collect specific fishery information. The act also requires that the foreign nation pay for the cost of

Table 6. Marine mammals which occur in the Bering Sea that have an interaction value of 10 or greater and the current and planned research for each.

Species	Inter-action value	Research type1/	Research group	Research location 2/	Interaction type3/
Pinnipeds					
N. fur seal	13	1 to 6	NMML	PI; S.E.BS	1a,1b,2a,2b
N. sea lion	13	1,2,5,6,	NMML	PI; S.E.BS Aleutian Is.	1a,1b,2a,2b
Walrus	11	1,3,4,5,7	U.AK FWS,ADF&G	E. BS	1b,2a
Harbor seal	13	1,2,3,6			1a,1b,2a
Spotted seal	11	4	U.AK	Captive	
Ribbon seal	10	?			
Bearded seal	10	?			
Cetaceans					
Beluga whales	12	1,2	ADF&G	Bristol Bay, Pt. Barrow	1a,2a,2b
Beaked whales	10	3	NMML	Central and S.E. BS	?
Dall's porpoise	10	1 to 7	NMML	S.central BS N.Pac.Ocean	1b
Harbor porpoise	12	3	NMML	NP; BS	1b
Gray whale	11	2,4	LGL	N.BS	1a,2b

1/ Research type
1. Direct fishery interaction
2. Food/energy/general ecology
3. Distribution/abundance
4. Behavior
5. Reproduction/vital rates
6. Physiology/anatomy
7. Disease/parasites

2/ Abbreviations are as in Table 5.

3/ Interaction type
1a. damage to gear or catch
1b. incidental catch
2a. reduction of fish availability to fishery
2b. reduction of available food for marine mammal

the fishery observer. As part of their duties the fishery observers also record observations of incidentally caught marine mammals. The collection of information on marine mammals incidentally caught by domestic fishermen is more difficult. Federal law requires that the fishermen report all incidentally caught marine mammals to the

National Marine Fisheries Service (NMFS), but there have been few reports thus far. There is no mechanism for placing observers onto domestic vessels without the fishermen's permission nor are there adequate funds to cover the costs of such observers. The situation is compounded by the number of independent fishermen in the United States. In our view, the number of marine mammals actually caught and killed incidental to domestic fishing operations is small (except for some joint venture fisheries) and the information that might be gained from placing observers aboard the vessels would not justify the costs.

One very important issue, but one for which data are extremely hard to obtain, is the mortality at sea of northern fur seals (and other marine mammals) by entanglement in net debris. Researchers were alerted to the problem only because of the increase in the number of subadult male fur seals occurring in the commercial harvest on St. Paul Island with fragments of debris around their necks. It is currently unknown how much debris is discarded or lost at sea, where it is lost and drifts to, how long it "fishes," or the number and species of marine mammals affected. Some research is being done in this area (Appendix I), but more is needed.

Probably the most important question, and the most difficult to study and understand, is the relationship between marine mammal stocks and the removal of fish by commercial fisheries. The impact of fish removal on marine mammal stocks (and vice versa) is of vital importance since it affects all species and the entire Bering Sea ecosystem as a whole. As yet there has been very little effort to integrate existing information or to initiate new studies addressing this problem. It is this subtle relationship between available prey and predator stocks that we view as the primary marine mammal-fishery interaction issue in the southeastern Bering Sea.

Management Programs

There are several federal laws that involve protection and management of marine mammals in U.S. waters.

Marine Mammal Protection Act of 1972 (MMPA)

The primary objective of marine mammal management under the MMPA is to maintain the "health and stability of the marine ecosystem." It is the intent that "marine mammals should be protected and encouraged to develop to the greatest extent feasible commensurate with sound policies of resource management." Although the act provides for management of marine mammals, it basically provides nearly complete protection for these animals. Although conceivably marine mammal populations could be managed to reduce competition with fisheries, reduction or manipulation of populations would be unlikely given current emotional or ethical considerations.

Under this act there is a moratorium on all taking (including harassment, killing, capture, or hunting and the attempt to do so) or importing of marine mammals. Exceptions include species managed under international conventions or agreements, take for scientific research or public display, and incidental take during commercial fishing operations. Domestic fishermen can obtain certificates of inclusion under general permits issued to a fishing federation to take marine mammals. In 1981 this process was simplified to encourage more fishermen to obtain the certificates and to report incidental takes. As a result, in 1981 the number of certificates issued in the Pacific Northwest Region increased from 13 to 3,000, and the number of reports from 87 in 1980 to 200 in 1981. In Alaska, 42 certificates were issued in 1981 but no take was reported.

Prior to 1972 the State of Alaska managed 10 marine mammal species: polar bear, sea otter, walrus, beluga whale, northern sea lion, and bearded (Erignathus barbatus), harbor, ribbon (Phoca fasciata), ringed, and spotted seals. Under the MMPA, management of all marine mammals was assigned to the federal government. The act provides for return of management to states and in 1983, new requirements for return were published. Alaska has attempted to obtain return of management for these 10 species several times and is in the process of meeting the new requirements. Included will be hearings on the status of the populations and on management procedures.

Endangered Species Act of 1973 (ESA)

The ESA provides for the conservation of endangered or threatened marine mammal species and their ecosystems. This act prohibits the importation or exportation, sale, trade, or shipment in commerce of endangered or threatened species. It also makes it illegal to harass, harm, capture, or kill an endangered species in the United States. It prohibits federal agencies from taking any action which jeopardizes the continued existence of such species or that results in destruction or modification of their critical habitat.

Magnuson Fishery Conservation and Management Act of 1976 (MFCMA)

This act established a fishery conservation zone out to 200 miles off the U.S. coast over which the United States maintains exclusive fishing management authority. One goal is to promote conservation while providing optimum yield of fishery resources. Under section 404 of this act, the jurisdiction of the MMPA was extended to the boundaries of the FCZ. Therefore, under the MFCMA, fishery management plans (FMPs) must address the issue of the impact of proposed plans on marine mammal populations and the ecosystem.

One FMP that includes consideration of marine mammals in the Bering Sea is for Bering Sea/Aleutian Islands area groundfish. This plan contains an estimate of the incidental mortality of marine mammals in the fishery and concludes that implementation of the FMP should reduce competition with marine mammals because of the reduction in total groundfish optimum yield from 1969-1975 levels. The plan recommends continued research on the biological interactions between marine mammals. A second FMP that considers marine mammals is for Pacific herring (Clupea harengus pallasi) in which the high seas fishery is prohibited partly because of the importance of this resource to marine mammal populations.

Marine Protection, Research and Sanctuaries Act of 1972

Section 4 of this act authorizes the Secretary of Commerce to designate areas of ocean waters out to the outer edge of the continental shelf as marine sanctuaries for the purposes of preserving or restoring such areas for their conservation, recreational, esthetic or ecological values. The Secretary must certify that any permitted activity in a marine sanctuary is consistent with the purposes of this act. Although portions of Alaskan waters have been nominated as sanctuaries, as yet none have been designated.

Several international conventions also are involved with marine mammal management, including the following.

Interim Convention on North Pacific Fur Seals

This convention was implemented by the North Pacific Fur Seal Act of 1966 and prohibits all pelagic take of fur seals other than by aboriginal Eskimos, Aleuts, and Indians using primitive methods. It permits a large harvest of subadult male fur seals near breeding colonies, strictly regulated by the party governments of Canada, Japan, U.S.S.R., and United States. It requires the signatories to work toward achieving "maximum sustainable productivity with due regard to their relations to the productivity of other living marine resources of the area." This convention is unique with respect to marine mammals in that it permits utilization of the fur seal.

Convention on International Trade in Endangered Species of Wild Fauna and Flora of 1975 (CITES)

CITES is implemented by the domestic ESA and prohibits importation or exportation of species listed as endangered or threatened. It establishes a permit system for import or export of listed species.

International Convention for High Seas Fisheries of the North Pacific

Although management of marine mammals is effected only within the FCZ under the MMPA general permit system, this convention establishes a cooperative research program to assess the impact of the Japanese high seas salmon fisheries on marine mammals. Under a U.S.-Japan Memorandum of Understanding, Japan reports the incidental take of all marine mammals by the landbased and mothership salmon fisheries, including the central Bering Sea.

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Appendix I. NMFS, NMML Marine Mammal-Fisheries Interaction Studies

The National Marine Mammal Laboratory (NMML), Northwest and Alaska Fisheries Center (NWAFC), National Marine Fisheries Service (NMFS) conducts a variety of studies dealing either directly or indirectly with marine mammal-fisheries interactions in the Bering Sea. These studies are summarized below.

Incidental take by foreign fisheries

Since implementation of the Magnuson Fishery Conservation and Management Act (MFCMA), the United States has placed fishery observers aboard foreign trawl and long-line fishing vessels in the U.S. fishery conservation zone to collect fishery data. Even though the primary objective of the observers was to collect fishery data, they have also collected data on marine mammals caught incidental to fishing operations, including species, number observed caught, sex, morphological measurements, location, and sometimes the collection of teeth for aging. These data are transmitted through the NWAFC observer program to the NMML for processing and analysis. There is no equivalent system for the reporting of incidentally caught marine mammals by domestic fishermen although they are required by law to report such incidents to the NMFS.

Pelagic net debris

The current decline in the northern fur seal population may be a result of increased mortality at sea since 1956, perhaps because of the increased abundance and character of commercial fishing net debris in the areas occupied by fur seals (Fowler, 1982). The present research program in this regard concentrates on the Bering Sea, principally the waters around the Pribilof Islands. This work involves several components. The debris found on animals (mostly those taken in the harvest) is collected for analysis to determine its origin and for comparison to debris collected from beaches. The animals themselves are being studied through tagging and collection of tissue samples to determine mortality rates associated with entanglement.

Dall's porpoise

This program is a U.S./Japan cooperative research project initiated in 1978 under the International North Pacific Fisheries Commission and pertains to the incidental catch of Dall's porpoise by the Japanese land-based and mothership high seas salmon gill-net fisheries. The objectives of the program are to assess the impacts of the incidental take and to work toward the reduction or elimination of the take. The fishery operates primarily in the central and western North Pacific Ocean and central Bering Sea. The studies from 1981 to the present include 1) marine mammal sighting surveys aboard Japanese salmon research vessels to estimate Dall's porpoise abundance and distribution, 2) collection of biological data and whole specimens from incidentally caught animals for analysis of life history parameters, 3) obtaining information on the incidental take, and 4) studying the behavior response of Dall's porpoise to survey vessels as a factor in abundance estimates. In addition, Japan is conducting research on the types of gear to reduce entanglement of marine mammals, and Dall's porpoise acoustic and life history parameters outside the area of the salmon fishery.

Shelikof Strait

High numbers of northern sea lions have been caught by domestic trawl vessels in the Shelikof Strait walleye pollock joint venture fishery. Research designed to assess the nature and magnitude of the catch included placing of a gear specialist aboard U.S. trawlers, sampling of dead sea lions after the net loads of fish were delivered to the processors, and aerial surveys of sea lion haul sites in and around Shelikof Strait. Although the research is not in the Bering Sea, the information obtained is relevant to understanding the overall interaction problem.

Fur Seal Diving Behavior

Female northern fur seals from St. George Island have been instrumented with time-depth recorders to study dive patterns, feeding depths, and other foraging parameters. For further information on the most recent accomplishments of this study, the reader is referred to the abstract in this volume by Dr. Roger L. Gentry.

Pinniped Population Monitoring

Biological information is collected on Pribilof Island fur seals including age of harvested males, the number of adult males on rookeries and hauling grounds, number of pups and older animals that died on the islands, and the estimated number of pups born. Northern sea lion populations on Walrus Island, Amak Island, Ugamuk Island, and in other areas are estimated by aerial and/or ship surveys.

Columbia River

Since early in 1980, the NMML has contracted with the Washington Department of Game, aided by the Oregon Department of Fish and Game, to study marine mammal-fisheries interactions in the Columbia River and adjacent waters. Results indicated substantial interaction between marine mammals and the commercial gill-net fishery for salmon. Currently the research group is studying methods to reduce or eliminate the interaction.

Appendix II-- Glossary of Abbreviations

ADF&G	Alaska Department of Fish and Game
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DBT	Data Base Total
DOC	Department of Commerce
ESA	Endangered Species Act
FCZ	fishery conservation zone
FMPs	fishery management plans
INPFC	International North Pacific Fisheries Commission
IV	Interaction Values
MFCMA	Magnuson Fishery Conservation and Management Act
MMC	Marine Mammal Commission
MMPA	Marine Mammal Protection Act
NMFS	National Marine Fisheries Service
NMML	National Marine Mammal Laboratory
NPFMC	North Pacific Fisheries Management Council
NPS	National Park Service
NSF	National Science Foundation
NWAFC	Northwest and Alaska Fisheries Center
OCSEAP	Outer Continental Shelf Environmental Assessment Program
USFWS	U.S. Fish and Wildlife Service
UW	University of Washington
WDG	Washington Department of Game

A Conceptual Assessment of Biological Interactions Among Marine Mammals and Commercial Fisheries in the Bering Sea

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Introduction

Over the past 2 centuries the Bering Sea has supported extensive harvests of marine mammals and, later, fishes and shellfishes. Human harvests resulted in drastic reductions in the population size of many major species such as sea otters (*Enhydra lutris*), walruses (*Odobenus rosmarus*), fur seals (*Callorhinus ursinus*), halibut (*Hippoglossus stenolepis*), herring (*Clupea harengus*), and yellowfin sole (*Limanda aspera*) (Pruter, 1973; Fay, 1981). Changing economic factors, improved scientific understanding of animals and processes, and implementation of programs for protection and management have allowed many populations to recover over the past few decades. Management regimes that have been implemented were based on primarily single-species, maximum sustainable yield concepts.

Recent trends in management philosophy reflect a desire to develop multi-species, ecosystem-based management programs. In particular, two pieces of federal legislation have had far-reaching impact on management of fishery and mammal resources in marine waters of the United States. The Marine Mammal Protection Act (PL-92-522) recognizes marine mammals as significant functional elements of marine ecosystems and requires the maintenance of "optimum sustainable populations," with the primary objective of maintaining the "health and stability of the marine ecosystem." The Magnuson Fishery Conservation and Management Act (PL-94-265) established a 200-mile Fishery Conservation Zone in seas adjacent to the United States and provided a framework for management and development of commercial fisheries within that zone. However, in spite of the recent desire and requirements for ecosystem-based management of resources in areas such as the Bering Sea, such has yet to become a reality.

Attempts to incorporate marine mammal food requirements into the Bering Sea/Aleutian Islands fishery management plan have been only partially successful due to the lack of adequate data and models with which to analyze and simulate possible interactions (Lowry et al., 1982). Nonetheless, available data do allow a preliminary, conceptual assessment of biological interactions among marine mammals and commercial fisheries. In this paper I refer only to trophic interactions that primarily involve the responses of marine mammals and fisheries to changes in fish (and shellfish) stock abundance and characteristics. A listing of Bering Sea marine mammal species and an indication of their abundance are given in Table 1.

Documentation of Interactions

As one would expect, the earliest observations of stomach contents of marine mammals showed that marine fishes and shellfishes were major items in their diets. However, prior to 1950, few studies of marine mammals documented their foods in any quantitative fashion. In the Bering Sea and North Pacific, Soviet commercial harvests of ice-associated seals provided some data on foods of those species (e.g., Arseniev, 1941; Pikharev, 1941, 1946; Fedoseev, 1965; Shustov, 1965; Gol'tsev, 1971; Kosygin, 1971). Other experimental and opportunistic observations added data on foods of fur seals, sea lions, and harbor seals (e.g., Scheffer and Sperry, 1931; Imler and Sarber, 1947; Scheffer, 1950). Interestingly, although several samples were collected at areas and times when salmon (Oncorhynchus spp.) were present, fishes of the cod (Gadidae), herring (Clupeidae), and smelt (Osmeridae) families were usually the major prey. Nonetheless, due to acknowledged direct interactions with salmon fisheries and a perceived competition for resources, harbor seals and sea lions in particular were subject to bounties and control programs to reduce their effects on fisheries (Mate, 1980). Such control programs were terminated by 1970. Further studies of foods of pinnipeds generally confirmed the dietary importance of herring, smelts, and cods (see summaries by Lowry and Frost, 1981; Perez and Bigg, 1981; Pitcher, 1981).

General information on foods of cetaceans became available with the examination of animals taken in commercial harvests (e.g., Tomilin, 1957; Zimushko and Lenskaya, 1970). This has been supplemented by data from animals, particularly small cetaceans, that were taken by subsistence hunters (e.g., Seaman et al., 1982), caught in fishing gear (e.g., NMML, 1981), or washed up dead on shore (Scheffer, 1953). In general, zooplankton, squids, and small schooling fishes have been found to be the major prey of cetaceans, and, given the offshore distribution of most species and their observed foods, interactions with fisheries have appeared slight. A notable exception involves belukha whales in Bristol Bay. There, a systematic study (summarized in Lensink, 1961) documented the consumption of adult and smolt salmon by belukhas in the Kvichak and Nushagak River estuaries. Calculations indicated that belukhas consumed 2.7% of the sockeye (Oncorhynchus nerka) runs in 1954 and 1.0% in 1955, which was considered significant, especially in light of the depleted status of stocks. This led to the development of a nonlethal acoustic system which was used to displace the whales from the rivers at critical times (Fish and Vania, 1971). With improved management and recovery of sockeye stocks, use of this system was discontinued.

Table 1. Categorization of maximum numerical abundance and biomass of marine mammals in the Bering Sea.

Species	Maximum numerical abundance			Population biomass (mt)		
	< 10,000	10,000-100,000	> 100,000	< 10,000	10,000-100,000	> 100,000
BALEEN WHALES						
Gray whale *Eschrichtius robustus*		X				X
Fin whale * *Balaenoptera physalus*	X				X	
Minke whale *Balaenoptera acutorostrata*	X				X	
Blue whale * *Balaenoptera musculus*	X			X		
Sei whale * *Balaenoptera borealis*	X			X		
Humpback whale * *Megaptera novaengliae*	X			X		
Right whale * *Balaena glacialis*	X			X		
Bowhead whale *Balaena mysticetus*	X				X	
TOOTHED WHALES						
Sperm whale *Physeter macrocephalus*		X				X
Belukha *Delphinapterus leucas*		X		X		
Cuvier's beaked whale * *Ziphius cavirostris*	X			X		
Baird's beaked whale * *Berardius bairdi*	X			X		
Stejneger's beaked whale * *Mesoplodon stejnegeri*	X			X		
Killer whale * *Orcinus orca*	X			X		
Dall's porpoise *Phocoenoides dalli*		X		X		
Harbor porpoise * *Phocoena phocoena*	X			X		
PINNIPEDS						
Northern fur seal *Callorhinus ursinus*			X		X	
Steller sea lion *Eumetopias jubatus*		X			X	
Pacific walrus *Odobenus rosmarus*			X			X
Harbor seal *Phoca vitulina richardsi*		X		X		
Spotted seal *Phoca largha*			X		X	
Ribbon seal *Phoca (Histriophoca) fasciata*		X		X		
Ringed seal *Phoca (Pusa) hispida*			X		X	
Bearded seal *Erignathus barbatus*			X		X	
CARNIVORES						
Polar bear *Ursus maritimus*	X			X		
Sea otter *Enhydra lutris*		X		X		

* Indicates population estimated at 1,000 or less.

Major changes in the pattern of exploitation of Bering Sea fish stocks occurred during the period following the end of World War II (Bakkala et al., 1981), of which the development of the groundfish fishery is probably most significant. The aggregate catch of groundfish by all nations increased from 12,500 mt in 1954 to over 2.2 million mt in 1972; the 1972 harvest was 176 times greater than that in 1954. In addition, due at least in part to depletion of stocks of other target species (Pruter, 1973), the percentage of pollock (Theragra chalcogramma) in the harvest increased from 0 to 83% during that period (Bakkala et al., 1981).

The increased harvests of Bering Sea groundfish, particularly pollock, and the improved data base on marine mammal foods suggested a major potential competition for resources (McAlister and Perez, 1976; Lowry et al., 1979). Frost and Lowry (1981a) documented the presence of pollock in the diet of 11 species of marine mammals and 13 species of seabirds. Calculations by McAlister and Perez (1976) indicated that 2,853,000 mt of finfish were consumed annually by pinnipeds in the Bering Sea, an amount considerably in excess of the harvest by fisheries. Two questions could then be formulated, each of which could be applied either specifically to pollock and their predators or to the entire suite of Bering Sea marine mammals and fisheries. First, is predation by marine mammals impacting the harvests that can be taken by commercial fisheries? Second, is the take by commercial fisheries affecting food availability and therefore population status of marine mammals?

The magnitude of consumption of commercial fish resources by Bering Sea marine mammals is without doubt substantial (McAlister and Perez, 1976). However, predation by marine mammals has not been documented as a factor resulting in the depletion of commercially important fish stocks in the Bering Sea. Observations of sea otters in California (Lowry and Pearse, 1973) and walruses in the Bering Sea (Fay and Lowry, 1981) demonstrate the ability of certain mammals to deplete local stocks of fishable resources. Calculations by Winters and Carscadden (1978) for North Atlantic capelin have assumed that potential yields to fisheries are a direct function of marine mammal abundance.

The question of the effect of fisheries on marine mammals is more complex and is supported by a less well-developed array of observations, data, and theory. In order to postulate that the actions of a fishery affect populations of marine mammals, four criteria must be met. First, the removals of forage species by the fishery, in combination with other predators, must affect forage stocks differently than predation alone. Second, changes in forage abundance must affect intake of food by marine mammals. Third, a change in food intake must result in a change in vital parameters (e.g., growth, survival, reproduction) of individual marine mammals. Fourth, changes in individual parameters must affect population parameters such as abundance and productivity. If these four linkages must be established in order to conclusively demonstrate the existence of a significant interaction between marine mammals and fisheries in the Bering Sea, such interactions have not been documented. Instead, however, attempts have been made to correlate observed population characteristics of marine mammals with observed fisheries or presumed changes in fish stock characteristics. Such studies dealing with fur seals (Swartzman and Haar, 1980) and sea lions (Braham et al., 1980) have not succeeded in conclusively documenting causal relationships.

Despite the lack of adequate documentation for the Bering Sea, information from other areas suggests that marine mammals may respond to changes in their food supply. The evidence is based on the assumption that a reduction in population size of the principal or competing species changes the relationship of the population to its food resources in such a way as to eliminate or reduce the effects of food limitation. Populations should then respond to increased food availability by increased productivity and/or survival, and, in the absence of continued excessive harvesting, the population size should increase. In the North Atlantic, a reduction of the harp seal (Phoca groenlandica) population during 1952 to 1972 was accompanied by a significant increase in fertility rate (from 85 to 94%) and decrease in mean age at maturity (from 6.5 to 4.5 years) (Bowen et al., 1981). These responses should have increased productivity, and indeed the population size has probably increased in spite of continued harvesting (Bowen and Sergeant, 1983). A second example involves the Antarctic ecosystem, where a single species of krill (Euphausia superba) is the principal food of many species of birds and marine mammals. Recent increases in populations of several krill predators, including penguins (Aptenodytes patagonica and Pygoscelis spp.), minke whales, crabeater seals (Lobodon carcinophagus), and fur seals (Arctocephalus spp.), are thought to be the result of an increase in availability of krill brought about by the reduction of large whale populations which had formerly consumed great quantities of that species (Laws, 1977).

Thus, the available information suggests that populations of some marine mammal species can be limited by food availability and that individual and population parameters will respond to changes in levels of available food. It must be noted that the important factor is the relationship between abundance of predator and prey populations rather than the absolute size of either. That is, a reduction in a marine mammal population while abundance of prey remains constant would have a similar effect to enhanced prey abundance with a constant mammal population. In order to facilitate such considerations, many investigators have found it useful to consider this relationship in terms of per-capita food availability.

Conceptual Assessment of Marine Mammal-Fishery Interactions in the Bering Sea

It is comparatively easy to document which species of marine mammals consume commercial fish species. Analysis of opportunistically obtained specimens (e.g., stomachs) and observations of distribution and behavior of animals in fishing areas are usually adequate to detect which target species are eaten. For most species a careful evaluation of all available food habits data can provide a semi-quantitative assessment of the dietary importance of commercially exploited prey, as has been done by Fiscus (1979, 1980), Frost and Lowry (1981b), and Lowry and Frost (1981). An evaluation of this type for Bering Sea marine mammals and fisheries is given in Table 2, based on the data summarized in Lowry et al. (1982). However, such an evaluation must be accepted with caution since reasonably adequate descriptions of diet for mammals of the Bering Sea, including at least seasonal and

Table 2. Importance of present and potential commercial fishes and shellfishes in the diets of Bering Sea marine mammals.

	COMMERCIAL FISH SPECIES/GROUP											
	Present								Potential			
	Groundfish	Herring	Salmon	Halibut	Squid	King crab	Tanner crab	Snails	Capelin	Saffron cod	Shrimp	Clams
MYSTICETE CETACEANS												
Gray whale	0	1	0	0	0	1	1	1	1	0	1	1
Fin whale	3	3	1	0	3	0	0	0	3	2	0	0
Minke whale	3	2	0	0	2	0	0	0	2	1	0	0
Blue whale	0	1	0	0	1	0	0	0	1	0	0	0
Sei whale	1	1	0	0	1	0	0	0	1	1	0	0
Humpback whale	3	3	1	0	1	0	0	0	3	3	1	0
Bowhead whale	0	0	0	0	0	0	0	0	0	0	0	0
Right whale	0	0	0	0	0	0	0	0	0	0	0	0
ODONTOCETE CETACEANS												
Sperm whale	2	1	1	1	3	1	1	0	1	0	0	0
Belukha	2	3	3	1	1	0	1	1	2	3	2	0
Beaked whales	1	0	1	0	3	0	0	0	0	1	0	0
Killer whale	2	2	2	1	1	0	0	0	1	1	1	0
Dall's porpoise	2	2	1	0	3	0	0	0	3	0	1	0
Harbor porpoise	2	2	1	0	1	0	0	0	2	3	1	0
PINNIPEDS												
Northern fur seal	3	2	1	0	3	0	0	0	3	0	1	0
Steller sea lion	3	2	1	1	1	0	0	0	2	1	1	0
Pacific walrus	0	0	0	0	0	1	1	2	0	0	1	3
Harbor seal	3	3	1	1	1	0	0	0	3	0	2	0
Spotted seal	3	3	1	0	1	0	0	0	3	3	2	0
Ribbon seal	3	1	0	1	2	0	0	0	2	2	3	0
Ringed seal	1	1	0	0	1	0	1	0	1	3	3	0
Bearded seal	1	0	0	0	0	1	3	2	0	1	3	3
CARNIVORES												
Polar bear	0	0	0	0	0	0	0	0	0	0	0	0
Sea otter	1	0	0	0	0	2	2	2	0	0	0	2

3 = Known major
2 = Potentially major
1 = Known or potentially minor
0 = Probably not eaten

geographical resolution, are available only for fur seals and perhaps ringed seals, bearded seals, and walruses.

In order to derive the most elementary assessment of the impact of marine mammals on commercial fish stocks, it is necessary to know the quantities of commercial species consumed by each type of mammal on an annual basis. Obviously the distribution of this predation by age and sex class of prey and by area and time of year are also important but only represent levels of refinement of the initial estimate of total amounts. Published estimates of the amounts of finfish consumed by marine mammals in the Bering Sea are on the order of 1.6-2.5 million metric tons per year, an amount which equals or exceeds the annual harvest by commercial fisheries (McAlister and Perez, 1976; Dunn 1979; McAlister, 1981).

Calculations of the amount of food consumed by a marine mammal species are usually made by multiplying the population biomass (derived from population size and average individual weight) times the number of days spent feeding in the area (assumed to equal residence time), times a daily consumption rate (usually expressed as a percentage of body weight). The amounts of various prey species consumed can then be estimated based on knowledge of the species composition of the marine mammal's diet. Various refinements to this estimation technique can be made, for example, by making food consumption rate proportional to temperature.

Inaccuracy in the results of such calculations is likely to occur from two principal sources. First is that the required input data may not be available. In Table 3 I have indicated the general availability of necessary data for those species which may consume at least moderate amounts of commercial fishes (based on Table 2). There are major deficiencies in the data base, particularly with respect to population size, residence time, and weight of cetaceans, and diet composition of all species with the exception of fur seals. Although population size estimates are available for several large cetaceans, those estimates refer to entire North Pacific populations, and it is not known how many animals actually occur in the Bering Sea. For most species there are some data on the length-weight relationship; however, information on the size structure of the population is needed to calculate an average weight, and those data are not usually available. General observations on the diet of most species have been made (or the diet can be inferred from data from other areas), but sufficient data to quantify the diet in the Bering Sea, taking into account seasonal and geographical variations, are available only for fur seals.

The second source of inaccuracy results from variability and errors in assumptions and values chosen for input parameters. Assuming reasonable error bounds for parameters for the fur seal, which has the most extensive data base of any species, the total calculated food consumption in the Bering Sea could range from 0.2 to 1.5 million metric tons if all errors were cumulative (Lowry et al., 1982). Larger error bounds would be possible for species where little or no data are available for parameters such as population size or residence time, although in many instances it is likely that errors may tend to cancel one another, resulting in gross estimates that are close to the true value.

Table 3. Availability of data required for the calculation of quantities of commercial fishes eaten by marine mammals in the Bering Sea. (Based primarily on Lowry et al., 1982.)

Species	Population size	Residence time	Average weight	Consumption rate	Diet composition
CETACEANS					
Fin whale	*	*	*	**	*
Minke whale	*	*	*	**	*
Humpback whale	*	*	*	*	*
Sperm whale	**	*	*	**	*
Belukha	**	**	**	**	*
Beaked whales	*	*	*	*	*
Dall's porpoise	**	**	**	**	*
Harbor porpoise	*	*	*	*	*
PINNIPEDS					
Northern fur seal	***	**	***	***	***
Steller sea lion	**	**	**	**	*
Harbor seal	**	***	**	***	*
Spotted seal	**	**	**	***	*
Ribbon seal	**	**	**	*	*
Bearded seal	**	**	***	*	**
CARNIVORES					
Sea otter	***	***	**	***	*

*** - extensive data; ** - moderate data; * - little or no data

In considering the likelihood that a particular species of marine mammal may be affected by Bering Sea commercial fisheries, three factors in addition to diet composition appear to be of major importance. Those are:

1) Feeding strategy; i.e., specialist vs. generalist.
2) Overall importance of feeding which occurs in the Bering Sea in the annual nutrition of individuals and the population.
3) Relationship of the present population to carrying capacity; i.e., is per-capita food availability presently limiting population size?

A general assessment of these factors can be made given the presently available data base. For example, although many types of prey are eaten by both walruses and bearded seals, walruses obviously specialize in clams, while bearded seals can and do eat large amounts of clams, shrimps, crabs, snails, and fishes. Minke, fin, and humpback whales are generalists, while right and bowhead whales are much more specialized.

Although distinctions are not completely clear-cut, residency of Bering Sea marine mammal species can be largely classified into three categories: 1) year-round residents (harbor seal, ribbon seal, sea lion, and some belukha whales, Dall's porpoise, and harbor porpoise); 2) summer seasonals (fur seals, sperm whales, and all baleen whales except bowheads); and 3) winter seasonals (ringed seals, bearded seals, most walruses, and bowhead whales). Generally speaking, feeding in the Bering Sea is most important for resident species and summer seasonals, although winter feeding in the Bering is considered important for ice-associated seals and walruses. Summer feeding in the Bering Sea may be somewhat optional for most baleen whales since their relative summer distributions in the Bering and North Pacific appear to fluctuate in different years, presumably based on where optimum feeding conditions exist (e.g., see Bryant et al., 1981).

We have considered two factors as indicative of the relationship of a population to carrying capacity: 1) the present abundance compared to historical levels as indicated by direct estimates of population size or by harvest records, and 2) the recent trend in abundance. Obviously, it is unlikely that a population that is increasing in numbers or is at a low level compared to previous abundance will presently be limited by food availability. Where no data on abundance are available, we have considered populations to be stable and at abundance levels comparable to historic.

We have assigned ranked values to feeding characteristics, based on whether they suggest a probable interaction with fisheries, and to population size and trend values, based on whether they indicate probable food limitation (Table 4). A species that is stenophagous on commercially exploited prey, uses the Bering Sea as a major feeding area, and is near carrying capacity would receive high ranks (maximum total of 15). Conversely, a mobile and omnivorous species that consumes prey not exploited by fisheries, feeds only briefly in the Bering Sea, and is below carrying capacity would receive low ranks (minimum total of 5).

Results of this analysis, considering all factors combined (Table 5), produce total rank values ranging from 13 (highest probability of significant interaction) to 8 (lowest probability of interaction). Species are ranked in order of probability of interaction in Table 6 as categories 1 (ranked value of 13) through 6 (ranked value of 8).

The species for which there is greatest potential for interaction are the northern fur seal, Steller sea lion, and harbor seal. For all three species the Bering Sea is a major feeding area, and commercially exploited fishes (principally pollock, herring, and salmon) comprise substantial portions of the diet. In addition, although they are somewhat opportunistic, their feeding areas may be limited at times by the proximity of terrestrial hauling areas. Based on available data, populations are probably at levels close to carrying capacity, and reductions in prey abundance would be likely to affect ingestion rates and population productivity.

Species in category 2 also rely on the Bering Sea as an important feeding area and are thought to be presently near carrying capacity. In the case of the sea otter the probability of interactions with fisheries is lessened slightly due to a moderate proportion of commercial species in the diet. Although belukha and harbor porpoise forage extensively on commercial species, their mobility may reduce the probability of significant interactions. Much of the feeding of spotted

Table 4. Criteria for assigning ranked values of the likelihood of marine mammal-fishery interactions in the Bering Sea. Low values indicate that the described characteristics suggest a low probability of significant interactions.

	Feeding			Relation to carrying capacity	
Rank value	Composition of the diet	Feeding strategy	Importance of Bering Sea as feeding area	Relative population size	Population trend
1	Feed principally on noncommercial species	Omnivorous with high mobility of predators and prey	Important only for a small fraction of annual nutrition or feeding available elsewhere	Greatly reduced	Increasing
2	Feed moderately on commercial species	Moderately diverse diet (opportunistic)	Moderately important	Slightly reduced	Stable
3	Feed heavily on commercial species and use size classes similar to those targeted on	Stenophagous or with low mobility of predators and prey	Major feeding area without other regular or optional feeding grounds	Comparable to historic	Declining

Table 5. Ranked values of the likelihood of marine mammal-fishery interactions in the Bering Sea, based on characteristics of feeding and population status.

	Feeding			Status		
Species/group	Diet composition	Feeding strategy	Bering Sea importance	Relative size	Population trend	Total
MYSTICETE CETACEANS						
Gray whale	1	3	3	3	1	11
Fin whale	2	1	2	1	2	8
Minke whale	2	1	2	2	2	9
Blue whale	1	3	1	1	2	8
Sei whale	1	3	1	1	2	8
Humpback whale	2	1	2	1	2	8
Bowhead whale	1	3	1	1	2	8
Right whale	1	3	1	1	2	8
ODONTOCETE CETACEANS						
Sperm whale	1	1	2	2	2	8
Belukha	3	2	2	3	2	12
Beaked whales	1	1	2	3	2	9
Killer whale	2	1	1	3	2	9
Dall's porpoise	2	2	2	2	2	10
Harbor porpoise	3	1	3	3	2	12
PINNIPEDS						
Northern fur seal	3	2	3	2	3	13
Steller sea lion	3	2	3	2	3	13
Pacific walrus	1	3	3	3	1	11
Harbor seal	3	2	3	3	2	13
Spotted seal	2	2	3	3	2	12
Ribbon seal	2	2	3	2	1	10
Ringed seal	1	1	2	3	2	9
Bearded seal	2	1	2	3	2	10
CARNIVORES						
Polar bear	1	2	1	3	2	9
Sea otter	2	2	3	3	2	12

Table 6. Summary of probability of interaction with commercial fisheries for Bering Sea marine mammals. Species are not prioritized within categories.

Probability of interaction	Category #	Species
HIGH	1	Northern fur seal
	1	Steller sea lion
	1	Harbor seal
	2	Spotted seal
	2	Belukha whale
	2	Harbor porpoise
	2	Sea otter
MODERATE	3	Gray whale
	3	Pacific walrus
	4	Dall's porpoise
	4	Ribbon seal
	4	Bearded seal
LOW	5	Killer whale
	5	Minke whale
	5	Beaked whales
	5	Ringed seal
	5	Polar bear
	6	Fin whale
	6	Blue whale
	6	Sei whale
	6	Humpback whale
	6	Bowhead whale
	6	Right whale
	6	Sperm whale

seals occurs in the northern Bering Sea and is concentrated on species that are not presently fished commercially. Populations of all three species are probably near carrying capacity at present.

Species for which the probability of interaction is ranked as moderate are either stenophagous on noncommercial species (walrus and gray whales), or feed moderately on commercial species but are rather mobile and opportunistic (Dall's porpoise, ribbon seal, and bearded seal). Available data indicate that the populations of Dall's porpoise and ribbon seals may presently be somewhat below carrying capacity.

Species for which the probability of interaction is considered low either do not feed significantly on commercially important fishes or are opportunistic feeders that are presently at reduced levels of abundance. Although they may be affected by changes in trophic relationships caused by manipulation of other system components, the probability of a significant effect due to commercial fishing is low compared to other species.

Conclusions

The above assessment is admittedly limited in accuracy due to gaps in available data and is based on single-species rather than ecosystem-related considerations. However, in an area such as the Bering Sea with a rich marine mammal fauna and diverse commercial fisheries, ecosystem-based management schemes which allow decision makers to predict all the effects of possible actions may never become a reality. Therefore, it is of utmost importance at present to focus attention on the most probable areas of interaction such that the nature and significance of interactions can be assessed.

Although much of the data used in this assessment has been subjectively evaluated, the rankings derived are probably an accurate indication of the proximate probability of interaction, at least within the high, medium, and low categories, and generally agree with previously published reports (Lowry et al., 1979; Braham et al., 1980; Swartzman and Haar, 1980; Frost and Lowry, 1981; Lowry and Frost, 1981). The marine mammal-fishery combinations which merit immediate study are summarized in Table 7.

Table 7. Marine mammal species for which the probability of interaction with fisheries is high, and the fisheries with which they are likely to interact.

Marine mammal species	Fisheries
Northern fur seal	Groundfish, capelin, squid, herring
Steller sea lion	Groundfish, herring, capelin
Harbor seal	Groundfish, herring, capelin, shrimp
Spotted seal	Groundfish, herring, capelin, saffron cod, shrimp
Belukha whale	Herring, salmon, saffron cod, groundfish, capelin, shrimp
Harbor porpoise	Saffron cod, groundfish, herring, capelin
Sea otter	King crab, tanner crab, snails, clams

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In Search of Density Dependence

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Abstract

The existence of density dependent compensation is implicit in the concept of sustainable yields of fisheries. Recruitment is the principal process that determines fish population growth. Therefore, compensation should be evident in the relationship between spawning biomass and recruitment. There are numerous models of the relationship. Unfortunately, none of these models explains the observed variability.

Two mechanisms that result in compensation are cannibalism and competition for limited resources (e.g., food). Both mechanisms are probably operative on Georges Bank. Fish consumed from 33-56% of their potential food, depending on the period considered. There was the potential that food was limiting, particularly for the period prior to fishing when fish populations were larger. Furthermore, fish consumed about 70% of their own production. This predation should act as cannibalism at the community level.

Thus, there are biological reasons for expecting compensation, although it is usually not possible to demonstrate it empirically. There are deterministic and stochastic approaches for taking account of compensation, in spite of the uncertainties associated with it.

The effect of marine mammals on fish populations is analogous to fishing. Like fishing, marine mammals may have either a compensatory or depensatory effect.

Introduction

Density dependence has received a great deal of attention in the ecological and fisheries literature. Much of this literature has been highly theoretical, and papers concerning practical aspects of the subject have been few. The following paper attempts to explore the problem of density dependence from a practical standpoint.

