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The North Pacific Universities Marine Mammal Research Consortium

Annual Report 1999-2000

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The University of Washington
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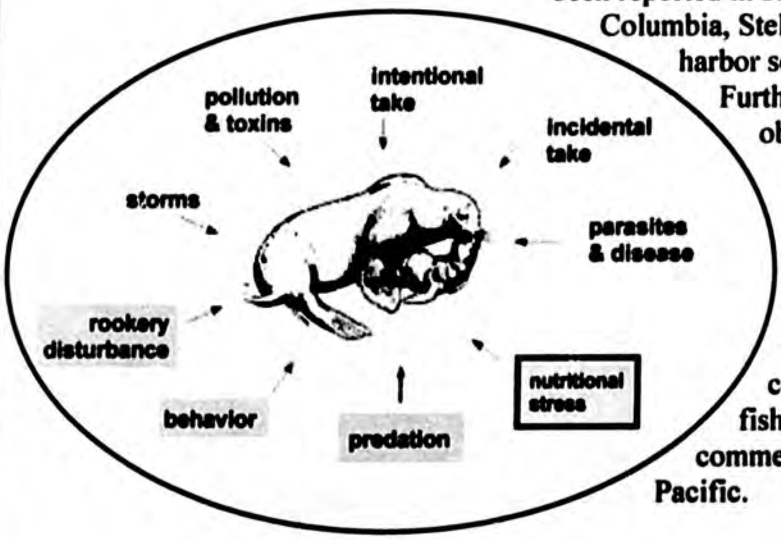
THE CONSORTIUM

In the summer of 1992, John Roos, Vice President of the Pacific Seafood Processors Association, on behalf of a group of representatives of the fishing industry, requested universities of the Pacific northwest to submit proposals for research on the impacts of fisheries on Steller sea lions. From that request, the *North Pacific Universities Marine Mammal Research Consortium* was formed with four participating institutions: the University of Alaska, the University of British Columbia, the University of Washington and Oregon State University.

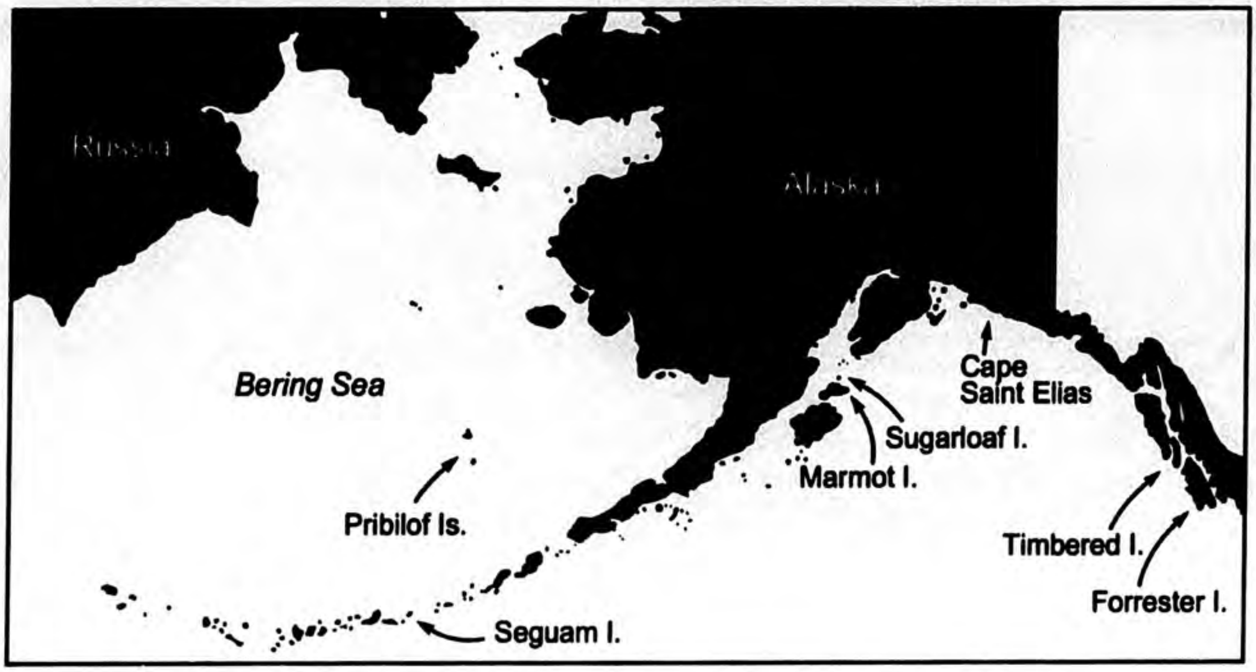
The mission of the Consortium is *to undertake a long-term program of research on the relation between fisheries and marine mammals in the North Pacific Ocean and Eastern Bering Sea. Studies will focus initially on Steller sea lion biology and could include research on the effects of species interactions and oceanographic conditions on changes in sea lion abundance. The scope could subsequently be broadened to include other marine mammals and possibly sea birds.*

THE PROBLEM

Over the past few decades, the North Pacific has seen major changes in the abundance of seals, whales and seabirds. In Alaska, harbor seal numbers are greatly reduced, northern fur seals are *depleted*, while Steller sea lions have been declared *endangered* in parts of their range. Similar declines have been reported in some seabird breeding colonies. In British Columbia, Steller sea lion numbers appear stable, while harbor seal populations have increased rapidly. Further south, striking increases are being observed in the range and abundance of elephant seals and California sea lions.



Such large-scale changes may be a natural phenomenon or may be connected with similar changes occurring concomitantly in a number of commercial fisheries. All told, they stand to affect commercial fisheries throughout the North Pacific.



BACKGROUND

In 1990, the Steller sea lion was listed as a *threatened* species under the *U.S. Endangered Species Act.* In 1997, the Steller sea lion was listed as two distinct populations, maintaining those east of Prince William Sound as *threatened*, while those to the west were re-listed as *endangered.* Such listings forbid commercial or industrial activity that could further imperil the species.

The question of why Steller sea lions have declined in western Alaska continues to puzzle biologists. Possible causes include increased incidence of parasites and disease, predation by killer whales, nutritional stress resulting from competition with man or other species for food, or nutritional stress caused by natural and/or human-induced changes in the abundance, quality and distribution of prey. Pollution and toxic substances, entanglement in marine debris, and incidental and intentional take by man may also play significant roles.

Whether the decline is caused by a single factor or a combination of all of the above is a matter of scientific debate. The data necessary to resolve the question have been limited. However, research into the nutritional stress hypothesis is receiving increasing amount of attention and funding in recent years.

Sound management policies governing human activities require a better understanding of the relationship between such activities and the ecosystem in which sea lions live. The North Pacific Marine Science Foundation, which funds the research program of the Consortium, was formed specifically for that purpose. Contributions to the Foundation have come from other foundations, federal grants, coastal communities and a wide spectrum of donors representative of the fishing industry.

The research program is overseen by a Scientific Advisory Committee with representatives of universities, industry, and government agencies. A Research Committee, composed of the research leaders at the four universities, is responsible for preparing a proposal for research each year and for reporting on progress to the Scientific Advisory Committee.

The Consortium has been greatly aided in its work by the guidance and assistance provided by the United States National Marine Fisheries Service, the Alaska Department of Fish and Game, Fisheries and Oceans Canada, the National Fish and Wildlife Foundation and the Vancouver Aquarium Marine Science Centre.

The Marine Mammal Research Unit of the Fisheries Centre at the University of British Columbia administers the Consortium. Core staff consists of a Research Director (Dr. A.W. Trites) and an Administrative Manager (P. Rosenbaum).

The interactions of fisheries and marine mammals are the subject of intensive research in many parts of the world, and will be a major focus of research in the North Pacific for many years. The Consortium coordinates university resources to help resolve the issues that arise.

Consortium researchers have completed their seventh full year of research. This report reviews the accomplishments from April 1999 to March 2000, and briefly sketches the work being undertaken for the 2000-2001 fiscal period.

RESEARCH PLAN

The Consortium's research program contains three components:

- field studies
- captive studies
- data analysis and laboratory studies.

The essence of the field studies is to contrast healthy sea lion populations in Southeast Alaska with declining populations in the Gulf of Alaska. Captive studies on Steller sea lions held at the Vancouver Aquarium Marine Science Centre are providing data about the animals' nutritional requirements and how they use the energy they derive from their food. Such information cannot be established in the wild. Captive studies also allow for the testing and development of new techniques for studying sea lions in the wild. Analysis of historical data sets and development of new laboratory techniques for processing biological samples comprise the third group of studies. The research plan balances short-term and long-term studies designed to test the various hypotheses that have been put forward to explain the decline of Steller sea lions. The projects are integrated and draw on the expertise and talents of university-based physiologists, ecologists, marine mammalogists, fisheries specialists and oceanographers. Only a concerted effort and a commitment to long-term research will determine the causes of changes in the North Pacific.

RESEARCH UNDERTAKEN

FIELD STUDIES

Behavioral Ecology

Observations of Steller sea lions in their natural habitat and analysis of these data continue to comprise significant portions of Consortium research efforts. Studies at Timbered Island in Southeast Alaska during the winter of 1996 recorded the time Steller sea lions and their young spent on shore and at sea during the late stages of nursing when the young were expected to move from milk to independent foraging. Behavioral data analyses completed in 1999 by Boyd Porter (Alaska Department of Fish and Game) and Dr. Andrew Trites (UBC) indicate that pups (7-9 months) and dependent yearlings (19-21 months old) tended to stay on or near the haulout while their mothers were away and showed no signs of weaning or consuming solid food during winter.

Average trips to sea by young sea lions were 50% shorter than lactating females, suggesting that pups and yearlings make independent trips away from the haulout while their mothers forage. The winter attendance cycle of lactating females (consisting of one trip to sea and one visit on land) averaged almost 3 days, with the mother spending about 19 hours of this time onshore with her offspring. The winter attendance cycle of pups and yearlings averaged just over 2 days, of which 25 hours was spent on shore. Lactating females spent more time at sea during winter than during summer.

Changes in Body Size

Lengths and weights of Steller sea lions shot in the 1970s and 1980s indicate that Steller sea lions were physically smaller in the 1980s than they were in the past. Body size is thought to be a sensitive indicator of feeding conditions and is likely a good measure to assess the nutritional stress hypothesis. The problem in continuing the existing time series is that the traditional methods of measuring sea lions requires capturing or killing individuals.

Xavier de la Bernardie and Dr. Trites (UBC) have been developing a new method of measuring body length using image processing that causes no disturbance and yields large sample sizes to accurately quantify body size. The technique requires taking digital photographs of animals lying on haulouts or rookeries. The photographs are transferred to a computer, which can measure the distance between any two fixed points.

The software to measure body lengths was written in 1999 and tested on plastic seal models. Tests are underway on captive Steller sea lions at the Vancouver Aquarium Marine Science Centre and are expected to be completed in 2001. Assuming that length can be measured with an acceptable degree of accuracy, the technique will be used in the field in 2001.

Changes in Diet and Foraging Success

Identifying the types of bones (by species of fish) found in scats (feces) of Steller sea lions is the best nondestructive means presently available to determine what they eat. Since 1993, more than 2,000 scat sample have been collected in a collaborative project with ADF&G in Southeast Alaska. Preliminary results indicate that this large and apparently healthy population of Steller sea lions has the most diverse diet of all populations studied to date. In comparison, the least diverse diet occurs in the Aleutian Islands, where the sharpest population declines have been reported. Species consumed in high abundance in Southeast Alaska include cod, herring, sandlance, salmon, pollock and arrowtooth flounder. Other studies are comparing diets of male and female sea lions, and using statistical (Monte Carlo) simulations to determine the optimum number of samples that need to be collected each year to accurately quantify diet.