We begin with a definition of density dependence and a discussion of its importance in relationship to the exploitation and management of fisheries. We then examine evidence for the existence of density dependence in marine fisheries and review potential approaches for considering this phenomenon during the decision-making process. Finally, we speculate about the possible density dependent impact of marine mammal populations on fishery resources.

Definition of Density Dependence

Let B equal the exploitable biomass of a population. Its rate of change, db/dt, is equivalent to the production rate. Production is defined as the sum of recruitment and growth minus natural mortality. Production per unit biomass ($\frac{1}{B}dB/dt$) may or may not vary in relationship to B (Figure 1a). In the former case, a density dependent relationship exists; the relationship is referred to as compensatory if $\frac{1}{B}dB/dt$ increases as B decreases, or depensatory if $\frac{1}{B}dB/dt$ decreases as B decreases. The case where there is no relationship between $\frac{1}{B}dB/dt$ and B is referred to as density independent.

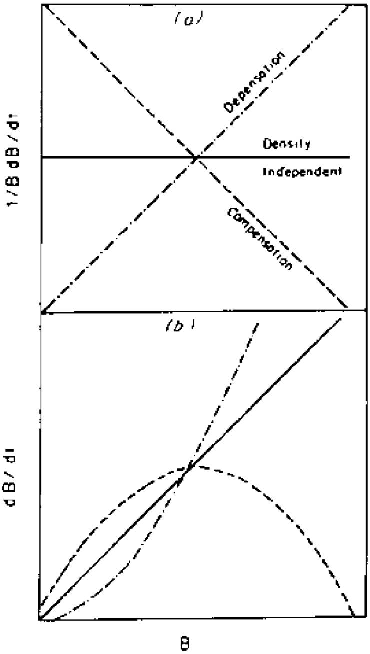

Figure 1. Definitions of density independence, compensation and depensation. B is population biomass.

Potential forms of the relationship between db/dt and B are given in Fibure 1b. Unless there is compensation, population biomass is in danger of growth without bound or extinction.

Implicit in our definition of compensation is the assumption that there is a constant amount of resource (e.g. food) limiting population growth. When the amount of resource (r) is variable, then there is compensation if $\frac{1}{B}dB/dt$ is a monotonically increasing function of r/B. The relationship between $\frac{1}{B}dB/dt$ and B may be linear (Figure 1a) or curvilinear, but the same properties of stability and persistence apply.

The theory of fishing depends on the existence of compensation. The theory is that an unexploited fishery remains in a quasi-equilibrium with no production. Fishing reduces biomass, resulting in a compensatory response of increased production which can be harvested as a sustainable yield.

Compensatory processes may involve an increase in recruitment or growth as biomass decreases or by a decrease in natural mortality as biomass decreases. For marine mammals, growth and other demographics (e.g. age at maturity) are so closely tied to biomass that changes in demographics are sometimes used to monitor population size. For fish populations, however, the relationships between demographics and biomass are not nearly as strong.

Fishery scientists have focused on the relationship between recruitment and spawning biomass (referred to as S-R relationships). They have done so because most production results from recruitment and, ultimately, population persistence requires that numbers be replaced by the recruitment process. Therefore, density dependent responses of demographic parameters must eventually effect recruitment.

Stock - Recruitment Relationships

There are numerous biological mechanisms that result in compensatory S-R relationships. Ricker (1954) noted several mechanisms including competition for breeding sites or living space, competition for food resulting in starvation, increase susceptibility to disease from crowding, cannibalism, and compensatory growth coupled with size dependent predation mortality.

Some of these mechanisms lead to characteristic mathematical relationships between spawning stock size and recruitment. The best known of these relationships are the Ricker (1954, 1958) function,

$$R = aSe^{-S/K} \tag{1}$$

and the Beverton and Holt (1957) function,

$$R = \frac{aS}{(a + S/K)} \tag{2}$$

where R is recruitment, S is spawning stock size and a and K are parameters. Families of Ricker and Beverton and Holt stock and recruitment functions are given in Figures 2 - 3. The dome shaped Ricker function is characteristic of cannibalism. According to Shepherd (1982, based on a personal communication from Robert May, Princeton University) it may also result from depletion of a key food resource due to the stock itself. The Beverton and Holt stock-recruitment function results from compensatory growth coupled with a decrease in predation mortality as size increases.

Unfortunately, neither function (or other S-R functions proposed in the literature, e.g. Cushing, 1973) account for the variability in stock-recruitment data (see Figures 4-7). It is usually hypothesized that the unexplained variability in recruitment results from environmental fluctuations. In a few cases, these environmental fluctuations have been taken into account. One such example is given by Sissenwine (1974, 1977). It was demonstrated that recruitment of southern New England yellowtail flounder is affected by temperature. Two simulation models were developed which superimposed the effect of temperature on

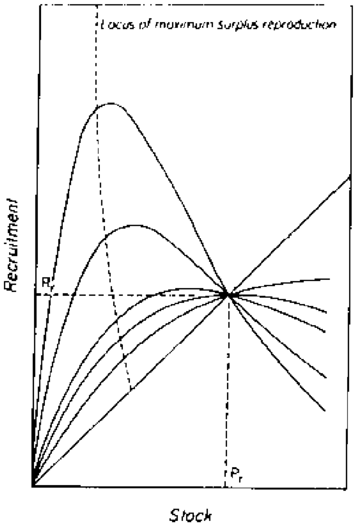

Figure 2. Family of Ricker (1954) stock-recruitment functions.

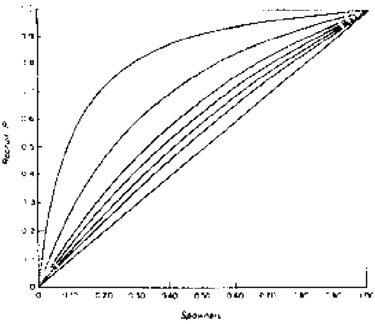

Figure 3. Family of Beverton and Holt (1957) stock-recruitment functions.

underlying stock-recruitment models. The results are given in Figures 8-9. In both cases, the models explain most of the observed variability in the fishery. They have apparent predictive value, since only information up to 1965 was used to fit the parameters of the models, yet they continue to predict beyond that date.

Unfortunately, although the models account for the environmental fluctuations that usually obscure stock-recruitment relationships, it is still not possible to quantify density dependence. While the simulations in Figures 8 and 9 are almost indistinguishable, they are based on fundamentally different stock-recruitment relationships; the former assumes density independence, the latter assumes strong compensation. Therefore, even if environmental fluctuations are taken into account, it may not be possible to identify the nature of biological control.

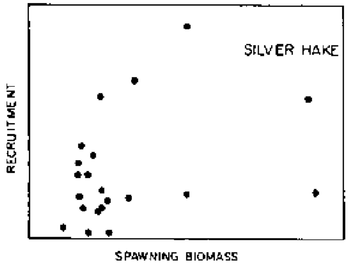

Figure 4. Stock-recruitment data (Fogarty et al., in press).

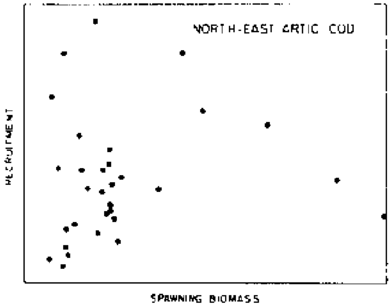

Figure 5. Stock and recruitment data (ICES 1983b).

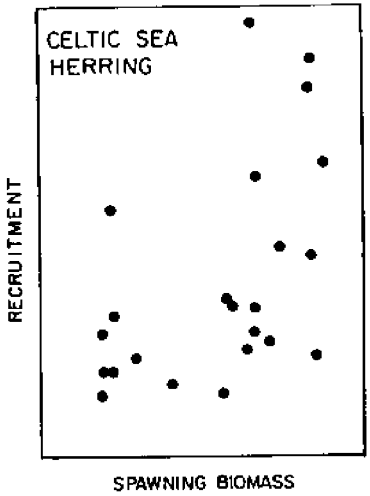

Figure 6. Stock-recruitment data (ICES 1983b).

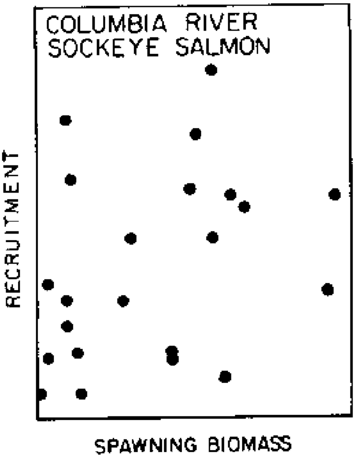

Figure 7. Stock-recruitment data (Van Hyning 1973).

Biological Evidence of Compensation

Does compensation exist or is it dogma? It is often argued (e.g., MacFadden 1977) that compensation must exist, or exploited populations could not persist. This argument is valid in a deterministic world. But Reddingius' (1971) work, "Gambling for Existence", proves that in a stochastic world density dependence is not required for a population to persist for a finite period of time. Since we can only observe a finite period of time, persistence does not demonstrate compensation. Reddingius

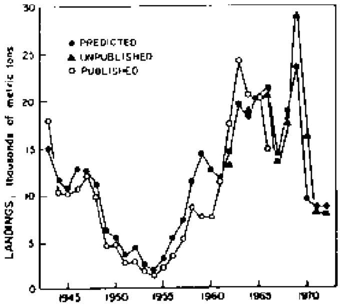

Figure 8. Simulations of southern New England yellowtial flounder with density dependent stock-recruitment (Sissenwine 1977).

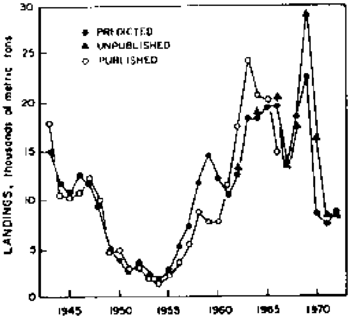

Figure 9. Simulation of southern New England yellowtail flounder with strong compensation in stock-recruitment (Sissenwine 1977).

concludes that "Deterministic theory in population ecology thus seems to be of little help in providing a framework for probabilistic theory".

Therefore we need to look for biological mechanisms that indicate compensation. We expect compensation if fish production is resource (e.g. food) limited or if fish are cannibalistic. We have examined both possibilities, using a holistic approach, for Georges Bank (Figure 10).

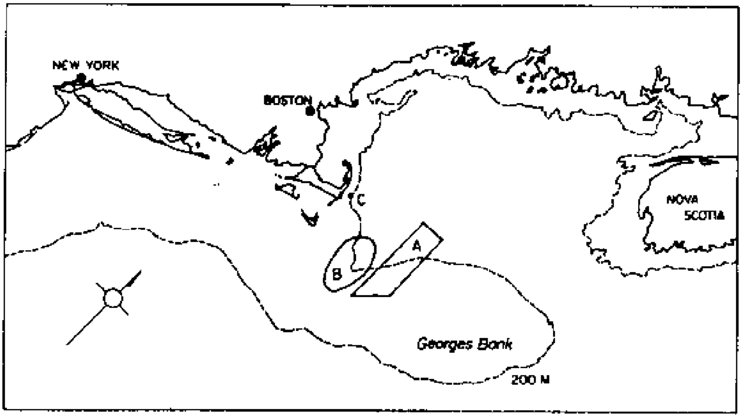

Figure 10. Georges Bank region. A indicates area where fishing was allowed during fall of 1977. B indicates area where Georges Bank herring spawned during fall of 1977, as indicated by distribution of newly hatched (from demersal eggs) larvae. C indicates location where herring were captured by a research vessel during fall 1977.

Georges Bank is a highly productive fishing ground off the northeast coast of the United States. The Bank and surrounding region has been the focus of intensive ecological studies (Grosslein et al., 1979; Sissenwine et al., in press (a); Fogarty et al., in press). These studies include research on phytoplankton, zooplankton, ichthyoplankton, benthos, and nekton (i.e., finfish and squid, hereafter referred to as fish); the $_{14}C$ method, bongo net plankton surveys, bottom trawl surveys, and benthic grabs samples have been employed. The results of these investigations have been summarized in the form of an energy budget of Georges Bank (Sissenwine et al., in press (b)).

The energy budget is most certain for primary productivity and fish production. Estimates of primary productivity are based on a three-year study, with samples collected throughout the year (O'Reilly and Busch, in press). Estimates of fish abundance, production and consumption are based on extensive bottom trawl surveys and fisheries statistics. These programs have been ongoing for more than 20 years. While estimates of other components (e.g., macrozooplankton) are less certain, conclusions based on the entire energy budget are generally robust. This robustness results from the bounding effect of the more precise information at the lowest (primary productivity) and at higher (fish) trophic levels.

Average biomass, annual consumption and annual production estimates for the fish of Georges Bank, for the periods 1964-1966 and 1973-1975, are given in Table 1 (Grosslein et al., 1980). The former period was one of increasing fishing pressure from distant water fleets in response to high fish abundance. The latter period was one of low abundance, following a decade of excessive fishing pressure.

Table 1. Georges Bank population density, consumption and production in Kcal/m^2 or Kcal/m^{2}yr, for exploitable individuals by species or species group and for pre-exploitable.

	Biomass	Consumption	Production
1964-1966			
Cod	1.9	5.6	1.1
Haddock	4.5	16.1	2.1
Redfish	<.1	0.1	<.1
Silver hake	10.1	48.6	5.8
Red hake	1.1	4.4	0.5
Pollock	0.3	1.1	0.1
Yellowtail flounder	0.6	2.9	0.4
Other flounder	0.3	1.3	0.1
Herring	19.3	87.5	5.4
Mackerel	1.3	5.4	0.4
Other finfish	1.7	6.9	0.8
Illex	0.2	1.6	0.2
Loligo	0.1	0.4	0.1
Pelagics	20.9	95.0	6.2
Demersal	20.4	97.1	11.1
Total Exploitable	41.3	192.1	17.2
Pre-exploitable	4.1	152.3	51.7
1973-1975			
Cod	0.9	3.0	0.6
Haddock	0.4	1.4	0.2
Redfish	0.1	0.2	<.1
Silver hake	7.4	36.3	4.4
Red hake	0.8	3.3	0.4
Pollock	0.1	0.5	0.1
Yellowtail flounder	0.5	2.2	0.3
Other flounder	0.2	1.0	0.1
Herring	6.2	28.5	1.8
Mackerel	2.7	11.7	0.9
Other finfish	2.3	9.3	1.0
Illex	1.7	12.0	2.6
Loligo	0.3	1.9	0.4
Pelagics	10.9	54.1	5.7
Demersal	12.7	57.2	7.0
Total Exploitable	23.7	111.3	12.7
Pre-Exploitable	2.3	85.4	29.0

Production is partitioned between 13 species or species groups. Herring, mackerel, Illex and Loligo are considered pelagic. The remaining species or species groups are considered demersal.

Pre-exploitable fish (individuals which are either too small or young to be captured by commercial or research vessel bottom trawl survey gear) are not represented in traditional abundance estimates. Nevertheless, they are an important component of the ecosystem.

Relatively little is known about the population dynamics of these young fish, particularly after the late larval stage and before they grow large enough to be caught in trawls. However, some valuable information is available. The initial number and biomass of a cohort of young pre-exploitable can be estimated from the abundance of the adults, the proportion of the total adult production used for reproduction, and the average size of an egg. As the young reach exploitable size, their number and biomasses can be estimated from traditional stock assessments based on trawl surveys and fisheries statistics. With these beginning and end points known for the pre-exploitable fish, a simple model can be used to calculate estimates of average biomass, production and consumption. The model assumes that growth of individual fish and of the entire cohort of pre-exploitable fish is exponential. Sissenwine et al. (in press (b)) applied this approach; his results are included in Table 1.

While pre-exploitable fish are only 10% of the biomass of exploitable fish, their consumption is nearly as great and their production is 2½ times as high. Extensive stomach content investigations indicate that fish consume macrozooplankton (e.g., herring, mackerel and redfish prey on planktonic crustaceans); benthos (e.g., haddock, yellowtail flounder and other flounder prey on polycheta, echinodermata, and benthic crustacea); and fish (cod and silver hake prey on other fish including their own species). Sissenwine et al. (in press (b)) noted that consumption of fish by silver hake and cod accounted for 40 to 50% of the total consumption by the demersal component. For the purposed of this discussion, we assume that approximately 50% of demersal consumption is of fish.

The Georges Bank energy budget is summarized in Table 2. Estimates of particulate phytoplankton, macrozooplankton, benthos, and fish production are from Sissenwine et al. (in press (b)), except that a different conversion for phytoplankton from grams carbon to kilocalories has been used (i.e., 11.4 kilocalories/gC, Platt and Irwin, 1973).

Fish production was from 1.0% to 1.8% of particulate primary productivity. Considering the complexity of the food web, trophic efficiency must be high relative to traditional thinking (10%, Slobodkin, 1961). One implication of the results is that the energy budget is "tight", and fish production may be limited by their food resource. In fact, Table 2 indicates that fish consume from 33 to 56% of production by suitable prey types, and they consume about 70% of their own production. Independent estimates of consumption by mammals, birds, large pelagic migratory fish (e.g., sharks) and humans approximately account for the remaining of fish production.

Cohen and Grosslein (in press) have revised some of the values used here, most notably macrozooplankton production. These revisions indicate that fish consume an even higher proportion of the total production by suitable prey and of their own production.

Table 2. Components of Georges Bank energy budget. Production estimates and fish consumption estimates are based on Sissenwine et al. (in press). Bird, mammal and large pelagic consumption estimates are based on Powers (in press), Scott et al. (1983), and Cohen and Grosslein (in press), respectively. Human consumption corresponds to the average catch, 1968-1982.

	Kcal/m^2yr	
Production		
Phytoplankton (particulate)	3780	
Macrozooplankton	350	
Benthos	200	
Fish (exploitable)	13- 17	
(pre-exploitable)	29- 52	
(total)	42- 69	(1.1-1.8% of Phytoplankton Production)
Potential Fish Prey	592-619	
Fish Consumption		
All Prey	197-344	(33-56% of Potential)
Of Fish	30- 50	(about 70% of Fish Production)
Consumption of Fish		
By Fish	30- 50	
By Birds	2.0	
By Mammals	5.4	
By Large Pelagics	2.0	
By Humans	6.1	
Total	45.6-65.6	(about 100% of Fish Production)

The above studies have demonstrated a biological basis for compensation by the Georges Bank fish community. Their production is probably food limited and they modify their own abundance by predation. It seems likely that these mechanisms are operative at the species and community level. Some species are cannibalistic (e.g., silver hake); furthermore, an abundance of fish as prey may enhance production of predators, ultimately resulting in compensation.

Cohen and Grosslein (in press) compared Georges Bank to other continental shelf ecosystems. These comparisons indicate that Georges Bank is not unique in its efficient conversion of primary productivity to fish production. For example, fish production is about 1% of particulate primary productivity for the North Sea and about 3% for the eastern Bering Sea. These ecosystems are also "tight" like Georges Bank, and food probably limits their production as well. Furthermore, North Sea and eastern Bering Sea fish also consume a significant proportion of their own production (Laevastu and Larkins, 1981; Daan, 1983).

While compensation is usually not indicated by stock-recruitment data, there is evidence of compensation in demographic parameters; e.g., size at age of Pacific Halibut (Deriso, 1983), size at age of Baltic Sea Sprat (ICES, 1983), fecundity at age or size of Georges Bank Herring (Anthony and Waring, 1980 (a)). Occasionally, compensation is indicated by a stock-recruitment relationship (Deriso 1983), but a long time series (i.e., about 50 years) and significant variation in stock size (i.e., a factor of 2 or more) is usually necessary.

Two Practical Approaches to Stock-Recruitment

Shepherd (1982) proposed the application of a versatile stock-recruitment model,

$$R = \frac{aS}{1 + (S/K)^{\beta}} \qquad (3)$$

(Figure 11). The parameter a is the slope of the function through the origin. K is the "threshold" biomass,(i.e., the level of the biomass above which density dependent effects dominate). The shape of the function is determined by β. If $\beta<1.0$, the function increases without limit (i.e., quiasi Cushing, 1973). If $\beta=1.0$, it increases to an asymptote (i.e., Beverton and Holt, 1957). If $\beta>1.0$, it is dome shaped (i.e. quiasi Ricker, 1954).

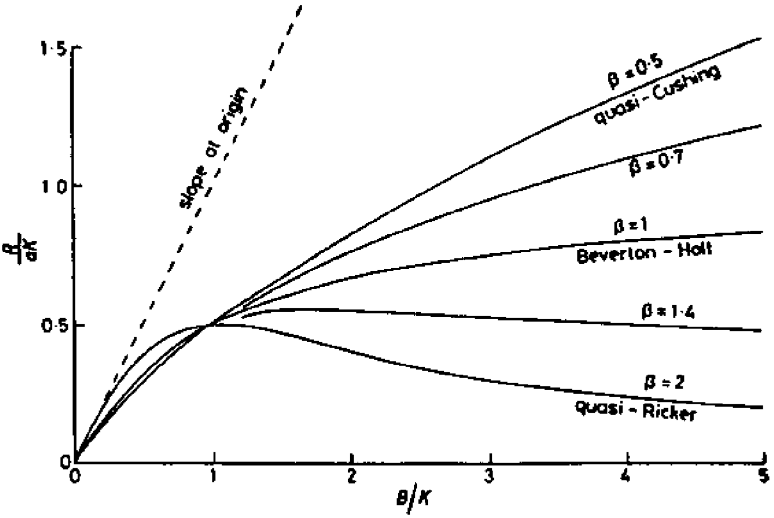

Figure 11. Versatile stock-recruitment function (Shepherd, 1982).

Shepherd describes an ad hoc method of fitting his model and its application to fisheries management decisions. We demonstrate his approach for Georges Bank haddock.

Stock-recruitment data for Georges Bank haddock are given in Figure 12. Shepherd notes that a is the most important parameter for fisheries management decisions, as it determines the maximum sustainable fishing mortality rate (F). It can be estimated by drawing a straight line through the origin just to the left of the bulk of the data points. For Georges Bank haddock, we drew a line to the left of 90% of the observations. Since the slope of the function increases as spawning biomass decreases, and there are, of course, no observations at the origin, this approach should provide a conservative (i.e., maximum sustainable F underestimated) estimate of a, according to Shepherd.

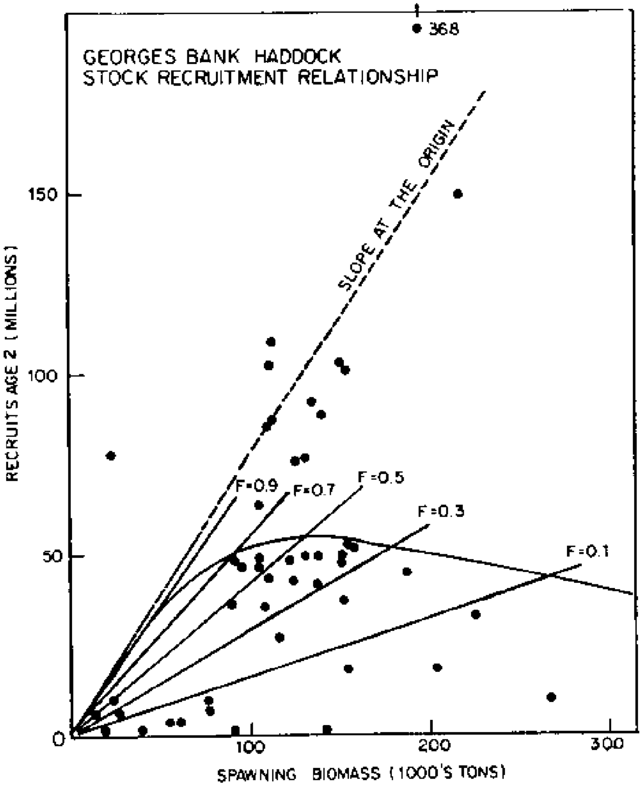

Figure 12. Application of Shepherd's function to Georges Bank haddock stock recruitment data. Lines of constant R/S ratios were derived by yield per recruit analysis (Figure 13). The intersection of these lines with S-R function determines the equilibrium recruitment for each F. The data is from Clark et al. (1982).

Shepherd recommends that β be selected subjectively based on the expected shape of the function. For Georges Bank haddock, we chose β=2.0. A dome shaped β>1.0 function is expected for a system dominated by predation. Furthermore, the data also suggest a dome shaped function (Figure 12).

Finally, K was estimated by forcing the function to pass through a cluster of observations (R=52,000,000 fish, S=100,000 tons), as suggested by Shepherd.

The stock-recruitment function is readily combined with yield-per-recruit analyses in order to derive a total yield function. The results of yield-per-recruit analysis for Georges Bank haddock are given in Figure 13. For each fishing mortality rate, there is a corresponding value of spawning biomass per recruit (S/R). Taking the reciprocal of these values, lines of constant R/S are plotted on the stock-recruitment function (Figure 12). The intersection of each line with the stock-recruitment function determines the equilibrium recruitment level. Note that the maximum F, for which there is an equilibrium recruitment, is about 0.9. The equilibrium yield, for each F, is obtain by multiplying the equilibrium recruitment by the appropriate yield-per-recruit. The resulting yield is given in Figure 14.

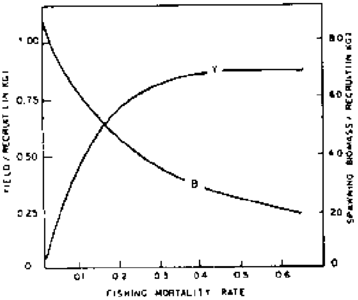

Figure 13. Yield-per-recruit analysis for Georges Bank haddock.

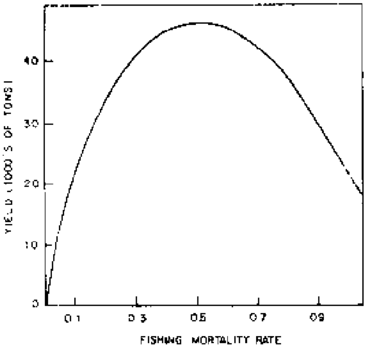

Figure 14. Equilibrium yield model (including the effect of a compensatory stock-recruitment function) for Georges Bank haddock.

The maximum sustainable yield (MSY) is about 47,000 tons. It occurs at an F level of 0.55 with a spawning biomass of 115,000 tons. As F increases, sustainable yield declines to about 25,000 tons at a biomass of about 47,000 tons. At this point, no further increase in F is sustainable. It is noteworthy that the situation changes from a sustainable yield of about one-half MSY to a situation where the population cannot persist, with only a small increase in F.

Shepherd's approach ignores the stochastic effect of a fluctuating environment. It is only applicable on average. While Shepherd contends that his method of estimating the parameter a is conservative, this conclusion is not necessarily valid for a stochastic system. The

R/S ratios for some years may be anomalously high due to favorable environmental conditions. If a is estimated by drawing a straight line through the origin just to the left of the bulk of the observations, the estimates may be inflated, relative to average environmental conditions. Therefore, it is useful to consider a stochastic approach.

One stochastic approach is a model of recruitment as probabilistic conditional spawning biomass. Once again, we use Georges Bank haddock data to demonstrate the approach. A Ricker (1954) stock-recruitment function was fit by non-linear least-squares. Then, a lognormally distributed multiplicative random error model was fit to the residuals.

The population was simulated using an age structured model, at various levels of F. Each simulation was for 100 years and the simulations were repeated ten times for each level of F. Two sets of initial conditions were considered. The first set was for a "healthy" population with an age composition and spawning biomass (150,000 tons) corresponding to the equilibrium situation for F_{MSY}. The second set of initial conditions was based on the current condition of the population. Spawning biomass has been reduced to 28,000 tons due to intensive fishing.

The results of the simulations, with the first set of initial conditions, are summarized in Figure 15. The 10, 25, 50 (median), 75, and 90 percentile catch levels are given for each F. The coefficient of variation of the catch is also given. The median catch at F=0.55 is almost identical to the MSY (47,000 tons) indicated by the deterministic analysis of the same data, using Shepherd's approach. In general, the median values of the catch are similar to the catch levels for various F's indicated by the deterministic analysis. The stochastic analysis indicates the degree of variability in the catch. The coefficient of variation of catch increases as F increases.

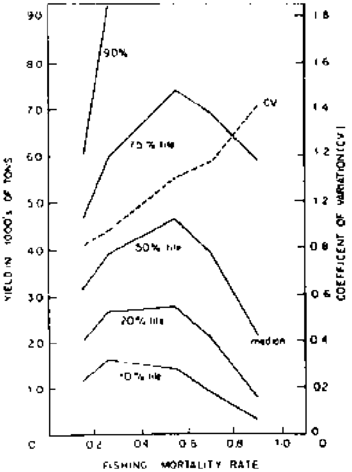

Figure 15. Results of stochastic simulations of Georges Bank haddock.

The results of the simulations based on initial conditions corresponding to the current situation are not shown. They indicate that the probability of the population recovering decreases sharply as F increases above 0.55. The median catch is about 40,000 tons for F=0.55, about 85% of the populations's potential. But for F=0.9, the median catch is only 1400 tons, and there is only a 10% probability of catch reaching 20,000 tons. The coefficients of variation for F=0.55 and 0.90 are 1.21 and 2.22, respectively; in both cases higher than for simulations based on "healthy" initial conditions.

Note that these analyses of Georges Bank haddock stock-recruitment data are for the purpose of illustration only. More thorough analyses are ongoing.

The Effect of Marine Mammals

The predation loss of fish due to marine mammals is usually assumed to be included as a component of natural mortality. If consumption rate of marine mammals is known, it may be treated explicitly in a similar manner to fishing.

Like a fishery, marine mammals have a potential for density dependent population effects. If a fishery, or marine mammals, switch to a more abundant target as a fish population becomes rare, then the system has the potential for compensation. On the other hand, if the fishery, or marine mammals, are able to remove a nearly constant amount of fish, even as fish abundance decreases, the system is potentially depensatory. Pelagic fisheries are particularly susceptible to depensation since such resources are usually aggregated into schools and the fishery is often efficient at locating and harvesting these schools (Paloheimo and Dickie, 1964; Pope and Garrod, 1975; Radovich, 1979).

The system involving Georges Bank herring, the fishery for them, and marine mammals may have been depensatory. The estimated stock size of the herring population declined from its peak of over 1,100,000 tons in 1967 to less than 300,000 tons in 1976. Until 1975, stock size declined more rapidly than catch. Thus fishing mortality was increased as population size decreased, a depensatory situation.

Catch was reduced significantly in 1976 in an effort to stabilize the population. The allowable catch limit established for 1977 should have prevented further declines. The fishery was restricted to the fall spawning season and to one of the traditional fishing areas on Georges Bank (Figure 10). In actuality, the commercial fishery failed, there was virtually no catch from the Georges Bank herring population during 1977. Apparently, there were some fish that spawned in the South Channel-Nantucket Shoals area (Figure 10). This is the area where larvae were found and spawning herring were captured by a research vessel (Anthony and Waring, 1980; Lough et al., 1979).

There has been virtually no evidence of the Georges Bank herring population since fall 1977. This is in spite of hundreds of days of research vessel operations, using trawls, ichthyoplankton samplers and hydroacoustics.

While the Georges Bank herring population was certainly overfished, there was at least a remnant population remaining after the last commercial catch had been taken. Anthony and Waring (1980) predicted a population of about 300,000 tons at the beginning of 1978. Yet, the population did not recover as would be expected, unless there was depensation.

Until recently, little was known about the abundance of marine mammal populations in the Georges Bank region. They were generally assumed to be ecologically unimportant (Cohen et al., 1982). Recent aerial surveys have, however, indicated that marine mammals are abundant (CETAP 1982). Figure 16. indicates that the distribution of fin whales (B.

physalus) 1979-1981. While the density of fin whales is relatively low during the fall, they were concentrated, in 1979-1981, in the same general area where herring were last observed in the fall 1977. In general, the distributions of fin whales and herring in this region overlap.

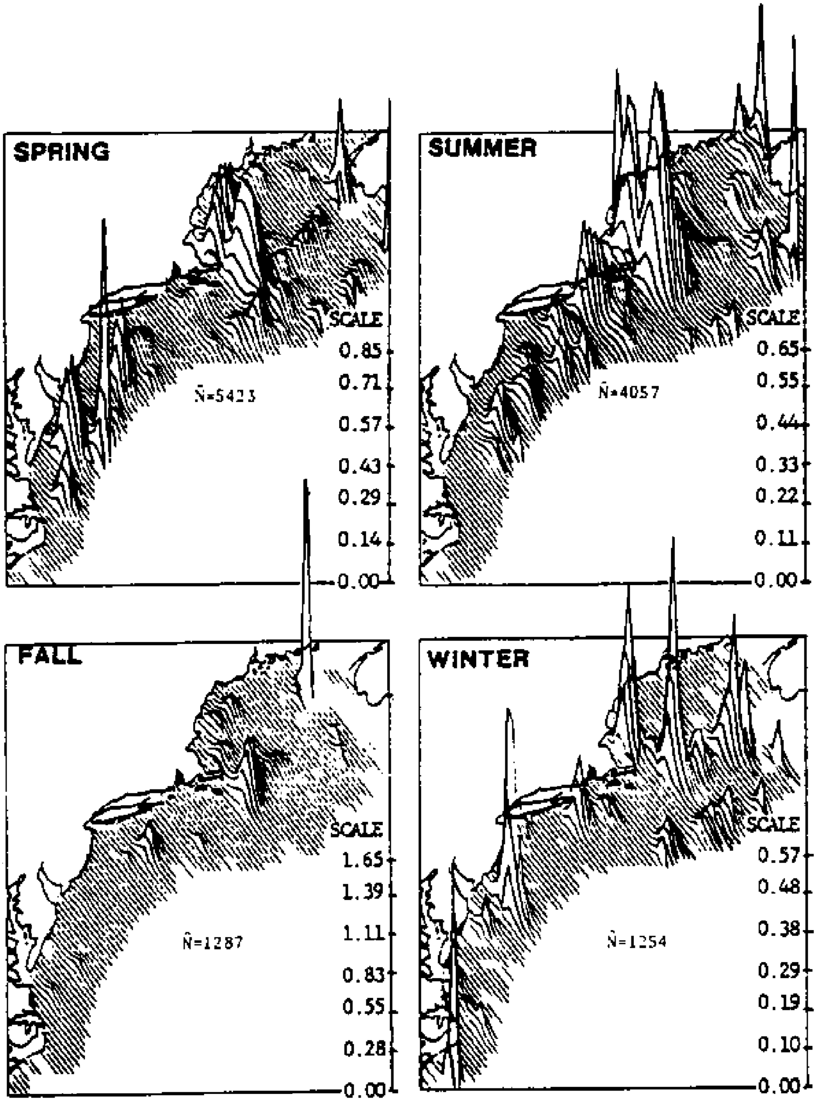

Figure 16. Distribution and abundance estimates (N) of fin whales (CETAP 1982).

Schooling fish are reported to be the primary prey of fin whales in the Georges Bank region (Katona et al., 1978; Watkins and Schevill, 1979). Herring are certainly suitable prey. Applying the seasonal fin whale abundances reported in Figure 16, an average weight of 30 tons (Kenny et al., 1983), and a consumption rate of 3% body weight per day, annual consumption by fin whales in this area is estimated as about 1,000,000 tons. We can only speculate about the role of fin whales and other marine mammals in the demise of Georges Bank herring. Clearly, they had motive, means and opportunity.

It is clear that sand lance now constitutes a substantial proportion of their diet (Overholtz and Nicolas, 1979). The large reduction in herring biomass has been offset by an increase in sand lance abundance since the mid-1970's (Sherman et al., 1981).

Concluding Remarks

Although it is difficult to demonstrate density dependence empirically, there is a biological basis for assuming it exists. Trophic efficiency of exploited marine ecosystems is high. This implies a potential for fish production to be limited by food resources. Furthermore, the consumption of a high proportion of fish production by fish should stabilize their abundance.

Fishery exploitation and management strategies may be based on either deterministic or stochastic approaches which incorporate density dependence. These approaches provide a framework for interpreting observations. Uncertainty associated with the deterministic component of the stock-recruitment problem is reduced as time series of observations accumulate and as the observed range of spawning biomass increases. Nevertheless, uncertainty in recruitment is inherent because of environmental fluctuations.

Marine mammals may contribute to density dependence, either compensation or depensation. One implication is that fisheries management and exploitation strategies may need to be more conservative when marine mammals are abundant, because of the possibility of depensation.

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A Review of Density Dependence in Marine Mammals

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Abstract

Two generalizations about density dependence in marine mammals are discussed: 1) Eberhardt's 1977 hypothesis about the order in which different life history parameters become density dependent, and 2) Fowler's (1981) hypothesis that the production curve for marine mammal species is skewed to the right. For the first hypothesis, it is pointed out that non-cetacean species seem to follow its predictions better than cetacean species. This may be the result of limited information on adult survival for all species of marine mammals and limited information on juvenile survival in cetaceans. It is suggested that Fowler's hypothesis should be used with caution if information on the shape of the density-time plot is not available. Several factors that work to skew the production curve to the left are also discussed. Finally, factors responsible for population fluctuations are discussed, and it is suggested that different assessment procedures and management strategies should be considered for different populations of marine mammals.

This paper presents a brief review of density dependence in marine mammals. Eberhardt (1977) initially described a general model for predicting the order in which life history parameters will become density dependent to retard further increases in population size, and Fowler (1981a, 1981b) predicted that in general the production curve of marine mammals will have its peak between .5K and K (carrying capacity). Siniff (1982) reviewed density dependence in pinnipeds, with a major emphasis on the Antarctic. Fowler (1981b), Fowler et al. (1980), and Fowler and Smith (1981) reviewed density dependence in large mammals in general. Finally, Fowler (in press) reviewed density dependence in cetaceans. The purpose of this paper is to review Fowler's and Eberhardt's generalizations, and to point out a few problems in defining, interpreting, and managing marine mammal populations within the framework of density dependence.

Defining What is Meant by Density-Dependence

Strictly speaking, density dependence refers to a relationship between some life history parameter (or population growth rate) and density (Keith, 1974). However, in general density dependence is said to be occurring whenever there is competition for a limited set of resources. In terms of the definition of density dependence this can be thought of as incorporating a per capita value for whatever resources are limiting into the density term. The working definition of density in this paper is the number of animals per capita unit of the (or one of the) limiting resources. Therefore, environmental factors that affect the availability of a resource (say food) may induce a density dependent response in survival, even though the number of animals remains constant. Throughout this paper, density dependence will refer to the more general definition. The implications of invoking this definition are two-fold. First, density dependence will always be found if a broad enough range of densities and the "appropriate" life history parameter are compared. Secondly, no one function will always correctly predict the appropriate density dependent response due to changes in environmental factors.

Problems in Generalizing about Patterns of Density-Dependence in Marine Mammals

There are two main generalizations used to describe density dependence in marine mammals. This section will investigate how useful they are. Eberhardt (1977) suggested that the pattern of life histories parameters that were progressively invoked to retard further increases in the population level would be: juvenile survival (JS), first age of sexual maturation (ASM), adult reproduction (AR), and adult survival (AS). Fowler (1981a, 1983) suggested that the shape of the density dependent relationship will be non-linear, such that the production curve will have its peak between .5K and K (I will refer to this as a right skew).

Concerning Eberhardt's hypothesis, it is necessary to look at which life history parameters have been found to be density dependent in the various groups of marine mammals. For pinnipeds, Fowler's (1983) data indicate that in general ASM and JS are density dependent, while AR and AS are not. However, exceptions do exist. For harp seals (Lett et al., 1981) AR was found to be density dependent. For Weddell seals, De Master (1978), Siniff et al. (1977) and Siniff (1982) indicate that AR and AS can be density dependent. For cetaceans, Fowler's (1983) data indicate that in general ASM and AR are density dependent. Two exceptions exist. For *Orcinus* JS and AS are density dependent, and for gray whales JS is density dependent (Fowler, 1983). Data for polar bears (Bunnell and Tait, 1981) and sea otters (A. Johnson, pers. comm.) indicate JS is density dependent. For the sirenians, the only published information indicates that ASM is density dependent in dugongs (Fowler, 1983).