There is considerable speculation about whether the declining population of Steller sea lions is nutritionally stressed. There is also uncertainty over what portion of the Steller sea lion population is at greatest risk and what is the most critical time of the year for them. In response, Drs. Kathleen Hunt (UW), Andrew Trites (UBC) and Samuel Wasser (UW) proposed to measure the concentration of stress hormones contained in Steller sea lion feces from different age classes and from different regions of Alaska. Scats were collected in Southeast Alaska in July 1999 and February 2000 for this analysis. This non-invasive technique for assessing physiological stress has been used on a number of species to gather information on physiological responses to various environmental stressors. It has yet to be applied to Steller sea lions and may provide new insights into the effects of seasonal and environmental stresses on Steller sea lions.

Telemetry

As part of the search for evidence of a link between Steller sea lion decline and reduced prey availability, Dr. Russ Andrews (UBC) and a team of researchers from Alaska, Washington, Texas and British Columbia used new datalogging equipment to compare foraging activity in healthy and declining populations. By fitting dataloggers to five sea lions from Southeast Alaska and three from the Aleutian islands, the team was able to record the dive behavior, prey ingestion and energetics of the animals while they searched for food. The results proved surprising and challenged the notion that total prey availability alone determines foraging effort.

The sea lions from the relatively healthy population in Southeast Alaska spent more than twice as much time away from their rookeries on foraging trips than members of the declining population in the Aleutian Islands. It also took the Southeast Alaska sea lions five times longer to find their first fish. In addition, the Aleutian sea lions made shorter, shallower dives than their Southeast Alaska counterparts. Analysis of trawl surveys of prey in both areas and scat samples for diet analysis show that while juvenile groundfish were more abundant in the Aleutians, prey diversity was higher in Southeast Alaska. It may be that despite access to a single abundant prey species, Aleutian sea lions are suffering from a lack of a diverse diet.

Changes in the Forage Base

Although the total number of sea lions in the Gulf of Alaska and Bering Sea has decreased over the past two decades, not all sea lion rookeries have been affected to the same degree. Irregularities between the rookeries could have resulted from differences in seasonal densities of fish or relative amounts of human disturbance.

In 1995, Dr. David Sampson (OSU) completed his analysis of groundfish fishing activities near Steller sea lion rookeries in Alaska. The study found that large winter catches of pollock occurred near sea lion rookeries that suffered large declines in the early 1980s. However, sharp sea lion declines were also reported in the late 1980s in areas where no winter catches of pollock occurred. There was no relationship between the declines and the amount of fishing effort, total catches of groundfish, or catches of Pacific cod and Atka mackerel. It may be that the only way to determine if there is a relationship between commercial fishing activities and sea lion numbers is to conduct a carefully monitored experiment that heavily fishes in one area while restricting fisheries in another.

Such an experiment has yet to be carried out. However, a comparison of forage fish abundance and distribution in Southeast Alaska with the results of previous surveys in the Aleutian and Pribilof Islands

discovered significant differences between the two regions.

- *Forage fish abundance and distribution at Forrester Island, Alaska*. Norcross et al. 2000. Final contract report, NOAA Award No. NA66FX0455. Institute of Marine Science, University of Alaska Fairbanks.

This analysis of trawls, conducted by Dr. Brenda Norcross (UAF) and colleagues, found higher species diversity but lower numbers of forage fish in Southeast Alaska than in the western regions. The topography and environmental conditions of the two regions of Alaska also showed marked differences.

Another possible explanation for the decline of Steller sea lions is that an ecosystem shift changed the food base in the North Pacific in the mid 1970s. For example, removals of whales, along with the collapse of Pacific Ocean perch, herring and yellowfin sole stocks during the same interval in the eastern Bering Sea and Gulf of Alaska (1950s-1960s), resulted in the rapid loss of several million tons of biomass from this region. Such an abrupt change may have had cascading effects that led to new patterns of energy flow through food webs of relevance to other species at higher trophic levels, and could have been the cause of recent declines of sea lions, harbor seals, fur seals and certain seabirds. Another hypothesis under consideration is that ecosystem change resulted primarily from variability in patterns of weather and climate, particularly as related to the Aleutian Low pressure system.

A team of researchers headed by Dr. Trites (UBC) constructed a mathematical model of the Eastern Bering Sea ecosystem. The model was used to test the hypothesized cascading effects on Steller sea lions of commercial whaling, overfishing and climate change. The team employed an integrated software package (Ecopath with Ecosim) to quantitatively compare the eastern Bering Sea ecosystem during the 1950s, before large-scale commercial fisheries were underway, with conditions during the 1980s, after many marine mammal populations had declined.

- *Ecosystem change and the decline of marine mammals in the Eastern Bering Sea. Testing the ecosystem shift and commercial whaling hypotheses.* Trites, A.W., et al. 1999. Fisheries Centre Research Reports 1999, Vol. 7.

The mass-balance ecosystem models showed that most of the top predators (those at trophic level IV, including Steller sea lions, seals, sperm whales, deep-water fish and other demersal fishes) declined from the 1950s to the 1980s. The only top predators to increase were arrowtooth flounder and other large flatfish. At the mid-trophic level (III), baleen whales and pelagic fishes declined, while small flatfish, pollock, walrus and bearded seals increased. Based on the model's assumptions, pollock contributed more than 50% of the total flow of energy at the mid-trophic levels during the 1980s compared with only 10% in the 1950s model. In contrast, pelagic fishes contributed nearly 50% of the flow in the 1950s. At the top trophic level (IV), no one species dominated the flow of energy during the 1950s. However, large flatfish contributed over 60% of the total energy flow in the 1980s model. Large flatfish and adult pollock that dominated the Bering Sea in the 1980s appear to be significant competitors of seals. Large flatfish are also competitors of Steller sea lions and there are large overlaps in the diets of pollock and baleen whales.

Removing whales from the 1950s ecosystem had a positive effect on pollock by reducing competition for food. However, whaling alone does not explain the 400% increase in pollock biomass that may have occurred between the 1950s and the 1980s. Nor do commercial fisheries account for these observed changes. In fact, the magnitude of changes that occurred in the biomass of all the major groups in the eastern Bering Sea cannot be explained solely through trophic interactions. Other environmental factors associated with a regime shift, such as water temperature or ocean currents, may have been at play.

According to a recent forecast, the northeast Pacific climate will cool through the coming decade and enter a "cold" regime by about the year 2005, characterized by conditions that prevailed in the 1950s through the 1970s. Biological correlates of atmospheric regime shifts continue to be discovered over a wide part of the North Pacific and Bering Sea. These include broad-scale changes in primary and secondary production, recruitment of several species of salmon and forage fishes, and the production and abundance of certain species of seabirds and marine mammals. Thus, the ecosystem structure and function may respond to the change in atmospheric forcing.

To shed light on those historic changes, Dr. Alan Springer (UAF) is continuing to collaborate with other investigators who are extracting core samples from anoxic basins in the Bering Sea and Gulf of Alaska. The samples record long-term (100+ year) records of variability of forage fish populations preserved in sediments. A one-meter core from Skan Bay, Alaska, for example, revealed a dramatic decline in the abundance of forage fishes coincident with the regime shift of the mid-1970s. A three-meter core has since been acquired that should allow an evaluation of the magnitude of variability in forage fish abundance over an interval of about the past 200 years. Mounting evidence suggests that climate change has a major effect on the structure of marine communities and the productivity of a variety of species from phytoplankton to seabirds and marine mammals.

Disease Pathology

While infectious diseases can degrade general health, reproductive capacity, and survival of Steller sea lions, the impact on population dynamics is not clear. Drs. Kathy Burek (Alaska Veterinary Pathology Services), Terry Spraker (Veterinary Diagnostics Lab, Colorado), Durrell Kapan (UBC) and Andrew Trites are exploring the possibility that disease is causing the decline. The study has two parts: a modeling exercise that tests whether the patterns of decline are consistent with the transmission of an infectious agent, and a serological survey of exposure of declining and control populations of Steller sea lions to various pathogens, including caliciviruses, *Brucella* species, influenza A, morbilliviruses, phocine herpes virus, *Leptospira interrogans*, canine parvovirus and *Chlamydia psittaci*. Results to date suggest diseases are not a primary cause of the decline because they are either not present, or are present in both declining and thriving populations. However, endemic agents may be more pathogenic in stressed animals. Further research is necessary to compare the immune responses of different populations to pathogens that are present.

CAPTIVE STUDIES

Overview

A number of hypotheses have been proposed to explain the drastic decline in Steller sea lions in the North Pacific over the last 20-25 years. An array of biological and physical changes in the environment have been suggested as possible reasons for the population decline, but the extent and manner in which these variables might adversely affect sea lions has been difficult to ascertain due to a lack of understanding of sea lion physiology and bioenergetics (the manner in which energy is utilized by an animal).

Physiological and bioenergetic data can only be obtained from empirical experiments conducted under controlled conditions. The research program with our captive Steller sea lions carries out studies that are designed to measure several key parameters of a sea lion's energy budget. This will enable scientists to determine how changes in behavior, environment and life history affect a sea lion's energy needs and, ultimately, its health and survival. With the aid of a newly developed computer simulation model of Steller sea lion bioenergetics, the results of these studies help scientists to evaluate specific hypotheses and to formulate new predictions.

Basic Energy Use

The captive Steller sea lion research project uses an array of studies to routinely measure key parameters that make up a sea lion's energy budget. The most central of these studies measure the energetic costs of growth and resting metabolic rate.

■ Resting metabolism

Resting metabolic rate reflects an animal's basic energy use. It influences and forms the basis of most other bioenergetic parameters, serving as a key comparative measure. Since they were pups, the metabolism of the captive sea lions at the Vancouver Marine Aquarium Marine Science Centre has been monitored using indirect calorimetry, a technique that measures oxygen consumption while the animals rest in a dry metabolic chamber. We have developed an unparalleled database that can trace changes in resting metabolic rate due to sea lion age, condition and the time of year.

Preliminary analysis indicates that sea lions undergo developmental and seasonal changes in metabolism. The sea lions exhibit an initial decrease in metabolism within the first 18 months of life. Metabolism then decreases at a much lower rate over the next several years. Overlaid on these developmental patterns is an emerging seasonal pattern of metabolic changes that increase in magnitude as the sea lion matures. There appears to be a peak in metabolism associated with the spring "fattening" period, and a period of low metabolism in the early winter. In addition to providing information on changes in the basic energy use of sea lions, these data have also been incorporated into concurrent bioenergetic studies, and serve as the backbone of a Steller sea lion computer model.

■ Body Morphology and Growth

Changes in nutrition can permanently affect the size or condition of individual animals, ultimately determining life history parameters such as reproductive success and survival. Quantifying the cost of tissue growth and the degree to which "normal" growth can be maintained under conditions of variable energy intake are central to understanding the impact of changes in prey availability, quantity or type on Steller sea lion populations. Understanding changes in body size, shape, and condition is critical to recognizing and evaluating the health of wild populations. In addition to obtaining data on individual parameters such as length, weight, and body girth, Consortium researchers have also used the primary data to construct and evaluate several indices of body condition. Previous studies highlighted the need for extensive longitudinal data sets to construct a reliable morphological measure of body condition that can be applied to animals in the wild.

The body mass of our captive sea lions has been measured daily since they were pups by training them to hold position on a platform scale. In addition, twice-weekly measurements of body length and body girth at three or four positions have also been obtained. Estimates of blubber depth at several key points have been obtained with the aid of a portable ultrasound machine.

The results of these studies provide an overview of how body size and shape change on a developmental and seasonal basis, and these data have been used to help construct a bioenergetic computer model of Steller sea lions. The data have also been used in a number of other studies, such as those which have quantified how body size, shape and condition change when energy or food intake is restricted. The construction and testing of species-specific condition indices that can be used to evaluate the condition of Steller sea lions in the wild also make use of this information.

The Effects of a Pollock Diet

Research continued into the possible role that switching diet from fatty fish (such as herring) to lean fish (such as pollock) may have played in the decline of Alaskan Steller sea lions. The captive sea lions were used in a number of experiments that examined the effect of several short-term diet switches between herring and pollock on body mass and metabolism, and also measured the amount of energy derived from different fish species. The results of these experiments were released in two scientific papers:

- *Digestive efficiency and dry-matter digestibility of Steller sea lions fed herring, pollock, squid, and salmon.* Rosen and Trites. 2000. Canadian Journal of Zoology 78:234-239.
- *Pollock and the decline of Steller sea lions: testing the junk food hypothesis.* Rosen and Trites. 2000. Canadian Journal of Zoology 78:1243-1250.

However, as with most scientific investigations, the experiments generated a number of additional questions. Another round of experiments was designed to test the effect of herring/pollock diet switches on sea lion growth and metabolism. Unlike the previous short-term experiments, in which the sea lions determined their own food intake, the sea lions were given diets of an equal energy value, and each trial was substantially longer (6 weeks). The food was distributed under two different conditions. It was either fed evenly throughout the week, or the majority was given on alternating days (which may more realistically mimic natural feeding patterns). Given that other studies have suggested pinnipeds may maintain body mass when eating a leaner diet, but at the expense of reduced body fat, the body condition of the sea lions was also measured using a deuterium dilution technique.

During the experiment, changes in body mass, morphology and condition, and overall activity have been monitored. Blood samples were also taken to measure the clinical effects of the diet on serological profiles (such as anemia, vitamin deficiency, etc.). Blood samples were also provided for collaborative studies examining the possible effects of diet on oxidative stress (Dr. David Kitts, UBC) and immune function (Dr. Kimberlee Beckmen, UAF). Results are expected in 2001.

Thermal/feeding Trials

Most parameters of an animal's energy budget are measured one at a time. For example, previous studies with the captive Steller sea lions have measured the additional energy expended by the animals to keep warm at different water temperatures (thermoregulation). However, documenting and understanding the interactions between bioenergetic parameters is important for a realistic interpretation of the energetic consequences of changes in an animal's energy budget.

One recent experiment examined the interaction between the heat generated from digesting a meal (known as the heat increment of feeding, or HIF) and the cost of thermoregulation. This question is critical to determining whether the heat increment of feeding is lost as a waste product or whether it can be used to offset thermoregulatory costs. The end result can significantly impact an animal's overall energy needs.

In this study, the apparent HIF was measured in the swim flume where water temperature was regulated between 2 and 10 degrees C by means of a water-chiller unit. The metabolism of the sea lions was measured by having the sea lion hold steady in the respiratory dome of the swim flume. The tests were run after an overnight fast to ensure the effects of digestion from the previous meal was complete. Another measurement was made under identical conditions 2 hours after eating a meal. Comparing the differences in these fed and fasted metabolic rates across different water temperatures should reveal whether HIF was substituted for thermoregulatory costs below the animals' thermoneutral zone. In addition, the experiments also measured the oxygen consumption of the sea lions while they were active within the swim flume. This will allow us to estimate the degree to which the sea lions use activity to offset the costs of thermoregulation, and how this interacts with the process of digestion.

The results from these tests suggest that, contrary to predictions, juvenile Steller sea lions do not use heat generated through digestion to offset the increased thermoregulatory costs of decreasing water temperature. The findings were presented by Dr. David Rosen (UBC) at the International Congress of Comparative Physiology and Biochemistry.

Heart Rate

Current techniques can only measure the energy expended by Steller sea lions in the wild as a gross average calculated over an extended time period. Measuring heart rate can be used to calculate the energy expenditure of Steller sea lions in the wild performing specific behaviours over short time periods. A project led by Jan McPhee (UBC) has established a linear relationship between heart rate and oxygen consumption across various levels of activity in four captive Steller sea lions.

To find the relationship, the sea lions were outfitted with two subcutaneous electrodes and a harness housing a computerized data-logger for monitoring and recording heart rate. Oxygen consumption data were collected simultaneously with heart rate data while an animal was at rest in the metabolic chamber or swimming against different water current speeds in the swim mill. From this relationship, recorded heart rate may be used to estimate metabolism and, thus, energy expenditure in wild Steller sea lions. However, further research is needed into how the relationship may change in a more natural environment before this monitoring method is used in the field.

Hydrodynamic Forces

A team of researchers has been studying the hydrodynamic forces encountered by Steller sea lions as part of the effort to estimate the energy requirements the animals face in their aquatic environment. Such information is vital if we are to understand the dietary choices of the species, and the possible effects of changes in diet associated with changing habitats and climate. Lei Lani Stelle videotaped six sea lions at the Vancouver Aquarium as they glided past an observation window. Measurements of the change in velocity as the animals decelerated, along with each animal's size, shape and mass, produced estimates of the drag coefficient for Steller sea lions.

The published results of the experiments showed that drag coefficients for Steller sea lions lie within the typical range expected for marine animals – greater than that of a Gentoo penguin, but less than values associated with bottlenose dolphins. In general, it appears that Steller sea lions experience relatively low levels of drag, resulting in a swimming performance that is similar to other otariids, including the California sea lion. They also appear to swim at close to an optimum speed, based on calculations for a minimum cost of transport. The next step is the development of models that can estimate the energetic costs of swimming and the contribution of swimming costs to their overall energy requirements.

- *Hydrodynamic drag in Steller sea lions* (Eumetopias jubatus). Lei Lani Stelle, Robert. W. Blake and Andrew W. Trites. 2000. Journal of Experimental Biology 203: 1915–1923.

Fasting Mechanisms

Given that changes in nutrition may be contributing to the decline of Steller sea lions in the wild, it is important to understand the physiological mechanisms they use to cope with periods of poor nutrition and to develop methods of detecting this condition in the wild. To that end, the Consortium undertook a joint research project with Dr. Lorrie Rea (University of Central Florida) to examine the effects of undernutrition on blood chemistry.

The recently completed study investigated whether sea lions are able to cope with food limitation equally well during all times of the year. Data from previous fasting trials suggested that sea lions experience faster rates of mass loss during the non-breeding seasons. Differences in blood chemistry also suggested that sea lions, which voluntarily fast during the breeding season, do not readily enter a fasting-adapted metabolic state when forced to fast outside of the breeding season.

Paired fasting trials (breeding season and non-breeding season) conducted on four sea lions held at the Vancouver Aquarium during 1999 supported the findings of this study.

DATA ANALYSIS & LABORATORY STUDIES

A Bioenergetics Model

Foraging activity records only tell part of the story of the relationship between fish stock and predator population trends. A complete explanation of the impact of predation on fish stocks requires a detailed understanding of the food requirements of the predators. Traditionally, researchers have relied on analysis of stomach contents from wild sea lions and studies of captive animals. The former suffers from considerable logistical and economic hurdles, while captive studies are often limited by small sample sizes and the difficulty in approximating conditions in the wild. A third option is the development of a bioenergetics model. Such a model for Steller sea lions in Alaska constituted a major portion of a study conducted by Arliss Winship (UBC). Using existing physiological, diet and population data from a variety of sources, including captive sea lion studies, Winship constructed a model of how much food the sea lions needed at each stage of their lives and what those requirements imply for populations of prey.

Winship was able to provide estimates of the amount and type of fish necessary to support each population, in effect evaluating the nutritional stress hypothesis. The model showed that changes in the energy density of a sea lion's diet leads to significant changes in the amount of fish the animal needs to eat. Sea lion populations from Southeast Alaska consumed fewer fish per individual during the breeding season than sea lions in the Aleutians. The trend is associated with the relatively low energy density of the main prey species in the western region compared with the high-energy prey in the east. On average, sea lions in the central Aleutian Islands had to eat 12 per cent more fish than did sea lions in Southeast Alaska.

The model predicts that a 10-year-old male needs between 20 and 32 kg of herring or other small schooling fish, which are high in energy content, each day. To get a comparable amount of energy from a diet comprised of pollock, cod or other gadids typically low in energy content, the same animal would have to consume between 32 and 48 kg of fish. Those differences may be even greater when digestive efficiency of each prey type is taken into account. A comparison of the amount of energy required to digest different types of fish was undertaken by Dr. Rosen (UBC), who concluded sea lions use more energy digesting pollock compared with herring and squid due to the high proportion of bony material in pollock. Winship also analysed the sensitivity of the model to uncertainty in the data. He found that, while uncertainties associated with estimating diet and population can affect the model's predictions, they are not as important as variation in metabolism estimates. This suggests that the largest improvements in the model's accuracy will come from studies of sea lion metabolic processes and activity rates.

Steller Sea Lions Sample Catalog

A new web-based catalog of biological samples and specimens from Steller sea lions stored at the National Marine Mammal Laboratory was unveiled in 2000. The laboratory, a division of the Alaska Fisheries Science Center but located in Seattle, houses a diverse collection of hard and soft anatomy samples currently of great potential value in evaluating population trends and trophic interactions. The samples include soft tissues (muscle, stomach, kidney, heart, liver, brain, blubber, skin), blood, vibrissae, teeth, skulls, bacula and other bones. In the past, much of the information about these samples was stored in numerous types of electronic files, making comparative analysis a logistical challenge.

In order to organize the information into an easily accessible format, Laura Litzky (UW) consulted staff from museums and other institutions, including the University of Alaska Fairbanks, the University of Washington (Burke Museum), the University of California at Berkeley (Museum of Vertebrate Zoology), the Santa Barbara Museum of Natural History and the Alaska Department of Fish and Game. The resulting database includes all information from the specimen data record (i.e., date of collection and measurements recorded) along with housing location, type of storage, analyses previously or currently being done on the sample, reference to results of analyses, and availability of the sample for loan. It is available at www.nmml.afsc.noaa.gov/pinniped.htm.

OTHER ACTIVITIES

Consortium researchers undertook a number of studies in 1999-2000 that fell within our mission statement, but were either not formally proposed in the Research Plan or were completed with outside funding. The Consortium participated in Seattle's Fish Expo. In addition, Dr. Trites made presentations to the Marine Mammal Commission and the North Pacific Fisheries Management Council describing of the Consortium's work. Dr. Trites also presented a number of papers to symposia and conferences, including:

- *Ecosystem change: Unraveling the effects of fisheries from natural oceanographic changes* (American Association for the Advancement of Science)
- *Ecosystem change and the decline of marine mammals in the eastern Bering Sea: testing the ecosystem shift and commercial whaling hypotheses* (13th Biennial Conference on the Biology of Marine Mammals)
- *Ecosystem effects of fishing in the eastern Bering Sea: insights from trophic mass balance assessments* (ICES Symposium on Ecosystem Effects of Fishing).

Talks and posters were also presented at the 13th Biennial Conference on the Biology of Marine Mammals by:

- Dr. Russ Andrews (*A comparison of the foraging ecology of Steller sea lions from declining and stable populations*)
- Jan McPhee (*Heart rates as an indicator of metabolic rates in captive Steller sea lions*)
- Linda Milette (*Behaviour of lactating Steller sea lions in Alaska: are they nutritionally stressed?*)
- Dr. David Rosen (*Hold the hot sauce: heat increment of feeding does not contribute to thermoneutrality in juvenile Steller sea lions*)
- Laura Williams (*Maximizing meals: digestive and assimilation efficiency in yearling Steller sea lions*)
- Arliss Winship (*A bioenergetics model for Steller sea lions: effects of diet and growth on food requirements*).

Dr. Rosen made several other presentations in 1999-2000, including:

- *The bioenergetic interactions of thermoregulation, activity, and digestion in juvenile Steller sea lions* (5th International Congress of Comparative Physiology and Biochemistry 1999).

Further presentations are planned in 2000-2001.

CONTINUING AND FUTURE RESEARCH

Energy Consumption Patterns

To understand the ecological impact of sea lions and other marine mammal predators at the top of the trophic pyramid, reliable estimates of just how much energy these animals consume are required. Ecopath, a computer model developed at the UBC Fisheries Center, is designed to aid ecosystem management and policy design, but requires accurate consumption rates to predict the effects of competition between marine mammals and fisheries for shared prey and primary production.

At present, limited basal metabolic and consumption rates are available for marine mammals, and such information is of little value when developing detailed models. Andrea Hunter (UBC) is collecting data from published and non-published studies of metabolic and consumption rates conducted at aquariums and research facilities around the world. Over the next year, she will create a database from the information and generate a mathematical model that will predict consumption rates of all species of marine mammals based on diet, season, activity level, morphology and demography, and other variables.