The pattern that emerges from these data is that populations of pinnipeds, sea otters, polar bears and dugongs seem to follow Eberhardt's hypothesis, with polar species of pinnipeds providing a few exceptions. For cetaceans the hypothesis does not seem to hold. However, these results may be related to sampling biases. Two problems are worth noting. First of all, there are very few data on adult survival for any species of marine mammal. Secondly, for large whales the data are mostly from harvests of adults where pregnancy rates and ASM can easily be determined, but few other life history parameters can be estimated. For the other species, tagging studies and information from harvests have produced estimates of JS, ASM, and AR. Therefore, the apparent agreement for pinnipeds may be related to the lack of information on AS, and the apparent lack of agreement for cetaceans may be due to a lack of information on JS and AS. As an example, for two species of pinnipeds where most of the life history parameters are known, one species has only JS being density dependent [gray seals: Prime (1981)] and another species has JS, AR, and ASM density dependent, with AS being unknown [harp seal: Lett et al. (1981)].

The second generalization I would like to discuss was proposed by Fowler (1981a). This hypothesis needs to be examined with a number of sampling biases in mind. First of all, the production curve is a function of all of the life history parameters. It is not clear that if one life history parameter (LHP) exhibits a non-linear density dependent response, and the other parameters are either linear functions or unknowns, one is secure in concluding the production curve is skewed to the right. Fowler's hypothesis would be much more convincing if actual production curves could be constructed or if density-time plots were available. Such an approach was taken by Fredin (in press); his results for a number of species indicated the production curve was not excessively skewed to the right. In addition, it is worth noting that in the five cases where more than one LHP was found to be density dependent (Fowler, 1981b), three of these have both linear and non-linear functions; the other two have all non-linear functions.

Another sampling bias that may affect Fowler's hypothesis concerns marginal habitat. Pella and Tomlinson (1969) and McCall (pers. comm., Southwest Fisheries Center, La Jolla, CA) show that the production curve is skewed to the left in a number of population models. McCall specifically relates this to the amount of marginal habitat that is utilized by a species. This is related to the increased degree of environmental uncertainty that occurs in marginal habitat. For many species of marine mammals the concept of marginal habitat is probably meaningless, but for species like the sea otter, walrus, polar bear and Weddell seal, where the habitat quality varies significantly over the occupied range of the species, this consideration may confound Fowler's conclusion. There may also be problems with applying Fowler's hypothesis to species where habitat quality has been greatly reduced by man's impact, or where the total amount of habitat has been greatly reduced.

A final comment on Fowler's hypothesis has to do with the statistical interpretation of the LHP-density plot. It has been argued by some that the form of the functional relationship between LHP and density would be considered linear if a linear regression produces a significant correlation, and if non-linear functions do not significantly increase the fit. This, of course, assumes that the linear fit would hold over the entire density range, and not just the observed density range (see Fowler et al., 1982). Therefore, caution must be used in stating a function is linear, when in reality a linear regression was the best fit over the observed range of densities.

Problems in Managing Populations of Marine Mammals within a Density Dependent Framework

Population dynamics has been a field where few generalizations have proven very useful in managing specific populations of marine mammals. However, a number of concepts have proven useful. They are:

1) All populations fluctuate (Keith, 1974).

2) The pattern of fluctuation will be either regular (tend to return to an equilibrium), cyclic, or irregular (Keith, 1974).

3) Fluctuations are caused by either changes in the environment (which change the equilibrium population) or time lags (delayed-density-dependences, Varley, 1947).

4) Populations that exhibit density-dependent mechanisms need not be regulated to a specific equilibrium.

5) All populations are limited by competition for resources at "some" density.

The statement that all populations fluctuate is relative. Keith (1974) refers to a regulated population of wolves that persists within 10% of the long term equilibrium. Snowshoe hare populations change by 200% in their 10-year cycle (Keith, 1974), and populations of ringed seals (Stirling et al., 1977), polar bears (De Master et al., 1980) and Weddell seals (De Master, 1978) all have been observed to fluctuate by at least 50%.

Concerning marine mammals, it is generally assumed that they are k-selected and do not fluctuate. This statement is not testable because there are very few populations of marine mammals that are at equilibrium conditions and that have been monitored for any length of time. Certainly the large whales do not qualify. They are probably not at any kind of equilibrium and are very difficult to monitor on a routine basis. Many species of pinnipeds are still recovering from over-exploitation (e.g. California sea lion, northern elephant seal, southern elephant seal, most species of fur seals, harp seal, monk seal, etc.), so their equilibrium behavior cannot be described. For those polar species of marine mammals that have not been reduced and where monitoring studies have been done, irregular fluctuations would certainly best describe most of the population fluctuations.

Marine mammal management has generally taken place in the absence of information on the behavior of the population at equilibrium levels. In fact, few data are available on the shape of the production curve, but a great deal of information does exist on which LHPs are density dependent as populations recover from previous over-exploitation. Populations are required under an interpretation of the Marine Mammal Protection Act by the National Marine Fisheries Service and the Fish and Wildlife Service to be managed in such a way that populations remain above the level where net production is maximized (referred to as the MNP level). This has generally been done in one of three ways. The MNP level can be estimated as some function of the current population level, assuming that the current population is near historic levels. If populations have been reduced by direct or indirect take, and levels of take are known for the entire period of exploitation, back-calculation of historic population levels are made (see Smith and Polacheck, 1982). Back-calculating historic levels requires information on the current population level, a complete history of takes, and knowledge of how the rate of population change varies with population size. Both of the above approaches assume that the environment is constant. Furthermore, because the shape of the production curve is known for very few species of marine mammals, it is usually necessary to generalize about its shape from functional relationships between LHPs and density. Recently, Fowler (1981b and in press) has suggested that the peak of the production curve will generally lie between 65-80% of the equilibrium population level. Finally, for some species it is possible to estimate historic levels of population abundance (e.g., northern fur seals) from censuses done prior to exploitation.

One problem with these management approaches is that the form of the density dependence that leads to a right-skewed production curve will also tend to overshoot the equilibrium population level more than those populations that have a symmetric production curve. This can happen in either of two ways. First of all, if adult fecundity or recruitment has a steep enough non-linear relationship with density, the population will initially overshoot the carrying capacity due to time lags. Secondly, if the environment fluctuates at all when the population is near maximal levels, the resulting change in the population will be much larger than if the population had been at a lower level. Therefore, trying to manage populations at very high levels (relative to equilibrium levels) may result in periodic situations, where the population is above K, and therefore not at optimum. The effects of these fluctuations on the ecosystem are not known, but they should be considered.

A recently developed method to determine if a population is above the MNP level is called the dynamic response method (De Master et al., 1982). This approach assumes that a recovering population will grow at an increasing rate when it is below the MNP and increase asymptotically when it is above the MNP. Therefore, second degree curves fit to a density-time plot should indicate the population level relative to the MNP level in a qualitative sense. Two advantages of this technique are that it is not necessary to assume the environment is constant, and that it is not necessary to assume what fraction the MNP level is of K. However, precision can be a major problem if fewer than 8-10 years of data are available and if density estimates or density indexes have a coefficient of variation that is greater than 20%. Also, populations that have maximum rates of population change less than 5% are difficult to assess with this method.

The three procedures currently used to evaluate the status of marine mammal populations (back-calculate k, estimate K directly, and DRM) cannot generally be applied to the same population. This is because the different procedures require different information and rely on different assumptions. Futhermore, some populations may not fit the assumptions or requirements of any of the currently used assessment procedures. It may be that managers have to live with this situation, but three other approaches have been suggested recently that should be considered.

The first approach involves what has been called the "critical" density (Lett et al. 1981). This is the density below which the population ceases to accommodate further population declines with an increase in the rate of population growth. It is the highest population level below which the per capita rate of population change remains essentially constant. Obviously, with a strictly linear function of growth rate versus density, the concept of a critical level is lost, and this approach would not be acceptable. However, if the growth rate-density plot is non-linear as Fowler (1981b) suggests, there may be a wide range of densities over which the per capita rate of population change is essentially constant. This approach has the advantage that certain LHP could be used to monitor the population status as opposed to population indexes or total population estimates. Fowler et al. (1980, Appendix G) discusses this approach in more detail.

The second approach that should be discussed was described by Botkin and Sobel (1975). They argued that populations fluctuate due to variability in environmental factors, but that different populations vary by different amounts. They referred to the terms "persistence" and "recurrence" to describe different types of fluctuations. This approach could be applied to management of marine mammals by assuming that density dependent mechanisms are more variable at higher population levels than lower. If this were true, we should be able to define a range of population levels where there is a specified probability that the population will increase in the following year. Once this range is determined, the upper level of this range could be used as the lower limit of the optimum sustainable population. This approach has the advantage that populations managed in this way will be less variable than populations managed at higher levels, and yet still be at a level that is within the recurrent range of the undisturbed population.

A third approach has to do with what I have called "K" and "P" indexing. Eberhardt and Siniff (1977) propose criteria for apprising whether or not a population is close to the maximal or carrying capacity (K). These criteria include behavioral attributes (e.g., activity patterns), individual responses (e.g., growth rates), reproductive characteristics (e.g., age of first reproduction), and population aspects (e.g., survival rates of young). Unfortunately, it is impossible to determine which of the following three reasons are responsible for a criteria changing: 1) the population is changing, 2) the carrying capacity is changing, and 3) both the population and carrying capacity are changing. It is generally assumed that the environment is not stable, and carrying capacities will change, at least around some average value. Therefore, it is essential in understanding the effect of exploitation on the ecosystem to be able to track both the size and the carrying capacity of the population.

The response of a population parameter to changes in density is actually a reflection of the fraction of the carrying capacity which is being utilized rather than a response to some change in absolute density. In that respect, the life history parameter serves to index the distance between the population size and K on a relative scale. For this reason, these parameters are referred to as K-indexes. For example, if a population is decreasing and the K index is increasing (i.e., population is approaching K in a relative sense) that suggests the environment is "deteriorating" for that species. If the K-index were decreasing while the population increased, this would suggest the environment is not deteriorating, and may be improving for that species. It should be remembered that these indices will be used as a time series and not as individual values. Population indexes over a number of years when combined with the life history parameter from this same time period offer a unique opportunity to determine whether or not the carrying capacity of target species is changing. The nine possible combinations of changes in the population level (which will be indicated by changes in the population (P) index) and changes in the relationship between the population size and K (which will be indicated by changes in the life history parameters, called K indexes) can be compared to see which one best fits the observed data.

All of these approaches, along with the previous three assessment strategies are based in part on density dependent relationships. Due to the diverse dynamics of different marine mammal populations it may be necessary to "tailor" specific management approaches to specific populations. It does not seem reasonable to base management decisions on generalizations that may apply to a subset of marine mammal populations, but do not apply to a specific marine mammal population.

To develop this argument further let me refer to the questions raised by Estes (1979): 1) Are marine mammal populations food-limited in general?; and 2) if so, does the marine mammal population regulate its prey population? In general, population dynamicists (and others) have argued that K-selected species should not be predator-limited or disease-limited. (Two exceptions may exist. Ringed seals and crabeater seals may be predator limited). Therefore, marine mammal populations are either food-limited or space-limited by elimination. A number of pinniped populations do seem to be space limited (gray seals - Coulson and Hickling, 1964; elephant seals - Reiter et al., 1981, Bryden, 1968; northern fur seals - Chapman, 1981). These species are all colonial breeders where pup mortality or pup growth rates are affected by density. However, for most other species food-limited population growth may be a reasonable hypothesis.

The next question; do these food limited species regulate their prey? This is where generalizations fall apart, and this is why different management regimes may have to be initiated for different populations of marine mammals. Some species like California sea lions feed on 40 or more species (Antonelis and Fiscus, 1980) and are highly opportunistic in their feeding habits. Most sea lion feeding may be related to the availability of a certain prey species and not its absolute abundance. Therefore, sea lion predation may limit only those prey species that are at very low levels, where incidental feeding could be significant. For other species like sea otters and walrus, the impact of marine mammal predation has been shown to cause changes in the species composition of the prey community and size frequency distribution of the prey (Estes et al., 1978; J. Oliver, pers. comm., Moss Landing Marine Laboratory, CA).

My belief is that most cetaceans, polar bears, sea otters and some species of pinnipeds are food limited. These species are likely to have juvenile growth rates affected by food shortages and this should lead to changes in the ASM and AR. Space limited species may be more likely to experience changes in JS as populations increase. More importantly, some of the food limited species, but not all, contribute to the structuring of the ecosystem of which they are a part. This is determined by whether or not a species is being limited by food availability or by the absolute abundance of food. It seems reasonable that different management strategies should be applied to different species. Managing a species which dictates the prey composition of a community should require different information than managing a species which is space-limited. Similarly, the management objectives for species that contribute to the structuring of the community may be different from those that do not.

Finally, it has been suggested (Holt and Talbot, 1978) that multispecies management be directed at avoiding irreversible changes in the community. May et al. (1979) suggest that this be done by managing the top level predators according to the MSY concept, and by managing prey populations such that neither they nor their predators have significantly reduced productivity. May et al. (1979) recommended some fixed percentage of the original population level that should be used as a minimum. It should be clear that May et al., are not equating this fixed percentage with the fraction of K, where a marine mammal population has its MNP.

Conclusion

I have tried to cover a lot of ground in this paper; I hope not too much. I have pointed out that the phrase density dependence has more than one commonly accepted meaning. In discussing two of the basic generalizations about density dependence in marine mammals, I have pointed out where these generalizations seem to hold or where they do not. The reader should also remember that "no data" does not necessarily imply support for a theory, and that certain sampling biases should be addressed before either generalization is applied to a specific population. Finally, I have pointed out that the equilibrium behavior of most marine mammal populations is unknown, and that different populations will have different patterns of fluctuations and different degrees of influence in structuring the ecosystem of which they are a part. Therefore, it seems reasonable to consider applying different management strategies to different populations. In addition, it may prove prudent to develop new assessment procedures for those populations that can not be assessed with procedures currently in use due to logistic or fiscal constraints.

It seems unfortunate, but it may be the case that current assessment procedures may be limiting the range of applied research on certain species. To manage effectively a group of species as diverse as marine mammals, it may be necessary to have management procedures that are equally diverse. This will require cooperation between management agencies, research institutes, and all of the environmental constituent groups that currently affect the management of marine mammals. It may require a change or at least a new interpretation of the MMPA, but the overall goal should be the effective management of marine mammals.

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Review of Status of Knowledge of Marine Mammal Energetics

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Introduction

Studies of marine mammals, to date, have concentrated mainly on stock differentiation and assessment. Only recently have we begun to examine seal and whale stocks as significant components of marine ecosystems (Sergeant 1973; Laws, 1977; Gaskin, 1978; May et al., 1979; Hinga 1979; Lavigne et al., 1982; Lowry, 1982). To better understand their importance as consumers and producers requires a different approach and with different kinds of questions. This paper describes the progress to date and attempts to demonstrate the potential of utilizing studies of functional morphology and energetics as a practical and cost-effective means of defining food requirements of marine mammals. The rationale goes beyond simply understanding the energy turnover of individuals but ultimately the incorporation into multi species management strategies (Mercer, 1982; Lavigne et al., 1982; Lowry, 1982; Frost and Lowry, 1981; Lowry and Frost, 1981; Laevastu and Larkins, 1981), of prey allocations to the marine mammal stocks themselves. With petroleum related industrial activity increasing near the coastal habitats of marine mammals such studies provide a better understanding of the priorities of seals and whales, thus a measure of predictability with respect to their potential response to unnatural disturbances (Peterson, 1981).

Estimation of Metabolic Parameters for Large Cetacea

The extremely large body size and radical variation in cetacean morphology relative to terrestrial mammals, is further complicated by an oceanic habitat thus a different thermal regime. Far-ranging migratory behaviour associated with feeding and reproduction prevents year round observation in order to construct an energy budget. Parry (1949); Rice and Wolman (1971); Brodie, (1975); Sumich, (1982); and Lockyer, (1982) focused on both the quality of blubber insulation as well as its energy content in studying the energy budget of cetaceans. Brodie (1975) described the thermal profile of fin whales (Balaenoptera physalus) through calculation of the energy density of fat and muscle accumulated during the intensive feeding season in the Antarctic. Through measurement of the oil and protein yield of similar sized whales taken by the whaling fleet before and after the feeding season, estimates were made for the energy "ration" consumed during the long fasting period at lower latitudes. It was assumed here that the bulk of feeding takes place during the Antarctic summer and that there was rather limited feeding in the subtropical waters. The study concluded that energy requirements for large cetaceans had previously been overestimated. Furthermore it suggested that the larger body size of Antarctic baleen whales, in general, was not attributable to the cold environment as proposed by Mayr (1965) but reflected an optimization of morphology and behaviour. The large body size permitted storage of energy available over a restricted but intensive feeding season and, when economical densities of prey were no longer available, migration to warmer waters allowed the extended utilization of fat reserves due to lower thermal costs. It was in these warm, but less productive waters that there was a selective advantage for large body size in order to extend energy reserves, although Hinga (1979) concluded that a low level of feeding is required. Simply stated, body size was found to be inversely correlated with the length of the feeding season. The hypothesis may shed light on the question of clines in body size suggested for the northwest Atlantic fin whales (Sergeant, 1977) which may be more a reflection of variation in feeding strategy than age distribution.

Marine Mammals as Indicators of Production

While large whales are energy efficient on a per unit basis they still require large amounts of prey. The distribution of baleen whales has the potential for defining, at both low and high levels of resolution, the distribution of prey species and provides an interesting "crosscheck" for conventional study techniques.

Sutcliffe and Brodie (1977) plotted the distribution of baleen whales taken by the whaling vessels during the brief period of whaling off Nova Scotia from 1964 to 1972. Since the whales were invariably feeding when captured. The distribution of species by month and year describe a useful picture of the Scotian Shelf with respect to zones of high productivity showing relative constancy from year to year. There is a strong correlation of distribution with shelf and bank slopes as well as with the entrances to underwater inlets or canyons.

While seasonal distribution described the system on a large scale, of equal importance were the actual densities of zooplankton sufficient to attract and sustain these large filter feeders. After a study of the zooplankton densities (in particular Meganyictiphanes norvegica) indicated by net samples and sonar, Brodie et al. (1978) contrasted these with the measured contents of an adult fin whale stomach, representative of the amounts usually observed in fin whales taken by the commercial whaling fleet. The densities necessary to fill the stomach were estimated by assuming realistic swimming speeds (5 km hr^{-1}), mouth aperture and digestion rate. The study indicated that fin whales required, as a minimum, food concentrations greater, by more than two orders of magnitude, than those estimated to be present by conventional sampling methods and emphasized the importance of prey patchiness for baleen whale feeding efficiency (Kawamura, 1978). Gaskin (1978) described the digestive tract of baleen whales as a mechanism for feeding on high densities of prey of short-term availability while Lockyer (1982) has also taken into account the patchiness of prey distribution in the Antarctic.

Once a basic framework of the parameters required for energetic studies of the better known species has been established and tested against what is known of their life history we can attempt to examine those species for which there exists little basic knowledge. For example, the bowhead whale (Balaena mysticetus) is intriguing both for its unique body form and arctic habitat, yet it is not well understood due to the remoteness of its distribution and the very limited catch by aborigional hunters. However, it is a simple exercise to see what can be gleaned from historical data. Lubbock (1937) included morphometric data for bowhead from the log of the Hull whaling vessel "Cumbrian" taken during the 1823 whaling season in "Baffin Basin" (Baffin Bay). The data were sufficient to allow the construction of a morphological model (Brodie 1981) from which insulation quality and approximate energy costs could be estimated. By this method the unusual features were explained in terms of reduced surface area to volume ratio and heat loss reduction through heavy insulation. The study concluded that circa 18 cm of blubber insulation was sufficient to maintain thermoneutrality at a near basal metabolic rate in arctic waters and that the fat stores, in excess of this, were adequate to permit fasting for approximately six months. The bowhead exhibits the qualities necessary for subsistence in regions that could be, by the standards apparently required of other baleen whales, suboptimal in terms of available prey densities. Studies of bowhead ecology by Lowry et al. (1978) as well as their ongoing research will provide the basis for construction of a more detailed energy profile.

Density Dependent Energy Requirements of Marine Mammal Populations

Whales, as well as seals and seabirds, are significant consumers of marine production, often in direct competition with fishes and fishermen. Bioenergetic analysis of multi-species fisheries requires realistic appraisal of the energy requirements of all major consumers within the production system. In particular we need to understand how energy requirements change in response to dynamical variation of demographic parameters (Swartzman and Haar 1983). Brodie and Paasche (1980) considered the possibility that, contrary to existing theories (Winters 1975), per capita utilization of energy might increase in a nonlinear fashion with increasing stock size. The basis of the hypothesis was simply that marine mammals are homeotherms and therefore must maintain mammalian body core temperatures against the steep thermal gradient of their surrounding environment. This would place thermal maintenance as one of their major expenditures and as the number of individuals increases the total mammalian surface area increases accordingly. Based upon this simple argument, thermal costs would increase in a linear relationship. But in an expanding marine mammal population, individuals must, at some level of abundance, encounter a reduced per capita availability of prey due to increased intra specific competition. In consequence, either blubber reserves should decrease on average due to lower food intake or, if blubber thickness is maintained, foraging costs must increase. The study demonstrated that decreasing blubber reserves below a certain threshold further exacerbates energy requirements because of the increased costs of thermo-regulation. Taken together, we viewed these factors as arguing for a proportionately greater energy requirement by large, expanding herds of marine mammals. With marine mammals stocks often numbering in the millions of individuals, this is a highly significant factor within the context of multi-species fisheries management.

A Thermal Index for the Trophic Ranking of Marine Mammals

While numbers of individuals and biomass have often been used to describe the trophic significance of marine mammal populations (Lander 1981) it does not take into account that important variance from poikilotherms of maintaining a high body temperature.

If metabolically important surface areas provide a reasonable approximation of thermal maintenance costs for individual marine mammals (Brodie, 1975) they should have equal application at the population level as a measure of the relative trophic importance of individual stocks. Other parameters such as costs of propulsion have been estimated for some species (Kermack, 1947; Kawamura, 1975; Sumich, 1982; Lavigne et al., 1982) while Lockyer (1978, 1981) addressed the energy costs reproduction and lactation.

The range of body size from 50 kg to 100,000 kg and diverse morphology of marine mammals underlines the inadequacy of a universal, length/surface area ratio, and individual species require examination of their unique morphology. In a recent study (Brodie, 1982) surface areas were estimated for the northwest Atlantic stocks of harp seals (Pagophilus groenlandicus), grey seals (Halichoerus grypus) and a population of fin whales (Balaenoptera physalus) of hypothetical numbers. The rationale was simply to compare numbers of individuals, biomass and aggregate thermal costs in order to determine the parameter which would most appropriately describe the trophic significance of various stocks.

A population of harp seals exceeding 2×10^6 individuals (Roff and Bowen, 1981) in terms of biomass would be circa 2×10^5 metric tons, approximately equal in weight to 7×10^3 fin whales. While these measures provide numbers of individuals as well as biomass there is no direct way by which the trophic significance of these stocks can be quantified from these parameters. If, however, these stocks are described in terms of metabolically important surface areas by assigning, for the purpose of illustration here, $1m^2$ and $50m^2$ respectively for individual seals and whales, the stocks can be seen in an interesting perspective. The seals would have an aggregate surface area of some 2×10^6 m^2 while the equivalent biomass of fin whales would total 0.35×10^6 m^2, an approximate sixfold difference. In perspective, the grey seal population of 4.5×10^4 individuals (Zwanenberg et al., 1981) at an estimated $1.5m^2$ surface area per animal would total $0.068 \times 10^6 m^2$ or approximately 3% that of the harp seal and 19% of the hypothetical stock of fin whales.

The use of surface area as an index of metabolism is a century old concept (Rubner, 1883; Richet, 1889; Voit, 1901), however it has rarely seen practical application. In view of the increasing use of energetics in ecosystem studies, the simple technique described above warrants further examination. Surface area might be used in better understanding species interaction where smaller, but more numerous, marine mammals are replacing or being replaced by species which are larger, but fewer in number. In such a case, biomass and number of individuals is a poor measure, however the cumulative surface area may better reflect the balance between the two consumers. The suspected competition between Antarctic blue and minke whales (B. musculus, B. acutorostrata) is one such example.

Marine Mammals and Industrial Activity

Studies of seals and whales based upon functional morphology and energetics provide some understanding with respect to requirements both in terms of food and of habitat (Brodie, 1981). From the preceeding discussion it becomes apparent that marine mammals, through body design, have low specific metabolic rates relative to their thermally expensive habitat and possess a large energy storage capacity, these are qualities which permit extensive migrations into regions of intensive, seasonal food production. Baleen whales have sufficient storage capacity in their stomachs to allow the intake of large quantities of prey when available in economical concentrations during some portions of the day (Gaskin, 1978). We thus complete a picture of animals which are not only designed to capitalize on short-term, seasonal production but may also have the capacity to take advantage of short-term food availability on an hourly basis. As marine mammals feed in these highly productive, generally colder regions of the ocean they reestablish their energy reserves and, at the same time, upgrade their insulation.

Migratory patterns have evolved not only to take advantage of seasonal concentrations and peaks of maximum energy content of prey, but may be further complicated by incorporating part of the reproductive cycle. In the case of harp seals, pack ice provides the platform essential for giving birth while an estuary is sought out by the white whale (Delphinapterus leucas) (Sergeant and Brodie, 1969). Newly weaned seals and whales require catchable prey of high nutritional value at this critical period in their life so, for the above reasons, it is not a simple matter for populations to change their traditional feeding sites and shift migration routes. There are priorities, either related to food or other features of the habitat which necessitate toleration of foreign activity either because there is no unacceptable stress imposed or because there are simply no alternative sites. Historical and present day evidence demonstrates the long-term coexistence of fisheries, shipping and even whaling and sealing in areas traditionally inhabited by marine mammals. Whaling, both by sail and powered vessels has been conducted on whale feeding grounds for centuries yet these stocks return annually to the same site. The fishery for capelin (Mallotus villosus) off Newfoundland supported fleets of forty trawlers concentrated in a small area. Both fin and humpback whales (Megaptera novaeangliae) continued to feed in close proximity to the vessels despite the apparent noise generated while these same species are observed feeding in the shipping lanes of Halifax harbour despite the vessel traffic. Commerical sealing has been conducted for generations using small, ice breaking vessels in the immediate vicinity of the seals, yet the stock returns annually to the same site.

It seems apparent that marine mammals are able to "tolerate" what would be interpreted by humans as significant levels of underwater noise and pressures from associated hunting. This tolerance underscores the high priority which marine mammals place on their habitat from the aspects of food availability, ice substrate, and probably in the case of the beluga, thermal reliability. Whatever stresses are imposed is difficult to quantify for animals which simply have no choice in the matter.

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Present and Future Potential Models for Examining the Effect of Fisheries on Marine Mammal Populations in the Eastern Bering Sea

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Introduction

Recently there has been a great deal of concern that the rapidly expanding fisheries in the eastern Bering Sea since the mid 1960's have contributed to the observed decline in some resident and migratory marine mammal populations. While general approach to marine mammal-fisheries interactions involving field data collection and models would be desireable, little work has been done on most marine mammal species. Since so much research has been done on the energetics, diets and population dynamics of the northern fur seal (Callorhinus ursinus), the fur seal can serve as a test case for examining marine mammal-fishery interactions in the eastern Bering Sea with the hope that the methods used and recommendations made may be applied to other marine mammals as well.

The fur seal population of the Pribilof Islands has been dropping (Figure 1) over the past 25 years with perhaps some population stabilization during the early 1970's on St. Paul Island. While some of this decline is certainly related to the pelagic research samples and land harvests of seals from 1956-1968, York and Hartley (1981) have demonstrated, using a Leslie matrix model, that these harvests can account for at most 70% of the decline. The further reductions since 1975 cannot be linked to the earlier harvests. Since pollock (Theragra chalcogramma) form a major part of the diet of the northern fur seal in the eastern Bering Sea there has been some concern that the

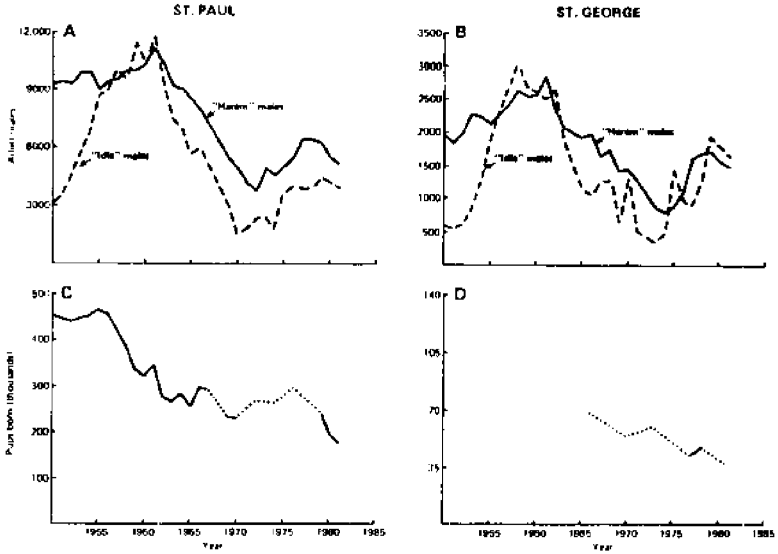

Figure 1. Observed declines in the fur seal population of the Pribilof Islands as indicated by numbers of pups and large males for both St. Paul and St. George Island, 1950-1981. Dotted lines are for periods during which data are not available for consecutive years. (from Lander 1980, Kozloff 1982).

pollock fishery has reduced food availability thus reducing the carrying capacity of fur seals in the Bering Sea. Two alternatives proposed to explain the decline of the northern fur seal population relate directly to the Bering Sea fisheries. The first, as discussed above, implicates the pollock fishery, which rapidly expanded between 1965 and 1975 to a current average annual harvest of over 1 million metric tons _ presently the largest single species fishery in the world. According to this hypothesis the reduced food availability is conjectured to have affected the seal energetics status and thence some population parameter such as mortality, or age of maturity which in turn is causing the current population decline. The second hypothesis (Fowler 1982) related to fishery operation is that entanglement in discarded netting material has led to direct mortality on seals which has been a (or the) major contributor to the population decline.

In this paper I will review models which have been used to evaluate the plausibility of each of these hypotheses for the Pribilof Island fur seal population. I will also, where relevant, review other models which are similar to those discussed here for the purpose of putting them into a more general perspective. Initially I will review the data evidence in support of (or in contradiction to) both hypotheses.

Data relating to the first of the fur seal-fisheries hypotheses mentioned above were reviewed by Swartzman and Haar (1983) and Fowler (1982). They found that four out of five fur seal population parameters estimated from the data changed in a direction such as to suggest that the population condition was improved or did not change significantly over the period of rapid pollock fishery development. These parameters included weight at age, pup mortality on the rookery, survival to age 2, and average time spent at sea by lactating females between pup feedings. The only seal population parameter that appeared to indicate reduced carrying capacity after development of the fishery was the age at maturity which increased somewhat.

Reduced pollock abundance in the environment would be expected to reduce their relative abundance in fur seal diets. Swartzman and Haar (1983) found, however, that pollock appeared to be more abundant in fur seal diets in the 1970's than earlier years. This fits with the following observations: 1)although the average size of pollock in the fishery catches has been dropping while catch tonnage has not; and 2)pollock, being cannibalistic, may have a higher total stock biomass when older individuals are removed from the population by the fishery. These observatins suggest that pollock may be becoming more available to thefur seal in the eastern Bering Sea as a greater biomass of smaller sized fish. Another factor that contradicts the hypothesis that the fishery has reduced seal food availability is that seals are opportunistic feeders (Kajimura 1981) and can shift target species when a particular species is not available.

Despite all this evidence to the contrary there are some other factors that indicate that food limitation may be important for the general dynamics of fur seal populations, especially when feeding in the neighborhood of St. Paul Island. Feeding during the pupping period takes place over a relatively small area on the edge of the continental shelf which makes the seals somewhat vulnerable to fish removal in this area. Also there is evidence (Figure 2) that pup mortality on land is higher when numbers of pups born is high. One possible explanation for this is that having more lactating seals, with their very high food demands, may result in less milk per pup which will put some pups at an energetic disadvantage and might cause more pup starvation that with fewer feeding females. Another possible explanation for increased pup mortality at higher densities is increased incidence of hookworm infection (Lander and Kajimura 1976) under denser rookery conditions.

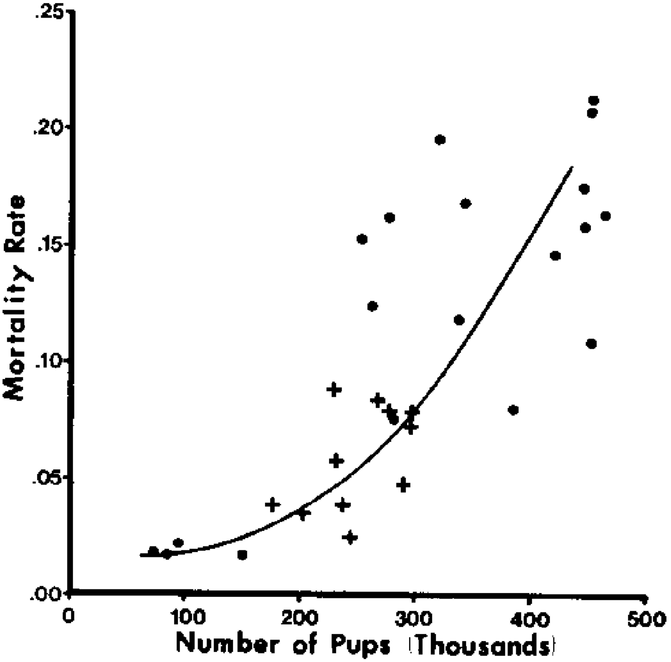

Figure 2. Mortality of pups on land as related to total numbers of pups born on St. Paul Island for various years from 1914 to 1982. Filled circles are for 1914 though 1965; crosses for 1966 to 1982. Line is drawn by eye. Data from Lander 1980.

At this point most of the evidence relating to these fur seal-fishery hypotheses is indirect. In order to demonstrate the existence of a direct connection we must show:

1. Fishing reduces seal food availability.
2. Reduced food availability has some energetics effect on the seals such as reduced average milk production

3. The energetics are linked to some population fitness parameter. (e.g. reduced milk production implies reduced weight gain for pups implies increased pup mortality.)
4. The change in the population parameter(s) results in some demonstrable long or short term change in the population.

Several of these connections may be explored using models and these will be discussed below. The most difficult connection to demonstrate, either with data or with models, is the third, and at present no models have been attempted in this area.

The evidence concerning the effect entanglement of seals has on fur seal population dynamics was considered by Fowler (1982). He observed that a significant number of entangled subadult males have been taken in the harvest on St. Paul Island. He furthermore noted that multiple entangled animals in the same netting have been observed at sea and that these animals probably would not survive long enough to reach land if entangled in a larger piece of debris due to interference with feeding activity. By using data on the relative abundance of various sized net material on Amchitka and St. George Islands and assuming the population to be under equilibrium conditions, Fowler (1982) estimated the annual mortality loss due to entanglement as being between 3 and 18% depending on the average survival time of seals caught in small net debris, an uncertain parameter. One other uncertain factor is whether the entanglement is more selective on younger individuals or whether the entire fur seal population is equally susceptible. I will later discuss the implications of age structure and the age range over which entanglement applies on short and long term population change using an age structured population model having density dependent pup survival (Figure 2).

Food availability models

As mentioned earlier, in order to demonstrate a fishery effect on seal populations via reduced food availability four linkages must be considered. The first, that a fishery reduces food availability, may be addressed using a multi-species fishery oriented model like that developed by Laevastu and Larkins (1981) for the eastern Bering Sea or by Andersen and Ursin (1977) for the North Sea. Such a model must involve specific hypotheses concerning the growth rate and mortality rate of fish and how these respond to fishing pressure. It must be a multi-species model to reflect possible shifts in dominance and species abundance in response to fishing pressure. Both the models above have some provision for these factors, although both are limited in their ability to represent the highly variable year to year changes in fish recruitment and specifically provide no linkage between year class strength and environmental conditions.

The model should preferably have some spatial resolution so that local depletions, such as around the Pribilof Islands, can be considered. The Laevastu model, DYNUMES, has this capability. However, since the DYNUMES model includes marine mammals solely as a driving variable to provide initial estimates for fish standing stock, the second link, between food availability and mammal energetics is not addressable within the DYNUMES framework.

A model, SEAL, has been built by Swartzman and Haar (1982) to consider the possible energetics effects on lactating seals on the Pribilof Island due to reduction in food or to changes in seal abundance. The SEAL model focusses primarily on female seals during their period of residence in the eastern Bering Sea. The seals are separated into lactating and non-lactating seals by age class. Computations are made on a monthly time step and keep track of average seal weights and populations at age as they are influenced by temperature, food availability of five functional groups of prey (Figure 3), and seal respiratory and growth demand. A preliminary subroutine is used to translate the seal arrivals and pupping and weaning cycle into monthly averages of seal abundance and to compute an average time per month spent on land and at sea. Information on lactating seals for SEAL is based primarily on data sources reviewed by Perez and Mooney (1982). Behavioral data (e.g. average time spent at sea between pup feedings) is primarily due to Gentry (pers comm.) and population information is primarily from Lander (1980).

Prey respond to seal predation as well as to natural and fishing mortality and are annually increased by recruitment which is read in as a model driving variable There is no predation considered on the prey other than seal predation _ fish predation and other predation sources are included as 'natural' mortality. Since the prey abundances used are from surveys (Pereyra et al. 1976), adjustment to the prey available is necessary to account for the limited feeding area of the seals relative to the entire area surveyed when computing available prey abundance. This, of course, changes from month to month as fish migrations proceed and is included as a month specific availability factor for each prey type. All seal age classes are assumed to have the same diet and reproductive pattern, the only differences between age classes (from age 3 to age 13+) being the fraction of mature and fecund females (lower for younger age classes) and the average weight, which affects the maximum ration and respiratory demand.

The SEAL model is structured as a set of difference equations with the period May to October being represented

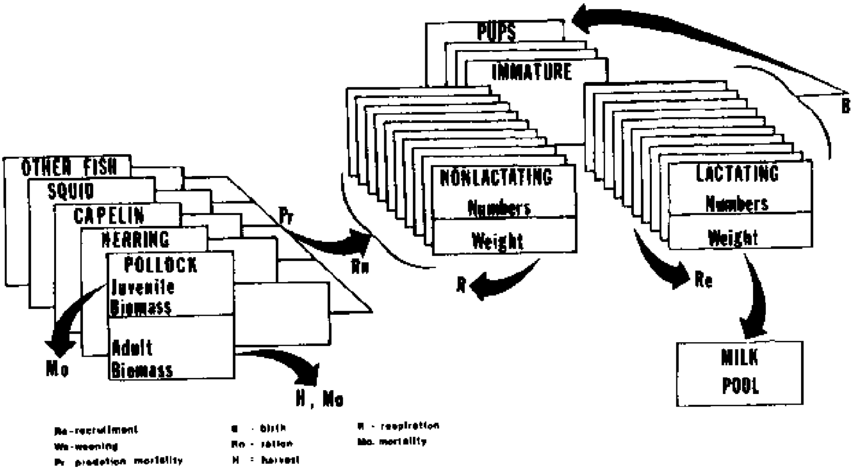

Figure 3. Flow diagram for SEAL model.

by monthly time steps and November to April being a single 6 month time step. Thus seven time steps comprise a model year. Seals in the model can be sampled at any month for average weight, age and numbers in each age class for both lactating and non-lactating seals. Milk production by age class and prey abundances are also available outputs as are any model rate or parameter. (e.g. prey effect on ration, maximum feeding rate, etc.). A complete model documentation is available in Swartzman and Haar (1982) which includes model equations, rationale, parameter values and data sources. The model is written in AEGIS (Aquatic Ecosystem General Impact Simulator) a general simulation language developed to facilitate model input/output and to provide clear event scheduling.