Dietary Quality

As the nutritional stress theory proposed to explain the decline of Steller sea lions attracts increasing attention, researchers are demanding more sophisticated explanations of how changes in diet can affect a marine mammal. Recent studies of sea lion stomach contents show that small schooling fish such as herring have been largely replaced over the last few decades with pollock and other gadid species. It is over this same period that Steller sea lion populations have fallen so dramatically in the Gulf of Alaska. This change in diet and the resulting reductions in growth rates, fur quality and pup survival, has given rise to what is colloquially known as the "junk-food hypothesis."

Testing the metabolic effects of a switch in diet from herring to pollock is relatively straightforward, and Dr. Rosen continues to explore this question with the sea lions at the Vancouver Aquarium. Testing for reproductive effects, however, is more problematic, because of the difficulty and length of time associated with breeding sea lions in captivity. Such effects are much more readily observed in small terrestrial mammals, and Carolyn Donnelly (UBC) is doing just that with rats. She is feeding her subjects meals consisting of a variety of mixes of Alaskan pollock and herring, and measuring the resulting growth and reproductive parameters. By early next year, it is expected she will have enough data on the effects of the dietary mixes on metabolism to compare with Rosen's data on captive sea lions. If the data are comparable, it may be possible to extrapolate the nutritional effects of pollock and herring from the rats to the sea lions.

Foraging Strategies

Nutritional quality may not be the only factor affecting sea lion prey choice. Olivier Cheneval (UBC) is exploring the possibility that prey behavior and foraging strategies employed to catch and consume prey also determine the energetic value of different species. Sea lions may expend more energy foraging for pollock and consume fewer fish per dive than they do foraging for herring.

To estimate the costs of foraging, the number of fish that can be caught per dive and the amount of time spent handling each species, Cheneval is videotaping three adult Steller sea lions as they forage for fish in a covered pool. The cover allows for gas exchange rates to be measured through a single breathing hole topped with a respiratory dome. The cover limits trainer-animal interactions and supplies a dim environment comparable to the aquatic conditions in which sea lions forage.

In addition to supplying vital data on the energetics of foraging, the project is designed to shed light on the physical details of foraging. Frame-by-frame analysis will be used to study capture, handling, swallowing and other events.

SUMMARY

The Consortium was formed to address issues related to marine mammal/fishery interactions in the North Pacific. We have undertaken a solid field program, a strong captive research program, and a major analytical research initiative. Research in 2000-2001 will continue with a balance of short-term and long-term projects designed to address and draw conclusions about changes occurring in the North Pacific and the role that commercial fisheries may have played in causing them. We have mounted a multidisciplinary research program to elucidate the factors responsible for the decline of Steller sea lions in Alaska. Our studies also take into account issues related to harbor seals, northern fur seals and whales that will attract greater attention in the years to come. Understanding the causes of change in the North Pacific requires a commitment to long-term research. Solutions are unlikely to come quickly and need a concerted effort.

ACKNOWLEDGEMENTS

The Consortium has been greatly aided in its work by the guidance and assistance provided by the U.S. National Marine Fisheries Service, the Alaska Department of Fish and Game, and Fisheries and Oceans Canada. We are particularly grateful for the field support provided by the Alaska Department of Fish and Game.

We extend our thanks to the Vancouver Aquarium Marine Science Centre and its staff, who provide us with research space and expertise in training and caring for our Steller sea lions. We are particularly grateful to the subsistence hunters from the Pribilof Islands and Aleutians East Borough for collecting and providing scientific data from subsistence hunts. We are also grateful to the members of the Research and Scientific Advisory Committees for the many hours they have spent preparing and reviewing the Consortium research plans.

We wish to thank our volunteers and the many and varied donors for their support and continued interest. We would particularly like to acknowledge the At Sea Processors Association for donating pollock and the support of the National Fish and Wildlife Foundation, and the National Oceanic and Atmospheric Administration.

Finally, we would like to thank John Roos, who retired this year as President of the North Pacific Marine Science Foundation. We are indebted to him for his guidance and foresight, which were responsible for the creation and accomplishments of the Consortium.

CONTRIBUTORS AND FUNDING

Alaska Ocean Seas Fisheries Research Foundation
Aleutian Pribilof Island Community Development Association
Aleutians East Borough
At Sea Processors Association
City of Unalaska
High Seas Catchers Cooperative
National Bank of Alaska
National Oceanic and Atmospheric Administration
North Pacific Seafood Coalition
Pacific Seafood Processors Association
Pollock Conservation Cooperative
Trident Seafoods
University of British Columbia
Vancouver Aquarium Marine Science Centre

The Consortium received start-up funding in the latter part of 1992 and full-year funding in 1993. The fiscal period was changed in 1994 from the calendar year to April 1 – March 31.

1992	(Sep. 1 – Dec. 31)	$ 32,000
1993	(Jan. 1 – Dec. 31)	$290,056
1994	(Jan. 1 – Mar. 31)	$ 75,000
1994-95	(Apr. 1 – Mar. 31)	$278,124
1995-96	(Apr. 1 – Mar. 31)	$300,000
1996-97	(Apr. 1 – Mar. 31)	$294,000
1997-98	(Apr. 1 – Mar. 31)	$485,286
1998-99	(Apr. 1 – Mar. 31)	$371,040
1999-00	(Apr. 1 – Mar. 31)	$581,367

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UNITED STATES DEPARTMENT OF COMMERCE
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NATIONAL MARINE FISHERIES SERVICE

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January 12, 2001

Dr. Bob Small
Alaska Department of Fish and Wildlife
Division of Wildlife Conservation
1255 West 8th Street
Juneau, AK 99802-5526

Dear Dr. Small:

You may be aware that the FY2001 NMFS appropriations language contains a large increase in funding for Steller sea lion protection and management, and includes a directive for the development of a comprehensive and coordinated research program with those funds. With very little lead time, we must frame a series of complex research questions to address a broad range of factors, both natural and anthropogenic, that may relate to the ongoing Steller sea lion decline. The scope of the projects, as well as their prioritization must be carefully determined in order to craft a research program that is scientifically sound, responsive to Congressional intent and consistent with the appropriations language. This new program will incorporate and expand the Steller sea lion investigations already underway. Additionally, we need to determine the most practical process for utilizing the residual, "no year" funds that are neither earmarked for a particular recipient nor required by the Alaska Region to meet groundfish management obligations precipitated by the 2000 Biological Opinion. Needless to say, this process and its results will receive considerable public and Congressional scrutiny.

To facilitate the construction of the requisite research program, the AFSC will host a planning meeting 24-25 January at our offices in Seattle (agenda attached). For these discussions, we hope to bring together representatives from each of the parties designated in the appropriations bill as well as scientists experienced in Steller sea lion research. Your participation is both welcomed and encouraged. Please refer to the agenda and the attached draft research framework for details. If you have questions regarding the meeting, do not hesitate to contact me (206-526-4000) or Doug DeMaster (206-526-4047) for assistance. I am looking forward to a frank and productive discussion, and thank you in advance for your contribution to this effort.

Sincerely,

James M. Coe
Acting Science & Research Director

Attachments(2)

Distribution:

OAR - Emory Anderson, Ron Baird, John Calder
OAR/PMEL - Eddie Bernard
NOS - Dave Johnson, Beth Turner
Sea Grant - Ron Dearborn, Louie Echols, Kate Wynne
NPFMC - Chris Oliver, Dave Witherell
ADF&G - Bob Small, Gordon Kruse
NPUMMRC - AndrewTrites
ASLC - Shannon Atkinson
SSL Recovery Team - Lloyd Lowry
F/AKR - Jim Balsiger, Mike Payne, Ron Berg, Peter Jones
F/NWC - John Stein
F/ST - Bill Fox
F/PR -Don Knowles
F/SF - Clarence Pautzke

cc: F/AKC - Doug DeMaster, Gary Stauffer, Rich Marasco, Rich Ferrero

Draft Framework for FY2001 Steller Sea Lion Research
(Alaska Fisheries Science Center)

The FY2001 appropriations language identifies a total of $43.2 million in the NOAA budget for the implementation of Steller sea lion protective measures. This constitutes a very large increase of over $36.8 million for Steller sea lion research and management. Recipients of the funding include NMFS, OAR, NOS, North Pacific Fisheries Management Council, State of Alaska, University of Alaska, Alaska Sea Life Center, and the North Pacific Universities Marine Mammal Research Consortium. The collective expertise of these organizations, supported by these new appropriations, provides an opportunity to significantly increase our knowledge of the Steller sea lion decline and to identify the most effective means of meeting conservation and management goals under both MSFCMA and ESA. However, the breadth of the Steller sea lion research questions, and the large number of research participants suggest that early and ongoing coordination of programs will be needed to effectively address the problem as specified by Congress. Recognizing that plans for the 2001 field season need to be developed immediately, and drawing upon the AFSC experience with Steller sea lion biology/management issues, we offer the following draft framework for potential research project development as a starting point for discussions among the endowed parties. This approach specifically incorporates all of the topics of interest expressed in the appropriations language (Secs. 209(a)(2) and 209(d)) in a format that will allow participants clarify the relationship between the primary research questions and the various component projects necessary to answer them.

The draft framework (Table 1) consists of 3 elements:

1. Identification of the principle hypotheses (causal factors) related to the Steller sea lion decline. These are extracted from the appropriations language.

Noting that the western population of Steller sea lions has declined substantially over the last 25 years, Congress has directed that a broad research program be conducted to examine "all possible factors relating to such decline, including the possible interactions between commercial fishing and Steller sea lions and the localized depletion hypothesis"(Sec. 209(a)(2)). The intended scope of this research effort is further specified in Section 209(d) where a collection of 12 topics are listed:

(d) SEA LION PROTECTION MEASURES.-$20,000,000 is hereby appropriated to the Secretary of Commerce to remain available until expended to develop and implement a coordinated, comprehensive research and recovery program for the Steller sea lion, which shall be designated to study–

(1) available prey species;

(2) predator/prey relationships;

(3) predation by other marine mammals;

(4) interactions between fisheries and Steller sea lions, including the localized depletion theory;

(5) regime shift, climate change, and other impacts associated with changing environmental conditions in the North Pacific and Bering Sea;

(6) disease;
(7) juvenile and pup survival rates;
(8) population counts;
(9) nutritional stress;
(10) foreign commercial harvest of sea lions outside the exclusive economic zone;
(11) the residual impacts of former government-authorized Steller sea lion eradication bounty programs; and
(12) the residual impacts of intentional lethal takes of Steller sea lions.

Although these twelve items are specifically referenced to the $20 million appropriated for sea lion protective measures, they identify topics that relate to the entire research effort. While the list points out various "things to study", it is also problematic in that it contains both categorical areas of research and individual topics that relate to one or more categories. For instance, a regime shift (5), could precipitate nutritional stress (9), manifested by changes in juvenile and pup survival rates (7). Nonetheless, with slight interpretation, the list provides the starting point for the research framework. Five principle hypotheses for the Steller sea lion decline were distilled from the 12 items in the appropriations language:

1. fisheries competition (item 4);
2. environmental change (item 5);
3. predation (item 3);
4. anthropogenic effects of disturbance/intentional mortality/harvests (items 10,11 and 12); and
5. disease (item 6);

A 6th principle, pollution, was also added to our list. Each of these are listed in the first column of the draft framework. The second column lists the various ways in which the general categories of causation expressed by the principle hypotheses might result in adverse impacts to steller sea lions (i.e. the vectors). We suggest that these vectors be discussed and carefully articulated because they constitute different research orientations and designs.

These six principle hypotheses then form the overall headings under which more specific research questions fall. Thus, the second step is:

2. Expansion of the general hypotheses into individual research questions that represent the vectors through which the interaction between the causal factor and the Steller sea lion may occur.