As almost all available data was used in building and calibrating SEAL there is little that can be done to validate it. About the best measure of model validity is that the predicted growth pattern over the summer pupping period is realistic and that the weight at age doesn't vary drastically from year to year under average prey abundances. Figures 4 and 5 show average seal weights for 5 and 9 year old seals respectively. Weights of both lactating and non-lactating seals are shown in each figure. Lactating seals start the pupping season at lower average weight at age due to weight loss with parturition. Lactating seals gain weight at a faster rate than non-lactating seals (since they do more feeding). The model indicates that younger lactating seals will not make up their parturition weight loss over the summer (Figure 4), while older lactating seals (Figure 5) appear to make up their parturition weight loss.

The SEAL model was used to investigate the effect of increased pup abundance (i.e. having more lactating seals) and of reduced prey abundance and/or availability on seal energetics, primarily indicated by the average milk production per lactating female over the summer. Milk production was the primary energetics index since it was felt that if any energetics effect would influence seal populations it would be during the critical first year of life. Any food related increase in pup mortality should show up in this model as a significantly reduced average milk production. We wanted to see if it was feasible to have a significant reduction in milk production result from either reduced prey abundance or availability or increased number of competing feeding seals.

The effect of changing seal abundance or prey abundance was simulated by either 1)doubling the number of seals, 2) reducing recruitment for all prey, by a factor of 5 or , 3) reducing prey availability by a factor of 3. Various combinations of the above changes were also tried. Another change made in this simulation experiment was to change the half saturation parameter for the effect of prey density on feeding rate. This parameter, which controls the prey level at which seal feeding would be reduced to half the maximum rate, was first introduced to models by Holling (1966). This half saturation parameter has not been determined by any seal feeding experiments and its value is thus poorly known. For this reason three values were used _ the nominal value and 10 and 100 times this value (these latter values make prey more limiting on seal feeding). These alternatives were explored primarily to see what their effect is on seal energetics and how they work in combination with the first three changes suggested, but also to help decide which of these values is most appropriate for this parameter for fur seals.

Table 1 and 2 show the results of the simulation experiment to determine the effect of changing prey and seal abundances and prey availability on lactating seal milk production and reduction in pollock biomass respectively. The magnitute of the changes in these parameters in the

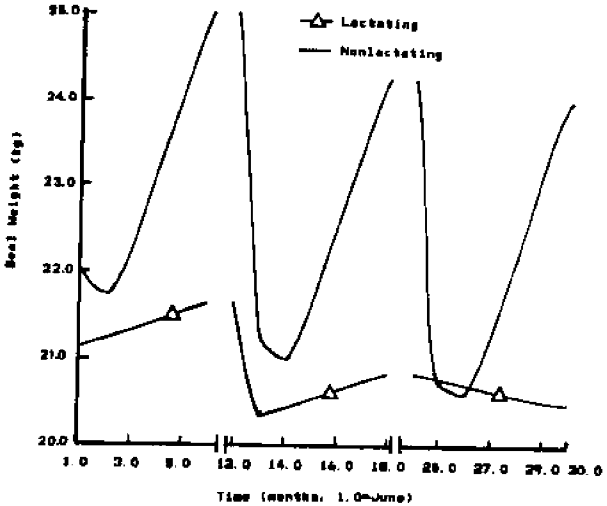

Figure 4. Age five female seal weight for lactating and nonlactating seals.

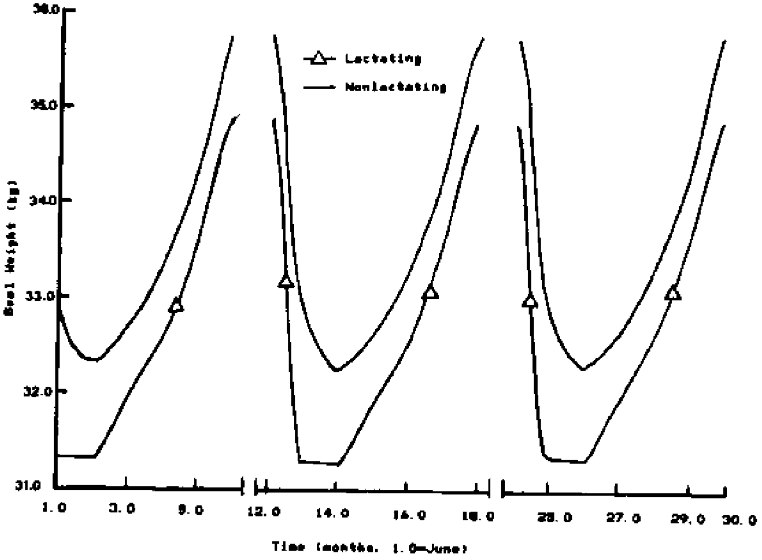

Figure 5. Age nine female seal weight for lactating and nonlactating seals.

TABLE 1. PERCENTAGE LOSS IN AVERAGE ANNUAL MILK PER PUP AFTER 6 YEARS OF ALTERED CONDITIONS FROM THE NOMINAL RUN IN SEAL

RECRUITMENT	PREY AVAIL- ABILITY	NO. PUPS	PREY HALF SATURATION FOR FEEDING 1	X10	X100
X1	X1/3	X1	0.28	4.0	32.6
		X2	0.0	4.7	35.6
	X1	X1	0.0	1.3	13.4
		X2	0.0	1.6	15.0
	X3	X1	0.0	0.37	4.8
		X2	0.0	0.44	5.5
X1/5	X1/3	X1	0.6	7.5	49.8
		X2	10.0	60.0	94.3
	X1	X1	0.0	2.8	23.9
		X2	7.7	26.1	78.9
	X3	X1	0.0	0.78	8.7
		X2	0.78	20.7	78.9

TABLE 2 CHANGE IN PERCENTAGE LOSS OF POLLOCK BIOMASS RELATIVE TO NO NOMINAL RUN AFTER 6 YEARS (NOMINAL RUN HAS 47.2% LOSS

RECRUITMENT	PREY AVAIL- ABILITY	NO. PUPS	PREY HALF SATURATION FOR FEEDING 1	X10	X100
X1	X1/3	X1	+0.2	0.0	-2.0
		X2	+9.5	+9.1	+3.9
	X1	X1	0.0	0.0	-0.9
		X2	+9.5	+9.5	+8.6
	X3	X1	0.0	0.0	-0.3
		X2	+9.5	+9.4	+8.5
X1/5	X1/3	X1	+10.6	+9.1	+1.6
		X2	*	*	+34.2
	X1	X1	+10.4	+9.9	+6.0
		X2	*	*	+34.2
	X3	X1	+10.4	+10.3	+8.6
		X2	*	*	+34.2

* denotes prey are eliminated in run

experiment are quite large. It is unlikely that the number of pups would increase by a factor of 2 for a 5 year period or that the recruitment of fish and other prey would all be reduced by a factor of 5 for several years running. However, considering the wide range of parameter values over which relatively small changes in milk production and pollock loss due to seal predation occur, we can conjecture that the seals are very resilient predators and probably are not greatly affected by reduced prey abundance unless this is accompanied by a drastic increase (2x) in pup abundance.

One caveat to this conclusion is that the half saturation parameter for the effect of prey density on seal consumption is not well known. In the simulation experiment this was varied over two orders or of magnitude from 10**7 to 10**9 kg. For the larger half saturation value there is an indication that seals would be seriously affected by prey reduction. However this value may be overly large since it would imply that food is a serious problem even under average prey densities and pup densities (13% annual milk reduction for the 10**9 half saturation case). In the case of the 10**8 half saturation, seal milk production is not seriously affected by reduced prey abundance unless it is accompanied by drastically reduced prey availability _ an unlikely combination of events given present fish population levels. For the 10**7 half saturation value seals are almost unaffected by all combinations of prey reduction, although prey (pollock) may be reduced by seals by up to 10% more than under the nominal run. There is a trade-off in these runs between having reduced milk production and reduced prey biomasses which depends on the half saturation value. At lower half saturation, having more pups or fewer prey results in little milk production reduction but more drastic drops in prey abundance, while at high half saturation levels the reverse is true.

The SEAL model provides us with a tool for examining the energetics implications of reduced prey abundance and increased pup or seal abuandance. Using simulation experiments like the one discussed above we can examine various scenarios and make conjectures on the meaning of the output. Several of the parameters in the SEAL model, as in most simulation models of natural ecosystems, are not well known. These include the half saturation for prey density effect on feeding rate of seals and the availability of fish. Also the absolute abundances of prey are not highly accurate. The effect of temperature on feeding rate and respiration demand in seals is another area where there is relative uncertainty. The model also assumes monthly averages and average weight at age for each seal cohort, while in fact weight at age can vary somewhat. Nonetheless, this model does combine much of what is known about fur seal energetics with the relatively strong population dynamics information available on these animals and uses this information to investigate the effect of changes in prey and seal abundances.

From my perspective it seems that the SEAL model is adequate to investigate the link in fisheries-fur seal interaction it was built for. The major limitations to confidence in the quantitative accuracy of the model predictions is in the data base specifically in those areas indicated above. Surveys of prey abundance in primary seal summer feeding areas are needed. Better energetics studies of the seals preferably in vivo are needed to see the effect of the range of Bering Sea temperatures on seal respiration and feeding rates. Finally some controlled food limiting experimentation is needed to get a better idea about the effect of prey limitation on feeding rate. An example of such a controlled situation is the study by Power and Gregoire (1978) on a freshwater seal population in Lower Seal Lake, Quebec. They observed that the fish population species mix and size distribution was very different in this lake than in neighboring lakes due to the presence of an isolated harbor seal (Phoca vitulina) population. It would be interesting to compare the growth rates and feeding rates of these seals, in a system where food is likely limiting, with the growth and feeding rates of marine harbor seals in the same area.

Population models - The effect of entanglement

Fur seals entangled in small (less than 500 gm.) net fragments have been observed regularly during the subadult male harvest since the late 1960's. At present the fraction of subadult male seals in the harvest that have been entangled either in net fragments or plastic bands appears to have stabilized at about 0.4% (See Figure 6 from Fowler 1982). Fowler (1982) has used this information, along with a number of assumptions about entanglement mortality and the size distribution of the net material, to estimate the probable range of entanglement rates inflicted upon the fur seal population and the resultant annual loss rates for fur seals. The basis of this estimate is the following differential equation:

$$\frac{dN(t)}{dt} = C * P(t) - M * N(t) \qquad (1)$$

where $N(t)$ = population of entangled animals
$P(t)$ = population of unentangled animals
C = rate of entanglement (1/yr.)
M = mortality rate due to entanglement (1/yr.)
t = time (years)

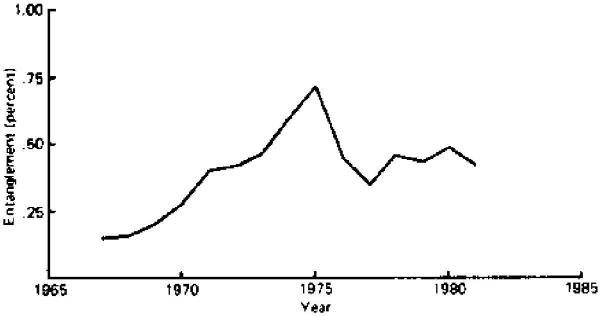

Figure 6. The percent of the harvested animals taken on St. Paul Island which were entangled in debris from 1967 to 1981.

The main assumption in using this differential equation is that all animals in the population are equally susceptible to entanglement irrespective of age or sex and that entanglement rate does not change over time.

It was then assumed that the population is in equilibrium so that dN/dt = 0. Under this assumption and equation 1 the entanglement rate C can be calculated by C = M * N / P. The mortality rate for entangled animals, M, is estimated by assuming that 75% of the entangled animals die within a period of time ranging from 2 months to 12 months. The range of time to death is wide since little information is available on how long animals entangled in small net fragments actually live. The 75% comes from the observation (Scordino and Fischer 1983) that 75% of the entangled animals in the sub-adult male harvest show scarring on their flesh. To illustrate the computation in estimating C assume 75% of the entangled seals are dead within 6 months. Then, assuming equilibrium and no seasonal pattern in entanglement we have first that exp[-M * 0.5] = 0.25 (i.e. the fraction surviving half a year is 0.25) so that M = 2.77. Thus C = 2.77*.004 = .0111 (N/P =

.004, the fraction of entangled seals in the subadult male harvest and [assumed] for the entire population).

Estimates using the above method for mortality rates of entangled animals and for the rate of entanglement in small net fragments are given in Table 3 taken from Fowler (1982) for the range of assumed average times for 75% of the entangled seals to die. Also included in Table 3 are estimates of the mortality due to entanglement in larger net fragments. These are assumed to die very quickly, or at least to rarely ever reach land. These estimates assume that the larger fragments comprise about 80% of the total net debris at sea and that there is no selection by the seals for particular sizes of net fragments. With these assumptions the entanglement in large net fragments is assumed to be 4 times that in small net fragments. The assumption about the size distribution of net fragments at sea is based on data from Merrell (1980) on the size distribution of net debris on Amchitka Island. Figure 7 shows this distribution as well as the size distribution of net fragments collected on St. George Island and on entangled seals. 60% of the net fragments on Amchitka are not present at all on seals, while of the remaining 40% half of these are underrepresented. This gives a total of 80% of the seal entanglement occurring in large net fragments, and these seals are not observed to return to land. Another assumption here is that the size distribution of net fragments on land is similar to that at sea. Direct evidence for seals entangled in large net fragments is difficult to obtain since all cases must be at sea and since the seals are probably short-lived after entanglement. Nonetheless, seals entangled in large debris have been observed at sea and, in some cases, several seals have been observed entangled in the same net fragment (evidence given in Fowler 1982 and Fowler pers. comm.).

The weakest part of the entanglement estimates is ascertaining how long an entangled animal lives. Although .4% of harvested sub-adult males are entangled, no information is available on how long these have been entangled or how much longer they will live. Work planned this summer by NMML (Fowler pers. comm.) to tag and release the entangled animals might provide some insight into this problem. Another possible source of data is to observe entangled animals in the laboratory. Other weak assumptions in this model are reviewed by Swartzman (1983).

An age structured model with density dependent pup mortality

The long and short term effects of entanglement on the fur seal population were examined by expanding Fowler's (1982) model to a multi-age class, female based (since female populations are important for the future population) population model by Swartzman (1983). This model includes a density dependent pup survival hypothesis which has been

TABLE 3.--Estimates of mortality rates within the Pribilof fur seal population created by entanglement in debbris as related to various estimates of the survival (and mortality) rate of entangled animals.

Time (month) for mortality	m[1]	Monthly survival of animals in small net fragments	Annual rate of entanglement		Total mortality due to entanglement (percent)
			in small net fragments (percent)	in large net fragments (percent)	
2	8.32	0.50	2.50	9.98	13.31
4	4.16	0.71	1.25	4.99	6.65
6	2.77	0.79	0.83	3.33	4.44
8	2.08	0.84	0.62	2.50	3.33
10	1.66	0.87	0.50	2.00	2.66
12	1.39	0.89	0.42	1.66	2.22

[1] a yearly instantaneous total mortality rate of animals entangled in small fragments of net (annual survival is e^{-m}).

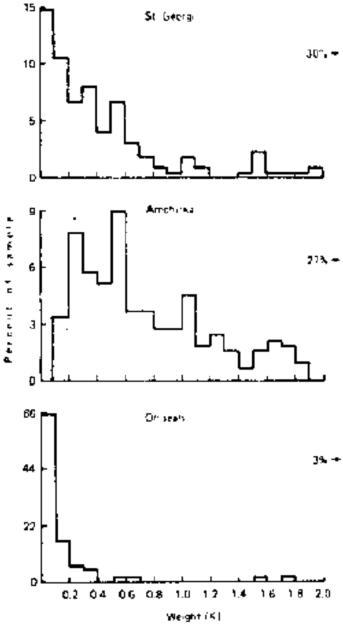

Figure 7. Distribution of fishing net debris on St. George Island, Amchitka Island and on harvested subadult male fur seals.

supported by data on St Paul Island indicated in Figure 2. Density dependent pup (or juvenile) mortality has also been included in other marine mammal population models by

Frisman et al. (1982) [fur seals on Tyuleniy (Robben) Island], Eberhardt (1981) [fur seals], Lett et al. (1981) [harp seal (Pagophilus groenlandicus)], Harwood (1981) [gray seal (Halichoerus grypus)], and Demaster (1981) [Weddell seal (Leptonychoes weddelli)].

The single differential equation in the original (Fowler 1982) model is replaced by a set of differential equations relating the rate of change of populations of both entangled and non-entangled seals at each age class to age specific rates of entanglement, natural mortality and mortality due to entanglement. By assuming the population is in equilibrium the ratio of entangled seals to non-entangled seals at each age class can be calculated.

When the set of differential equations is combined with a density dependent function for the survival of pups on land (Figure 2) a total equilibrium population can be computed using the solution method presented in Getz(1980) and Reed (1980) for Beverton-Holt type models with a density dependent stock-recruit relationship which this model in effect is. The mathematical development and analytical solution for this model are given in Swartzman (1983).

Table 4 gives the equilibrium solution for numbers of pups X0 and total mature female population S for the cases in Table 3, where mortality of 75% of the entangled animals is assumed to occur within 2 months, 4 months, 6 months and 12 months. Two scenarios are considered. The first applies entanglement to all age classes, while the second applies it only to pups and the first 3 age classes of females. Age specific natural mortalities were obtained from Lander (1980) as were age class specific fecundities. All entanglement related parameters are given in Table 3. The density dependent parameters for pup survival on land, k1 and k2 were estimated from a regression using data in Figure 2.

Results from Table 4 on the long term (equilibrium) populations resulting from entanglement show the following: 1) The population cannot come to equilibrium if entanglement is applied to all age classes except when the 12 month mortality case is considered. 2) The population will come to equilibrium if entanglement is applied only to the pups and the first 3 age classes unless 75% of the entangled individuals die within 2 months (the heaviest entanglement mortality considered). 3) For the 12 month entanglement survival case the number of pups leaving land is higher than in the unentangled case, although the number of pups born is less. This is due to the compensatory effect of pup mortality on land being strongest on the number of pups leaving land. Over the population range being considered, the additional mortality after leaving land translates into a modest boost in the number of pups surviving to leave land over what would occur in the

TABLE 4 -- Equilibrium number of pups leaving land (XO) and the number of fecund females or pups born (S) as a function of the level of entanglement.

	Case number						
	1	2	3	4	5	6	7-9
XO (eq.) $x10^5$	3.63	3.67	3.60	3.32	0.00	3.16	0.00
S (eq.) $x10^5$	5.30	4.95	4.50	3.85	0.00	3.57	0.00
RATIO	1.46	1.35	1.25	1.16	----	1.13	----

Legend

Case 1 -- No entanglement
Case 2 -- 12 month mortality ages 0-3
Case 3 -- 6 month mortality ages 0-3
Case 4 -- 4 month mortality ages 0-3
Case 5 -- 2 month mortality ages 0-3
Case 6 -- 12 month mortality all ages
Case 7 -- 6 month mortality all ages
Case 8 -- 4 month mortality all ages
Case 9 -- 2 month mortality all ages

unentangled case. 4) For higher levels of entanglement, both the number of pups leaving land and the fecund stock are lower than in the unentangled case. As the entanglement mortality increases, the equilibrium population drops at an increasing rate until the equilibrium population is forced to zero.

The effect of the density dependent mortality is assumed to occur only in the first year of life. If other forms of density dependence also obtain, such as density dependent mortality in older age classes or the effect of density on the age of maturity, the effects of entanglement would be even further lessened by the density dependence. However, since available data support density dependent mortality of pups on land, while little evidence is available for the other effects of density dependence in the fur seal, I worked solely with density dependent pup mortality.

A sensitivity analysis presented in Swartzman (1983) showed model results to be highly sensitive to density dependent parameters k1 and k2. This implies that if we wish to study the long term effect of entanglement on the population we should look closely at the density dependent pup mortality hypothesis. One approach to utilizing the variability in the density dependence relationship is to focus on empirical evidence and examine how variability in the data translate in a direct fashion into variability in either the population over time or in the equilibrium population. A model like Getz and Swartzman (1981) developed to handle recruitment variability in an age structured population model would be appropriate here.

The short term response of the seal population to entanglement or to the removal of entanglement was explored by simulation. Table 5 shows simulation results, starting with the equilibrium population and age distribution obtained for the unentangled population, for various levels of entanglement (including those resulting in zero equilibrium). This table serves to show how the female seal population might have responded to entanglement if it had started in the mid 1950's (a time of relatively stable population) and there had not been a female harvest. The numbers of fecund females and of surviving pups leaving land are shown as well as their ratio after 10, 20 and 30 years. Populations in those cases that had zero equilibria drop off and the ratio of pups to total adult population (RATIO) drops toward 1.0 over time. The other cases approach fairly close to their equilibria after 20 years. The number of pups born approach their equilibrium values more rapidly than the number of surviving pups in these cases. This is because imposing additional mortality due to entanglement drops the adult population rapidly while this drop is compensated for somewhat by reduced pup mortality on land.

Application to other marine mammals

Single species models of the Leslie matrix type discussed above for entanglement have been applied to several other seal species including gray seals, weddell seals, and harp seals and blue whales (Balaenoptera musculus) (Usher 1976). In most of them the effect of some other mortality source, usually harvesting, is considered. The difficulty in applying models of this type to project long term populations resulting from some management scheme or mortality source in addition size to natural mortality is in assessing the population_ a job which is made easier for the fur seal by their colonial breeding habit.

Energetics models like SEAL could be applied to other marine mammals, but again the major limitation would probably be the data base both for population estimates, energetics information and food availability since feeding for so many marine mammals is spread over a wider region of the Bering Sea than fur seals are. This widespread nature of most feeding marine mammal populations makes some consideration of spatial aspects of feeding necessary. A model of this sort would probably be most useful for looking at density dependent food limitation in walrus which feeds on sessile prey and whose feeding range is fairly well established.

TABLE 5 -- Dynamic response of fur seal population to various levels of entanglement starting with an unentangled population at equilibrium.

		TIME (Years)			
CASE		10	20	30	RAT
2	$XO(k) \times 10^5$	3.65	3.67	3.67	1.35
	$S(k) \times 10^5$	4.71	4.91	4.95	
	Ratio	1.29	1.338	1.349	
3	$XO(k) \times 10^5$	3.59	3.60	3.60	1.25
	$S(k) \times 10^5$	4.46	4.48	4.49	
	Ratio	1.242	1.244	1.247	
4	$XO(k) \times 10^5$	3.51	3.43	3.39	1.16
	$S(k) \times 10^5$	4.23	4.06	3.97	
	Ratio	1.205	1.184	1.171	
5	$XO(k) \times 10^5$	3.19	2.70	2.34	.918
	$S(k) \times 10^5$	3.62	2.94	2.49	
	Ratio	1.135	1.089	1.0641	
6	$XO(k) \times 10^5$	3.37	3.31	3.29	1.13
	$S(k) \times 10^5$	3.94	3.83	3.75	
	Ratio	1.169	1.157	1.1398	
7	$XO(k) \times 10^5$	3.06	2.74	2.49	.976
	$S(k) \times 10^5$	3.42	2.99	2.67	
	Ratio	1.118	1.091	1.072	

TABLE 5 -- Continued

CASE		TIME (Years) 10	20	30	RAT
8	XO(k) x 10^5	2.61	1.98	1.52	.819
	S(k) x 10^5	2.82	2.09	1.58	
	Ratio	1.081	1.056	1.0395	
9	XO(k) x 10^5	1.51	.643	.275	.462
	S(k) x 10^5	1.56	.658	.280	
	Ratio	1.033	1.0233	1.0182	

Legend

Case 2 -- 12 month mortality ages 0-3
Case 3 -- 6 month mortality ages 0-3
Case 4 -- 4 month mortality ages 0-3
Case 5 -- 2 month mortality ages 0-3
Case 6 -- 12 month mortality all ages
Case 7 -- 6 month mortality all ages
Case 8 -- 4 month mortality all ages
Case 9 -- 2 month mortality all ages

Multi-species and multi-trophic level models such as those built by Green (1977) and Laevastu and Larkins (1981) could be used to explore multi-species interactions such as food competition between marine mammals. However, the difficulties inherent in single species population and energetics models become multiplied for multi-species interactions and I doubt that this approach would prove valuable except to serve as a preliminary energy budget much as Green (1977) did for the Ross Sea with a linear model. A further complication in multi-species interactions with marine mammals arises from the fact that all marine mammals are not on the same trophic level.

Thus, while seals prey directly on pollock and may have benefitted from the fishery via increased abuandance of smaller pollock via reduced pollock cannibalism, euphausid feeding cetaceans might experience increased competition via increased feeding pressure on euphausids by these same pollock.

Conclusions

A review of a model for seal energetics built to examine the effect of reduced food availability on seal energetics indicated the resilience of seals to function close to normal over a relatively wide range of prey abundance. However, several parameters in this model, especially the effect of prey density on feeding rate are not well known and so this conclusion is to be viewed cautiously. Energetics models like SEAL would be promising for marine mammals which feed over a relatively limited area, whose population size is well known, and whose energetics have been studied or who are similar to a species whose energetics have been studied. Only the walrus and perhaps the Stellar sea lion (Eumetopias jubatus) appear to satisfy these criteria sufficiently to hold promise for such a model for eastern Bering Sea marine mammals.

Models of energetics are only useful in establishing one link in the marine mammal fishery interaction picture_ namely demonstrating the feasibility of energetics consequences of reduced food availability. Further field research is needed to support models examining the linkage between marine mammals and fisheries. These data must establish the existence of food limitation and must help to examine the implications of this food limitation on marine mammal population parameters. Some important facets of this question which might be examined in the field are: 1) How does an individual respond to reduced food availability, both behaviorally and energetically? (e.g. Does a lactating marine mammal with reduced food intake stop feeding her young or lose weight or do something else?) 2) What are the energetics of blubber formation and milk production and of blubber degradation? 3) How long can an individual sustain reduced food intake?. Answers to these questions can only come, I think, with a controlled manipulation of an isolated seal herd.

Once a change in some population parameter has been definitely linked to a fishery then age structured population models can be used to explore the long and short term implications of this change for the population. The model for seal entanglement presented here is an example of such a model. Results from this model indicate that entanglement might well be a (or the) dominant factor in the present decline in fur seal populations in the eastern Bering Sea. Model outcomes are highly dependent on how long entangled seals survive and on which age classes are susceptible to entanglement. Results are also sensitive to the parameters in the density dependent function for pup mortality on land. This density dependent pup mortality function was used partly because it was supported by data from a number of fur seal populations (see Swartzman (1983)) and partly because it represents a conservative assumption which allows the seal some ability to compensate for entanglement loss. This density dependence assumption is, however, hypothetical. The justification for using it in terms of food limitation has not been satisfactorily demonstrated.

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Research Papers

Diving Patterns of Fur Seals Feeding in the Bering Sea: Implications for Fisheries

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Note. The printed version of this research report will appear in an upcoming monograph on diving in eared seals (R.L. Gentry and G.L. Kooyman Eds., "Fur Seals: Maternal Strategies on Land and at Sea" in active preparation as of October 1983, intended for Princeton University Press).

Abstract

Lactating female *Callorhinus ursinus* were instrumented with time-depth recorders during feeding sojourns from St. George Island, Alaska. Data were recorded on a long strip of film by means of a Light Emitting Diode which was attached to the rotating arm of a pressure transducer for which the arc of swing was proportional to depth. A timing circuit marked 12 min increments on the film by a second LED. Computer analysis of the film gave depth, duration, ascent, and descent rates for each dive, as well as time of day and interval to the next dive. The depth LED also indicated periods of inactivity (sleep). The films were analyzed for trends in depth, duration, time of day, and grouping of dives.

Dive records averaged 7.5 days in duration and contained an average of 252 dives, or 1.5 dives per hour at sea. Active swimming (without diving) occupied 57% of time at sea whereas diving and resting occupied 26% and 17% respectively. About 85% of all resting occurred in daylight hours. Transit times to and from feeding averaged 6-7 hours each way.

Dives occurred in about 16 groups (bouts) per sojourn with <40 min between dives in a bout. This repetitive diving suggests systematic exploitation of food patches. From 3% to 14% of dives did not occur in definable bouts and may have represented exploration for

food patches. Dives occurred throughout the day, but peaked in frequency at dusk and dawn. This pattern is consistent with the Twilight Hypothesis regarding fish susceptibility to predation. Seals dived to all depths from 10-207 m, but depth frequencies peaked at 55m ("shallow"), and at 175m ("deep"). Dives were shaped like simple spikes, showing that seals spent no time searching at maximum depth. Feeding probably occurred during the ascent from depth because descent rates always exceeded ascent rates.

Most shallow dives occurred at night, but deep diving occurred throughout day and night. The depth contour within bouts of shallow diving changed consistently with time, suggesting that prey were moving vertically. The depth contour of deep dive bouts did not change with time. Shallow dive bouts accounted for the peak dive frequencies at dusk and dawn. Some (4/13) individuals performed only shallow dives, some (3/13) had only deep dives, and most (6/13) individuals mixed shallow and deep dives, although not usually on the same day. Preliminary results suggest that individuals are "specialists" in these patterns, and retain them within and between seasons.

Generally the deeper the diving the slower the rate in dives/hr (35 dives per hr at 40 m vs. 4 dives per hour at 160 m). The depth and duration of each dive were closely related to each other (r^2 =81%). Therefore the range in dive rates reflected the recovery times needed to replenish oxygen stores between dives. Probably as a result of this relationship, and the probabily of finding food at different depths, most females specialize in taking prey when it rises to shallow depths, mainly at dawn and dusk. Only a few females appear able to maintain offspring by performing only deep dives. Therefore, although individuals can dive to 200 m, the largest impact of northern fur seals on food resources of the Bering Sea, both in total individuals and total dives, probably occurs in the top 75 m of water at night.

The duration of feeding sojourns has not changed during the past 26 years as the Bering Sea groundfish fishery developed. However, this result does not imply that the fishery has had no measureable impact on fur seals, only that duration of feeding sojourns is an inadequate measure. The complex feeding patterns may have changed in many ways without affecting the overall duration of sojourns. A better measure of the effect of fisheries will be the continued application of time depth recorders as the fishery continues to change.

Belukha Whale Studies in Bristol Bay, Alaska

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Introduction

The river systems of Bristol Bay support the largest single-species salmon fishery in the world. In 1983, the catch of red salmon (*Oncorhynchus nerka*) was over 35 million fish, and the total run exceeded 45 million fish (C. P. Meacham, Alaska Department of Fish and Game, pers. commun.). During the peak fishing period in 1983, an estimated 1,000 drift-net boats and 344 setnet sites were fished in Kvichak Bay, and an additional 300-600 drift-netters and up to 230 setnetters were in Nushagak Bay. Collectively, over 450 km of gillnet were fished in the two bays.

Bristol Bay also supports a substantial number of belukha whales (*Delphinapterus leucas*) during the summer. During winter, these whales occur in the ice fringe and front from the Alaska coast to Siberia, as well as in regions of the Bering and Chukchi Sea pack ice where open water regularly occurs (Seaman and Burns, 1981). As the ice recedes in spring, a large segment of the population migrates north to summer in the coastal zone and along the pack-ice edge of the northern Bering, Chukchi, and Beaufort seas. Another group moves into Bristol Bay in April and May and remains there through the summer, feeding primarily on seasonally abundant smelt (*Osmerus mordax*), red salmon smolt, and adult salmon (Brooks, 1954; 1955). While there, belukhas are most commonly seen in Kvichak and Nushagak bays and their associated river systems.

In Bristol Bay, fishermen have long considered belukhas to be serious predators of salmon and in years of poor salmon returns have urged action to control the depredation of salmon. In response to that concern, in the mid-1950's the Alaska Department of Fisheries undertook studies of the natural history and ecology of belukhas, including detailed analyses of stomach contents (Brooks, 1954; 1955). Those studies concluded that belukha predation on outmigrating red salmon smolt was a serious mortality factor which retarded the restoration of depleted salmon stocks and was costly to the greatly depleted fishery. Beginning in 1956, action was taken to displace belukhas from the Kvichak River during May and June. Nonlethal harassment by motorboats and small dynamite charges was conducted from 1956 through 1960, with moderate success (Lensink, 1961; ADF&G, 1969). After a break of 4 years, harassment activities were again undertaken in 1965, this time utilizing acoustic devices which transmitted the vocalizations of killer whales (Orcinus orca) (Fish and Vania, 1971). The "belukha spooker" program was discontinued after 1978, and organized attempts to displace the whales no longer occur. Since then, only limited studies have been made of whales in Bristol Bay. A project to consider the possible effects of belukha predation on red salmon stock-enhancement efforts in the Snake River was conducted by the Fisheries Rehabilitation, Enhancement, and Development Division of the Alaska Department of Fish and Game (ADF&G) (Fried et al., 1979). That study consisted of a series of aerial surveys flown in Nushagak Bay during summer 1979.

In 1982, this study was initiated through joint support of the Outer Continental Shelf Environmental Assessment Program and the ADF&G to study the distribution, abundance, and foods of belukha whales in Bristol Bay; to develop techniques for attachment of visual and radio tags; and to investigate the magnitude and causes of mortality to belukhas during their stay in the bay.

Methods

Field work was conducted from 15 June through 11 July 1982 and from 9 May through 15 July 1983. In 1982, studies were confined to Nushagak Bay and its associated river systems. In 1983, both Nushagak and Kvichak bays were included in our studies, with Kvichak Bay serving as the site of radio-tagging and tracking operations.

Information on the distribution, abundance, and movements of belukhas was obtained through systematic aerial surveys, radio-tracking of tagged whales, helicopter and boat observations made in conjunction with catching and/or tracking operations, and observations from shore. Nushagak and Kvichak bays were surveyed at approximately 2-week intervals from 15 April through 15 August. Surveys were flown along the coastline approximately 0.5-0.9 km offshore at an altitude of 305 m and speeds of 183-274 km/hr. Observers did not survey a specified transect width but instead counted all of the whales they could see on their respective sides of the aircraft. When large groups of whales were encountered and a single observer was present, the aircraft sometimes circled the groups in order to obtain the best possible estimate. The single exception to this method was a line-transect survey on 29 July, when a predetermined grid of both bays was flown and observations were confined to a 0.9-km strip on either side of the aircraft.

Radio transmitters were attached to two whales in 1983. One whale was caught by a local fisherman in a salmon setnet. The second whale was caught by herding into shallow water. OAR (Ocean Applied Research) backpack transmitters weighing approximately 575 g and measuring 24 cm long by 11 cm wide by 7 cm high were attached to the whales by bolting through the dorsal ridge. Movements and activity patterns of the whales were monitored using Telonics receivers and two-element YAGI antennas. Each radio operated with a saltwater switch and therefore transmitted only when the antenna broke the surface. The radios had a range of from 20 to 60 km, depending on height of the receiving antenna.

Beach-cast and floating dead belukhas were located from aircraft and boats. During 1982, most observations of beach-cast belukhas in Nushagak Bay were made on an opportunistic basis. In 1983, systematic surveys were conducted in June and July. Aerial surveys were flown along the beach at altitudes of 25-50 m. Boat surveys were conducted by motoring along the shore, scanning the beach both visually and with the aid of binoculars. When a carcass was located, the animal was examined for cause of death and measured, its sex was determined, the lower jaw or several teeth were taken for age determination, and if condition permitted the stomach was examined for food remains. Additional information was obtained from ADF&G biologists in King Salmon and Dillingham and from salmon fishermen.

Fish remains in stomach contents were usually identified by their otoliths or characteristic bones. Information on probable foods was also obtained by observing feeding whales and by examining salmon caught in nets for the presence of belukha tooth marks. Since these types of information are not quantitative, most of the food habits data used in making calculations of fish consumption by belukhas are from the work of Brooks (1954; 1955).

Results and Discussion

Distribution and abundance.

The distribution of belukha whales in Nushagak Bay was similar in 1982 and 1983. Most whales were seen in four areas: the Igushik River, the Snake River, between the Snake River mouth and Clarks Point, and near the junction of the Wood, Little Muklung, and Nushagak rivers (Fig. 1). Small numbers of whales, usually fewer than 20, were present in the Igushik River during June 1982 and from April-June 1983. They were most often seen near or below the large horseshoe bend approximately 18 km upriver. Belukhas were not sighted in the Igushik in July of either year, although surveys were flown there on several occasions.

Whales were regularly seen in the Snake River and in both 1982 and 1983 were seen upriver as far as the junction of the Snake and Weary rivers, approximately 12 km from the river mouth. The largest sightings were of 15-25 whales on 13 and 14 July 1983. All others were of fewer than 10 individuals. No whales were seen in the Weary River.

The largest observed concentration of belukhas in Nushagak Bay occurred between the Snake River mouth and Clarks Point. Although the number seen there varied considerably, there was a clear trend of increasing abundance from late June to mid-July. From mid-April to mid-June, sightings were of fewer than 20 whales. In late June to mid-July, the number estimated to be in this area ranged from 30 or 40 to 400 to 600 in 1982 and from 150 to over 400 in 1983. Many cows with newborn calves were in the area. In 1979, belukhas were also reported to be concentrated near the Snake River mouth in late June (Fried et al., 1979).

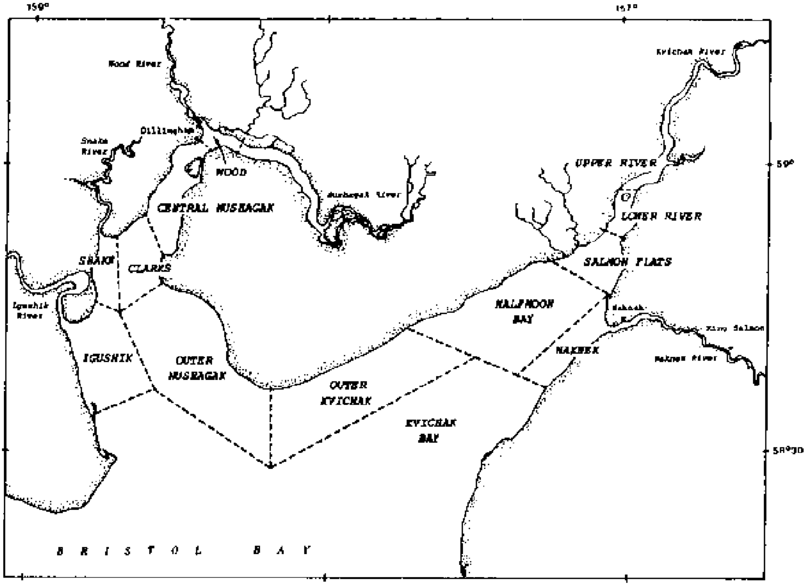

Figure 1. Bristol Bay study area showing geographical subareas.

Belukhas were sighted near the mouth of the Wood River and the Little Muklung River during May through early July. The number seen there varied considerably but was usually fewer than 50 in 1982, and in 1983 it was never more than 24. In both years we received reports of belukhas at Portage Creek, approximately 50 km up the Nushagak River from the Wood-Little Muklung area. Fried et al. (1979) also reported that belukhas regularly occurred off the mouth of the Little Muklung.

Observations on the distribution of belukha whales in Kvichak Bay were made from April to August 1983. In summarizing those observations, the region was divided into six geographical subareas, including the upper and lower Kvichak River, Salmon Flats, the Naknek River-Big Flat area, Halfmoon Bay, and outer Kvichak Bay (Fig. 1). The use of these areas changed markedly during spring and summer.

From mid-April to mid-May, belukhas were present in Halfmoon Bay, outer Kvichak Bay, Salmon Flats, and near the mouth of the Naknek River. On several occasions, the group at the mouth of the Naknek consisted of 70 or more whales. From mid-May to early June, belukhas were not seen near the mouth of the Naknek. From 25 May to 4 June, up to 225 whales were seen in the upper Kvichak River each day. Twice daily, groups of whales moved upriver on the flooding tides, usually traveling at least to the mouth of the Alagnak River (18 km upstream), and returned downriver on ebbing tides. The whales were usually seen traveling in mid-river or milling in rips or current eddies, probably feeding on smelt or red salmon smolt present in the river during this period. Prior to 25 May, we did not make regular observations in the Kvichak River and were thus unable to determine when regular use of the upper river began. Brooks (1954) also reported that, from early May until mid-June 1954, belukhas swam up the Kvichak on each incoming tide and returned to the bay on ebbing tides. He estimated that about 250 whales used the river in 1954 and about 100 in 1955. During the same 2-week period that belukhas used the upper Kvichak River on high tides, they were common in the lower river, Salmon Flats, and Halfmoon Bay on low tides. After 7 June, belukhas were not again seen in large numbers in the Kvichak River. Small groups of fewer than 10 whales were occasionally seen later in the summer. These whales were usually swimming close to the riverbank and appeared to be feeding on adult salmon.

From 6 to 16 June, belukhas were present off and south of the mouth of the Naknek River. At least 100-200 were present most days, feeding at low tide over Big Flat. At high tide they moved up toward Salmon Flats. At least some whales were also present in Halfmoon Bay. After about 16 June, belukhas were no longer seen in the Naknek River-Big Flat area. Instead, from then until our studies terminated in mid-July, they occurred in the lower Kvichak River-Salmon Flats area at high tide and moved to Halfmoon Bay, or in some instances outer Kvichak Bay, at low tide.

Our best information on abundance of belukhas comes from systematic aerial surveys in which an attempt was made to cover all areas of Kvichak and Nushagak Bays where whales regularly occurred. The total number of whales present was estimated by using counts from those surveys, multiplied by correction factors developed from dive time-surface time data from radioed whales. The correction factors are applied to account for whales not at the surface during passage of the aircraft and vary depending on speed of the survey aircraft. For the two aircraft used, the correction factors were 2.75 (survey speed of 180 km/hr) and 3.7 (survey speed of 275 km/hr).

The most complete survey was an aerial strip-transect survey flown at 180 km/hr on 29 June (Fig. 2). In known concentration areas, transect lines were spaced 1.8 km apart. In intervening areas, a single track was flown approximately 1 km offshore from the coast. On that day 126 belukhas were counted in Nushagak Bay and 208 in Kvichak Bay, for a total of 334 whales. When the correction factor is applied to these counts, it yields estimates of 347 whales in the Nushagak and 572 in the Kvichak, for a total of 919 whales (Table 1). Total counts on all other days were lower and yielded corrected estimates of 237-692 whales. In Nushagak Bay, the highest estimated number of whales, 496, occurred on 14 July in the Snake River-Clarks Point area. In Kvichak Bay, maximum corrected counts of 584 and 572 occurred on 5 May and 29 June. The correction factor was not considered applicable to the counts made in Kvichak Bay on 14 August as the whales were in very shallow water and the observer considered that more than the usual proportion was counted. Brodie (1971) concluded that dark-colored

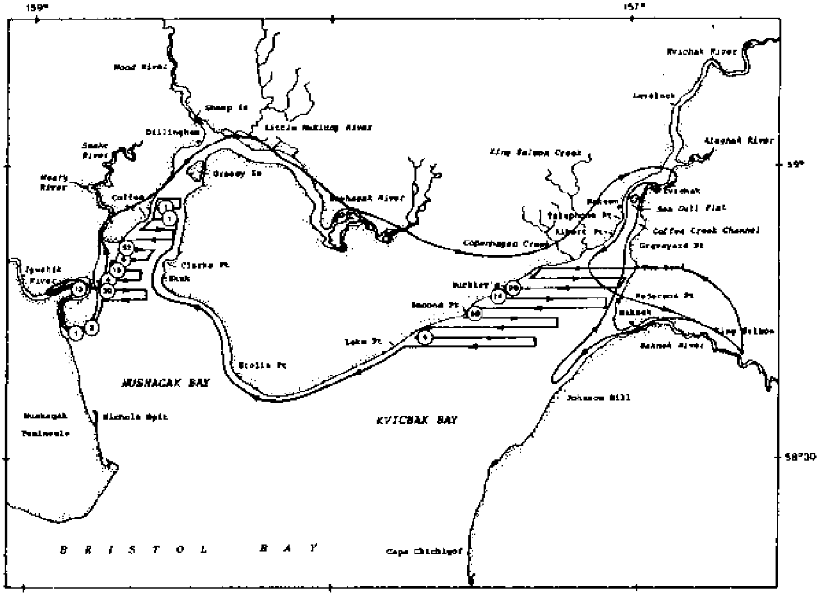

Figure 2. Aerial survey for belukha whales in Nushagak and Kvichak bays, 29 June 1983. Numbers indicate the number of belukhas counted along the survey track.

Table 1. Aerial survey counts and corrected estimates of abundance for belukhas in Nushagak and Kvichak bays, April-August 1983.

	Nushagak Bay		Kvichak Bay		Total	
Date	counted	corrected estimate	counted	corrected estimate	counted	corrected estimate
15 Apr	59	218	128	474	187	692
2/5 May	11	41	158	584	169	625
17 May	23	85	74	274	97	359
31 May	10	27	77	212	87	239
4 Jun	--	--	101	278	--	--
14 Jun	18	49	94	259	112	308
18 Jun	--	--	126	347	--	--
24 Jun	66	182	20	55	86	237
27 Jun	93	256	--	--	--	--
29 Jun	126	347	208	572	334	919
14 Jul	134	496	49	181	183	677
14 Aug	0	0	309	n/a	309	n/a

neonates and yearlings were not counted during aerial surveys. This was also evident during our studies. Since neonates and yearlings are probably not feeding independently, we will use 920 as an estimate of the number of whales feeding in the study area. The total number of whales can be computed by increasing the survey estimates by 8% for yearlings and 10% for neonates (Brodie, 1971), which yields an estimated total number of whales in the area of 1,100.

Foods and feeding.

During the 1982 and 1983 field seasons, five whales were examined in which the stomachs were suitably fresh for examination and contained food. The three 1983 whales had died in May. Two had mostly flatfish (F. Pleuronectidae) remains in their stomachs, while the third contained primarily rainbow smelt with lesser amounts of flatfish and shrimp (Crangon sp.). None of the stomachs were full; the largest volume of contents was 163 ml. Of the 1982 whales, one had probably died in late May or early June; its stomach contained mostly otoliths from rainbow smelt and a few from sculpins (F. Cottidae). The other whale died in the Snake River in late June and had eaten entirely red salmon. Its stomach was the fullest of the five and contained 415 ml.

Most available data on the foods of belukha whales in Bristol Bay were collected in the 1950's and 1960's (Brooks, 1954; 1955; Lensink, 1961; ADF&G, 1969) and are summarized below. During May and early June, belukhas feed in the rivers, particularly the Kvichak, on smelt and red salmon smolt (Table 2). Smelt were eaten in the greatest numbers in the earliest May samples from a given year, followed later by red salmon smolt. Smelt overwinter near the mouths of rivers, move upriver in March to early May to spawn, then return to the bay after spawning (R. B. Russell, ADF&G, pers. commun.). Belukhas congregate in the rivers and at river mouths to feed on smelt during and after spawning. In mid- to late May, the red salmon smolt outmigration begins, and almost immediately the diet of belukhas switches to primarily smolt. Smolt travel downstream in large, dense schools, moving within a few feet of the surface, and are apparently more easily caught by belukhas than smelt, which also may be abundant but swim closer to the bottom (Brooks, 1955). In the Kvichak River, most of the red salmon smolt outmigration occurs within a few weeks, and by mid-June it is largely over.

The first adult red salmon appear in Kvichak and Nushagak bays around mid-June, with peak numbers usually present from the last week in June through the first 2 weeks in July. A few king salmon (Oncorhynchus tshawytscha) are present in early June. After mid-July, the red salmon run tapers off and other species of salmon (chums, O. keta; pinks, O. gorbuscha; and silvers, O. kisutch) are present, although their runs are much smaller than that of the red salmon (Nelson, 1981). Brooks collected no belukhas between mid-June and 1 July. By 1 July, smelt and red salmon smolt had disappeared entirely from the whales' diet and had been replaced by adult salmon, which composed the bulk of the diet for the subsequent 7 weeks (Table 3). During the first 3 weeks of July, reds were the predominant species of salmon eaten. After that, chums, pinks, and silvers became relatively more important. Chums first showed up in the diet during the 2nd week of July, pinks in the 3rd week, and silvers in the 4th week. Only a very few kings were eaten. After the 15th of August, stomachs contained very few salmon. Some had small quantities of shrimp or other fish such as sculpins, flounder, or lampreys (*Lampetra japonica*), as did stomachs of eight belukhas taken in September 1959 and 1960 (Lensink, 1961).

Table 2. Stomach contents of belukha whales from the Kvichak River and its estuary, May and June 1954, 1955, 1965, and 1966. (Brooks, 1955; ADF&G, 1969).

Date	Mean number per stomach			
	smelt	salmon smolt	shrimp	other fish
26-28 May 1954 n = 3	501	*		
22-24 May 1955 n = 2	548	73		
20-22 May 1966 n = 3	62	0	2	*
31 May-6 Jun 1954 n = 5	17	983	*	
26-31 May 1955 n = 8	29	607	6	*
29-31 May 1965 n = 3	0	283		
1-7 Jun 1955 n = 9	20	873		*
11-17 Jun 1954 n = 4	3	399	*	7
8-14 Jun 1955 n = 6	90	201	4	*
11-12 Jun 1965 n = 4	0	125	*	

* Trace (average of < 1 per stomach).

Table 3. The occurrence of adult salmon in belukha stomachs on a weekly basis from 1 July-18 August 1954-1955 (Brooks, 1955).

Date	No. of belukhas (excl. calves)	No. of salmon		Average/belukha	
		red	all species	red	all species
1-7 Jul	6	32	34	5.3	5.7
8-14 Jul	10	33	45	3.3	4.5
15-21 Jul	14	41	74	3.0	5.3
22-28 Jul	5	5	50	1.0	10.0
29 Jul-4 Aug	10	8	31	0.8	3.1
5-11 Aug	15	10	59	0.7	4.0
12-18 Aug	10	8	21	0.8	2.1

Consumption of Salmon.

In 1955, Brooks estimated the consumption of red salmon smolt in the Kvichak River using the following assumptions, which were based on his 1954-55 field studies: an average meal consisted of 685 smolt; each whale averaged 1.5 meals/day and fed on smolt for 19 days; and 150 belukhas fed in the river each day during the smolt run. Based on these assumptions, he calculated that belukhas ate approximately 3 million salmon smolt per season.

The consumption of smolt by belukhas in 1983 was estimated in the following manner. During late May and early June, the number of whales estimated to be in Kvichak Bay ranged from 210 to 280. We regularly counted groups of 75-225 in the river and consider 200 to be a reasonable estimate of the average number feeding there during this time. The large groups of whales were in the river for 14 days from 25 May through 7 June, after which we did not see them there. We made no observations in the Kvichak prior to 25 May. In recent years, the smolt run in the Kvichak has lasted for about 30 days from approximately mid-May to mid-June (Meacham, 1981). Since whales clearly did not use the river after mid-June, and since they probably did use it before 25 May, 19 days seems a reasonable approximation of the period spent feeding on smolt.

Daily ration can be calculated as a product of predator size and consumption rate. Brooks (1954; 1955) and Lensink (1961) collected and measured 82 belukhas of all ages from Nushagak and Kvichak bays. Mean length of those animals, excluding calves, was 326 cm. Similar mean lengths were reported by Nelson (1887), who found that the average adult in the Yukon-Kuskokwim area was 305-366 cm long, and by Doan and Douglas (1953), who found that the average length of 1,077 belukhas from Churchill, Northwest Territories, was 308-325 cm. Weight data are not available for belukhas from Bristol Bay. However, Sergeant and Brodie (1975) plotted a length-weight regression for belukhas from Churchill, which are similar in size to those from Bristol Bay. On the basis of Sergeant's and Brodie's data, a whale averaging 326 cm in length will weigh about 350 kg.

Sergeant (1969) summarized data on the daily ration of six captive belukhas and found that they consumed 4-7% of their body weight per day. The average for four of those measuring 300-400 cm in length was 5.1% per day; therefore, a 350-kg whale will consume about 18 kg per day. Based on estimated weight of prey items, we calculated that the stomach of an average whale collected during the smolt run in 1954-55 contained 7-8 kg. Estimated numbers of smolt, and therefore weight of food per stomach, are almost certainly low due to the difficulty of counting partially digested fishes. During the peak of the adult salmon runs, that average was 15 kg per stomach and, later in the season, 6-11 kg. Assuming two meals per day, daily consumption (based on stomach contents) would therefore be about 15 kg of smolt or 12-30 kg of adult salmon, which is very close to the calculated daily ration of 18 kg. Using data on the number of fishes eaten, and information on the average size of fishes, it was estimated that smolt composed 73% of the diet during the 19 days when the whales ate them, or approximately 13 kg (of a total 18 kg) eaten per whale per day. That number can then be divided by the average weight per smolt (± 8 g, taking into account the ratio of age I and II smolt and their mean sizes based on the 20-year average provided in Meacham, 1981) to estimate the number of smolt eaten per whale per day. Using the above assumptions, the consumption of red salmon smolt can be calculated as follows:

200 belukhas X 1625 smolt/day X 19 days = 6,175,000 salmon smolt

The average annual smolt run in the Kvichak from 1971-1980 was approximately 122 million (Meacham, 1981). Consumption by belukhas represents about 5% of that average. If no predation had occurred and 10% of these smolt survived to spawn (Huttenen, 1982), they would number about 618,000, or approximately 3% of the 1983 commercial salmon catch in Kvichak Bay. Belukha predation on salmon smolt undoubtedly also occurs in the Nushagak, but we do not have the information necessary to make calculations for that area.

Brooks (1955) calculated the predation on adult salmon based on the average number of salmon per stomach for the whales he collected (2.1 reds, 5 total), a 49-day period of eating salmon, and an estimated 800 whales in 1954 and 450 in 1955. In 1954, estimated consumption was 196,000 (82,320 reds), and in 1955 it was 99,225 (41,674 reds).

Based on observations of feeding and data on the duration of salmon runs in 1983 (ADF&G, unpubl.), we consider 70 days as a more realistic estimate of the period during which belukhas prey on adult salmon. Brooks's data indicate that fewer salmon are taken in August than in July and that even during the peak salmon run other prey are eaten. By multiplying data on the number and kinds of salmon and other species eaten per day over a 7-week period by average fish size, and assuming a total daily ration of 18 kg per whale, the average daily consumption of salmon from 17 June through 25 August was estimated as 13 kg. Based on our most complete aerial survey in late June 1983 (Table 1), we consider 920 whales to be a reasonable estimate of the number of belukhas (older than neonates and yearlings) present during the adult salmon runs. Using these assumptions, then, the estimated 1983 consumption of adult salmon by belukhas is:

920 whales X 70 days X 13 kg salmon/whale/day = 837,200 kg adult salmon

If the total amount of salmon is allocated by species according to Brooks's data, excluding pinks since there were essentially none present in 1983, then the 837,200 kg represents approximately 182,000 red salmon and 101,000 salmon of other species. The catch of red salmon in Kvichak and Nushagak bays in 1983 was close to 27 million, out of a run of slightly over 33 million, so that belukha predation was the equivalent of less than 1% of the commercial catch and just over 0.5% of the total run. Catch of other species was approximately 1.1 million, with belukha consumption equaling about 9% of that number.

Mortality.

During June and July 1983, we conducted 856 km of systematic aerial or boat surveys for beach-cast, dead belukhas and located 25 carcasses, of which 19 were original sightings and six were resightings. Of the 19, 15 were recently dead (within the past 2-3 months), and four probably had been dead for over 6 months. Five additional dead belukhas were located in the course of other activities. Carcasses were found in both Kvichak and Nushagak bays, with the greatest number on the exposed beaches of Etolin Point, Halfmoon Bay, and near the Igushik River mouth. It is probable that most carcasses flushed out with the tide, then washed back onshore with incoming tides and onshore winds.

Measurements were taken and sex was determined for 21 carcasses. Of those, one was probably an abortus and seven were recently born calves. Standard length for the seven neonates ranged from 137 cm to 150 cm, with a mean of 141 cm. The remaining animals ranged from 192 cm to 410 cm standard length. Sex ratio for all 21 carcasses was 13 males: 7 females (1 unknown). Of the eight neonates (including the abortus), six were males and two females. Of those 1 year or older, seven were males and five were females.

By combining information from all sources, an estimate was compiled of the rates and causes of mortality during May-July 1983 (Table 4). In general, it was difficult to ascertain cause of death of beach-cast carcasses unless fishermen were present nearby to tell us whether or not the whales had been caught in nets. In some instances net marks in the form of superficial cuts around the caudal peduncles and flukes were obvious. The flukes had been cut off of one large whale and a pectoral flipper from each of two neonates, presumably to disentangle carcasses from nets. However, in at least two instances when whales were known to have been killed in setnets within the previous few days, no net marks or other indications of cause of mortality were obvious. Rapid degradation of the skin upon exposure to wind and sun aggravated this problem. Of the known fishing-related mortalities, two were caught in king salmon setnets, four in king salmon drift nets, three in red salmon setnets, and one in a red salmon drift net. In addition, the small whale we radio-tagged had been caught in a king salmon setnet.

Table 4. Known mortality of belukha whales in Nushagak and Kvichak bays, May-July 1983.

Area	Cause of death: hunting	Cause of death: fishing-related	Cause of death: unknown	Total
Nushagak Bay	2	6	3	11
Kvichak Bay	2	6	12	20
				Total 31*

* Four of these are possibly duplicate sightings.

Hunting mortality was determined through interviews with ADF&G biologists and with local residents. One of the deaths attributed to hunting was a beach-cast carcass with obvious bullet wounds in the mid-body region. It could have been a hunting loss or possibly an animal shot at for some other reason. One of the remaining carcasses was probably an abortus. The others had no obvious marks, bullet holes, or wounds indicating cause of death.

When belukhas are caught in nets, they become entangled in two ways. Some, especially neonates and juveniles because of their small size, become entangled in the web of the net, catching pectoral flippers or tail flukes. In at least some instances, fishermen are able to disentangle and release these individuals before they drown. The small male animal that we tagged on 9 June had been caught in a net. He had superficial cuts in the skin and blubber and slightly dry skin but apparently suffered no long-term damage when set free. Several days later he was over 20 km from the release site and swimming with other whales. Larger individuals are able to break through net webbing but sometimes become entangled in the lead and cork lines. They roll and thrash when hitting the net, wrapping themselves so tightly that they have to be cut out. The tail flukes may be cut off in the process.

Approximate time of entanglement was known for six whales, five of which were caught by set-netters and one by a driftnetter. All but one (the small whale that was rescued and radio-tagged) were caught at night or on early morning tides.

In Nushagak Bay in 1982, carcasses of six dead belukhas were located. One of those was missing the tail flukes and had a bullet wound in the head; its death was considered to be fishing related. Cause of death for the other four, two of which were neonates, could not be determined.

If the number of belukhas present in Nushagak and Kvichak bays in summer 1983 is estimated at 1,100, the number extrapolated from maximum aerial survey counts on 29 June, and corrected to include neonates and yearlings, then the 27-31 dead animals located in May-July represent 2.5-2.8% of that total group of whales. Gross productivity for belukhas has been estimated at 10% (Brodie, 1971), which means in a group of 1,100 whales 110 would be calves. The seven dead neonates located by us in summer 1983 would represent 6% of that year's calf production. Actual mortality is undoubtedly greater as our mortality figures are based only on carcasses we personally located or happened to hear about. We did not systematically interview fishermen, yet heard of at least four dead belukhas through casual conversation. Although aerial survey efforts were considerably more extensive in 1983 than in 1982, carcasses were probably missed in the Nushagak system which we surveyed less frequently and less intensively. In 1982, three of the six carcasses we found were located up the Snake River in the grass along the riverbank. Such carcasses are extremely difficult to see from the air and probably would not have been noticed on the 1983 aerial surveys.

Conclusions

A comparison of studies conducted in the 1950's and our more recent work suggests that the distribution and abundance of belukha whales in Bristol Bay are largely the same today as they were 30 years ago. Like Brooks, we conclude that the predation by belukhas on adult red salmon is negligible, accounting for less than 1% of the commercial catch of that species. Predation on other species may be somewhat more significant, amounting in total to almost 9% of the commercial catch of king, silver, and chum salmon. Since the 1950's, the then-depleted red salmon runs have recovered fully, attaining close to all-time high levels in the last few years. Predation by belukhas on red salmon smolt, once considered to be a major source of salmon mortality, amounts to less than 5% of the total smolt outmigration.

The major change in the interaction between belukhas and fisheries in the past 3 decades has been the apparent increased incidence of entanglement of whales in nets during the red salmon fishery. In the 1950's, Brooks documented no net-caused mortality (J. Brooks, National Marine Fisheries Service, Juneau, pers. commun.). Since then, some mortality (estimated at about 5-10 whales per year) has been known to occur in conjunction with the king salmon fishery (J. J. Burns, ADF&G, pers. commun.). In 1983, we documented a minimum of 27 dead whales, at least 12 of which were known to have been killed in nets. Six of those were killed in king salmon nets, four in red salmon nets, and two in nets of unknown type. The cause of this apparent increase in entanglement warrants further study.

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Endangered Whale Abundance and Distribution in the Navarin Basin of the Bering Sea During the Ice-free Period

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Abstract

Density, distribution, and habitat use of endangered species of whales in the Navarin Basin of the Bering Sea were determined during the spring, summer, and fall 1982. Vessel and aerial surveys were conducted along systematic tracklines randomly distributed over the outer continental shelf, slope, and rise. Fin, gray, and right whales were encountered during the almost 3,900 nautical miles (nm) of aerial and 1,750 nm of vessel surveys completed in the 54,078 nm^2 Navarin Basin. Fins were present during all three seasons, while right whales were observed only during the summer and gray whales only during the fall. The three species were distributed in the outer continental shelf waters in significantly higher numbers than in the slope or rise waters. Observed densities were 10.7, 6.2, and 1.1 animals per 1,000 nm^2 for gray, fin, and right whales, respectively. No calves were observed with the four endangered whale species. The results confirm that the Navarin Basin is a feeding ground for gray, fin, and right whales during the ice-free period, particularly the shallow shelf waters where the availability of food organisms is commensurate with the diving characteristics of these species. Densities of endangered whales in the Basin were variable within their range. Other whales recorded in the Basin were minke and killer whales, and Dall's porpoises.

Introduction

Little information is available on whale utilization of the northcentral Bering Sea, particularly in the Navarin Basin. Most information derives from catch (Aldrich 1889, Cook 1926, Townsend

1935, and Tomilin 1957) and scouting (Berzin and Rovnin 1966, Nishiwaki 1974, and Wada 1981) expeditions by commercial whaling vessels. Since the cessation of commercial whaling in the Bering Sea during the 1960s, additional information has been largely limited to the National Marine Fisheries Service's Platforms of Opportunity Program (Consiglieri and Bouchet 1981). This program relies on vessels of opportunity collecting marine mammal data primarily on species composition and distribution in the Bering Sea and elsewhere. The only recent dedicated study of whales was conducted by Brueggeman (1982), who examined the abundance, distribution, and habitat use of bowhead whales in the northcentral Bering Sea, including the Navarin Basin, during early spring. Few additional studies have been conducted in this area because of the high costs and difficult logistics required to study it.

Based on the historic and recent literature, at least five of the world's ten species of baleen whales seasonally inhabit the Navarin Basin. Three of these species--fin (*Balaenoptera physalus*), gray (*Eschrichtius robustus*), and right (*Balaena glacialis*) whales--migrate from lower latitudes to feed in the Basin during the ice-free period (Tomilin 1957, Berzin and Rovnin 1966, Rice and Wolman 1971, Rice 1974, Votrogov and Ivashin 1980, Marquette and Braham 1982). Conversely, bowhead whales (*Balaena mysticetus*) migrate from northern latitudes to winter in the Basin during the seasonal ice period (Braham et al. 1980, Brueggeman 1982). The minke whale (*Balaenoptera acutorostrata*) also occurs in the Basin and is probably present yearlong in varying numbers (Tomilin 1957, Sleptsov 1961, Ivashin and Votrogov 1981). All of these whales, except the minke whale, are classified as endangered species throughout their range (U.S. Dept. Comm. 1979). Other whales occurring in the Basin are the beluga (*Delphinapterus leucas*), killer whale (*Orcinus orca*), Dall's porpoise (*Phocoenoides dalli*), and possibly some beaked whales. Sperm (*Physeter macrocephalus*), sei (*Balaenoptera borealis*) and humpback (*Megaptera novaeangliae*) whales, while found in the Bering Sea, primarily occur south of the Navarin Basin (Berzin and Rovnin 1966, Wada 1981).

The Navarin Basin is scheduled for petroleum exploration and development in 1984. The Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973 mandate that studies be conducted to determine whether these proposed habitat alterations will have any adverse effects on populations of endangered species of marine mammals. In 1982, the National Oceanic and Atmospheric Administration awarded Envirosphere Company a contract to develop baseline data on endangered and other marine mammals in the Navarin Basin for assessing potential petroleum development impacts on these species. The objectives of the contract were:

1. Assess winter habitat use of the Navarin Basin by cetaceans, emphasizing the seasonal population size and distribution of bowhead whales relative to ice and other environmental parameters;

2. Assess habitat use by endangered species of whales during the ice-free season. Identify and enumerate the endangered species of whales in the Basin and correlate their temporal and spatial distribution with environmental parameters; and

3. Document sightings of other species of marine mammals observed during the surveys, and provide estimates of their abundance and distribution within the region.

This paper addresses Objective 2, while subsequent reports will discuss Objectives 1 and 3.

We thank the survey team members of Drs. A Erickson and T. Newby and J. Joyce, and H. Hartley. Thanks also go to R. Fairbanks, Dr. D. Chapman, Dr. T. Quinn, and J. Laake for their advice on data analysis. Dr. D. Chapman, D. Rice, R. Fairbanks, and M. Athey reviewed the manuscript. Field support was provided by the crew of the NOAA ship Surveyor, whom significantly contributed to the enjoyment, success, and safety of the cruises. Funding was by the Outer Continental Shelf Environmental Assessment Program, NOAA (Contract Number NA82RAC00055).

Study Area

The Navarin Basin is located in the northcentral Bering Sea, approximately 200 nautical miles (nm) off the coast of Alaska (Figure 1). It covers over 54,000 nm^2, an area approaching the size of the State of Michigan, and is bound by the U.S.-U.S.S.R. Convention Line to the west, 174°W longitude to the east, and latitudes 63°N and 58°N to the north and south. Water depth in the Basin ranges from about 44 m on the outer continental shelf to over 3000 m outside the shelf. The shelf comprises approximately half of the total area in the Basin, while the continental slope and rise comprise 36 percent and 14 percent, respectively. The Basin is ice free from approximately June through November (Potocsky 1975).

Methods

The Basin was stratified into three survey zones (Figure 1). The shallow water zone coincided with the outer continental shelf, while the transition and deep water zones corresponded to the outer continental slope and rise, respectively. The former zone was the area northeast of a point 10 nm northeast of the 200 m contour line, and the latter zone was the area southwest of a point 10 nm southwest of the 3000 m contour line. The area between these points was the transition zone, which featured the greatest topographic relief. The Basin was stratified in this manner to account for distributional differences of marine mammals relative to major changes in water depth. Moreover, areas of potential petroleum development in the Basin may be closely linked to the feasibility of extracting petroleum in various water depths.

Twenty-two sampling units were distributed over the three zones (Figure 1). The shallow water zone contained 11 units, the transition zone eight units, and the deep water zone three units. Each unit was approximately 34 nm by 72 nm and comprised about 2,450 nm^2. Nine transect lines, 30 nm long, were equidistantly spaced every 8 nm, corresponding to the longitude lines in each sampling unit (Figure 2). This configuration provided thorough coverage of a sampling unit and prevented double surveying of adjacent lines or units.

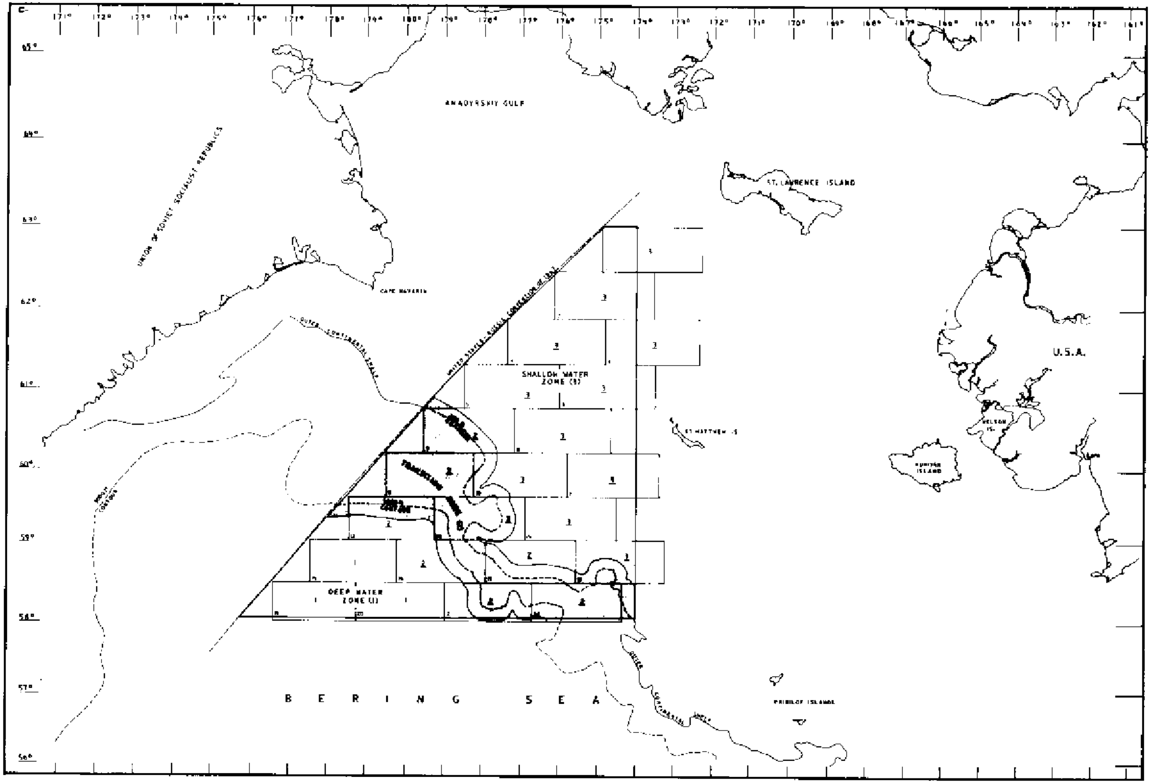

FIGURE 1 STUDY AREA AND SAMPLING DESIGN IN THE NAVARIN BASIN.

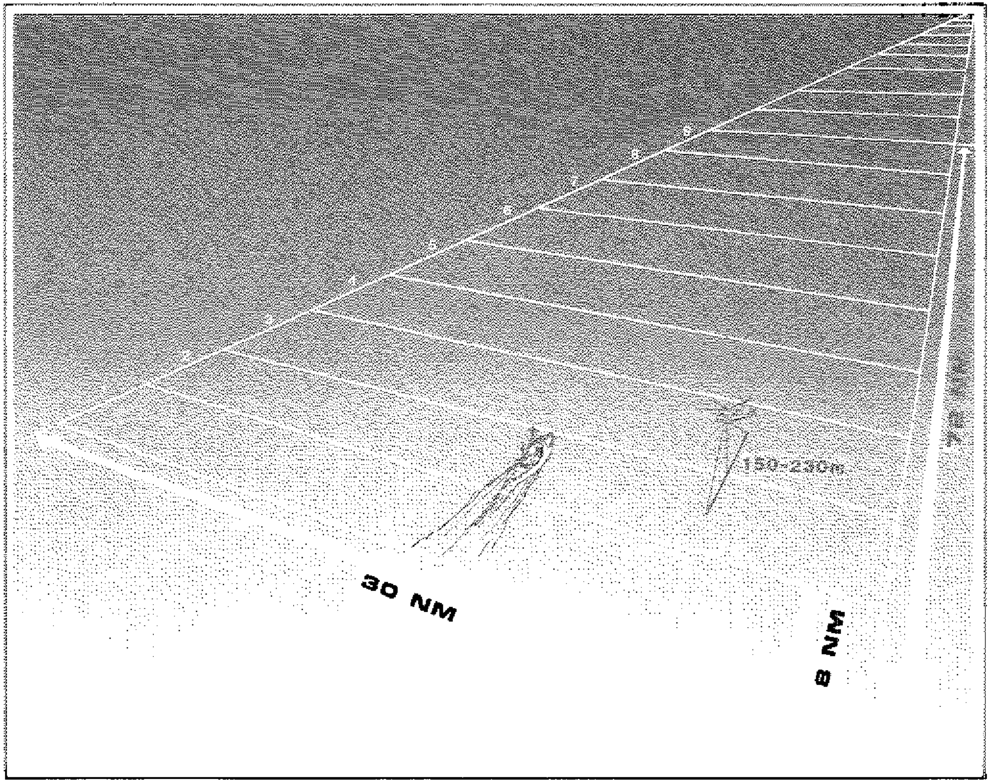

FIGURE 3 TRACKLINE ORIENTATION OF AERIAL AND VESSEL SURVEYS DURING SPRING THROUGH FALL PERIOD.

Aerial and vessel surveys were conducted along the transect lines of randomly selected sampling units (Figure 2). Survey effort in a given zone was allocated in proportion to the relative amount of area in each zone. Consequently, we attempted to allocate 50 percent of the survey effort in the shallow water zone, 36 percent in the transition zone, and 14 percent in the deep water zone. This approach assumed that marine mammals were distributed in proportion to the amount of area available in each zone; an assumption that was the best available at the initiation of the study from the marine mammal literature for the Basin.

Aerial surveys were conducted from a UH1M helicopter based on the NOAA ship Surveyor. Surveys were flown at altitudes of 500-750 ft and at speeds of 65-75 kt. Two observers, one positioned in the co-pilot's seat and one in the right-aft section of the helicopter, provided data on marine mammals and environmental conditions to a data recorder; all data were recorded on computer-ready-forms. Data collected on marine mammals during a survey were number, species, vertical angle when an animal was perpendicular to the trackline, direction of travel, reaction to the aircraft, group size, time, and position. Environmental conditions including visibility, Beaufort Wind Scale, and glare were evaluated at the start of each transect line surveyed, or whenever the conditions changed. Vertical angles were taken with clinometers. Positions were recorded from a GNS-500 every 3 nm along a transect line. The pilot was responsible for providing positions of the aircraft to the data recorder, maintaining a constant altitude and airspeed, and when possible, searching for marine mammals.

When the wind speed was greater than a Beaufort 4, the visibility less than 2 nm, or the ceiling below 500 ft, vessel surveys were conducted along the transect lines in place of aerial surveys. Surveys were performed from the flying bridge, approximately 60 ft above the water, and at a vessel speed of 12 kt. Two observers, individually stationed on the port and starboard sides of the vessel, recorded marine mammal and environmental data on the same variables described for the aerial surveys. Radial angles, instead of vertical angles, were taken with a sighting board or 10 minute surveyors transit; animal distances from the vessel were estimated by observers who generally had substantial experience with this estimation procedure. Water depth was recorded every 3 nm. Vessel surveys were terminated when wind speed exceeded a Beaufort 6.

Vessel surveys were also conducted in conjunction with the aerial surveys (Figure 2). The ship travelled an east-west route along the mid-latitudinal points of the north-south transect lines. One observer, positioned on the flying bridge, recorded marine mammals encountered along the trackline. The use of the ship during the aerial surveys was for the purpose of collecting distributional information on marine mammals and providing safeguards to the helicopter crew.

Data analysis

Population estimates were derived from the strip-transect method (Eberhardt 1978). The strip-transect method involves calculating abundance from the density of animals in a survey strip. Although this method assumes that all animals in the designated strip are counted, confirmation of this assumption is impossible and probably violated for marine mammals. However, the method provides the best relative index of whale abundance for this study. This method was preferable to the line-transect method (Burnham et al. 1980) because of sample size problems. Small sample sizes caused poor or unreliable fits of the data to standard population estimation models (Fourier Series, negative exponential, normal, half normal, power series, and exponential) and large variances. This problem persisted throughout numerous manipulations of the data, including different forms of pooling. Burnham et al. (1980) recommended a minimum sample size of 40 observations for the line-transect method, which exceeded our sample sizes.

Whale abundance was estimated from systematic aerial and vessel surveys. Estimates were made from whale observations occurring in a strip width of 1.0 nm (0.5 nm per side of the trackline). Chi-square analysis showed that data collected during fair and good to excellent conditions could be pooled for aerial surveys (x^2 = 0.35, 1df, P>0.50) but not for vessel surveys (x^2 = 4.85, 1df, $P < 0.05$); thus only observations collected under good to excellent conditions were used for vessel surveys. The number of whale observations recorded from the two survey platforms did not indicate an observation bias for either side of the aircraft or vessel, so the observations for the two sides were treated equally in estimating abundance. Whales observed during non-systematic surveys were used to describe temporal and spatial distribution.

Frequency histograms of perpendicular distances were constructed to determine strip widths for estimating abundances of individual species or groups of similarly sized species (fin, gray, and minke); pooling of species and also seasons were necessary to increase sample size (Figure 3). Histograms were constructed by pooling perpendicular distances of whales from the trackline into 0.25 nm intervals. The set of intervals from the transect line with the majority of observations defined the strip width. The strip width for the vessel surveys was assumed to be the same as for the aerial surveys, since the number of whale observations was insufficient to compile frequency histograms and we felt confident most whales within that distance were observed. Dall's porpoise abundance was estimated entirely from vessel surveys using a 0.5 nm (0.25 nm per side of trackline) strip width (Figure 3) because these animals were not readily detectable from the helicopter at the altitudes flown.

Density and abundance of whales and associated variances were estimated from methods described by Estes and Gilbert (1978) for strip-transect analysis. Density and abundance were calculated by summing the sampling unit estimates for each zone and then summing the zone estimates for the Navarin Basin. Estimates do not account for animals below the surface or otherwise missed during the surveys.

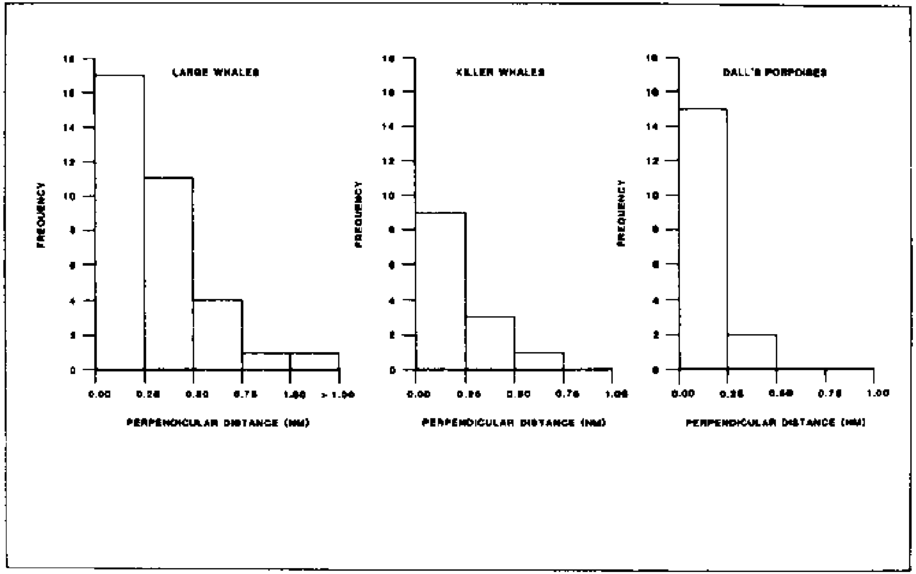

FIGURE 3 FREQUENCY DISTRIBUTION OF PERPENDICULAR DISTANCES OF LARGE (FIN, GRAY, MINKE) AND KILLER WHALES SIGHTED DURING AERIAL SURVEYS AND DALL'S PORPOISE SIGHTED DURING VESSEL SURVEYS.