Each hypothesis contains multiple pathways or vectors by which impacts on Steller sea lions may manifest themselves. For instance, fisheries competition could effect Steller sea lion foraging success either by altering prey abundance (e.g. globally or locally) or by disturbance of prey fields (e.g. via redistribution or changes in density). This would be the appropriate context to address how such modifications of habitat (natural or anthropogenic) relate to other elements on the list such as nutritional stress or changes in survival or reproduction.

Articulation of the many research directions underlying each causal element category is a prerequisite to their prioritization and consideration of feasibility. To help determine feasibility and to move closer to the development of proposals or spending plans, the third step in the framework is necessary:

3. List the research project elements that would be required to address each of the questions posed in the previous step.

The building blocks needed to fully address each pathway or vector are represented by the set of individual research elements supporting the projects. In nearly every case, all proposed studies will ultimately involve additional research on either Steller sea lion biology or the habitats (both physical and biological) that influence their recovery. It is likely that much of the work identified under one hypothesis could contribute to testing other hypotheses and this step will help to identify opportunities for research plan integration among the participants.

Overall, the development of a framework such as the one proposed will help participants identify aspects of an overall research program that their resources and expertises are most suited to address. Using this framework as a starting point, we hope to encourage the participants to contribute to the full development of a comprehensive and coordinated research program. Further, agreement on the overall context of the research effort will encourage cooperation and avoid duplication of effort.

Table 1. Draft Framework for FY2001 Steller Sea Lion Research (Alaska Fisheries Science Center)

		Research Project Elements
1. Fisheries Competition	**V1 - *Removals of prey* by commercial fisheries reduce the abundance/availability of prey on the global scale (i.e., FMP area or ecosystem wide)** **V2 - *Removals of prey* by commercial fisheries reduce the abundance/availability of prey at local scales of relevance to foraging Steller sea lions** **V3 - *Disturbance of prey fields* by commercial fisheries reduce the availability of prey by reducing patch densities** **V4 - *Disturbance of prey fields* by commercial fisheries reduce the availability of prey by redistribution of prey patches**	**V1 Project Elements:** **Requires expanded knowledge of a) prey base, stock dynamics (i.e. spatial/temporal distributions, seasonal movement patterns, factors effecting predation, survival and productivity), b) effects of fisheries removals on the prey base (recognizing these dynamics) and Steller sea lion response to associated differences in prey availability.** **- Improve ability to assess Atka Mackerel, GOA Pollock, GOA Pacific cod** **- Develop an ability to assess forage species for the BSAI and GOA** **- Improve catch monitoring for groundfish vessels less than 125 feet** **- Develop methods for monitoring catch of forage fish at the species level species reference points** **- Develop and update ecosystem models indicators of the GOA and BSAI ecosystems** **- Expand studies of predator/prey interactions AND Update analysis of existing samples for predator/prey models** **- Improve knowledge of the role of oceanographic factors on large scale fish distribution** **- Improve knowledge of the role of oceanographic factors on fish production on fecundity and maturity of groundfish species**

		- Develop multi-species biological reference points and evaluate impacts relative to single- - Improve knowledge of the impact of gear allocations on fish distribution and abundance - Improve knowledge of the impact of fisheries - Implement seasonal resource surveys - Design and implement tagging projects to improve knowledge of seasonal Pacific cod and Atka mackerel movements - Update and develop new multi-species seasonally explicit predator/prey models - Design and Implement seasonality studies in regions of contrasting Steller sea lion abundance trends V2 Project Elements: - Design and implement resource surveys to determine the impact of fisheries on local groundfish abundance and distribution - Conduct studies to examine the densities of fish utilized by commercial fishermen and Steller sea lions - Determine the role of oceanographic conditions availability at the local scale - Determine the availability and ecosystem utilization of fish-prey at the local scale - Improve, update and develop new spatially explicit multi- species models

		V3 Project Elements **-Conduct studies associated with commercial fishing that characterizes the prey field before, during and after fishing** **V4 Project Elements** **-Conduct studies associated with commercial fishing that characterizes the prey field before, during and after fishing**
2. Environmental Change	**Theme: changes in K** **V1. Changes in primary production have lead to conditions which effect Steller sea lion survival or reproductive capability** **V2 *Changes in the physical environment* have lead to conditions which effect Steller sea lion survival or reproductive capability** **V3 *Changes in species composition* have lead to conditions which effect Steller sea lion survival or reproductive capability**	**V1 Project Elements** **- Correlate changes in the life history of steller sea lions based on collections made in the 1970s and 1980s with features of the physical and biological marine environment from the same period** **V2 Project Elements** **- Correlate changes in the life history of steller sea lions based on collections made in the 1970s and 1980s with features of the physical and biological marine environment from the same period** **V3 Project Elements** **- Correlate changes in the life history of steller sea lions based on collections made in the 1970s and 1980s with features of the physical and biological marine environment from the same period** **Notes: time series late 70's to present;** **requires Stellers branding project for contemporary vital rate data** **modeling: ECOSYM, ECOPATH** **moorings, drifters** **diet diversity trends (longitudinal across range of w. stock;** **re-analysis of diet diversity data**

3. Predation	**V1 Predation by *killer whales* has a) increased as a function of their increased populations or per capita predation rates and is contributing significantly to their decline or b) remained constant but has increasing effect at lower Stellers population levels.** **V2 .Predation by *sharks* (sleeper or salmon) has a) increased as a function of their increased populations or per capita predation rates and is contributing significantly to their decline or b) remained constant but has increasing effect at lower Stellers population levels.**	**V1 Project Elements** **Killer whale studies** **- population trends and abundance** **- diet (% Stellers)** **-free fatty acid signature (Stellers in killer whales)** **- direct observation** **- distribution and movements, especially with respect to activity near rookeries** **V2 Project Elements** **shark studies** **- population trends and abundance** **- stomach sampling (longline fishery for large sleeper sharks off sea lion rookeries Aug-Oct 01 and Mar-May 02)** **- direct observation?** **- live predation vs scavenging**
4. Anthropogenic Effects of Disturbance/ Intentional Mortality/Harvests	**V1 One or more sources of *anthropogenic disturbance*, including direct mortality, harvesting, incidental take and intentional killing lead to and continue to contribute to the ongoing Steller sea lion decline**	**V1 Project Elements** **-retrospective summary of removals from all sources by year, by area prior to the onset of the decline** **- modeling of population responses given combinations of sources** **- effects of disturbance as it translates to decreased reproductive capacity or increased mortality**
5. Disease	**V1 Disease has reduced the reproductive capacity of steller sea lions** **V2 Disease has increased the mortality of Steller sea lions**	**V1 and V2 Project Elements** **- antigen analyses of tissues (via 1 time biopsy or carcass sampling)** **- longitudinal studies of branded animals (blood, and biopsy)** **-contaminant pathways** **- risk analyses** **- contrast SE w/ GOA w/ BS**
6. Pollution	**V1 Pollutants have reduced the reproductive capacity of steller sea lions** **V2 Pollutants have increased the mortality of Steller sea lions**	**V1 and V2 Project Elements** **-contaminant analyses of tissues (via 1 time biopsy or carcass sampling)** **- longitudinal studies of branded animals (blood, and biopsy)** **-contaminant pathways** **- risk analyses** **- contrast SE w/ GOA**

Steller Sea Lion Research Coordination Meeting
Building 3, Room 2104
NOAA Western Regional Center
7600 Sand Point Way NE, Seattle, WA
24 - 25 January 2001

Wednesday, 24 January

0900 ~ Opening Remarks (Jim Coe - AFSC)
- Welcome from the chair (Ron Dearborn - Alaska Sea Grant)
- Statement of purpose
- Review of the agenda
- Introductions

0940 ~ Perspectives on Steller sea lion research
- National Perspective (Ron Baird - Sea Grant)
- Regional Perspective (Jim Coe - AFSC)
- Industry Perspective (Dave Frasier - NPFMC Advisory Panel)

1010 ~ Background and issue orientation

- Summary of the events leading up to expansion of the Steller sea lion research program (Doug DeMaster - AFSC/NMML)
    - Steller sea lion trends and current status
    - ESA listing research based on Recovery Team recommendations
    - Current lines of research
    - Fisheries management connection: requirements under ESA, MSFCMA & NEPA
    - Litigation based on ESA and NEPA compliance
    - Comprehensive Biological Opinion and responses to it

1055 ~ *Break (20 min)*

1115 ~ Congressional response to the Steller sea lion issue

Essence of the appropriations language:
- Senate Report
- Conference Report
- Senate debate

Thumbnail sketch of the gross operating budget

1130 ~ The need for applied management - NPFMC decisions and time lines

(Dave Witherell - NPFMC)

1145 ~ Physical oceanographic and climatic research as applied to the Steller sea lion case
(Eddie Bernard - PMEL)

1200 ~ *Lunch Break (1hr 30 min)*

1330 ~ The development of an integrated research plan

- Chair lead discussion of today's approach
    - Proposed use of AFSC or other framework
    - Identify hypothesis and operationally feasible research questions
    - Relating research needs to preferences and expertise of participants
- Identify potential and real overlapping expectations
    - Gross estimates of project costs

1500 ~ *Break (20 min)*

1520 ~ Continuation of integrated research plan discussions

1700 ~ *Adjourn*

Thursday, 25 January

0900 ~ Recap of progress toward research plan development

0915 ~ Continuation of integrated research plan discussions (as needed)

1040 ~ *Break (20 min)*

1100 ~ Fiscal and Logistical Considerations: Protocols for Research Plan Assembly, Reviews and Distribution of Funds

- Earmarked vs. unspecified funds
- Spending plans and RFPs
- Spending plan deadlines and format
- Executable plans vs. RFPs (Feb 15 deadline for spending plans)
- Format for spending plans
- Reviews - when and by whom
- Special considerations for grants process
- Consideration of an advisory group formation

1200 ~ *Lunch Break (1 hr 30 min)*

1330 ~ Continuation of the morning's discussions

1500 ~ *Break (20 min)*

1520 ~ Summary and Consideration of Future Actions

- Subsequent meetings
- Time line for research plans
- Assignments for the advisory group (?)

1700 ~ *Adjourn*

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Steller Sea Lions and Fisheries

Community Update #4 January 22, 2001

Background

November 30, 2000
The National Marine Fisheries Service (NMFS) released a Biological Opinion (BiOp) concluding that food stress continues to be the agency's leading hypothesis for why sea lions are not recovering. The agency found that the Bering Sea/Aleutian Island and Gulf of Alaska (GOA) pollock, Atka mackerel, and Pacific cod fisheries are jeopardizing the recovery of the Steller sea lion. An accompanying management measure called an RPA (Reasonable and Prudent Alternative--a legal term) restructures the fixed gear and trawl fisheries to reduce the rate and level of fishing, especially near rookeries and haulouts. Although the RPA may protect sea lion feeding grounds, the measures also severely limit fishing near many of Alaska's coastal communities in the 2001 fishery and potentially beyond.

December 5, 2000
The U.S. District Court acknowledged completion of the BiOp and dissolved the trawl prohibition that it put in place in July of 2000. The Court did not rule on the adequacy of the BiOp or the fairness of the RPA; it will only do that if the BiOp and/or RPA is appealed.

December 15, 2000
Congress passed a Steller sea lion "rider" (federal law) requiring that Steller sea lion conservation measures be phased in over 2001 to allow time for a scientific review of the BiOp and for input from the public and North Pacific Fishery Management Council (NPFMC).

January 11-12, 2001
The North Pacific Fishery Management Council met in Seattle to consult with NMFS about their draft emergency rule (part of the phase-in of sea lion conservation measures), which the Stevens rider requires NMFS to put into effect by January 20, 2001.

Upcoming Meetings

February 5-12, 2001 -- North Pacific Fishery Management Council meeting at the Anchorage Hilton
February 6, 2001, 1 p.m. -- Joint Board of Fish/North Pacific Fishery Management Council meeting at the Fourth Avenue Theater in Anchorage
Early February (Date to be Announced) -- Board of Fisheries meeting to address Steller sea lion issues in relation to the state water fisheries

For More Information

Check out these web sites for further information:

- North Pacific Fishery Management Council: www.fakr.noaa.gov/npfmc/
- National Marine Fisheries Service (Alaska Region): www.fakr.noaa.gov/
- Board of Fisheries: www.state.ak.us/local/akpages/FISH.GAME/boards/fishinfo/bofhome.htm

AMCC is a community-based organization working to minimize bycatch, protect habitat, prevent overfishing, and promote clean, community-based fishing opportunities.

What are the new rules regarding the federal groundfish fishery in 2001?

New measures to be implemented based on the November 30, 2000 biological opinion include:

- Prohibition on groundfish fishing by federally permitted vessels within 3 nautical miles of more than 75 important (currently used by sea lions) haulout sites. NMFS has stated that the current common practice of forfeiting federal permits to fish the state fishery, then reverting back to federal permits will soon no longer be allowed.
- Establishment of two fishing seasons for Pacific cod in both the Bering Sea/Aleutian Islands and Gulf of Alaska, January 1-June 10 (60% of allocation) and June 11-December 31 (40%).
- Reduction in the allowable catch of GOA pollock from the NPFMC's recommended 2001 level by 10%. This is less than the 20% reduction that would have been required by the BiOp, because Senator Stevens' rider limits the reduction in allowable catch to 10%.
- Capping of the 2001 Bering Sea pollock catch in the sea lion conservation area to no more than the amount authorized in 2000. The purpose of this measure is to require that the increase in 2001 pollock quota be caught outside critical habitat. This cap will remain in place until the BiOp RPA is fully implemented in 2002.
- Implementation of the closed areas in the BiOp ("red zones"), starting June 10, 2001 for pollock, Pacific cod and Atka mackerel fisheries. The NPFMC can recommend modifications to these closures for the 2nd half of 2001 as long as the changes meet the requirements of the BiOp, which are to close at least 50% of critical habitat to the three fisheries and maximize protection of Steller sea lion pups and juveniles. In 2002, the closed areas must also provide for the statistical design of a monitoring program to evaluate the effectiveness of protection measures.

Alphabet Soup

AMCC -- Alaska Marine Conservation Council
BSAI -- Bering Sea/Aleutian Islands
BiOp -- Biological Opinion
GOA -- Gulf of Alaska
NMFS -- National Marine Fisheries Service
NPFMC -- North Pacific Fishery Management Council
Prey Field -- the fish available to sea lions for food
RPA -- Reasonable and Prudent Alternative

What actions did the North Pacific Fishery Management Council take?

At its January meeting, the NPFMC made minor adjustments to the emergency rule that NMFS presented, including shifting some halibut bycatch caps among seasons. They also responded to the request of AMCC and others to direct NMFS (again) to analyze the effects of different gears on the availability of prey to sea lions. The NPFMC had directed National Marine Fisheries Service to do this last September, and raised the issue again in December, but NMFS has not to date incorporated differential gear impacts in their sea lion protection measures. The NPFMC also committed to forming a sea lion committee soon.

AMCC's Comments to the North Pacific Fishery Management Council

AMCC testified that while we recognize a variety of factors have caused the decline of Steller sea lions, sea lion conservation management measures should be driven by the need to protect the integrity of the "prey field," or the fish available to sea lions for food. We supported the BiOp's requirement to lower the allowable catch level when populations of prey species are low (called the global control rule). AMCC also called for the NPFMC to:

- Analyze gear-specific differences in fishery impacts on Steller sea lion prey fields. Differences in the impacts of various gear types is described in the BiOp: *"The various gear types used in these fisheries (trawl, pot, hook and line, jig) have differential effects on the environment. ...In terms of effects on Endangered Species Act-listed species, the slower and more dispersed nature of the hook and line and pot fisheries make localized depletion less likely than would be possible with trawl gear."* (p. 215, BiOp, November 30, 2000)

- Provide a clear schedule for how sea lion research currently being commissioned feeds into the development of future sea lion conservation measures.
- Use weekly delivery limits for vessels fishing in critical habitat as a way to slow down the rate of harvest and make it possible for small boats and fixed gear vessels to participate effectively.
- Vessels with substantial cod bycatch (such as trawlers in flatfish fisheries) should be allowed only 5% maximum retainable bycatch (instead of 20%, as currently allowed) when fishing in critical habitat. This will help protect the integrity of the prey field by everyone who catches cod. Increased monitoring of fishing through vessel monitoring systems and observer coverage should be increased on all vessels that fish in critical habitat.
- In 2002, regulations for fisheries that occur in sensitive habitats should encourage less selective gears to convert to more selective gears with slower rates of extraction (for example, conversion from cod trawling to pots).
- Consider findings of and coordinate with the various working groups analyzing the sea lion issue, including the State of Alaska Steller Sea Lion Recovery Team.

AMCC's Position on State Water Cod Fisheries

- AMCC supports preserving the status quo in the state waters fisheries because of the importance of these fisheries to local communities and because the gears fishing cod in state waters are the most selective and hold the most promise for long term sustainability of both sea lions and the ecological health of the fisheries.
- The differing impacts of various gear types on catch rates and levels and bycatch and habitat impacts should be the basis of any sea lion conservation measure.
- The State has more ability to control rates of removal (of fish) at a local level than federal managers do, and the State can use this to its advantage to work proactively to prevent localized depletions and slow down the fishery where warranted.
- AMCC supports establishing a state waters cod fishery in the Bering Sea around participating communities, in order to promote the use of less-impacting and more-selective gears.

A Call to Action

You can help communicate the importance of protecting Steller sea lions in a way that also enables appropriate levels of fishing to occur by writing the North Pacific Fishery Management Council and the Alaska Board of Fisheries. Make the points listed above or present your ideas on how the RPAs might be changed to better balance sea lion conservation objectives and fishing priorities. We encourage you to write TODAY to:

Federal Fisheries: Chairman David Benton, North Pacific Fishery Management Council, 605 W. 4th Ave, Suite 306, Anchorage, AK 99501-2252 Fax (907) 271-2817

State Waters Fisheries: Board of Fisheries Chair Dan Coffey and Groundfish Committee Chair Ed Dersham, c/o Diana Cote: ALASKA DEPARTMENT OF FISH AND GAME, Boards Support Section, P.O. Box 25526, Juneau, AK 99802-5526
ph: (907) 465-4110, fax: (907) 465-6094, email: Diana_Cote@fishgame.state.ak.us

Please contact AMCC if you would like more information on the sea lion issue, and please send us a copy of letters or e-mails you send out on this subject.

FY01 Steller sea lion-Groundfish Budget

$43.15 million

Studies Identified in Steven's Rider

- Available prey
- Predator/prey
- Predation by other marine mammals
- Fishery-SSL interactions
- Regime shift
- Disease
- Survival rates

- Population counts
- Nutritional stress
- Foreign harvests
- Residual impacts of former eradication programs
- Intentional lethal takes
- Non-lethal measures to protect SSL from predators

“Endowed Organizations”

Organization	*Funding Level in FY01*
NMFS	$7.85 million
Alaska SeaLife Center	$6.0 million
ADFG	$2.5 million
Univ. of Alaska	$1.0 million
NPUMMRC	$0.8 million
OAR/PMEL	$6.0 million
NOS	$2.0 million
NPFMC	$2.0 million
Commerce	$15.0 million
Total	$43.15 million

National Marine Fisheries Service FY01 Budget-$7.85 million

Study (*Preliminary*)	Cost (000s)
Localized depletion (cod, pollock, Atka mackerel	1600
Satellite tagging SSL	400
Food habits/foraging behavior	350
Forage fish assessment	550
Regime shift- AI passes (with PMEL)	400
Implement Recovery Plan	2300
Predation studies	750
AKR Management Activities	1500

Alaska SeaLife Center
FY01 Budget-$6 million

Study (*Preliminary*)	Cost (000s)
Feeding behavior	1000
Remote monitoring/branding	1500
Collection of pups-short term hold	1500
Endocrine and immune function	300
Chiswell Island prey study	500
Chiswell Island predation study	200
Disease and reproductive biology	500
Instrumentation (e.g., implants)	500

Alaska Dept. of Fish and Game FY01 Budget- $2.5 million

Study (*Preliminary)*	Cost (000s)
SSL body condition and life history	2000
Estimation of vital rates	300
Model response to incidental take	150
Survey of blood borne diseases	25
Measurement of contaminants	25

University of Alaska FY01 Budget- $1 million

Study (*Preliminary*)	Cost (000s)
Seasonal diets of SSL at Kodiak	200
Prey availability at Kodiak	300
Prey quality at Kodiak	100
Diet of SSL competitors	200
Killer whale/shark diets at Kodiak	200

North Pacific Universities Marine Mammal Research Consortium FY01 Budget- $0.8 million

Study (*Preliminary*)	Cost (000s)
Bioenergetics of SSL	250
Bias in scat analysis	35
Telemetry (implants)	40
Amack food quality/SE scat collection	24
Bioenergetic modeling/timing of molt	31
KW predation model/subs. Harvest	120
Diet in Oregon/WA/forage fish abund.	22
SSL vital rates and condition indices ?	120

North Pacific Fisheries Management Council FY01 Budget- $2 million

Study (*Preliminary*)	Cost (000s)
NAS Independent review	700
Management and legal compliance	1300

Oceanic and Atmospheric Research
FY01 Budget- $6 million

Study (*Preliminary*)	Cost (000s)
Analysis of existing environmental data	500
2-yr field study and modeling-combination of PMEL and RFP (CIFAR)	5000
Coordination, communication, outreach	500

National Ocean Survey FY01 Budget- $2 million

Study (*Preliminary*)	Cost (000s)
Competitive process for directed research on predator/prey relationships (CIFAR)	2000

Dept. of Commerce
FY01 Budget- $15 million

Study (*Preliminary*)	Cost (000s)
Competitive process for directed research on predator/prey relationships	15,000

% of Funds in FY01 Budget to inhouse research, contracts, management and reviews $43.15 million

- 36% in-house research
- 56% contractual studies (research determined by competitive process)
- 6% management related to ESA/NEPA
- 2% external reviews
- Possible Problem- FY02 budget currently has $7-10 million assigned to SSL-groundfish research and management
- Possible Problem- Contractual studies may not provide information in time for October 2001 review

A Review of the Effects of Regime Shifts on the Production Domains in the Eastern North Pacific Ocean

Ashleen J. Benson[1] and Andrew W. Trites[2]

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November 27, 2000

The intent of this review is to identify the timing of regime shifts in the north Pacific Ocean and to characterize the nature of the biological responses, from primary producers through to the top predators in the food chain. The available data indicate that large-scale, low frequency variations occurred in climatic and oceanic conditions in 1925, 1947, 1977 and 1989. They also indicate that these changes occurred abruptly and were not random variations. Changes in atmospheric pressure can alter wind patterns that affect oceanic circulation and physical properties such as salinity and depth of the thermocline. This in turn affects primary and secondary production. Regime shifts can have opposite affects on species living in different domains, or can affect different species living within a single domain in opposite ways. The effects of climatic forcing on fish and marine mammals are not easy to predict, and may indirectly affect these populations through changes in the distribution and abundance of predators and prey. Direct effects of regime shifts on marine ecosystems are manifested more quickly than indirect responses. Natural variability in the productivity of fish stocks in association with climate indicates that new approaches to managing fisheries should incorporate climatic as well as fisheries effects.

Contents

1. The Regime Concept

Isaacs (1975) introduced fishery scientists to the concept of 'locked in" trends in climatic, oceanic and biological systems (MacCall, 1996; Beamish et al., 2000). He called these persistent trends *regimes*. Regimes have been defined as multiyear periods of linked recruitment patterns in fish populations or as stable conditions in physical data series (Beamish et al., 1999). Concurrent (and sometimes abrupt) changes in these biological and physical variables indicate a *regime shift*. These natural patterns of variability raise questions about the biological basis of sustainability of fisheries (Beamish, 1995), and are leading ecologists away from a single, steady state view of ecosystems to one that recognizes that ecosystems fluctuate because of internal and external sources of variability (e.g., Steele, 1996; Trites et al., 1999).