The estimator has the following form:

Estimated density is:

$$D_i = \Sigma y_i / \Sigma x_i$$

where D_i = the density of whales per nm^2 for a zone
y_i = the number of whales in the i^{th} transect strip, and
x_i = the area of the i^{th} transect strip

Estimated variance of D_i is:

$$S_{D_i}^2 = [\Sigma (y_i^2 / x_i) - D\ \Sigma y_i] \ / (n-1) (\Sigma x_i)$$

Estimated abundance for a zone is:

$$T_i = D_i\ A_i$$

where: T_i = abundance of whales in a zone, and
A_i = total area of that zone

Estimated abundance for all zones is

$$T = \Sigma T_i$$

Estimated variance of T is:

$$V(T) = A\ (A - \Sigma x_i)\ S_{D_i}^2$$

The 95 percent confidence interval for T is:

$$T \pm 1.96 \sqrt{V(T)}$$

Other statistical procedures used in the analysis were Chi-square goodness of fit for testing habitat utilization by whales and ANOVA for comparing group sizes of whales and testing habitat characteristics. All tests were performed at the 0.05 level of significance.

Results

One hundred and seven observations of 333 whales, representing six species, were recorded in the Navarin Basin during three seasonal surveys between 11 May and 12 November 1982 (Table 1). Three endangered species of whales--fin, gray, and right--were recorded during the aerial and vessel surveys. These species comprised 35 percent of the total groups and 27 percent of the individuals. Other species encountered in the Basin were minke, killer whales, and Dall's porpoises. Dall's porpoises were most abundant followed by killer, fin, gray, minke, and right whales. Fin, minke, and killer whales and Dall's porpoises were observed in the Basin every

TABLE 1

NUMBER OF OBSERVATIONS AND INDIVIDUALS OF WHALES RECORDED DURING THE THREE SEASONAL SURVEYS OF THE NAVARIN BASIN, 11 MAY-10 JUNE, 20 JULY-19 AUGUST, AND 29 OCTOBER-12 NOVEMBER 1982

	Spring				Summer				Fall				Total			
		No. Individuals				No. Individuals				No. Individuals				No. Individuals		
Species	No. obs.	Vessel	Aerial	Total	No. obs.	Vessel	Aerial	Total	No. obs.	Vessel	Aerial	Total	No. obs.	Vessel	Aerial	Total
Fin whale	11	-a/	26	26	3	-	6	6	5	-	13	13	19	-	45	45
Right whale	-	-	-	-	1	2	-	2	-	-	-	-	1	2	-	2
Gray whale	-	-	-	-	-	-	-	-	18	-	44	44	18	-	44	44
Minke whale	3	3	-	3	1	1	-	1	3	-	3	3	7	4	3	7
Killer whale	10	1	34	35	2	2	3	5	3	-	17	17	15	3	54	57
Dall's porpoise	17	61	4	65	18	37	17	54	10	34	22	56	45	132	43	175
Unidentified whale	-	-	-	-	-	-	-	-	2	3	-	3	2	3	-	3
TOTAL	41	66	64	129	25	42	26	68	41	37	99	136	107	144	189	333

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a/ Dash (-) signifies no animals were observed.

season. Right whales were observed only during the summer and gray whales only during the fall. There were also 2 observations of 3 unidentified baleen whales. Over 57 percent of all whales were observed from the helicopter, which travelled 69 percent of the 5,647 nm surveyed in the 54,078 nm^2 Navarin Basin. No calves were encountered in the Basin.

Spring survey period

Four species and 129 individual whales were observed during 2,482 nm of aerial and vessel surveys in the Basin (Table 2). The Dall's porpoise was the most commonly encountered species, followed by killer, fin, and minke whales. Fin and killer whales were chiefly recorded during aerial surveys, while minke whales and Dall's porpoises were observed primarily from the vessel. Aerial surveys accounted for approximately 74 percent of the 2,135 nm of systematic trackline censused; an additional 347 nm of opportunistic vessel surveys were covered in the Basin.

Eight sampling units were surveyed in the Basin (Table 2). Four of these eight were in the shallow water zone, three in the transition zone, and one in the deep water zone. Correspondingly, approximately 49 percent of the systematic survey effort was in the former zone, 13 percent in the latter zone, and 38 percent in the transition zone. Aerial surveys predominated the survey effort in each zone, although units 8 and 22 were primarily censused by vessel because of weather conditions. Virtually the entire 270 nm of trackline available in each of the eight sampling units were censused. Visibility was good to excellent during 80 percent of the survey time that included winds below Beaufort 5, glare less than 50 percent, and average wind speed of 11 kt. Surveys in the northern third of the Basin (units 1 through 4) were precluded by sea ice which the vessel could not penetrate.

Whales were observed in all three zones of the Navarin Basin (Figure 4). Animal counts were highest in the shallow water zone of the outer continental shelf and lowest in the transition zone. Species diversity was also greatest on the shelf. Fin and killer whales were observed only in the shelf waters, while Dall's porpoises occurred in all three zones, particularly the deep water zone. Fin and killer whales were in one sampling unit at water depths of 130 m and 100 m, respectively, and Dall's porpoises in 6 of the 8 units at depths ranging from 126 m to over 3,700 m. Minke whales were observed in both the shallow and deep water zones in depth ranges similar to those for Dall's porpoises. No whales were observed in units 5 or 21.

Movements of whales in the Basin were variable during spring (Figure 5). Fin and minke whales were observed moving in a northerly to westerly direction toward the Gulf of Anadyr in groups averaging 2.4 (n=11) and 1 (n=3) animals, respectively. Fin whales appeared to be feeding while travelling, since large concentrations of birds and water discoloration were associated with the whales (Harrison 1979). Killer whales also seemed to be primarily travelling in northerly to westerly directions, but along the fringe

TABLE 2
NUMBER OF WHALES OBSERVED DURING THE SPRING AERIAL AND VESSEL SURVEYS
OF THE NAVARIN BASIN, 11 MAY - 10 JUNE 1982

Zone	Sampling unit	Trackline distance surveyed a/			Fin whale		Minke whale		Killer whale		Dall's porpoise		Total	
		Aerial (%)	Vessel (%)	Total (nm)	No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv
Shallow water	6	53	47	210 [23] b/	-	- c/	-	-	-	-	-	-	-	-
	8	30	70	298 [21]	-	-	2	2	-	-	3	8	5	10
	10	100	0	270 [71]	11	26	-	-		-	1	2	12	28
	11	100	0	270 [33]	-	-	-	-	10	35	1	2	11	37
Subtotal		71	29	1048 [148]	11	26	2	2	10	35	5	12	28	75
Transition	7	100	0	270 [63]	-	-	-	-	-	-	1	2	1	2
	21	100	0	270 [64]	-	-	-	-	-	-	-	-	-	-
	22	6	94	277 [0]	-	-	-	-	-	-	5	14	5	14
Subtotal		68	32	817 [127]	-	-	-	-	-	-	6	16	6	16
Deep water	20	100	0	270 [73]	-	-	1	1	-	-	6	37	7	38
Subtotal		100	0	270 [73]	-	-	1	1	-	-	6	37	7	38
TOTAL		74	26	2136 [347]	11	26	3	3	10	35	17	65	41	129

a/ Total trackline length available in each sampling unit was 270 nm.
b/ Brackets [ ] include nautical miles surveyed by the vessel during aerial surveys; incidental marine mammal sightings were recorded for determining species distribution in the Basin.
c/ Dash (-) signifies no animals were observed.

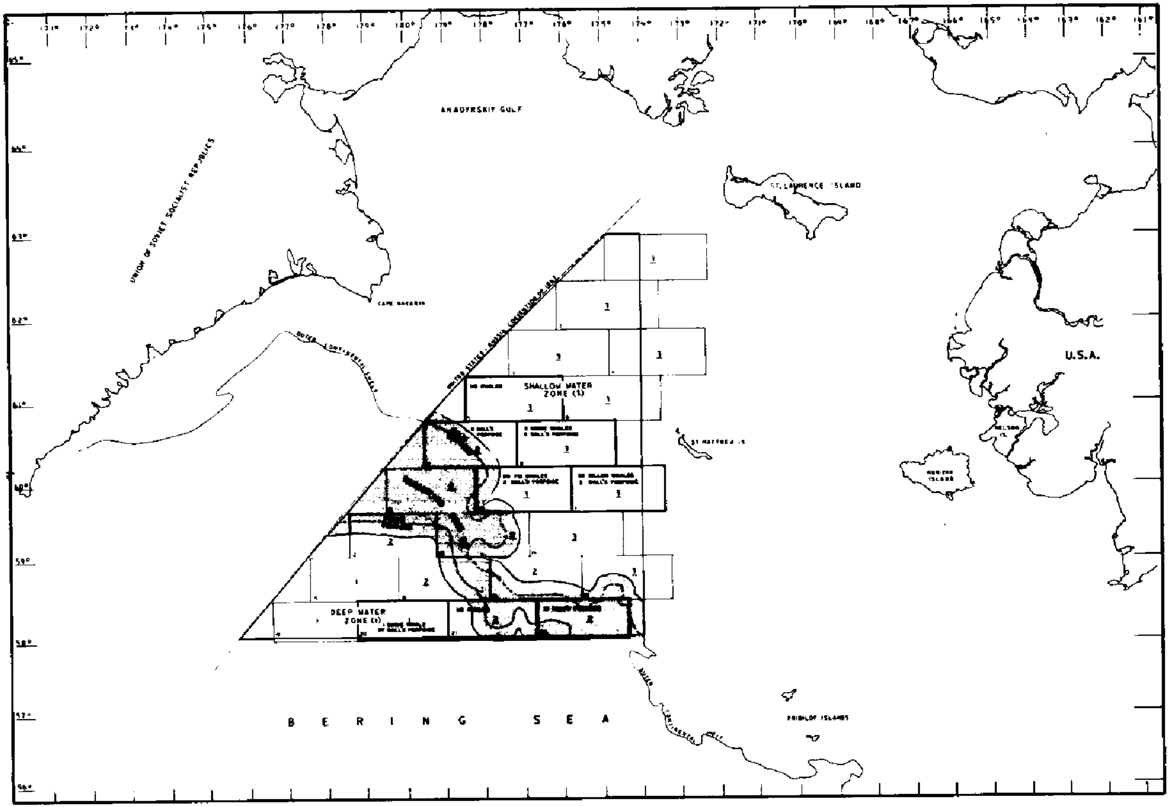
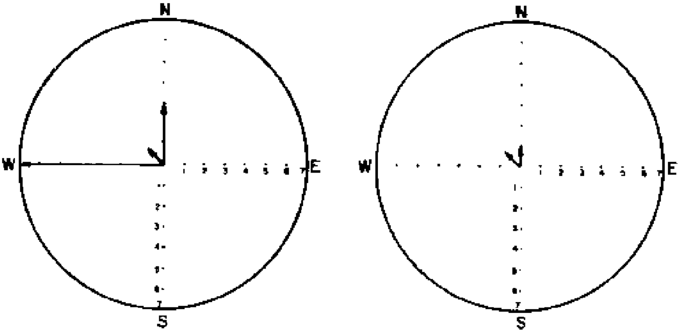
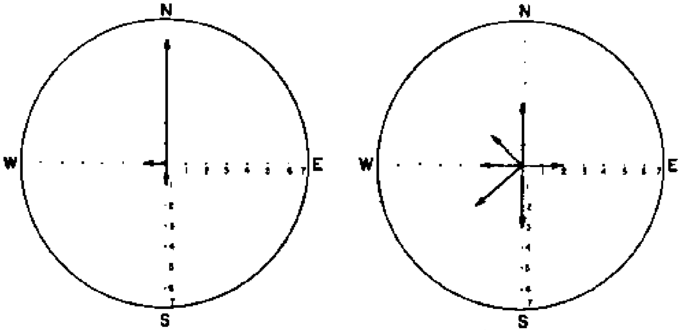


FIGURE 4 DISTRIBUTION OF WHALES IN THE EIGHT SAMPLING UNITS SURVEYED IN THE NAVARIN BASIN DURING SPRING, 11 MAY – 10 JUNE, 1982.



FIN WHALE

MINKE WHALE



KILLER WHALE

DALL'S PORPOISE

FIGURE 5 FREQUENCY OF WHALE OBSERVATIONS FOR A GIVEN DIRECTION OF TRAVEL IN THE NAVARIN BASIN DURING SPRING, MAY-JUNE 1982.

(Burns et al. 1980) of the pack ice in groups averaging 3.5 (n=10) animals where pinnipeds were prevalent. There was no consistent direction of movement for Dall's porpoises, which had an average group size of 3.8 (n=17) animals.

An estimated 670 fin, minke, and killer whales or 16 animals per 1000 nm^2 were in the Basin during spring (Table 3). This estimate was based on observations of 49 animals along 1,769 nm of systematic trackline, representing approximately 4 percent coverage of the Basin. Killer whales were most abundant and minke whales least abundant. Fin whales had an estimated abundance of 259 animals or 6 animals per 1000 nm^2. All whales occurring within the boundaries of the survey strip were solely in the shallow water zone, although coverage in the transition and deep water zones was 2.8 percent and 3.7 percent, respectively, compared to 6.3 percent in the shallow water zone. Dall's porpoise abundance was not estimated because too little area was surveyed under acceptable viewing conditions to provide a meaningful value. The confidence limits around the abundance estimates for the other species were wide because of the small sample sizes. Since these estimates do not account for animals below the surface or otherwise missed during a survey, the actual abundance is undoubtedly higher, particularly since replicate counts of whale pods commonly exceeded twice the number of animals initially recorded.

Summer survey period

Sixty-eight whales comprising five species were recorded during 1,590 nm of aerial and vessel surveys in the Basin (Table 4). Dall's porpoises represented almost 80 percent of the total observations, while six or fewer fin, killer, right, and minke whales were recorded. The majority of the fin and killer whales were observed during aerial surveys, whereas most animals of the other three species were counted from the vessel. Aerial surveys accounted for 71 percent of the 1,385 nm of systematic trackline examined; the remaining 402 nm of systematic and 205 nm of opportunistic trackline were censused by vessel.

Eight sampling units were surveyed in the Basin during summer (Table 4). Five units were censused in the shallow water zone, two in the transition zone, and one in the deep water zone. Systematic survey effort in these zones was 66 percent in the former zone, 14 percent in the latter zone, and 20 percent in the transition zone of the total 1,385 nm censused. Helicopter surveys predominated the census effort in each zone except for the transition zone, which was primarily censused by vessel. The vessel was predominantly used in sampling units 22 and 11 where weather conditions limited use of the helicopter. Visibility was good to excellent approximately 75 percent of the survey time and wind was below Beaufort 5, 91 percent of the time; under these environmental conditions glare was less than 50 percent and wind speed averaged 14 kt. There was no sea ice in the Basin during the summer period to cause access problems similar to those reported in the spring.

TABLE 3
ESTIMATED ABUNDANCE OF WHALES IN THE NAVARIN BASIN DURING SPRING, 11 MAY - 10 JUNE 1982

Zone	Sampling unit	Total area (nm²)	% area coverage			Fin whale		Minke whale		Killer whale		Total	
			Aerial	Vessel	Total	Obs.[a/] No.	Est. No.	Obs. No.	Est. No.	Obs. No.	Est. No.	Obs. No.	Est. No.
Shallow water	5	2458	4.5	1.3	5.8	-[b/]	-	-	-	-	-	-	-
	8	2452	3.7	6.5	10.2	-	-	1	10	-	-	1	10
	10	2461	11.0	0	11.0	19	173	-	-	-	-	19	173
	11	2461	11.0	0	11.0	-	-	-	-	29	264	29	264
Subtotal		9832	7.5	2.0	9.5	19	173	1	10	29	264	49	447
All units		14,740	5.0	1.3	6.3		259		15		396		670
Transition	7	2452	11.0	0	11.0	-	-	-	-	-	-		-
	21	2461	11.0	0	11.0	-	-	-	-	-	-		-
	22	2461	0.7	0.4	1.1	-	-	-	-	-	-	-	-
Subtotal		7374	7.6	0.1	7.7	-	-	-	-	-	-	-	-
All units		19,651	2.8	T	2.8		-		-		-		-
Deep water	20	2461	11.0	0	11.0	-	-	-	-	-		-	-
Subtotal		2461	11.0	0	11.0	-	-	-	-	-		-	-
All units		7379	3.7	0	3.7		-		-		-		-
TOTAL		41,770	3.8	0.5	4.3	19	259 ± 559[c/]	1	15 ± 40	29	396 ± 713	49	670

a/ Number of whales recorded in survey strip.
b/ Dash (-) signifies no animals.
c/ Ninety-five percent confidence limits.

TABLE 4
NUMBER OF WHALES OBSERVED DURING THE SUMMER AERIAL AND VESSEL SURVEYS
OF THE NAVARIN BASIN, 20 JULY - 19 AUGUST 1982

Zone	Sampling unit	Trackline distance surveyed[a/]				Fin whale		Right whale		Minke whale		Killer whale		Dall's porpoise		Total	
		Aerial (%)	Vessel (%)	Total (nm)		No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv
Shallow water	1	94	6	255	[50][b/]	-[c/]	-	-	-	-	-	-	-	-	-	-	-
	5	100	0	270	[63]	3	6	-	-	1	1	1	3	12	38	17	48
	6	64	36	210	[24]	-	-	1	2	-	-	-	-	-	-	1	2
	8	100	0	75	[18]	-	-	-	-	-	-	-	-	-	-	-	-
	11	18	82	101	[6]	-	-	-	-	-	-	1	2	2	5	3	7
Subtotal		81	19	911	[161]	3	6	1	2	1	1	2	5	14	43	21	57
Transition	9	81	19	129	[18]	-	-	-	-	-	-	-	-	2	5	2	5
	22	0	100	150	[0]	-	-	-	-	-	-	-	-	2	6	2	6
Subtotal		38	62	279	[18]	-	-	-	-	-	-	-	-	4	11	4	11
Deep water	20	69	31	195	[26]	-	-	-	-	-	-	-	-	-	-	-	-
Subtotal		69	31	195	[26]	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL		71	29	1385	[205]	3	6	1	2	1	1	2	5	18	54	25	68

[a/] Total trackline length available in each sampling unit was 270 nm.

[b/] Brackets [ ] include nautical miles surveyed by the vessel during aerial surveys; incidental marine mammal sightings were recorded for determining species distribution in the Basin.

[c/] Dash (-) signifies no animals were observed.

Whales were observed in 2 of the 3 zones during the summer (Figure 6). The majority of whales were recorded in the shallow waters of the outer continental shelf where the species diversity was also highest. Fin, right, minke, and killer whales were exclusively encountered in the shelf waters. Right whales were observed in unit 6 at a water depth of 104 m, while fin, minke, and killer whales all occurred in sampling unit 5 at depths ranging from 110 to 120 m; killer whales also were in unit 11. Dall's porpoises were more widespread than the other species since they occurred in 4 units distributed in the shallow water and transition zones where depths ranged from 110 m to over 1,000 m. No whales were observed in sampling units 1, 8, or the deep water zone.

Summer movement patterns of whales in the Basin were unclear (Figure 7). Directions of movement of fin whales and Dall's porpoises were quite variable, possibly suggesting these species were feeding in the Basin. Fins travelled in average group sizes of 2.0 (n=3) and Dall's porpoises in groups of 3.0 (n=18) animals. Too few observations were recorded for the other species to suggest any definite movement patterns; one group of 2 right whales and 2 groups of 3 and 2 killer whales were recorded.

During the summer period, 183 whales at a density of 3 animals per 1,000 nm^2 were estimated in the Basin (Table 5). This estimate was based on observations of 8 whales along 1,085 nm of strip transect representing 2 percent coverage of the Basin. Densities were highest for fin whales and lowest for killer whales; right whales were intermediate in abundance. Abundance estimates for these species were 84 fin whales or 2 animals per 1,000 nm^2, compared to 57 right whales and 42 killer whales at densities of 1 and 1 animals per 1,000 nm^2, respectively. All animals recorded in the designated strip boundaries were in the shallow water zone where survey coverage was 2.9 percent; coverage in the deep water zone was 1.8 percent and 0.7 percent in the transition zone. Abundance was not estimated for Dall's porpoise because of an insufficient amount of trackline surveyed under acceptable visibility conditions and no minke whales were encountered in the survey strip. The confidence limits of these estimates were wide because of small sample sizes.

Fall survey period

During the fall survey period, 136 whales comprising five species were recorded during 1,575 nm of aerial and vessel surveys (Table 6). As with the previous two survey periods, the Dall's porpoise was most abundant, followed by gray, killer, fin, and minke whales; three unidentified baleen whales were also recorded. All of these species, except for the unidentified baleen whales and the majority of the Dall's porpoises, were observed from the aircraft. Approximately 99 percent of the 1,346 nm of systematic trackline surveyed was by helicopter and the remainder by vessel; vessel surveys were also conducted along 229 nm of opportunistic trackline in the Basin.

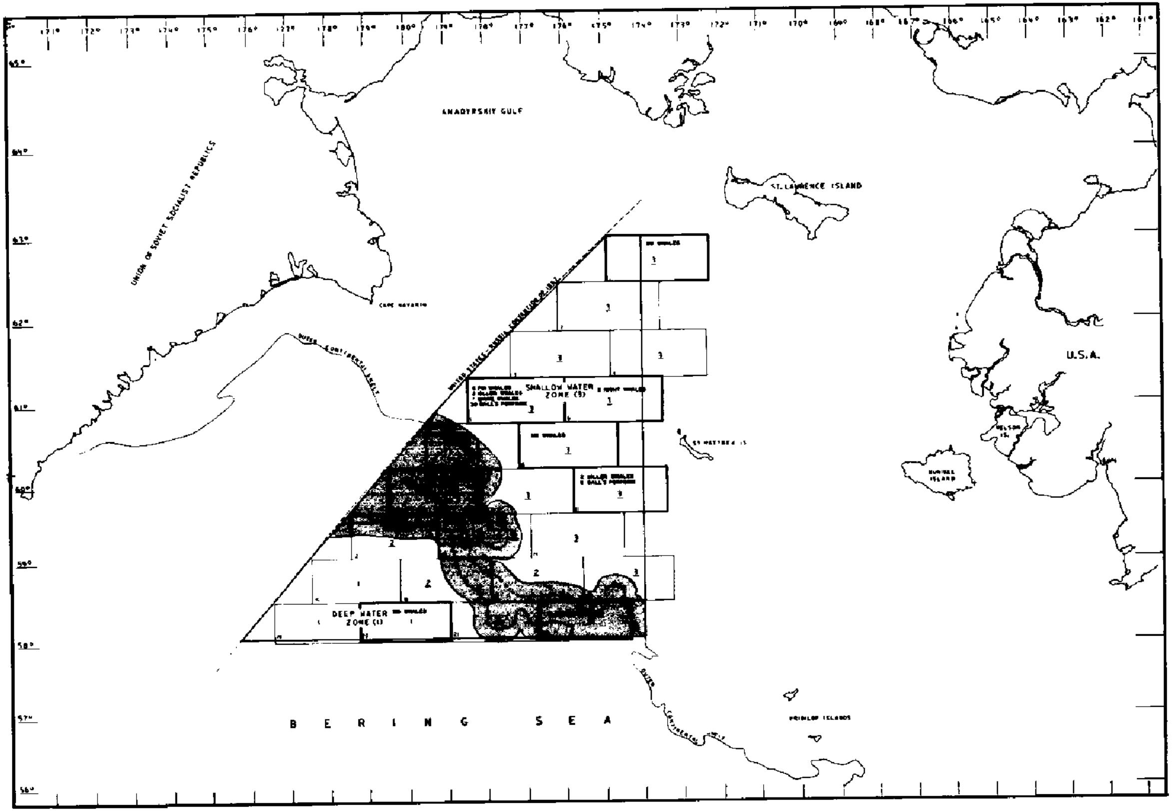
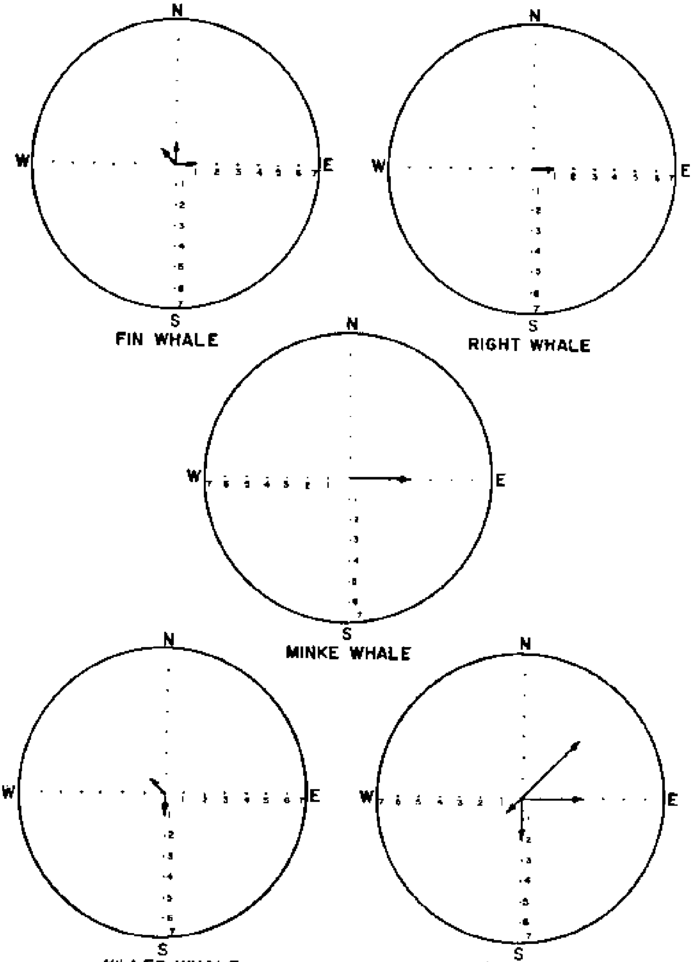


FIGURE 6 DISTRIBUTION OF WHALES IN THE EIGHT SAMPLING UNITS SURVEYED IN THE NAVARIN BASIN DURING SUMMER, 20 JULY – 19 AUGUST, 1982.



FIN WHALE

RIGHT WHALE

MINKE WHALE

KILLER WHALE

DALL'S PORPOISE

FIGURE 7 FREQUENCY OF WHALE OBSERVATIONS FOR A GIVEN DIRECTION OF TRAVEL IN THE NAVARIN BASIN DURING SUMMER, JULY-AUGUST 1982.

TABLE 5

ESTIMATED ABUNDANCE OF WHALES IN THE NAVARIN BASIN DURING SUMMER, 20 JULY - 19 AUGUST 1982

Zone	Sampling unit	Total area (nm²)	% area coverage			Fin whale		Right whale		Killer whale		Total	
			Aerial	Vessel	Total	Obs.a/ no.	Est. no.	Obs. no.	Est. no.	Obs. no.	Est. no.	Obs. no.	Est. no.
Shallow water	1	2463	9.8	0.2	10.0	-b/	-	-	-	-	-	-	-
	5	2458	10.4	0	10.4	4	38	-	-	2	19	6	57
	6	2458	5.4	2.4	7.8	-	-	2	26	-	-	2	26
	8	2452	3.1	0	3.1	-	-	-	-	-	-	-	-
	11	2461	0.5	1.1	1.6	-	-	-	-	-	-	-	-
Subtotal		12,292	5.8	0.7	6.5	4	38	2	26	2	19	8	83
All units		27,048	2.6	0.3	2.9		84		57		42		183
Transition	9	2461	4.3	0	4.3	-	-	-	-	-	-	-	-
	22	2461	0	1.6	1.6	-	-	-	-	-	-	-	-
Subtotal		4922	2.1	0.8	2.9	-	-	-	-	-	-	-	-
All units		19,651	0.5	0.2	0.7		-		-		-		-
Deep water	20	2461	5.5	0	5.5	-	-	-	-	-	-	-	-
Subtotal		2461	5.5	0	5.5	-	-	-	-	-	-	-	-
All units		7379	1.8	0	1.8		-		-		-		-
TOTAL		54,078	1.8	0.2	2.0	4	84 ± 184	2	57 ± 118	2	42 ± 118	8	183

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a/ Number of whales recorded in survey strip.
b/ Dash (-) signifies no animals.
c/ Ninety-five percent confidence interval.

TABLE 6
NUMBER OF WHALES OBSERVED DURING THE FALL AERIAL AND VESSEL SURVEYS
OF THE NAVARIN BASIN, 29 OCTOBER - 12 NOVEMBER 1982

Zone	Sampling unit	Trackline distance surveyed[a/]			Fin whale		Gray whale		Minke whale		Killer whale		Unid. whale		Dall's porpoise		Total	
		Aerial (%)	Vessel (%)	Total (nm)	No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv	No. obs	No. indiv
Shallow water	1	100	0	269 [52][b/]	5	13	18	44	1	1	1	6	2	3	-[c/]	-	27	67
	5	94	6	270 [54]	-	-	-	-	-	-	-	-	-	-	5	20	5	20
	6	100	0	267 [61]	-	-	-	-	1	1	-	-	-	-	-	-	1	1
	11	100	0	270 [61]	-	-	-	-	1	1	-	-	-	-	3	19	4	20
Subtotal		99	1	1076 [229]	5	13	18	44	3	3	1	6	2	3	8	39	37	108
Transition	22	100	0	270 [0]	-	-	-	-	-	-	2	11	-	-	2	17	4	28
Subtotal		100	0	270 [0]	-	-	-	-	-	-	2	11	-	-	2	17	4	28
Deep water			Zone not surveyed															
TOTAL		99	1	1346 [229]	5	13	18	44	3	3	3	17	2	3	10	56	41	136

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a/ Total trackline length available in each sampling unit was 270 nm.
b/ Brackets [ ] include nautical miles surveyed by the vessel during aerial surveys; incidental marine mammal sightings were recorded for determining species distribution in the Basin.
c/ Dash (-) signifies no animals were observed.

Five sampling units were surveyed in the Basin (Table 6). Four units were in the shallow water zone and one in the transition zone; no surveys were done in the deep water zone because of persistent high seas. Survey effort in these zones relative to total systematic trackline covered was 80 percent in the shallow water zone and 20 percent in the transition zone. Visibility conditions were good or better during 81 percent of the survey time, which included sea states always less than Beaufort 5, glare less than 50 percent, and average wind speeds of 13 kt. Virtually the entire 270 nm of trackline in each sampling unit were censused.

Whales were seen in both zones surveyed in the Basin during fall (Figure 8). All of the species occurred in the shallow water zone, while only Dall's porpoises and killer whales were in the transition zone. Fin and gray whales occurred in 1 unit at depths averaging 65 m, whereas killer whales were in 2 units and minke and Dall's porpoises in 3 units. Killer whales occurred in water depths ranging between 78 and 2043 m, compared with 78 to 95 m for minke whales and 97 to 930 m for Dall's porpoises. All five of these species, except Dall's porpoises, were encountered in sampling unit 1. Whales were recorded in every sampling unit surveyed.

Movement patterns of whales in the Basin during fall were indefinite because of the small sample sizes (Figure 9). Direction of movement observed for fin, gray, and killer whales was primarily southward. Grays and fins were encountered in the same geographic vicinity feeding in groups averaging 2.4 (n=18) and 2.6 (n=5) animals, respectively. Killer whales travelled in groups averaging 5.7 (n=3) animals. Dall's porpoises showed no specific directionality in their movements while minkes travelled northerly and westerly. Dall's porpoise group sizes were 5.6 (n=10) and minkes occurred in singles.

An estimated 1,548 whales at a density of 33 animals per 1,000 nm^2 were in the Basin during fall (Table 7). This estimate was derived from observations of 41 animals along 1,342 nm of systematic transect line comprising 2.9 percent coverage of the Basin. Killer whales had the highest abundance at 798 animals and minke whales the lowest abundance at 25 animals. Fin and gray whale abundances were intermediate at 500 and 225 whales, respectively. Dall's porpoise, while recorded in the Basin, were not enumerated because none were seen in the 0.5 nm survey strip. As noted for the other survey periods, confidence limits of the estimates were wide because of small sample sizes.

Discussion

Seasonal abundance and species composition varied during the ice free period. A total of 6 species of whales inhabited the Basin. Fin, minke, and killer whales, and Dall's porpoises were consistently observed each season. Right whales were encountered only during the summer season and gray whales only during the fall season. Species diversity was greatest in the summer and fall and lowest in the spring when survey effort was highest.

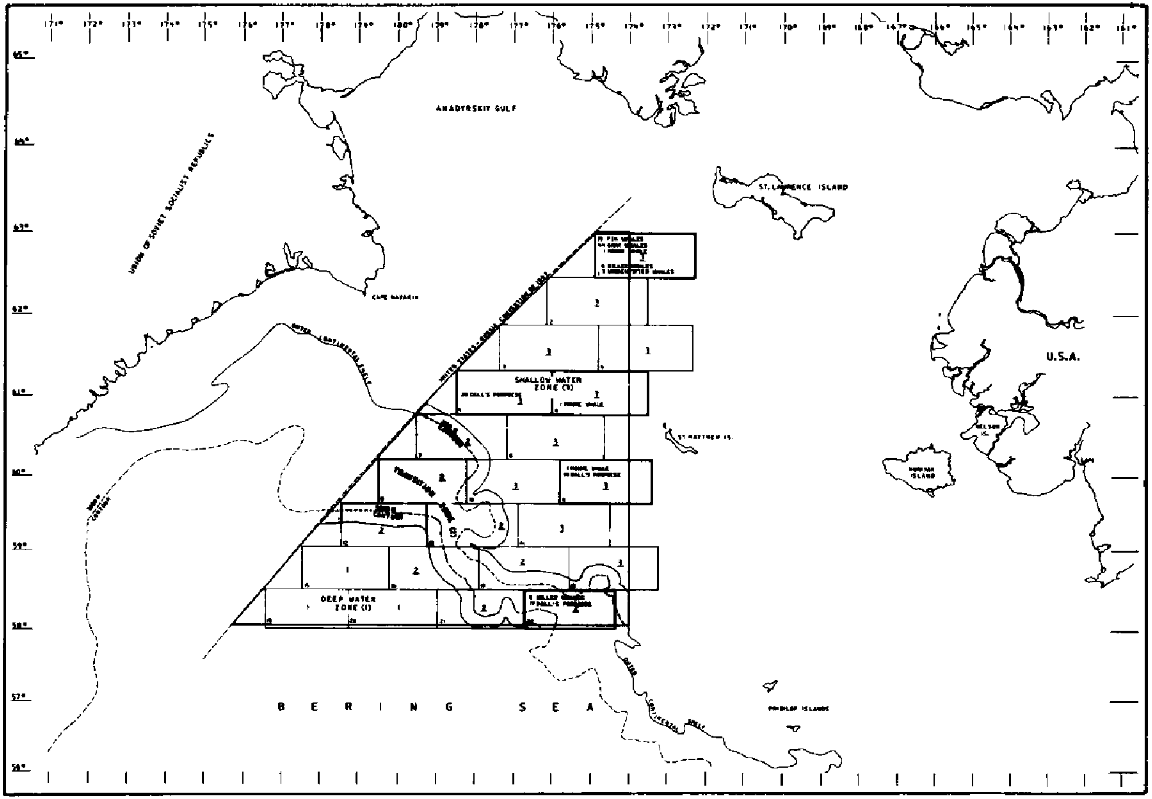

FIGURE 8 DISTRIBUTION OF WHALES IN THE FIVE SAMPLING UNITS SURVEYED IN THE NAVARIN BASIN DURING FALL, 29 OCTOBER – 12 NOVEMBER, 1982.

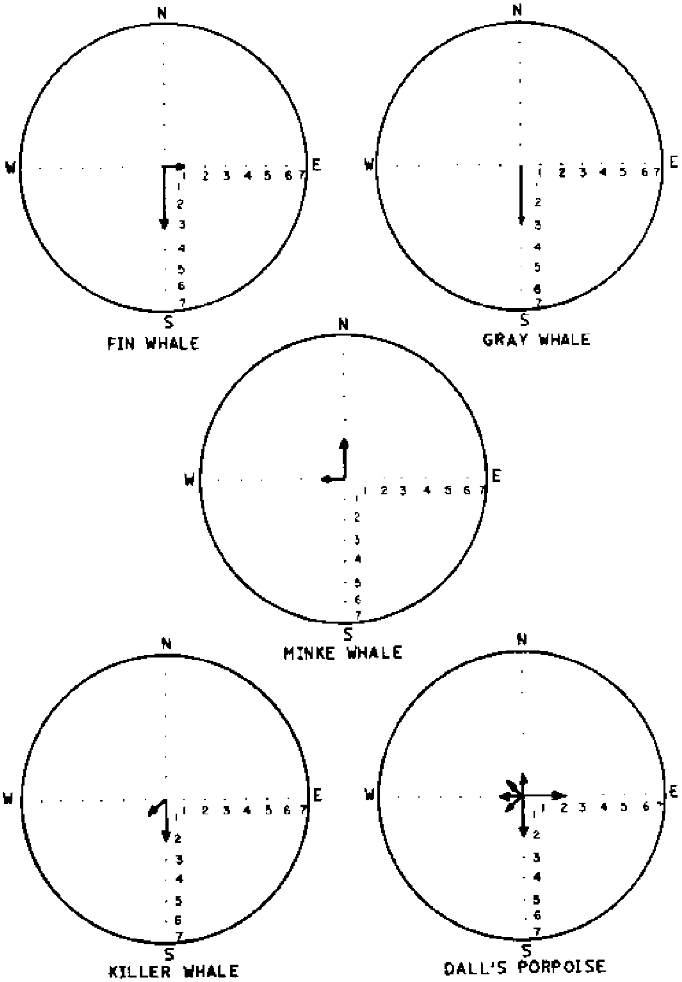

FIGURE 9 FREQUENCY OF WHALE OBSERVATIONS FOR A GIVEN DIRECTION OF TRAVEL IN THE NAVARIN BASIN DURING FALL, OCTOBER-NOVEMBER 1982.

TABLE 7
ESTIMATED ABUNDANCE OF WHALES IN THE NAVARIN BASIN DURING FALL, 29 OCTOBER - 12 NOVEMBER 1982

Zone	Sampling unit	Total area (nm²)	% area coverage Aerial	% area coverage Vessel	% area coverage Total	Fin whale Obs.[a] no.	Fin whale Est. no.	Gray whale Obs. no.	Gray whale Est. no.	Minke whale Obs. no.	Minke whale Est. no.	Killer whale Obs. no.	Killer whale Est. no.	Total Obs. no.	Total Est. no.
Shallow	1	2463	11.0	0	11.0	9	82	20	182	-	-	-	-	29	264
water	5	2468	10.4	0.5	10.9	-[b]	-	-	-	-	-	-	-	-	-
	6	2468	10.9	0	10.9	-	-	-	-	1	9	-	-	1	9
	11	2461	11.0	0	11.0	-	-	-	-	-	-	-	-	-	-
Subtotal		9860	10.8	0.1	10.9	9	82	20	182	1	9	-	-	30	273
All units		27,048	3.9	T[c]	4.0		225		500		25		-		750
Transition	22	2461	11.0	0	11.0	-	-	-	-	-	-	11	100	11	100
Subtotal		2461	11.0	0	11.0	-	-	-	-	-	-	11	100	11	100
All units		19,651	1.4	0	1.4		-		-		-		798		798
Deep water		Not surveyed													
TOTAL		46,699	2.9	T	2.9	9	225 ± 520[d]	20	500 ± 966	1	25 ± 48	11	798 ± 1558	41	1,548

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[a] Number of whales recorded in survey strip.
[b] Dash (-) signifies no animals.
[c] T signifies percentage less than 0.05.
[d] Ninety-five percent confidence intervals.