2. Climate/Ocean Variability

The basic state of the atmosphere-ocean climate system over the north Pacific Ocean shifted abruptly in the late 1970's (Ebbesmeyer, 1991; Graham, 1994). Atmospheric circulation changed throughout the troposphere (Trenberth, 1990), and the Aleutian Low pressure system deepened (Miller et al, 1994) and shifted eastward (Trenberth, 1990). This in turn advected warm, moist air over Alaska and colder air over the north Pacific. Concurrently, sea surface temperatures cooled in the central Pacific and warmed along the west coast of North America (Miller et al, 1994). Sea ice decreased in the Bering Sea (Manak and Mysak, 1987) and changes were observed in the surface wind stress (Trenberth, 1991) that would have affected ocean currents in the north Pacific.

Indices[1] of climate-ocean conditions indicate that a synchronous change occurred in the north Pacific in 1977. Since then, there has been a tendency for more frequent El Niño and fewer La Nina events (Trenberth and Hoar, 1996). Such large-scale changes suggest that an as yet unidentified common, global event may be responsible for the shift (Beamish et al., 2000).

The climatic shift noted in the late 1970's was not the first time such a change had occurred. In fact, it appears to have occurred three other times in the 20th century. Mantua et al. (1997) and Minobe (1997) identified shifts in the atmosphere-ocean climate record in 1925, 1947 and 1977. Overland (1999) and Beamish et al. (1999) also report that a fourth shift occurred in 1989.

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[1] Our review is limited to the most common indices that characterize climate and ocean conditions over the north Pacific Ocean. Other indices developed include the Pacific Circulation Index (PCI) (King et al., 1998), the Northern Hemisphere surface (land and ocean) temperatures (NHST) (Jones, 1994), and the length of day (LOD) (Stephenson and Morrison, 1995) which demonstrates changes in the earth's rotational speed. Others have been developed for the Atlantic Ocean, these include the North Atlantic Oscillation Index (NAOI) (Walker and Bliss, 1932) and the Atmospheric Circulation Index (ACI) for the Atlantic basin (Beamish et al., 1999).

The climatic and biological events noted in the north Pacific in the mid 1970s and at other times this century have been quantified by a number of different indices. Four of the more commonly cited ones are 1) the Southern Oscillation Index (SOI), 2) the Aleutian Low Pressure Index (ALPI), 3) the North Pacific Index (NPI), and 4) the Pacific Decadal Oscillation (PDO). A comprehensive review of climate indices may be found in Beamish et al. (2000).

2.1 *Southern Oscillation Index*

The Southern Oscillation Index (SOI) describes the oscillation of air masses between the eastern and western tropical regions of the Pacific Ocean (Walker, 1924). It is commonly (but not always) linked with El Niño events and is termed the El Niño – Southern Oscillation (ENSO). This index measures the difference in sea level atmospheric pressure between Tahiti and Darwin, Australia (Beamish et al, 2000). Anomalously high pressure at Darwin (negative SOI) results in weakened westerly winds and warmer sea temperatures (El Niño) in the eastern Pacific Ocean (Trenberth and Hoar, 1996). The converse (intense westerlies, lower sea level pressure in the west, positive SOI) occurs in a La Nina event.

Figure 1 shows average monthly SOI oscillating between the negative (El Niño) and positive (La Nina) states. It also shows that a major change occurred after the 1977 El Niño when the familiar oscillations between positive and negative were replaced by persistent negative (El Niño) conditions. Since 1990, more exceptionally intense and frequent El Niño events have occurred than at any other time in the past 113 years of records (Trenberth and Hoar, 1996).

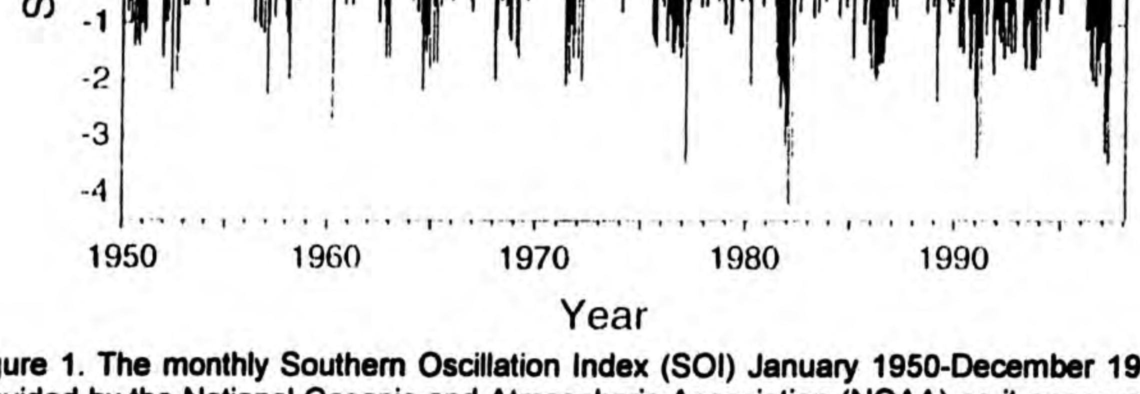

Figure 1. The monthly Southern Oscillation Index (SOI) January 1950-December 1998 provided by the National Oceanic and Atmospheric Association (NOAA) as it appears in Beamish et al. (2000).

2.2 Aleutian Low Pressure Index and the North Pacific Index

The Aleutian Low Pressure Index (ALPI) (Beamish and Bouillon, 1993) and the North Pacific Index (NPI) (Trenberth and Hurrell, 1995) are both measures of the intensity of the Aleutian Low atmospheric pressure system, which affects the strength of winter storms. The ALPI measures the area of low pressure while the NPI is the area weighted mean sea level pressure over the region 30°N to 65°N, 160°E to 140°W (Trenberth and Hurrell, 1995). The ALPI and the NPI are negatively correlated (Beamish et al. 2000), which means that a large Aleutian Low (positive ALPI) will have very low pressure (negative NPI). From 1947-1976, the ALPI was generally negative (i.e., the Aleutian Lows were smaller), while from 1977-1988, the ALPI was positive (reflecting a period of more intense Aleutian Lows) (Figure 2). The intense period ended after 1989. These decadal variations are also evident in the NPI (Figure 3).

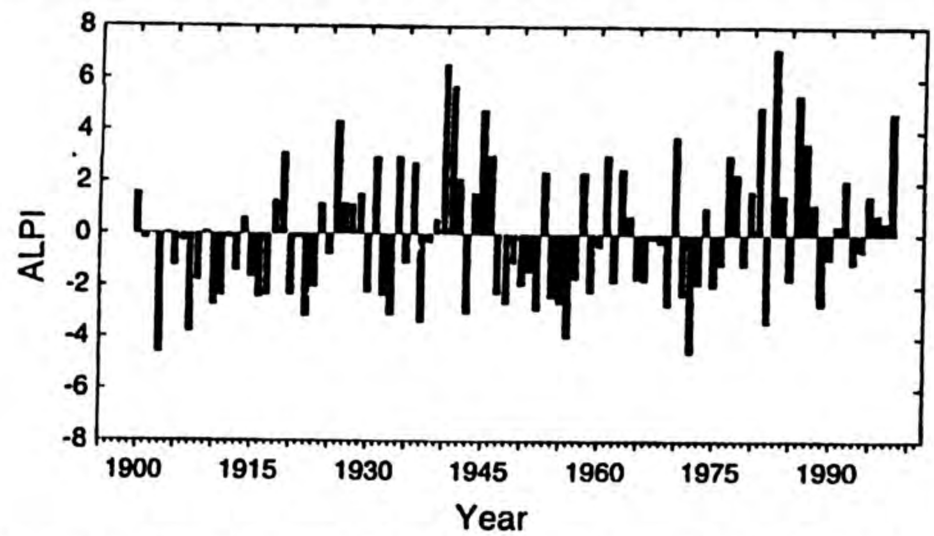

Figure 2. The Aleutian Low Pressure Index (ALPI) from Beamish et al. (2000).

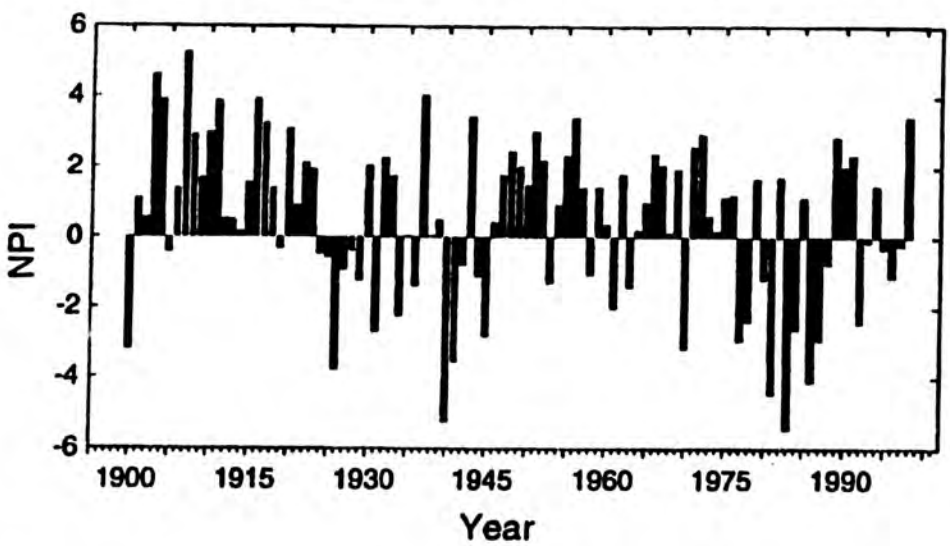

Figure 3. The North Pacific Index (NPI) of Trenberth and Hurrell (1995) from Beamish et al. (2000).

2.3 Pacific Decadal Oscillation

Mantua et al. (1997) examined a broad collection of data including sea surface temperatures (SST) and sea level pressure (SLP) from the tropical, extra tropical and coastal north Pacific. They also considered land surface temperature during winter and precipitation over North America, as well as North American river discharge rates and winter atmospheric pressure. Mantua et al. identified an interdecadal oscillation between phases (regimes) in the records they compiled. They called this decadal scale variability in the North Pacific climate-ocean environment the Pacific (inter) Decadal Oscillation (PDO). Like the NPI, ALPI, and SOI, the PDO has positive and negative phases. When the PDO is positive, a cooling occurs in the central North Pacific and a warming occurs along the coast of Canada. When it is negative there is a warming in the central North Pacific and cooling along the Canadian coast. Mantua et al. (1997) noted that the PDO was positive between 1925 and 1946, negative between 1947 and 1976, and positive since 1977 (Figure 4). They did not identify a significant change in 1989 (Beamish et al. 2000).

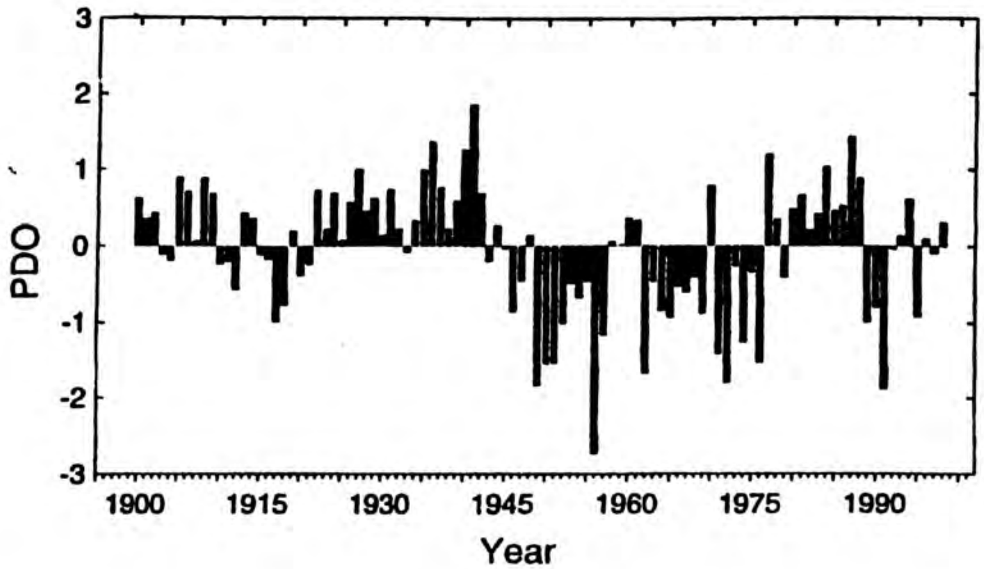

Figure 4. The Pacific Decadal Oscillation of Mantua et al. (1997) from Beamish et al. (2000).