The density of whales in the Basin was highest during fall and lowest during summer. An observed density of 33 whales per 1000 nm^2 was estimated for fall compared to 16 whales per 1000 nm^2 in spring and 3 whales per 1000 nm^2 in summer. The species having the highest seasonal density was the killer whale, followed by the gray, fin, minke, and right whales. Densities for species encountered each season were greatest in the spring and fall and lowest in the summer. Although Dall's porpoises were the most commonly recorded species each season, seasonal densities were not calculated because most observations were outside the census strip or recorded during unacceptable viewing conditions. A pooled estimate of Dall's porpoise density for all seasons was 49 animals per 1000 nm^2 or 2,623 animals (+ 2,499) based on observations of 17 animals over 350 nm of vessel trackline surveyed during acceptable viewing conditions.

Whales were most abundant and diverse in the shallow water zone of the outer continental shelf each season (Figure 10). Fin, gray, and right whales were exclusively observed in this zone. Although right and gray whales were encountered in only 1 sampling unit, fin whales were observed in 3 different units, suggesting they were more widespread in their distribution than the other endangered species. Also observed in this zone were killer whales and minke whales. In addition, killer whales occurred in the transition zone, and minke whales in the deep water zone. Dall's porpoises were the only species found in all three zones. Moreover, Dall's porpoises occupied more sampling units during each season than any other species. The distribution of all whales in these three zones was significantly different from that expected from the survey effort ($X^2 = 27.6$, 2df; $p < 0.001$).

Seasonal movement patterns of whales in the Basin suggested directional trends for some species although the sample sizes were small. Trends were possible to examine only for fin, minke, and killer whales and Dall's porpoises; right and gray whales were observed in the Basin only one season. Fin whale movement patterns were in a northwesterly direction in the spring, varied in the summer, and southeasterly in the fall. Movements of minke whales were northwesterly in the spring and fall, and easterly in the summer. Killer whales were encountered moving primarily in a northerly direction in the spring, southerly in fall, but in no specific direction in summer. Dall's porpoises displayed no consistent movement orientation during any season. While the movement patterns of the Dall's porpoise and minke whale may have been influenced by the vessel, since they were primarily recorded during vessel surveys, the other species showed no obvious negative reaction to the aircraft.

Most whales recorded in the Basin travelled in relatively large aggregations with animals clustered in small groups. This was particularly the case for fin and gray whales. Fin whales were clustered in large concentrations each season. The average group size of 2.4 animals, however, did not differ significantly ($F=0.23$; 2,17df; $p > 0.10$)among seasons. The same situation was observed for

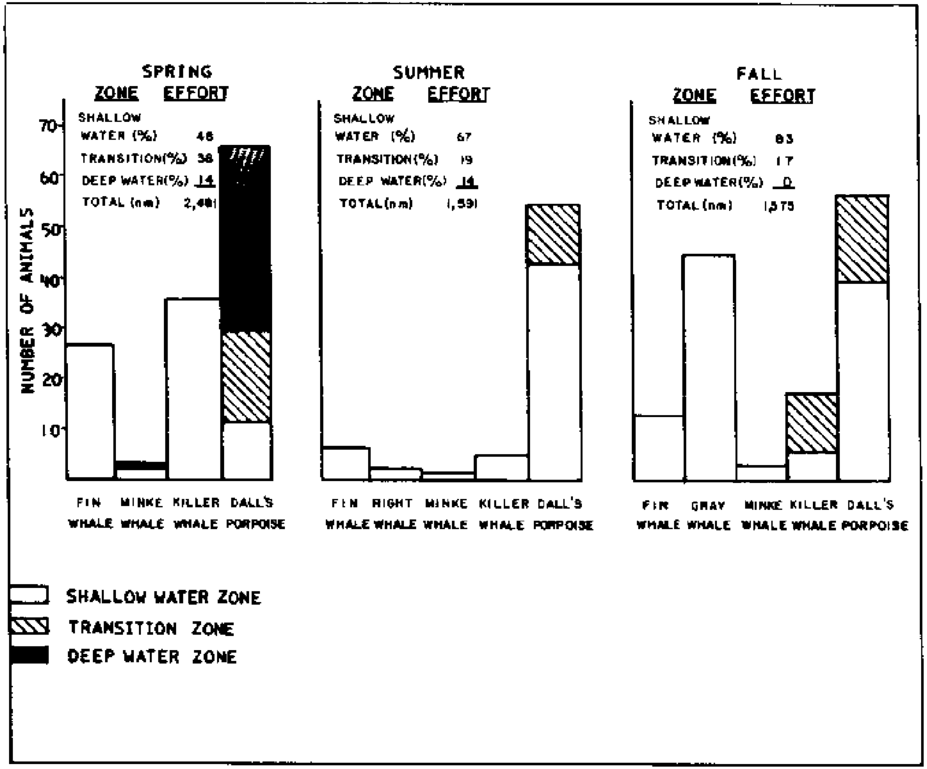

FIGURE 10 DISTRIBUTION OF WHALES AND PORPOISES IN THE THREE SURVEY ZONES OF THE NAVARIN BASIN DURING THE ICE FREE PERIOD.

gray and to a lesser degree killer whales which had average group sizes of 2.4 and 3.8 ($F=0.96$; 2,12df; $p>0.50$) animals, respectively. Minke whales were very solitary, travelling as single animals each season. Less solitary, but widespread were Dall's porpoises, which were in group sizes averaging 3.9 ($F=2.02$; 2,31df; $p>0.20$; vessel surveys only) animals. There was only one observation of two right whales.

The combined results of the three seasonal surveys suggest that the Navarin Basin is a feeding ground for species migrating through or summering in the Basin. Fin, right, minke, and killer whales and Dall's porpoises probably were resident in the Basin during the ice free period, while gray whales and some fin whales migrated through the Basin to or from the primary feeding grounds. Fin whale occurrence and movements observed in the Basin agree with reported findings that these whales migrate through the Basin in the spring to feed in the Gulf of Anadyr and in the fall to their wintering grounds in the Pacific Ocean, while some summer west of St. Matthew Island and off Cape Navarin (Berzin and Rovnin 1966, Nasu 1966, Nishiwaki 1974, Votorgov and Ivashin 1980, and Wada 1981). We observed fin whales moving toward the Gulf of Anadyr in the spring and away from the Basin in the fall in large feeding aggregations. Conversely, fin whales observed during summer showed no directionality in their movements to suggest movement out of the Basin. Movements of minke and killer whales were less clear but their irregular seasonal directionality and presence each season coincided with reports that these species probably reside in the Basin throughout the ice free period (Lowry et al. 1982). Also resident were Dall's porpoises as indicated by a consistent lack of directionality in their movements and absence of large aggregations each season as documented in the literature by other researchers (Lowery et al. 1982, Bouchet 1982).

The single season observations of right and gray whales suggested the former species may summer in areas of the Basin historically used (Scammon 1874, Townsend 1935, Wada 1980, Berzin and Doroshenko 1982), while gray whales seen in the fall moving through the Basin in large feeding aggregations coincided with the timing of their fall migration from more northern summering grounds (Kuz'min and Berzin 1975, Rugh In press). Gray whales may have also summered in the Basin but were not encountered during the surveys because of the small proportion of the total area covered.

The distribution of whales in the Basin coincided with their reported feeding habits. Fin, right, and gray whales feed largely in shallow waters (Nemoto 1970). The former two species feed primarily on pelagic crustaceans including euphausiids and copepods (Tomilin 1957, Nemoto 1959, Omura 1958, Klumov 1963, Omura et al. 1969, Lowry et al. 1982), while gray whales feed on benthic invertebrates including gammarid amphipods (Pike 1962, Rice and Wolman 1971, Marquette and Braham 1982). Correspondingly, we encountered these species only on the shelf where waters are relatively shallow compared to the rest of the Basin and which support the prey population these species feed upon. The more generalized feeding habits of minke and killer whales and Dall's porpoise coincided with their wider distribution in the Basin.

These species feed on squid, fishes, and euphausiids (only minke) which are distributed over the continental shelf, slope, and rise waters where these species occurred in the Basin (Nemoto 1959, Klumov 1963, Mizue et al. 1966, Nemoto 1970, Crawford 1980, Kajimura et al. 1980). Dall's porpoises were most widespread in the Basin and concurrently feed on the widest range of prey items. Some of the endangered species, particularly fin whales, may have been more widespread in the Basin than observed since they feed to some degree on fishes inhabiting the deeper waters.

Estimated densities of whales observed in the Navarin Basin were compared to estimates derived from line transect sampling procedure (Table 8) and to those reported in the literature by other researchers (Table 9). Line transect estimates were generally higher than strip transect estimates but the differences were not significant. Abundance estimated by the two procedures fell within the calculated confidence intervals. Line transect estimates were calculated from the Fourier Series estimator of the probability density function (f(o)). Fin, gray, and minke whale perpendicular distances were pooled to calculate f(o) to increase sample sizes, which was then applied to the density calculations for each species by season. Line transect estimates were not calculated for the other species, since sample sizes were too small and sightability of each species was too different to pool. Calculation procedures followed Burnham et al. (1980) which are described in Brueggeman (1983).

Strip transect estimates were also compared with estimates reported by other researchers (Table 9). Caution must be taken in interpreting density comparisons for the following reasons: (1) all estimates are extremely variable with low degree of reliability, (2) estimation procedures vary, and (3) density estimates will differ greatly for stocks in feeding areas versus those obtained for the whole range of the species. For instance, North Atlantic Ocean estimates were derived from line transect procedures, while those for the North Pacific Ocean and Gulf of Alaska were calculated from strip transect procedures; a combination of both procedures was used in estimates for the Bering Sea. The comparisons do, however, provide a relative index of abundance useful in describing the significance of the Navarin Basin to whales. Estimated densities of fin and minke whales in the Navarin Basin were below those reported in the North Atlantic Ocean (Scott et al. 1979) but were above that for right whales. Gulf of Alaska (Rice and Wolman 1981) estimates for fin whale densities were similar to the Basin, while those in the North Pacific Ocean (Nishiwaki 1974) were much lower; estimates for the right and minke whales were not available for these two areas. Both estimated densities for gray whales and Dall's porpoises were below those reported for the Bering Sea (Bouchet 1982, Rugh In press). No comparable estimates were available for killer whales. Thus, estimated densities of whales in the Navarin Basin during the ice free period were lower than elsewhere except for fin and right whales, which were generally similar or higher. None of these estimates account for submerged animals.

TABLE 8
ESTIMATED ABUNDANCE OF ENDANGERED WHALES IN THE NAVARIN BASIN FROM LINE-TRANSECT SAMPLING PROCEDURE

Species	Season	Study area (nm^2) (A)	Transect length (nm) (L)	Number of groups (n_i)	Density (groups/ nm^2) (Dg_i)	Mean[a] group size (g)	Standard deviation of group size	Density (individuals/ nm^2) (D_{ii})	Abundance (N)	Variance (Var(N))	95 percent confidence interval for line transect	95 percent confidence interval for strip transect
Fin whale	Spring	41,770	1,568	10	0.0049	2.37	1.16	0.0116	481	237,175	481±955	259±826
Fin whale	Summer	54,078	954	3	0.0012	2.37	1.16	0.0028	154	12,695	154±221	84±267
Fin whale	Fall	46,699	1,330	3	0.0017	2.37	1.16	0.0040	186	34,439	186±364	225±597
Gray whale	Fall	46,699	1,330	10	0.0056	2.44	1.98	0.0134	627	393,522	627±1299	500±1326
Minke Whale	Fall	46,699	1,330	2	0.0011	1	1	0.0011	51	1,279	51±70	25±66

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[a] Mean group size of fin whales did not differ significantly ($P > 0.10$) among seasons so the data were pooled to obtain a single group size figure.

TABLE 9

ESTIMATED DENSITIES OF WHALES AND PORPOISES REPORTED BY VARIOUS RESEARCHERS

Location	Source	Estimated density of whales and porpoises (no. per 100 nm^2)					
		Fin	Gray	Right	Minke	Killer	Dall's
Bering Sea	Present study	0.62	1.07	0.11	0.05	1.71	4.86
N. Atlantic Ocean a/	Scott et al. 1979	1.36	b/	0.04	0.20	-	-
N. Pacific Ocean	Nishiwaki 1974	0.04	-	-	-	-	-
Gulf of Alaska	Rice and Wolman 1981	0.67	-	-	-	-	-
Bering Sea	Bouchet 1982	-	-	-	-	-	21.62
Bering Sea	Rugh (In press) c/	-	2.53	-	-	-	-

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a/ Study area was outer continental shelf of western Atlantic Ocean.

b/ No estimates available.

c/ Estimate derived by dividing estimated population size of 17,000 animals by area of Bering Sea (671,830 nm^2). The exact proportion of the population summering on the Bering Sea is not known.

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Effects of Wind, Tide, Time and Date on Aerial Counts of Gray Whales

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Introduction

California gray whales, Eschrichtius robustus (Lilljeborg), feed in the Bering and Chukchi seas in summer. In the fall many of these whales migrate to the lagoons and bays of Baja California, Mexico where they calve and mate (Figure 1). The most important of these wintering areas are Guerrero Negro, Scammon's and San Ignacio lagoons and Magdalena Bay. Concentration of whales in and near these shallow lagoons has permitted convenient enumeration by airplane since 1952 (Gilmore, 1960; Hubbs and Hubbs, 1967; Gard, 1974). During earlier aerial censuses, counts of whales for a given lagoon were found to be higher in calm weather than they were in windy weather (Hubbs and Hubbs, 1967). On the windy afternoon of 18 February 1962, Carl and Laura Hubbs (personal communication) counted only 387 whales in and near the mouth of Scammon's Lagoon whereas they counted 681 whales in the same area on the

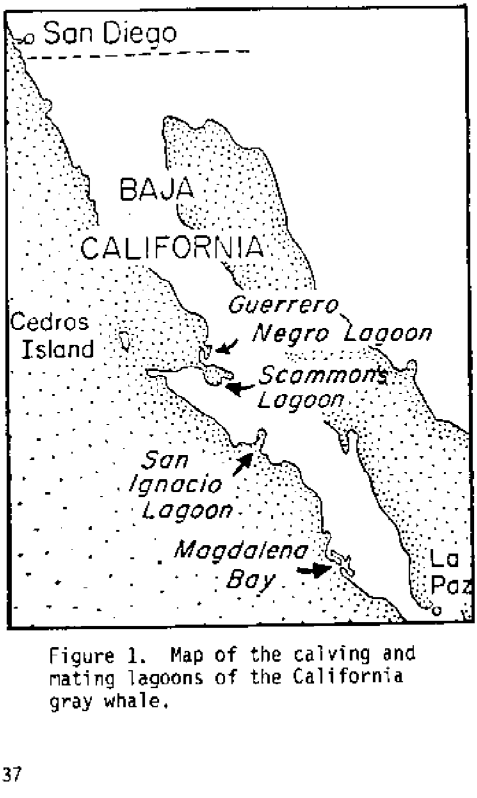

Figure 1. Map of the calving and mating lagoons of the California gray whale.

following calm morning. This observation stimulated initiation of the present investigation. Accordingly, our objectives were (1) to quantify the apparent effect of wind and the possible effects of tide, time of day and date on aerial counts of whales in Guerrero Negro Lagoon, and (2) to relate these findings to aerial censuses conducted in the Bering Sea and elsewhere.

Methods

We conducted eleven aerial censuses of whales in Guerrero Negro Lagoon between 14 and 22 February 1974. Censuses were carried out at moderately-sized Guerrero Negro Lagoon rather than at one of the larger lagoons because a relatively short period of time (about 45 minutes) was required for each census. Adults and calves were counted both inside the lagoon and in a small area just outside the mouth of the lagoon. We flew the same pattern over the lagoon during each census with an observer counting from each side of the airplane. Censuses were conducted from a Cessna 172 at an elevation of about 150 m and at a speed of 160 km per hour. Wind velocity was obtained with a hand-held anemometer.

We evaluated results using a multiple regression analysis, that is, we regressed number of whales on wind velocity, tidal height, time of day and day of the month in various combinations.

Results

Of the variables tested, wind was clearly most important in determining whale counts ($R^2=0.73$) and the regression was highly significant ($P<.001$)(Table 1 and Figure 2).

Table 1. Results of multiple regression analyses with different sets of independent variables to determine how factors affect gray whale counts at Guerrero Negro Lagoon, 1974.

Analysis	F	P	R^2
Whale count on wind	24.9	<.001	0.73
Whale count on wind and tide	16.6	<.01	0.81
Whale count on wind and time	17.2	<.01	0.81
Whale count on wind, time and date	10.3	<.01	0.82
Whale count on wind, tide, time and date	7.1	<.05	0.83
Whale count on wind and tide with one outlier removed	36.2	<.001	0.91

Inclusion of tide or time in the regresion increased R^2 somewhat to 0.81 (Table 1). As tide and time were highly correlated ($r=-0.84$), these variables were interchangeable. Addition of date to the regression gave negligible improvement ($R^2=0.82$) and inclusion of all variables in the regression gave little further improvement ($R^2=0.83$) while the significance of the overall regression decreased ($P<.05$). Elimination of one outlying observation gave marked improvement ($R^2=0.91$) and removed bias from the initial pattern of residuals; in the initial plot of residuals, seven of eleven observations were located below zero, but after the outlier was removed, equal numbers of observations were located above and below zero and the scatter was random. During the censuses, wind velocities ranged from 0 to 48 km/hr and tidal heights ranged from -0.2 to +5.9 ft.

Whale population estimates determined from the regression equations for whale count on wind and tide when all observations were included and when one outlier was deleted appear below:

$$Y = 73.5 - 1.69\ X_1 + 2.23\ X_2$$

$$= 73.5 - 1.69\ (0) + 2.23\ (5.9) = \underline{86.7}\ \text{(all observations)}$$

$$Y = 67.8 - 1.54\ X_1 + 3.06\ X_2$$

$$= 67.8 - 1.54\ (0) + 3.06\ (5.9) = \underline{85.8}\ \text{(outlier deleted)}$$

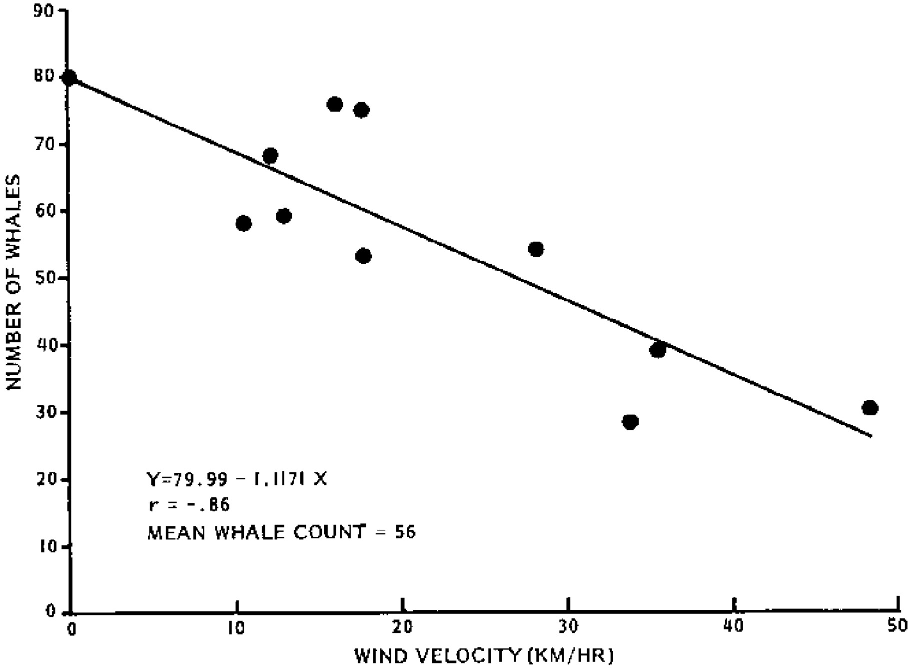

Figure 2. Regression of number of whales on wind velocity at Guerrero Negro Lagoon, 1974.

Discussion and Conclusions

Application of results to areas with strong tides

We selected the independent variables wind and tide for use in explaining variation in whale counts at Guerrero Negro Lagoon, an area with considerable fluctuation in these two environmental factors. Wind was selected because, with an R^2 of 0.73, it was the most important independent variable. Tide was chosen because White (1975) found that it influenced movement of whales into and out of nearby Scammon's Lagoon and it was equal to time of day as a predictor of whale count. High correlation between time and tide occurred because the censuses lasted only 9 days. Had the censuses extended over an entire tidal cycle, time and tide would have acted independently on whale count. Date was eliminated because its inclusion in the regression accounted for only an additional 1% of the variation in whale count. If the censuses had extended into March when many whales would have started on their northward migration, date would have been important.

Population estimates of whales based on regressions including wind and tide were 87 when all observations were included and 86 when the outlying observation was deleted. There may have been some turnover in the population during the census period as individual whales migrated into or out of the lagoon. However, the total number present during the period was nearly static because inclusion of date in the regression gave negligible improvement in R^2. Further, the estimated population was for whales on or near the surface where they could be observed from an airplane. Gard (1978) reported that at any given time about two-thirds of the whales present were beneath the murky water where they could not be seen.

Application of results to areas with weak tides

In the Bering Sea and other open ocean areas where tidal currents are relatively weak, wind velocity will probably be the most important environmental factor affecting aerial whale counts providing atmospheric visibility is good. A relationship better than the one between whale count and wind velocity for Guerrero Negro Lagoon (Figure 2) may exist because tidal effects would be nil. In such situations, variability in whale counts due to wind might be eliminated by use of a regression equation based on whale counts in a clearly defined area made at preselected wind velocities. Assuming a linear regression of whale count on wind velocity, an optimal allocation of observations would call for equal numbers of data points at the lowest and highest wind velocities ordinarily experienced in order to define the regression line accurately. Although accuracy in defining a regression line improves with increased observations, the actual number of censuses to be run in any particular situation would depend on the amount of money available for aircraft and observer expenses and the degree of accuracy required. Four counts may be sufficient to give useable data. In the present study, the estimate of number of whales (Y intercept) corrected for wind velocity using counts during the two extreme wind velocities and any two of the remaining wind conditions was in error by a maximum of 10% when compared to the estimate based on counts at all eleven wind velocities.

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Changes in Humpback (*Megaptera novaeangliae*) Abundance Off Northeast Newfoundland Related to the Status of Capelin (*Mallotus villosus*) Stocks (1973-1983)

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Summary

There have been major changes in whale abundance and whale damage to inshore fishing gear along the NE Coast of Newfoundland during the past ten years. In this paper we trace the changes and relate them to the status of the capelin stocks, both the Nfld./Lab. (2J3K) stock which spawns on the NE Coast of Newfoundland, and the Grand Banks stock (3LNO) which spawns on the SE Shoal of the Grand Banks, and to damage to fishing gear.

Between 1973-1983 shipboard surveys of whales along the NE Coast of Newfoundland from St. John's to St. Anthony were conducted each year. Numbers of humpbacks were low between 1973-1976. They rose sharply in 1977 and 1978, peaking in 1979 at about six times the earlier values. Between 1981-1983, numbers had returned to very low levels.

Capelin biomass estimates from the SCAM Model also varied considerably during this same period with biomass levels reaching their lowest point in 1979. Correlations with Nfld./Lab. immature capelin biomass were highly significant. When offshore biomass was low, humpback counts inshore were high. A step-wise regression indicated that about 80% of variance in inshore humpback counts was accounted for by biomass variation in the Nfld./Lab. immature stock. In total, 93% of the variance in inshore humpback counts is related to biomass variation in capelin.

Matches between sets of humpback fluke photographs taken inshore between 1977-1980 and offshore in 1982 are consistent with the regression analysis. Significantly more matches were obtained between inshore whales in 1977 to offshore areas in Labrador where the Nfld./Lab. immature capelin are found. When immature capelin biomass increased, humpbacks moved offshore to Labrador.

Fishing gear damage, gear entrapped whales and mortality correlate significantly with inshore abundance of humpbacks.

Working Group Summaries

Marine Mammals and Groundfish

Loh-Lee Low, Moderator
Robert J. Hofman and Susan Hills, Rapporteurs

Introduction

The objectives of the group were to:

1. identify the marine mammal species and populations that could affect or be affected by groundfish fisheries in the eastern Bering Sea;

2. indicate the nature and probable significance of the interactions;

3. determine whether existing data, models, and research/monitoring programs are sufficient to predict, detect, and mitigate the possible adverse effects of interactions on marine mammals, fish stocks, and/or fisheries;

4. describe critical data gaps, if any;

5. indicate how critical data gaps might best be filled; and

6. rank identified research needs in priority order.

Objective 1

The group identified 11 species of marine mammals and eight fisheries or fish groups that could be affected by interactions in the eastern Bering Sea. The marine mammals are: the northern fur seal (*Callorhinus ursinus*), the Steller sea lion (*Eumetopias jubatus*), the North Pacific walrus (*Odobenus rosmarus*), the harbor seal (*Phoca vitulina*), the spotted seal (*Phoca largha*), the ribbon seal (*Phoca fasciata*), the bearded seal (*Erignathus barbatus*), the beluga whale

(*Delphinapterus leucas*), the Dall porpoise (*Phocoenoides dalli*), the harbor porpoise (*Phocoena phocoena*), and the gray whale (*Eschrichtius robustus*). The fisheries are those for pollock (*Theragra chalcogrammus*), Pacific cod (*Gadus macrocephalus*), yellowfin sole (*Limanda aspera*), turbots (*Pleuronectidae*), other flatfish, Pacific halibut (*Hippoglossus stenolepis*), rockfish (*Sebastodes* spp.), and sablefish (*Anoplopoma fimbria*).

Objective 2

The group recognized four general categories of effects or interactions:

a) Direct effects on marine mammals from shooting, harassment, incidental entanglement during fishing operations, and/or entanglement in lost or discarded fishing gear;

b) Direct effects on fisheries when marine mammals take or damage caught fish, and/or damage fishing gear;

c) Indirect effects on marine mammals caused by fisheries reducing the quantity or quality of prey species available to marine mammals; and

d) Indicate effects on fisheries caused when marine mammals reduce the quantity or quality of fish available to fisheries.

Each fishery and marine mammal was evaluated subjectively, relative to each of these categories. The results of these evaluations are summarized in Table 1.

The group noted that, with the exception of entanglement in lost or discarded fishing gear, direct interactions (such as incidental take of Dall porpoise in the Japanese salmon gillnet fishery) were reasonably well documented and/or the subject of ongoing or planned assessment. It was agreed, therefore, to focus discussion on categories c) and d), indirect ecological interactions. Because time was limited, the group also agreed to select and focus discussion on one or two representative fisheries and species of marine mammals most likely to affect or to be affected by the selected fisheries. The fisheries selected for consideration were the pollock/cod fishery and the yellowfin sole/flatfish fishery. The marine mammals determined most likely to interact with these fisheries were the northern fur seal and the Steller sea lion relative to the pollock/cod fishery, and the Steller sea lion and harbor seal relative to the yellowfin sole/flatfish fishery.

Objective 3

Information needs were discussed and it was determined that it would be necessary to know the following in order to assess the nature, significance, and types of measures that might be required to mitigate the adverse effects of ecological interactions on marine mammals, fish stocks, or fisheries:

Table 1.--Type and degree of interactions between groundfish fisheries and marine mammals.

Marine Mammals	Pollock-cod A B C D	Yellowfin sole A B C D	Turbots (Deep water) A B C D	Other flatfish (Shallow water) A B C D	Pacific halibut (Long-line) A B C D	Rock-fish A B C D	Sable-fish (Long-line) A B C D
FISHERY, INTERACTION TYPE, AND DEGREE OF INTERACTION							
Pinnipeds							
Northern fur seal	2 0 2 3	2 0 0 0	2 0 1 0	2 0 0 0	0 0 0 0	2 0 0 0	0 0 0 0
Northern sea lion	3 3 3 3	2 2 1 2	2 1 0 0	2 1 0 0	1 1 0 1	0 0 0 0	1 1 0 1
Walrus	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
Harbor seal	1 1 1 2	1 1 1 2	1 0 0 0	1 0 0 0	1 1 0 0	1 1 1 1	1 1 0 0
Spotted seal	0 0 1 1	0 0 1 1	0 0 0 0	0 0 0 0	0 0 0 0	0 0 1 1	0 0 0 0
Ribbon seal	0 0 1 1	0 0 0 1	0 0 0 0	0 0 0 0	0 0 0 0	0 0 1 1	0 0 0 0
Bearded seal	0 0 0 1	0 0 0 1	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
Cetaceans							
Beluga whale	1 1 0 0	1 1 0 0	1 1 0 0	1 1 0 0	0 0 0 0	0 0 0 0	0 0 0 0
Dall's porpoise	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0
Harbor porpoise	0 0 0 0	1 1 0 0	0 0 0 0	1 1 0 0	0 0 0 0	0 0 0 0	0 0 0 0
Gray whale	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0

Footnote:

Interaction Type:

A--Direct affects on marine mammals due to shooting, harrassment, incidental entanglement during fishing operations or entanglement in lost or discarded gear.

B--Direct effects on fisheries due to marine mammals taking or damaging caught fish and/or damaging gear.

C--Indirect effects on marine mammals due to fisheries reducing the quantity or quality of prey species available to marine mammals.

D--Indirect effects on fisheries due to marine mammals reducing the quantity or quality of fish available to fisheries.

Degree of Interaction:

0 = no or insignificant
1 = minor interaction
2 = average interaction
3 = high interaction.

1. The demography and status (present distribution, abundance and productivity compared with historic distribution, abundance and productivity) of the affected or potentially affected marine mammal species or populations.

2. The food or energetic requirements, diet and prey preference (if any) of the affected marine mammal species or populations, by age, sex, area, and season.

3. The existence, location, and characteristics of definable feeding areas or feeding grounds, by age, sex, and season.

4. The probable numerical and functional responses of the marine mammal species or populations to changes in the species composition, distribution, size, density, or behavior of preferred or potential prey species.

5. The status of the affected or potentially affected fish stock or stocks.

6. The species composition, quantity, and age or size composition of the fish catch, including by-catch, by season and year, in and near marine mammal feeding areas.

7. The probable effect of the fishery and/or marine mammal predation on the species composition, distribution, size, density, or behavior (availability) of preferred or potential prey or target fish species.

Objective 4

The selected fisheries and marine mammal species were examined relative to these information needs to determine: the nature and adequacy of existing information; critical data gaps; how critical data gaps might best be filled; data gaps that will be difficult or impossible to fill; and steps that might be taken to avoid or minimize the consequences of management errors if critical data needs cannot be met promptly. The results of these examinations are summarized below.

Interactions between the northern fur seal and the pollock/cod fishery

The working group noted that: the demography, status and diet of the northern fur seal; and the history, size, and operational characteristics (number and size of vessels, gear type, etc.) of the pollock/cod fishery are reasonably well known. The Pribilof Island fur seal population has been declining since the mid-1950s; the harvest of females in the late '50s and early '60s accounts for much of the decline; and, while not proven, entanglement in lost or discarded fishing gear seems to be the most probable cause of the continued population decline. The group also noted that: pollock are cannibalistic; fur seals prey primarily upon the one- and two-year-old age-classes of pollock; and the fishery preferentially takes the larger size- and age-classes of pollock.

The group assumed that ecological interactions likely would be greatest in the vicinity of the Pribilof Islands during the fur seal pupping/ breeding season and concluded that:

1. Possible effects of the fishing on fur seals could be masked by the ongoing fur seal decline.

2. There currently is no evidence that either the fur seal population or the fishery have been adversely affected by presumed competition for the same fish species.

3. Since the fur seal eats smaller individuals than are taken by the fishery, the food requirements of the fur seal population generally will be met before pollock grow to the size where they will be subjected to fishing mortality.

4. Since the fishery generally takes large fish that may prey upon their own young, the fishery could result in more fish of the size eaten by fur seals, provided an adequate breeding stock is maintained.

5. The most critical gaps in existing knowledge are:

    a. The types, quantity and size distribution of lost and discarded fishing gear present in the eastern Bering Sea and other parts of the northern fur seal's range;

    b. The location and physical/biological characteristics of areas near the Pribilof Islands where post partrient female fur seals forage during the pupping/breeding season and their locality to those areas;

    c. The distribution and density of various species and age-classes of potential fur seal prey species in and near summer feeding areas are identified;

    d. The probable effects of different fishing intensities (levels) on the species composition, size and density of fish in and near the identified feeding areas;

    e. The probable functional and numerical responses of fur seals to changes in the species composition, density, size distribution and/or behavior of preferred or potential prey in and near the summer feeding areas.

The group noted that towing floating grappling hooks or fishing gear behind transiting fishing and research vessels could provide information on the types, quantity (diversity), and size distribution of lost and discarded fishing gear. Fur seal feeding areas can be located and characterized using a number of standard techniques, including mark/recapture studies, radio-tagging and tracking, and general oceanographic/fishery surveys.

The group noted that it would be difficult, if not impossible, to obtain the necessary biological/ecological information to prediction, apriori, of the probable numerical and functional relationships between the northern fur seal population, the pollock/cod fishery, and the affected fish stocks. In such cases, baseline/monitoring programs should be conducted to detect and monitor possible harvest-caused changes in key population or system parameters. In this context, it was agreed that:

1. A representative sample of fur seals should be collected in conjunction with fishery surveys in and near identified fur seal feeding areas to determine the relationship between potential prey abundance and stomach contents.

2. Pelagic collections of fur seals should be conducted periodically in selected areas to detect and monitor possible dietary changes.

3. Pup numbers, on-land pup mortality, individual growth rates, reproductive and mortality rates, parasite loads, blubber thickness and other population and individual characteristics should be monitored to detect changes that might be caused by changes in food availability.

4. Fishery and oceanographic surveys should be conducted periodically in and near identified fur seal feeding areas to detect changes and to monitor trends in the distribution, density, size, behavior, and so forth of preferred or potential fur seal prey species.

Interactions between the Steller sea lion and the pollock/cod fishery

The group noted that: like fur seals, Steller sea lions apparently are caught and killed in lost and discarded fishing gear. Unlike the northern fur seal, the Steller sea lion is present in the eastern Bering Sea year-round. The distribution, origins, trends and diet of Steller sea lions in the Bering Sea are not well documented. What little is known about diet is from outside the Bering Sea and indicates that all sizes of pollock, 5 cm to 60 cm, are eaten. Some dietary information is from animals caught incidentally in the cod end of trawl nets and may be biased since sea lions are known to be attracted to, and feed in, the vicinity of fishing and processing vessels.

The group determined that too little is known about entanglement in lost and discarded fishing gear and about the distribution, feeding habits, and food requirements of Steller sea lions in the eastern Bering Sea to do more than speculate about the possible direct and indirect effects of the pollock/cod fishery on the eastern Bering Sea population(s) of Steller sea lions. The group concluded that the most critical data needs are to:

1. Determine the number of sea lions, by age and sex, being caught and killed in lost and discarded fishing gear.

2. Improve knowledge of the distribution, density, and diet of sea lions, by area, season, age and sex.

3. Locate and characterize definable feeding areas, if any, in the eastern Bering Sea.

4. Improve baseline information and continue to monitor selected (representative) sea lion rookeries to detect possible changes in rookery size, pup numbers and weights, parasite loads; and other population or individual characteristics that may be sensitive to, and detectably change in

response to, harvest-caused changes in the distribution, density or behavior of preferred or potential prey species.

Task 1 would require surveys of pupping/breeding rookeries to determine the numbers, ages, and sexes of sea lions entangled in different types and sizes of fishing gear, coupled with at-sea surveys to determine the types, quantities and size distribution of net fragments and packing material present in the species range.

Task 2 would require shipboard population surveys and pelagic collections, in representative areas, in spring, summer, fall, and winter.

Task 3 would require mark/recapture studies and/or radio-tagging and tracking, and oceanographic/fishery surveys to characterize the physical and biological environment in and near any at-sea concentration (feeding) areas identified.

Task 4 would require periodic aerial surveys and on-site pup counts and other studies of selected rookeries. If definable feeding areas are identified, periodic oceanographic and fishery surveys would be necessary to detect and monitor changes in oceanographic/environmental conditions and/or changes and trends in the distribution, density, size, behavior, etc., of preferred or potential sea lion prey species.

Interactions between the Steller sea lion and the yellowfin sole fishery

The yellowfin sole fishery in the eastern Bering Sea is relatively small and stable. Approximately 8 percent of the estimated standing stock is harvested annually and the working group doubted that this would have any significant adverse effect on the quantity of sole available for consumption by sea lions. The group noted that sole is not an important component in the diet of the sea lions in the Gulf of Alaska and, as noted earlier, that relatively little is known about the distribution, origins, trends, and diet of Steller sea lions in the eastern Bering Sea. The critical data gaps and research needs are essentially the same as those described above for assessing ecological interactions between Steller sea lions and the pollock/cod fishery in the eastern Bering Sea.

Interactions between the harbor seal and the yellowfin sole fishery

The harbor seal is a coastal species inhabiting nearshore areas where foreign fisheries are prohibited or restricted to joint ventures with U.S. fishermen. Thus, the group concluded that harbor seals probably have not affected and will not affect or be affected by the yellowfin sole fishery unless there is a substantial expansion of the domestic sole or other nearshore fisheries in the eastern Bering Sea. In this regard, it was noted that the nature and size of inshore domestic fisheries, the movements, feeding habits, and diet of harbor seals, the existence, location and characteristics of definable harbor seal feeding areas, and the genetic relationship between harbor seal colonies in the eastern Bering Sea and elsewhere are not well documented. It was agreed that assessment of interactions between fur seals, sea lions and groundfish fisheries were of greater immediate importance than assessment of interactions between harbor seals and groundfish fisheries in the eastern Bering Sea and that known harbor seal haulout sites in the eastern Bering Sea could and should be surveyed in conjunction with regular sea lion surveys in the area.

Research Priorities

Following the general discussion, the working group reviewed, identified information and research needs, and determined that the priority needs are to:

1. Continue collection of reliable catch, effort, and related biological information concerning groundfish fisheries in the eastern Bering Sea.
2. Continue monitoring pup production and other key parameters of the fur seal rookeries on the Pribilof Islands and the Steller sea lion rookeries along the coast of the eastern Bering Sea.
3. Arrange for floating grappling hooks or fishing gear to be towed behind fishing and research vessels transiting the North Pacific to collect samples of net debris for use in determining the types, quantity, and size distribution of net fragments and packing material present in the North Pacific.
4. Design and conduct mark/recapture and/or radio-tagging and tracking studies, and oceanographic/fishery surveys to identify and determine the physical and biological characteristics of definable fur seal and Steller sea lion feeding areas in the eastern Bering Sea.
5. Complete the evaluation of existing fur seal stomach content data and design and initiate a pelagic fur seal sampling program to detect changes and monitor trends in fur seal feeding habits and diet.
6. Design and initiate a sampling program to detect changes and monitor trends in the species composition, size distribution, and density of fur seal and Steller sea lion prey species in identified feeding areas.

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Introduction

The initial efforts of the group were directed toward defining the interactions. This section presents these findings in three parts: herring stock characteristics, marine mammal population characteristics, and the known or potential interactions.

Herring Population

The Pacific herring (Clupea harengus pallasii) is one of a number of small, schooling fishes found in the Bering Sea. This species provides a food resource for fish predators (for example, walleyed pollock, Theragra chalcogramma; marine birds, and marine mammals), and is also the focus of a subsistence fishery and a commercial fishery.

The distribution of Bering Sea herring stocks indicates a large-scale pattern of seasonal movements. In winter, large concentrations of adult herring occur northwest of the Pribilof Islands (Shaboneen 1965), although some of the population may remain inshore and spend winter under the ice (for example, in the Norton Sound area) (Baron 1978). It is toward the end of the offshore period that herring attain their greatest caloric content, with 25 percent of their body weight attributable to lipids.

Herring migrate inshore to spawn in the spring (perhaps following the ice edge and then the 4°C isotherm). Spawning occurs from mid-April through early July, and usually begins when water temperatures reach 5°C. However, post-spawning fish caught through the ice in the MacKenzie River delta region indicate that some herring may spawn under the ice at lower temperatures (A.H. Kristofferson, Fisheries and Oceans Canada, unpublished data). Eighty-two percent of the total estimated herring spawning biomass occurs within northern Bristol Bay, 8 percent in Norton Sound, and the remainder elsewhere (Fried, Whitmore and Bergstrom 1983).

Spawning occurs in both the intertidal and subtidal zones. Eggs are usually deposited on aquatic vegetation (rockweed or eelgrass), but may also be deposited on rocks and gravel (Barton and Steinhoff 1980). Eggs hatch in 10 to 21 days, depending on water temperature. Larvae metamorphose into juveniles in six to 10 weeks (Wespestad and Barton 1981).

Little is known about either the larval or juvenile stages. Juveniles apparently feed in coastal waters in summer, and move to deeper, offshore waters in winter. A similar pattern of movement is followed by adults (Rumyantsev and Darda 1970). However, different wintering areas are used by adults and juveniles.

Sexual maturity is usually reached between years 3 and 5 (Naumenko 1979). Herring may live up to 15 years, but individuals older than 10 years are uncommon (Wespestad and Barton 1981). Average size of adults is 240 to 260 mm standard length (maximum length is 290 to 315 mm), and 190 to 260 grams weight (Fried, Whitmore, and Bergstrom 1982a and b).

Mean spawning biomass within the area encompassing northern Bristol Bay to Norton Sound was estimated at 168,700 mt from 1978 to 1983 (Fried, Whitmore and Bergstrom 1983). However, spawning stock size is highly variable and may have averaged 1,166,000 mt from 1960 to 1966 (Wespestad 1982). The coefficient of variation of the mean number of age I herring calculated from cohort analysis for the period 1959 to 1981 was 1.78 (Wespestad 1982).

The dynamics of this population can be explained as a component of the Bering Sea ecosystem (Figure 2). Herring represent an intermediate step in the food chain between the plankton upon which they feed and the many predators which feed upon herring. An ecosystem model developed by Laevastu, Favorite, and Larkins (1982) indicates that an inverse relationship exists between herring and pollock because older pollock prey on herring. Year-class success may also be heavily affected by the highly variable climatic and oceanic conditions in the area. Advection of larvae into cooler offshore water may result in significant mortality.

Because food habits, competitive relationships with other species, predator/prey interactions, and distribution differ with each, five life history stages of the herring stock must be considered: egg, larvae, juvenile, inshore spawning adult, and offshore wintering adult. The population is regulated by competitive interactions with other small schooling fish (eulachon, _Thaleicthys pacificus_, capelin, _Mallotus villosus_, and small pollock; predation by walleye pollock, marine mammals and marine birds; and by exogenous climatic and oceanic events).

All of this however, is largely conjecture. The significance of the various regulatory factors remains largely unproven.

Large-scale commercial exploitation began in 1959 when foreign factory fleets developed a winter, offshore fishery near the Pribilof Islands. The annual harvest peaked nearly 150,000 mt in the early 1970s and declined to 18,000 mt by 1975, largely due to a decline in the stock. The Fishery Conservation and Management Act (FCMA) of 1976 has prohibited foreign offshore herring fishing, and the population has since been slowly rebuilding. The current draft fishery management plan (FMP) allows for a harvest of up to 20 percent of the spawning biomass, allocated as follows:

1. subsistence fishery,
2. inshore roe fishery,
3. offshore domestic food and bait fishery, and
4. offshore foreign food and bait fishery.

To date, the allocation has been completely used by the subsistence and inshore roe fisheries.

In summary, the consensus of the group was that the most pressing needs were for distribution and abundance data, including offshore studies, and for basic data on regulatory mechanisms.

Marine Mammal Populations

Twenty-four species of marine mammals are known to inhabit the Bering Sea. Five have known potentials for significant biological interactions with the herring fishery:

1. Fin whales - Balaenoptera physalus
2. Minke whales - Balaenoptera acutorostrata
3. Harbor seals - Phoca vitulina
4. Spotted seals - Phoca largha
5. Northern sea lions - Eumetopias jubatus

Information about these animals in the Bering Sea is limited, particularly for the cetaceans. A summary of that available follows.

Fin whales were once one of the most abundant cetaceans species in the Bering Sea. Extensive whaling, which ended in the mid 1960s, considerably reduced the population. The North Pacific population is estimated at 16,000 animals, but it appears that few of these are in the Bering Sea. A survey conducted for NOAA between March 1982 and March 1983 (Leatherwood 1983) failed to find a single fin whale in the southeastern Bering Sea, the area of primary interaction with the herring fishery. However, animals are frequently observed along the northern edge of the Aleutian Island chain, as recorded in the Platform of Opportunity program, and in the Navarin Basin (Brueggeman 1983). The southeast Bering Sea must be traversed by many of these animals as they move between the Aleutians and the Navarin Basin.

Minke whales, because of their small size, were not subjected to intensive whaling in the Bering Sea. However, they are also not abundant in the area.

Both species usually migrate into the Bering Sea in the summer from their winter calving and breeding grounds in more temperate waters. Some Minke whales may winter in the southern Bering Sea. In the summer, both species are found along the continental slope, with fin whales found especially near the Pribilof Islands and the Minkes found in shallower inshore waters. Minke whales sometimes enter loose ice during summer and have penetrated as far north as the Chukchi Sea. Minke whales have also been reported around Nunivak Island, an area where juvenile herring congregate.

Maximum size of adult fin and Minke whales in the northern hemisphere is 24 m and 10 m, respectively.

Both species feed on small schooling fish, such as herring, in addition to krill. The significance of herring to their diet is unknown.

The three pinniped species are all abundant within the Bering Sea. Spotted seals are the most common, with 200,000 found in the Bering Sea. In the winter these animals are distributed along the ice front, with peak concentration found nearshore. This population follows the ice front as it recedes in the spring, with a large concentration appearing in the Norton Sound area when the herring spawn.

Harbor seals are found only in coastal waters, with at least 1,000 animals appearing in the Bristol Bay areas where herring spawn. It is not known whether this is the total number of individuals in the area or whether this represents an instantaneous count of larger number of animals moving in and out of Bristol Bay (4,000 animals have been recorded along the northern edge of the Alaska Peninsula). The number of seals in Bristol Bay continues to increase through the early fall.

At least 26,000 northern sea lions reside in the Bering Sea (Leatherwood 1983). Some of these animals are distributed along the ice front in winter (Oliver, unpubl. data, workshop abstract). These animals then move inshore when the ice recedes, with 2,500 recorded in the Bristol Bay area during the herring spawning season. No rookeries now exist in the Bristol Bay area.

Average sizes of the seals and sea lions are 1.5 m per 116 kg, and 2.7 to 4 m per 270 to 900 kg, respectively.

All of these pinniped species feed on herring, as well as on other small schooling fish and pollock. The few feeding studies have found that stomachs contain very little food, unless the animals are feeding on spawning aggregations of herring and capelin. Stomachs are then usually full. Pinnipeds may thus be laying on fat at times of peak prey abundance.

At least in theory, the presence of herring and capeline spawning runs may be critical to the seal's and sea lion's reproductive cycle. Seals give birth to a single pup just prior to the onset of the runs, so the fish concentrations may provide an energy resource for lactating females and weaning pups. The abundance of fish also occurs at the onset of the sea lion's pupping period, and may be important to the health of the near-term fetus, and for early lactation by nursing females.

Little information is available on this relationship. This and other topics relating to food habits (such as metabolic needs and prey switching) were considered by the group to be major areas of data deficiency. More information is also needed on the distribution and abundance of the cetaceans.

Known and Potential Marine Mammal Fishery Interactions

Two general types of interactions were considered: those in which the fishery impacts the marine mammal population, and those in which the marine mammal population impacts the fishery. These were further categorized by the level of fishery harvest (equal to or less than optimum yield (OY), and greater than OY), and by the size of the marine mammal population (less than optimum sustainable population (OSP), and equal to or greater than OSP). Table 1 indicates where the significance interactions may exist.

At present levels of fishing and marine mammal population, the only interaction of potential importance is the affect of spotted seals on the Norton Sound herring stocks. This is because of the small size of the herring stock there. The lack of other potential major interactions at present results from a combination of relatively small herring harvests and small marine mammal populations in the areas of potential interaction.

The potential for significant interactions will increase if herring harvests increase and/or marine mammal populations increase. A significant increase in the marine mammal population is only likely with the large cetaceans, as the pinnipeds may already be at OSP. A large fin whale population could significantly affect the fishery, and conversely, an expanded fishery or an increase in natural herring mortality could prevent further increases in the fin whale stock. A reduced food resource, such as herring, could also have significant impact on pinnipeds, particularly during their critical periods (such as during lactation). However, if the marine mammals are able to switch to other prey without increased energy expenditure and decreased energy intake, then a reduced herring abundance would probably have little affect. Since so little is known about marine mammals feeding habits in the Bering Sea, these considerations are highly speculative.

Data Requirements for Assessment of Interactions, Existing Research, and Needed Research

Discussion of herring and marine mammal populations and their possible interactions led the group to consider the data required to assess the occurrence and magnitude of these interactions. Available data and research needed to fill data gaps are presented below:

A. Herring populations

   1. Abundance and distribution

Table 1. Gross interaction matrix

Species by Pop. Level	Direction of Impact of Fishing Level			
	Fishery > Marine Mammal		Marine Mammal > Fishery	
	<OY	>OY	<OY	>OY
Fin Whale				
at Ex.	None	None	None	None
at OSP	Possible	Possible	Possible	Possible
Minke Whale				
at Ex.	None	None	None	None
at OSP	?	?	?	?
Spotted Seal				
at Ex. & OSP	None	?	Yes, in NS	Yes, in Norton Sound
Harbor Seal				
at Ex. & OSP	None	Possible, in critical periods	None	Possible, in critical periods
Northern Sea Lion				
at Ex. & OSP	None	Possible, in critical periods	None	Possible, in critical periods

Ex. = Existing marine mammal population
OSP = Optimum sustainable marine mammal population (the existing pinniped populations may approach this)
<OY = Harvest less than or equal to the current OY for the herring population
>OY = Harvest greater than the current OY of the herring population (could include higher than expected natural mortality

- a. Required data
    - 1) Stock composition and distribution
    - 2) Co-occurrence with other marine mammal prey species
- b. Existing research
    - 1) Annual stock assessment studies at inshore spawning sites (ADF&G)
    - 2) Population model (ADF&G and NMFS)
    - 3) Initial research on identification of stocks (ADF&G, NMFS, Universities of Alaska and Washington) through scales
- c. Needed research
    - 1) Offshore distribution and movement studies
    - 2) Development of methods for stock identification
    - 3) Distribution and abundance studies of other marine mammal prey (such as capelin)
    - 4) Refinement of assessment techniques

2. Caloric content
    - a. Required data
        - 1) Seasonal and geographic variation in herring caloric content
        - 2) Similar data on other marine mammal prey
    - b. Existing research
        - 1) Caloric content of northern fur seal prey (M. Biggs, Fisheries and Oceans Canada)
        - 2) Similar research by NMFS/NMML
    - c. Needed research
        - 1) Caloric content of herring and other marine mammal prey
        - 2) Seasonal and geographic variations of herring and other marine mammal prey.

3. Regulatory mechanisms
    - a. Required data

            1) Climatic and oceanic effects
            2) Predator-prey interactions
            3) Competitive interactions (intra- and inter-specific)
        b. Existing research - ecosystem modeling in the Bering Sea
        c. Needed data - all required data

B. Marine Mammal Populations

    1. Abundance and distribution
        a. Required data
            1) Inshore and offshore abundance
            2) Seasonal and daily movements
            3) Age, sex and reproductive status of the population
            4) Seasonal and geographic association with prey stocks
        b. Existing research
            1) Some census of cetacean stocks, but current technique may not be sensitive enough for such small stocks
            2) Several land-based censuses of pinniped populations in various areas of the Bering Sea
        c. Needed data
            1) More offshore data, particularly cetacean
            2) Data on seasonal and daily movements, including residence times, dive profiles, number of dives, and feeding bouts, particularly for pinnipeds in the southeast Bering Sea
            3) Association with prey stocks
    2. Metabolic needs
        a. Required data
            1) Basic metabolic requirements of marine mammal populations
            2) Seasonal and life history effects

        a) Importance of herring runs to reproductive success

        b) Total consumption greater than daily maintenance requirements during spawning runs, as a means of storing calories for lean times

  b. Existing Research

    1) Little data from the Bering Sea populations

    2) Canadian phocid studies from University of Guelph and Bedford Institute

  c. Needed research - Local data on cetacean and pinniped energetics, including seasonal and life history data.

3. Diet composition

  a. Required data

    1) Seasonal and geographic food habits

    2) Diet differences by age, sex, and reproductive status

    3) Switching and foraging strategies

  b. Existing research

    1) Old studies of ice seal and sea lion food habits in the central and southeast Bering Sea

    2) Other Alaskan pinniped studies

  c. Need research

    1) Significance of herring in the diet - seasonally and geographically

    2) Food habit data in general, particularly for cetaceans

    3) Switching and foraging, and significance of alternative prey species

<u>Recommendations</u>

High priority research

Research recommendations were ranked within categories as follows:

1. Herring data

- a. Abundance and distribution
    - 1) Offshore studies: NMFS staff felt this was their greatest need.
    - 2) Inshore studies: ADF&G staff felt this was their greatest need. Since stocks were separated on inshore spawning grounds, this would be the best time for assessment studies.
- b. Regulatory mechanisms: virtually nothing is known about this for Bering Sea herring stocks. At least one group member felt obtaining this information was of equal importance to obtaining abundance and distribution information.

2. Marine mammal data
    - a. Studies of pinniped daily and seasonal movements, residence times and dive characteristics in the Bristol Bay and Norton Sound regions.
    - b. Pinniped feeding habits in the Bristol Bay and Norton Sound regions, including the potential for switching from herring to other prey (food habits, for example, should be determined before, during, and after the herring spawning season).
    - c. Metabolic requirements for pinnipeds in the Bering Sea: the Canadian studies may provide much of the data for this, at least for the phocids.

Monitoring

The goal of the workshop was to determine whether significant biological interactions exist now or could exist in the future. From such discussions a framework should evolve for joint management of herring and marine mammal populations. This requires two types of tools: predictive techniques that would evaluate contemplated management decisions, and monitoring programs to determine the outcome of these decisions.

Monitoring programs can, and probably should, be implemented now to evaluate the affects of current fishery management policies. Herring stock monitoring occurs as part of ADF&Gs annual stock assessment program. However, monitoring of marine mammal populations should begin as soon as possible. Such studies should include:

1. Annual estimates of population size, by sex and age group
2. Annual estimates of pup production (for example, fecundity) and survival
3. Examination of size difference between Bering Sea animals and those in other areas of Alaska

4. Examination of fine structure of teeth to determine feeding success.

Monitoring of marine bird populations may also provide an index of herring abundance.

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Introduction

The objectives were to:

1. identify marine mammal species that are known to be or could be affected by or affect salmon fisheries in the Bering Sea;
2. indicate the nature and significance of the interactions;
3. determine availability of data on marine mammal species involved;
4. determine whether models are available and effective for management decisions;
5. examine present management procedures and management needs; and
6. determine research needs.

The working group began by reviewing the salmon fisheries. Three commercial salmon fisheries operate in the Bering Sea: nearshore gillnet, Japanese high seas gillnet, and purse seine. The salmon fisheries and management of salmon stocks were reviewed by Chuck Meacham and the following information is his summary.

Salmon returning to coastal streams of western Alaska have been harvested by man for subsistence purposes for thousands of years, and for commercial purposes for approximately 100 years. Sport utilization of salmon is a recent phenomenon and this harvest is relatively insignificant. Subsistence harvest, while extremely important to a number of rural residents, is greatly exceeded by the commercial harvest, considering the Bering Sea as a whole. The 1978-1982 average commercial harvest (in millions of fish) by species and major geographical area is as follows:

	Chinook	Sockeye	Coho	Pink	Chum	Total
Kotzebue	.000	.000	.000	.002	.343	.345
Norton Sound	.010	.000	.038	.236	.172	.456
Yukon	.132	.000	.021	.000	1.157	1.310
Kuskokwim	.065	.060	.345	.022	.389	.881
Bristol Bay	.200	19.389	.354	1.836	.949	22.728
North Peninsula	.019	1.503	.140	.162	.384	2.208
Aleutian Islands	.000	.006	.000	.966	.003	.975
Total	.426	20.958	.898	3.224	3.397	28.903
%	1.5%	72.4%	3.1%	11.2%	11.8%	100.0%

For western Alaska, the total salmon population can be approximated by assuming some average commercial exploitation rate. A 50 percent rate of exploitation would result in an annual western Alaska inshore abundance of nearly 60 million adult salmon, the majority of which are sockeye salmon from Bristol Bay. These salmon stocks are presently at historic record-high abundance. In addition to salmon originating from western Alaska coastal streams, the Bering Sea contains millions of salmon of Asian origin. The Japanese salmon mothership gillnet fishery catches an average of 8.5 million salmon (1978-1982), primarily of Asian origin. The Japanese land-based gillnet fishery occurring south of the Aleutian Islands catches an average of 16.5 million salmon (1978-1982), believed to be largely of Asian origin. Salmon harvests by the U.S.S.R. average 68 million (1978-1982). Therefore, the total harvest of Pacific salmon from the Bering Sea averages approximately 148 million (including 16.5 million taken south of the Aleutians by the Japanese land-based gillnet fishery).

Management of salmon stocks returning to western Alaska streams is based, insofar as possible, on discrete stocks. In Bristol Bay, optimum escapement levels are based on 25 years of spawner-recruit analysis. Escapement objectives are identified for each of the major contributing river systems. Fishermen are allowed to take salmon in excess of spawning requirements. Fishing effort is restricted by vessel number and size; gear length, depth, mesh size, and construction materials; by fishing time; and by fishing location (specifically, to the river mouth). Essentially, all species and geographical stocks are fully exploited in these domestic nearshore gillnet fisheries. One rather unusual fishery is that occurring in the Shumigan Islands and at South Unimak Island. In addition to gill nets, purse seines are utilized in this area. The harvest levels are largely determined by projected run size and harvests of sockeye salmon returning to Bristol Bay.

Since management of the salmon fishery is based on an optimum escapement level to the rivers, natural mortality, including predation by marine mammals, is automatically accounted for when harvest levels are set. If marine mammals take a constant or increased amount of salmon, then the amount available to fishermen will change as stock levels change. At present, salmon stocks are healthy (reflected by high abundance levels) having recovered from low levels in the 1950s and 1970s.

After review of the salmon fishery and management, the group addressed the question of marine mammal-fishery interaction for each of the three salmon fisheries. In evaluating interactions, the working group based ratings upon interactions in the Bering Sea only, but noted cases where the levels of interaction may be different in other parts of the species' range.

Nearshore Salmon Gillnet Fishery (Set and Drift Nets)

Types of interactions between marine mammals and the nearshore salmon gillnet fishery discussed included entanglement of marine mammals, illegal intentional take by fishermen, damage to fish and gear, and competition between marine mammals and fishermen for salmon. These were discussed and rated according to the known level of interaction (Table 1). Discussion focused on the six mammal species for which interactions with fisheries were considered most likely (Table 1). These species were beluga whales, northern fur seals, northern sea lions, harbor seals, spotted seals, and harbor porpoise. Other species were mentioned with regard to specific problems in particular areas but because of generally low levels of interaction with fisheries, were not discussed further. These included:

1. Gray whales: damage to fishing gear,
2. Walrus: illegal intentional take on coastal haul-out areas, such as Cape Seniavin,
3. Killer whales: predation on salmon in some areas of their range, however, no data are available from the Bering Sea.

Entanglement in nearshore drift gill nets or set nets was rated as an insignificant problem for each of the six species except beluga whales. It was thought to be a significant problem for beluga whales only in Bristol Bay, where recent data show an increasing number of whales being caught in king and red salmon gear during the last 30 years. Some entanglement of harbor porpoises occurs in Bristol Bay and Norton Sound, but the number of animals involved is probably less than 10 to 20 per year.

Illegal intentional take, mostly by fishermen shooting at animals near their nets or on haul-out areas near fishing grounds, was a problem restricted mostly to sea lions, particularly in the False Pass and Sea Lion Rocks areas. Harbor seals are sometimes shot at but probably seldom hit. Walruses at the Cape Seniavin haul-out area on the Alaska Peninsula are subject to harassment and shooting, but the recent

Table 1. Interactions between marine mammals and the nearshore salmon gillnet fishery in the Bering Sea

Species	Entanglement*	Illegal Intentional Take*	Damage to Fish*	Gear Damage*	Competition**	Total
Beluga whale	4[a]	2	3[a]	3[a]	4	16
N. fur seal	2	2	2	2	3***	11
Harbor seal	2	2	4	2	3	13
Harbor porpoise	2	2	2	2	2	10
N. sea lion	2	2[b]	4	4	4	16
Spotted seal	2	2	2	2	2	10

*where 4 = Significant level of interaction (≥3% of percent population for cetaceans and ≥5% for pinnipeds)
3 = Moderate amount
2 = Insignificant interaction (little or no impact)
1 = Insufficient or no data

**where 3 = Significant proportion of the diet (≥10%)
2 = Some predation on salmon
1 = Insignificant in diet

***Some participants thought the rating should be lower for Bering Sea

[a] Most interactions with beluga whales occur in Bristol Bay. In more northern areas, the entanglement level is insignificant (rating of 2).

[b] In most areas illegal intentional take is insignificant, however in localized areas (such as Sea Lion Rocks), there is significant intentional take (rating of 4).

establishment of the Seniavin Game Sanctuary may help to alleviate the problem.

Fish and gear damage caused by marine mammals was rated by the group to be the most significant interaction in the nearshore fishery. Fishermen said harbor seals and sea lions damaged substantial numbers of salmon, making the fish unsalable. Beluga whales leave tooth marks on fish, but the extent of this problem is poorly known. Major damage to gear is done by sea lions in the False Pass area. In Bristol Bay, some net damage by beluga whales occurs in conjunction with entanglement.

Direct competition for the salmon resource occurs among fishermen, beluga whales, and sea lions. Salmon smolt and adults are the major dietary component of beluga whales in Bristol Bay, as well as in more northern areas such as at the Yukon River mouth during summer months. In 1983, beluga whales were estimated to eat 5 percent of the outmigrating red salmon smolts, and an amount of adult salmon equal to slightly less than 1 percent of the commercial catch of red salmon and approximately 9 percent of the commercial catch of other species. Although information from stomach contents of sea lions in the Bering Sea is lacking, sea lions are frequently observed eating adult salmon in areas north of the Alaska Peninsula. Harbor seals are known to eat salmon, but information concerning the magnitude of this consumption is not available. Since about 30,000 harbor seals haul-out along the northern Alaska Peninsula, their consumption of salmon could be considerable.

It was noted that the presence of harbor seals and perhaps northern sea lions can reduce the salmon catch in an area, possibly by the marine mammals scaring away fish.

The group generally agreed that there is little, if any, evidence that gill net is discarded into the sea by the nearshore salmon fishery. It probably does not pose a significant problem in marine mammal entanglements.

Japanese High Seas Salmon Gillnet Fishery

Interactions of marine mammals with the Japanese high seas drift net fishery are summarized in Table 2. Fish damage by marine mammals could not be evaluated by the working group. It was noted, however, that fish scarred with healed wounds caused by marine mammals are observed. However, there are no data on where or when the wounds were inflicted. It was noted that data on wounds may be available from the Japanese for high seas-caught salmon. Fishery observers have reported salmon damaged by marine mammals, but there has not been a systematic study of the magnitude of this damage.

The incidental take of Dall porpoises in the Bering Sea was discussed. It was decided that the number taken in the Bering Sea is low in comparison with estimated population size. Therefore, the entanglement category was given a low number or priority. However, it was noted that the number entangled is high enough to raise public concern (up to an estimated 835 Dall porpoises annually).

Table 2. Interactions between marine mammals and the Japanese gillnet fishery in the Bering Sea

Species	Entanglement*	Fish Damage*	Gear Damage*	Competition**	Total
N. fur seal	2	1	2	3	8
Harbor porpoise	2	2	2	2	8
N. sea lion	2	1	2	2	7
Dall porpoise	2	2	2	2	6

*where 4 = Significant level of interaction
3 = Moderate amount
2 = Insignificant interaction
1 = Insufficient or no data

**where 3 = Significant proportion of the diet (≥10%)
2 = Some predation on salmon
1 = Insignificant in diet

NOTE: Because of the Japanese legal restrictions on weapons, the category of "Illegal Intentional Take" was omitted for this fishery.

Purse Seine Fishery

The purse seine fishery in the Bering Sea operates near False Pass, taking about 4 million red salmon annually. Because of the concentration of salmon stocks in this area, fishermen frequently encounter marine mammals feeding on salmon. The major interaction is with northern sea lions and includes entanglement, illegal intentional take, damage to fish, and direct competition. Northern fur seals occasionally tangle in the seine nets and there may be an insignificant amount of intentional kill.

Data Availability

Size and age structure of salmon populations involved in interactions with these fisheries was not discussed because salmon management is based on adult escapement levels and does not involve consideration of age and size-classes. In addition, food habits of marine mammals with respect to prey size were too poorly known to include in discussion. In general, spotted seals and harbor porpoise feed on small fish (<20 cm), fur seals on small to medium-sized fish; while belugas, sea lions and harbor seals feed on a wide size range (up to 50 cm).

The working group discussed availability of data on the marine mammal species that had high (greater than or equal to 11) interactive values in Tables 1 or 2, and numerically rated the adequacy of information (Table 3). Categories for ranking the availability of data were used and ranged from 1, indicating that systematic studies have been done, to 3, indicating that few or no data are available (Table 3). The data topics are as defined in Loughlin and Jones (a paper presented at this workshop). Rankings were based on the availability of data from the Bering Sea, but it was noted when additional information was available from other areas.

The northern fur seal is the species for which there is the most information, with data from systematic studies available for all categories except fishery interactions. Data were judged to be at least adequate for harbor seals and northern sea lions. It was noted that information on ecology (including food habits), behavior, and vital rates is available for other areas such as the Gulf of Alaska, and is probably applicable to the Bering Sea. Studies, particularly with regard to food habits and vital rates, need to be conducted to verify this assumption.

The working group briefly discussed availability of models for use in salmon fishery-marine mammal interactions. It was agreed that appropriate models are not available and that development of models is limited by the lack of available data. A conceptual model of marine mammal-salmon fisheries interactions was provided by Douglas DeMaster and Charles Meacham (Figure 1).

Management of the nearshore salmon gillnet fishery was discussed. The concensus of the group was that the present management regime of regulation to ensure optimal escapement for each river system is an effective management method. This regime accounts for consumption by marine mammals and ensures that fisheries, rather than marine mammals, will be affected first by reduced harvests. It was noted that at present most of the marine mammal species that interact with the

Table 3. Availability of marine mammal data for the Bering Sea region

Species*	Fishery Interaction	Ecology	Distrib/ Abundance	Behavior	Vital Rates	Physiol.	Disease	Total
Beluga whale	2	2	2	2	2	3	3	16
N. fur seal	3	1	1	1	1	1	1	9
N. sea lion	3	3	1	2	3	3	2	17
Harbor seal	3	2	2	3	3	3	3	19
Dall porpoise	1	1	2	3	2	3	3	15

where 1 = Systematic studies have been conducted (sufficient information available for at least some modeling).
2 = Preliminary data are available.
3 = Little or no data available.

*Species selected are those with high interaction value (≥11; see Tables 1 and 2) with salmon fisheries in Bering Sea.

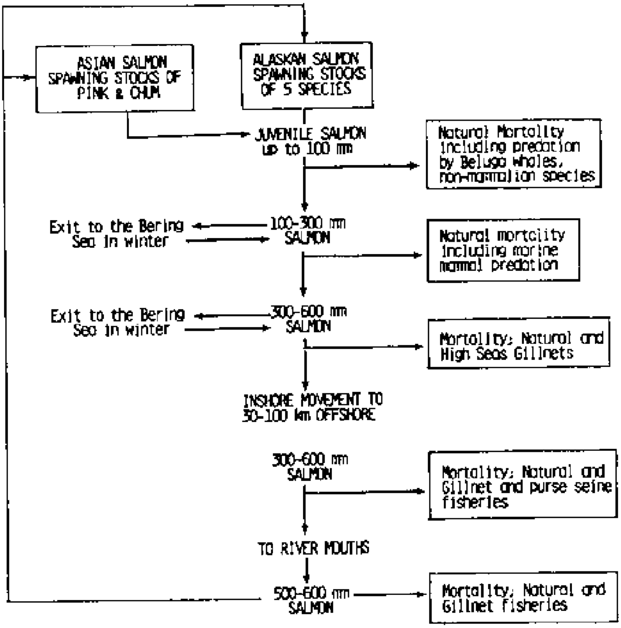

Figure 1: Model of marine mammal-salmon fisheries interactions.

salmon fishery are relatively abundant. Therefore, unless salmon abundance decreases greatly (from causes other than predation by marine mammals), it was not thought that conflicts between salmon fishermen and marine mammals over salmon resources were imminent. The need to determine the size of prey used by various marine mammal species by age class, and the changes in prey size distribution with time or population abundance levels, was noted.

Research Needs

The working group identified research needs for the marine mammal species that have high interaction with the commercial salmon fisheries. The need for an ecosystem perspective in approaching the interaction studies was emphasized. The group also discussed the need for information on prey of marine mammals: species and size composition. Items marked with an asterisk were given highest study priority.

Beluga whales

A. Collect abundance and information.

1. Determine when and where belugas can be found, particularly in Bristol Bay and Yukon River areas where there are large fishing operations.

2. Monitor beluga populations changes, using some index of population size.

3. Establish age and sex composition of beluga population(s).

It was recommended that census efforts concentrate on obtaining a maximal population number by taking the count at appropriate times of the year or at particular locations.

B. Determine incidental take (included subsistence and illegal, intentional takes).

1. How many are taken?

2. Where are they taken?

3. What age and size classes are taken?

4. Why do entanglements occur and in which gear?

*C. Determine food habits (using stomach content analysis).

*1. Identify prey species and the percentage of each species in the diet, particularly in winter.

*2. Establish temporal and spatial variations in beluga feeding habits.

3. Determine feeding energetics, including seasonal caloric needs of belugas and the caloric yield of its prey.

4. Determine how variation in available salmon effects the level of salmon consumption by beluga whales. For example, in a low salmon abundance year, do they switch to a different prey?

D. Determine fish and gear damage caused by beluga whales.

   1. Evaluate the economic losses to the fishery.

   2. Identify the salmon species involved.

   3. Determine how the presence of belugas influences salmon, particularly in terms of salmon catch.

E. Biological interaction: Identify the amount of overlap, if any, between the diet of belugas and that of other predators (other marine mammals, birds, fish species).

*F. Stock identification: Determine whether separate stocks of belugas exist. If there are separate stocks, determine which are affected by the salmon fishery. It was noted that the most efficient method for establishing stock differences in this species would also have to be developed.

G. Examine social and political concerns.

   1. Evaluate what is currently thought to be disruption to the fisheries caused by belugas, particularly changes in the disruption during the fishing season relating to catch levels.

   2. Survey trends in fishermen's attitudes toward marine mammals.

   When developing mitigating measures, the group discussed the desirability of assessing attitudes of fishermen, including seasonal or annual changes in those attitudes, with respect to marine mammals. In general, cetaceans probably do not evoke as strong a response from fishermen as pinnipeds, possibly because cetaceans are less visible predators on the fishery target species. It was pointed out that fishermen may have less animosity toward pinniped predators if they know more about marine mammal biology, particularly about food habits, abundance, and amount of prey consumed. The effectiveness of public education programs should not be overlooked in reducing illegal, intentional killing or harassment of marine mammals. In addition, fishermen should help develop methods for reducing marine mammal interactions with fishery operations. It was felt fishermen would be more supportive of mitigating measures if they helped develop them.

H. Deterrents to gillnet-marine mammal contact.

1. Develop devices to keep marine mammals away from nets or out of the fishery area.

2. Assess overall effects of such devices (a) on other organisms, (b) with long-term use under a variety of conditions, and (c) on fishing efficiency.

NOTE: The members of the working group agreed that for northern sea lions and harbor seals, research needs were similar to those outlined for beluga whales. Therefore, it was decided that for these remaining species only variations from the research needs identified for beluga whales would be listed.

Northern Sea Lions

A. Determine magnitude and effect of illegal, intentional killing. This may be more of a problem for pinnipeds than for cetaceans. There are reports of fishermen shooting animals at haul-out areas, but little information is available on the extent or effects of the incidents.

B. Observe behavior of sea lions near gillnets, particularly in offshore areas. Study should determine whether only certain individuals tend to remove netted fish or whether most animals in the area use netted fish for food. In addition, the ages of the animals removing fish from gillnets need to be determined.

C. Assess the magnitude of fishing gear damage.

In discussion on sea lions, the following suggestions concerning specific studies were made:

- Abundance estimates should be based on pup counts taken during the pupping season since this method is likely to result in the most accurate estimate of population trends.

- Prey studies should include both stomach and scat analysis.

- Tagging could be an effective method for identification of separate stocks.

Harbor Seals

*A. Determine movements of seals by age-class.

B. Establish behavior of individual seals at fishing areas by age group to determine the proportion of the population using the fishing nets for prey.

C. Identify and determine the importance of river prey resources for harbor seals, particularly at Bear and Sandy rivers and near Nelson Lagoon.

D. The following suggestions were made with respect to harbor seal research:

1. Emphasis should be placed on research along the northern Alaska Peninsula.

2. Abundance estimates should be based on total population counts made after the end of the pupping season to get the most reliable census.

*3. Food habit studies should include both stomach and scat analyses. This is an area where information is particularly needed.

4. Tagging would be the most useful tool for identification of separate stocks.

Salmon

A. Research needs with respect to salmon resources were to:

   1. Determine factors that control stock sizes.

   *2. Conduct studies on the first year of their ocean existence, particularly distribution, predators, diet, and environmental conditions.

   3. Determine changes in the population size structure with changes in stock size.

Recommendations

This working group agreed on the following recommendations:

1. With respect to examining salmon fishery-marine mammal interactions, an ecosystem approach is desirable but it would be premature to develop models of the system, particularly until more data are available on marine mammals.

   There is a need to identify indices for detecting changes in the ecosystem. If there are perturbations in the system, what factors should be monitored to ensure that salmon and marine mammal populations are sustained? It was suggested that a wide range of trophic levels, including non-target species, be examined as possible indicators.

2. Obtain information from fishery biologists and managers on the effects of changes in the population levels of salmon on the structure of the population within a range of salmon stock sizes.

3. Develop deterrents, particularly for northern sea lions, to keep them away from fishing nets or areas. By area, identify whether involvement with the fishery is limited to certain individuals. Before implementation of deterrent devices, evaluate the effects of such devices on non-target species and over long-term use.

As a final note, there was a consensus that the present salmon fishery management approach appeared to be effective in maintaining desired levels of salmon stocks and providing sufficient prey resources for marine mammal to maintain present population levels. However, it is desirable to monitor the system to identify problems if they should arise.

There was consensus that although there is not presently cause for concern about problems with salmon fishery-marine mammal interactions, we should look at cumulative effects of additional fisheries (such as the herring fishery) on these marine mammal populations. This last point was one the working group believed was especially important for consideration and action.

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The group identified a number of interactions for consideration. Categories of information needs follow:

I. Predator (marine mammal)

    A. Numbers by size or age-class
    B. Food intake
    C. Diet by time and size/age-class

II. Prey Species

    a. Numbers and distribution by area
    b. Population parameters and growth rates
    c. Regulatory mechanisms

The following diagrams summarize the level of information available and the direction of the effect considered to be of first priority for each of the interactions listed. Information levels are as follows:

3. Knowledge available is probably adequate for model building and management decisions.

2. Some knowledge is available but more is needed.

1. Knowledge available is quite limited even to bound range of possible parameter values.

Interaction (1)

Sea Otter	King Crab
A. 3	a. 2
B. 3	b. 2
C. 1	c. 1

Interaction (2)

Bearded Seal	Tanner Crab
A. 2	a. 3
B. 2	b. 2
C. 2	c. 1

Interaction (3)

Walrus	Alaska Surf Clam
A. 3	a. 3
B. 3	b. 2
C. 2	c. 1

Interaction (4)

Spotted, Ribbon Seals	Shrimp
A. 2	a. 2
B. 3	b. 2
C. 2	c. 1

Models That Could be Constructed

1. Food web models with numerical values

   For interactions (1), (2) and possibly (3)

2. Classical population dynamics or, alternatively, models for the marine mammal which include the interaction with the prey species. While the former seem to be more pertinent to determining the effects of the marine mammal on the fish stock, and hence on the fishery; the latter may be more meaningful to construct at this stage, where much of the data on marine mammal predators than on their current shellfish prey.

With regard to the food web models, it would be useful to extend them to energy input and output or net energy gain models as soon as the required information becomes available.

The following problems in model building or in using the models to answer management questions were noted:

1. Regional differences
2. Variability in prey species recruitment probably due to exogenous factors. Exogenous factors, such as ice, also play a role in marine mammal numbers and distribution. Thus, ice distribution may need to be included in the models.
3. The role of prey switching in marine mammals.

Research Needs

The group reviewed data for three proposed categories of predator and prey species for each of the interactions considered. The study group did not include all of those working on these species and hence there may be some information from recent and current studies not considered. Also, the group noted that in some cases there is uncertainty about the degree of overlap between the marine mammal and the prey species noted. If it were shown by more recent or further distributional studies that the overlap is negligible, this would imply the interaction is insignificant and thus further studies with respect to this species pair would be unnecessary from this consideration.

Studies Needed

Interaction (1)

Sea Otter	C.	Diet
King Crab	a.	Nearshore distribution
	b.	Population parameters for juveniles
	c.	Regulatory mechanism (some work is being done on this)

Interaction (2)

Walrus	A.	Distribution (particularly winter)
	C.	Diet in overlap area

It was noted that sampling walrus to get stomach samples might be difficult. Alternatively, some of this information could be obtained from examining walrus "trenches" on the sea bed.

Surf Clam	a.	Numbers and distribution

While substantial information was obtained from a pair of surveys taken in 1978 and 1979, it was agreed that there may have been changes since then and a further one or two surveys would be essential. Such surveys would also provide further samples for determination of population parameters, growth, and so on.

Interaction (3)

Bearded Seal	A.	Distribution and numbers (in area of commercial tanner crab fishery)
	C.	Diet (in this area)

(Some information is available on A and C but the group is unsure how much.)

Interaction (4)

Spotted, Ribbon Seals	A.	Distribution and numbers
	C.	Diet
Shrimp	a.	Distribution and numbers
	b.	Population parameters and growth

Research needs classified by priority and probability of success (or feasibility):

Probability of Success

Priority	Low	Medium	High
Low		Shrimp b	Shrimp a
Medium		King Crab c Walrus C Spotted, Ribbon Seals A, C	Walrus A a. Surf Clam a
High	Bearded Seal A, C	King Crab a, b Sea Otter C	

It is repeated that if new information on numbers and distribution shows interactions are not a problem, priorities will change. Priorities are assigned only within the research considered by this task group.

NOTE:

The task group was informed that shrimp are a prey of belukla whales at certain times and places. Whether this represents a potential interaction requires additional information on the distribution of both of these species. The group did not consider this potential interaction or attempt to rank this information need.

The task group considered what recommendation to make as a follow-up to this workshop. One proposal was to select a particular interaction and to convene a workshop of, say, four persons who would convene for a week bringing data needed or with data prepared in advance to build actual models: a hands on operation.

The task group did not identify any "experiments" that could be useful and feasible at this time though it noted that it might be possible to manage fisheries associated with (2) (Alaskan surf clam) and (4) (shrimp) in an experimental way if these fisheries develop. This might provide information with respect to the impact on the marine mammals involved. The required monitoring was not discussed.

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