3. Detecting a Change in a Time Series

Although the decadal variations in these four major indices of the north Pacific appear to be simple oscillations, Beamish et al. (1999) point out that there is no reason to assume regime shifts are cyclic. They point out, for example, that the weakening of the Aleutian Low after 1989 resulted in a different dominant wind direction than existed prior to 1977. The most common technique used to detect significant changes in regime shift time series (e.g. Mantua et al., 1997; Noakes, 1986) is called intervention analysis (Box and Tiao, 1975). A Box-Jenkins autoregressive integrated moving average (ARIMA) (Box and Jenkins, 1976) model is first fitted to the data to account for any autocorrelation (which is contained in most environmental data) in the time series. Interventions in the form of steps are then introduced to the model and their significance is tested as a change in the mean. The test is analogous to a two sample *t*-test (Mantua et al., 1997).

4. The Response of the North Pacific Production Domains

The dominant feature in the Central Subarctic Domain (Central Gulf of Alaska) (Figure 5) is the Alaska Gyre which rotates in a counter-clockwise (cyclonic) direction (Ware and McFarlane, 1989). This circulation results in divergence (upwelling) in the core of the gyre, which is believed to be the reason this domain is relatively productive (Reid, 1962). An intensification of winds might improve productivity by causing the gyre to accelerate and result in increased divergence and upwelling of nutrient rich water at the core (Brodeur and Ware, 1992, Reid, 1962).

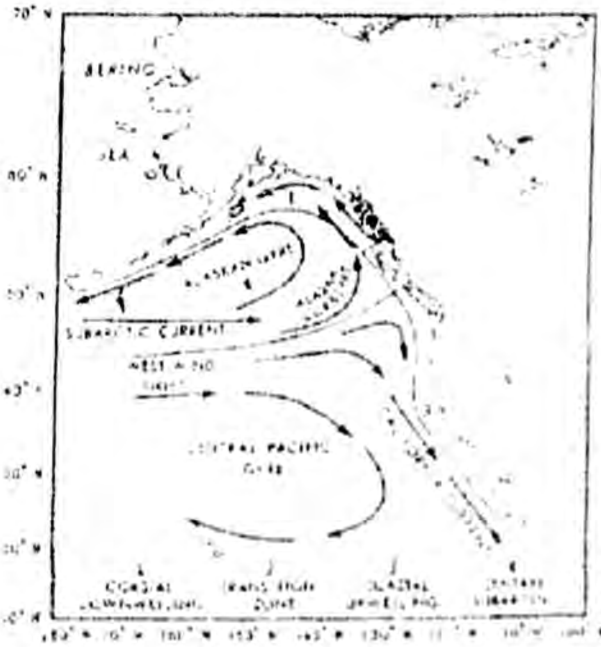

Figure 5. Prevailing ocean currents and the four major domains defined by Ware and McFarlane (1989).

McFarlane and Beamish (1992) found the biomass of copepods increased in 1976-77 in the Alaska Gyre, coincident with cooling of the central north Pacific and an intensification of the Aleutian Low (an index of winter wind stress). Brodeur and Ware (1992) examined zooplankton collections from the subarctic Pacific and found that the biomass more than doubled between the late 1950s and the 1980s. They also found a positive relationship between winter wind intensity and summer zooplankton biomass.

Venrick et al. (1987) showed that in the central north Pacific (just north of Hawaii) the total chlorophyll *a* (a proxy for phytoplankton production) nearly doubled around the time of the 1977 regime shift. Venrick (1994) subsequently showed that this was due to a deepening of the mixed layer, which resulted in increased phytoplankton production in deep water. Polovina et al. (1995) provided supporting evidence by demonstrating that concurrent with the intensification of the Aleutian Low and regime shift of 1977, there was a deepening of the mixed layer in the subtropical domain near the Hawaiian Islands, while the mixed layer became 20-30% shallower in the Gulf of Alaska. Polovina et al. also noted that primary and secondary production could be expected to improve in the two areas by increasing the exposure of phytoplankton to light in the Gulf of Alaska and by mixing deeper, nutrient rich water into the euphotic zone in the subtropical North Pacific.

The nature of the response to environmental variation is not the same for all production domains of the northeast Pacific. For example, Roemmich and McGowan (1995) found that the biomass of zooplankton in the Coastal Upwelling Domain (California Current) (Figure 5) exhibited an opposite response to that in the Gulf of Alaska and decreased by approximately 80% between the early 1950s and 1990s. At the same time, the surface layer also warmed in the upwelling domain (MacCall, 1996). It was unclear whether zooplankton declined gradually or rapidly. Roemmich and McGowan noted that the decline of zooplankton may be attributable to coastal warming associated with the 1977 regime shift that increased stratification and reduced upwelling of nutrient rich water in the California Current. They also noted that it might be the result of a climate-induced change in ocean circulation that might bring warmer water into the area and limit the supply of nutrients and/or advect zooplankton away from the coast.

Hollowed and Wooster (1992) noted that there appear to be two environmental states in the North Pacific Ocean. The first is strong circulation in the Alaska gyre (strong Aleutian Low) and weak upwelling along the west coast of North America. This state is specific to warm eras and is commonly initiated by El Niño events. In the second state, there is weak oceanic circulation in the Gulf of Alaska and strong upwelling along the coast. This is characteristic of cool eras (Figure 6). Gargett (1997) proposed a mechanism to explain the apparent opposite response to decadal scale climate change exhibited by the northern and southern production domains. In the subarctic north Pacific, the stability of the water column is determined mostly by salinity and light levels that limit primary productivity (Polovina et al. 1995). Turbulent mixing reduces stability. In the subtropical gyre, stability is determined primarily by temperature, and primary productivity is limited by nutrients, while water column stability is reduced by coastal upwelling.

The Aleutian Low (the winter low pressure system over the North Pacific Ocean) develops in the fall of each year and breaks down in the spring of the following year (Beamish and Bouillon, 1995). Onset of the Aleutian Low results in increased precipitation in the subarctic north Pacific. This freshwater input has a strong, stabilizing effect on oceanographic conditions. Intensification of the Aleutian Low leads to winds that are unfavorable for upwelling further south along the coast of North America. This also leads to increased water column stability. Although the water column stability might vary in phase between the two regions, the effects on production would be expected to differ. In the Gulf of Alaska, increased stability means that the phytoplankton can be maintained in the euphotic zone for longer periods of time, thereby increasing primary production. On the other hand, off California, increased stability and less upwelling results in a decreased nutrient supply. Since the phytoplankton in this area are limited by nutrients and not light, primary production (and by inference, secondary production) can be expected to decline.

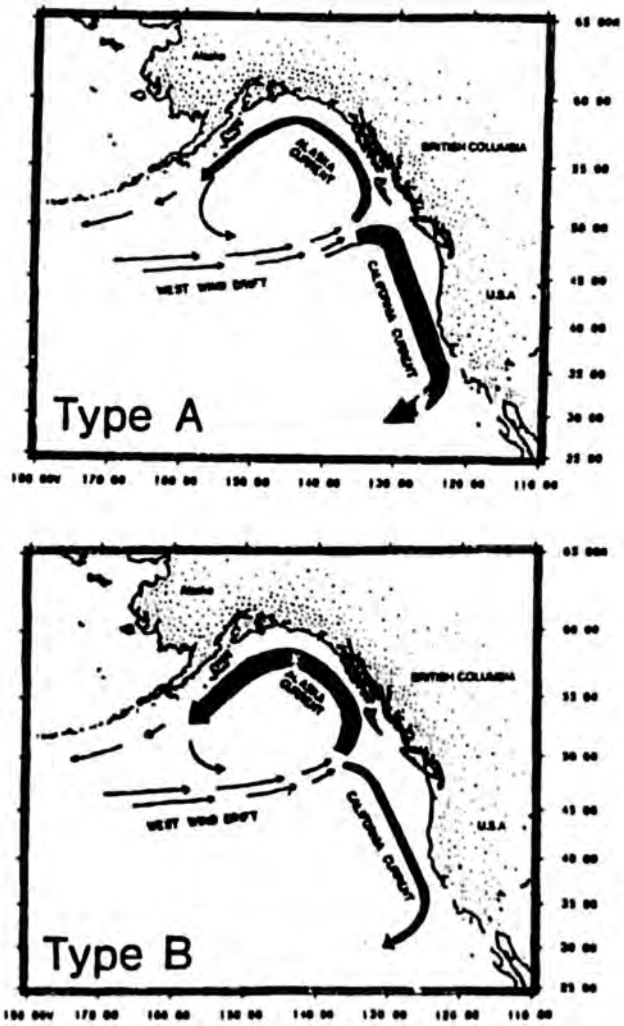

Figure 6. Circulation patterns associated with Type A and Type B conditions from Hollowed and Wooster (1992).

The Bering Sea reflects large-scale ocean variations, but the timing of the events is not necessarily synchronous with those further south (Wooster and Hollowed, 1995). There are indications of a cool era from about 1965 to 1978, and of a warm period beginning in 1978 (Wooster and Hollowed, 1995). Niebauer (1988) used sea ice as an indicator of Bering Sea conditions and noted a significant decrease in the winter ice cover after 1977. Variability in the climate-ocean conditions in the Bering Sea is related to ENSO and the mechanism that connects the two appears to be the Aleutian Low.

Sugimoto and Tadokoro (1997) examined short and long-term variations in summer plankton biomass in the entire subarctic Pacific and in the Bering Sea during 1954-1994. They found that the zooplankton biomass and chlorophyll concentration in the eastern Bering Sea and eastern subarctic Pacific increased in the mid-1960s and remained high until the end of the 1980s. They demonstrate a significant positive correlation between summer plankton biomass and winter wind speed in the eastern Bering Sea. They also found that the zooplankton biomass and chlorophyll concentration during the mid 1960s to early 1970s were higher than those in the preceding and following decades for the central and western subarctic Pacific. The values declined in the late 1980s.

5. Fish and Climate Change

5.1 Coastal Upwelling Domain

Long-term variability has persisted in fish populations for centuries. Soutar and Isaacs (1974) analyzed fish scale depositions (a proxy for fish abundance) in the anaerobic sediments of the Santa Barbara Basin and found evidence of large, natural, long-term fluctuations in the abundance of pelagic fishes, including Pacific sardine (*Sardinops sagax*) and northern anchovy (*Engraulis mordax*). Baumgartner et al. (1992) examined these scale depositions over a much longer time period, spanning the last 1700 years, and found persistent variability in both sardine and anchovy deposition that showed peaks approximately every 60 years. Ware (1995) identified a peak in the range of 50-75 years. MacCall (1996) examined coastal pelagic fish abundances throughout the 1900s in the California Current ecosystem and found low frequency fluctuations in the dominant species that are cyclic and related to cold and warm periods that occur every 50 to 70 years. Interestingly, the sequence appears to alternate between piscivores (bonito and Pacific mackerel) and planktivores (sardine and anchovy).

Kawasaki (1991) examined catches from three sardine populations in the Pacific Ocean and the European pilchard in the Atlantic Ocean from 1910 to the late 1980s, and found simultaneous changes in their abundance. In the same study, Kawasaki examined Pacific and Atlantic herring and showed that their abundance also fluctuated synchronously, although with a different phase than the sardines. McFarlane and Beamish (1999) note that sardines were the focus of the largest fishery in British Columbia from the 1920s to the mid-1940s, after which they disappeared. This collapse occurred simultaneously off the coast of Canada and the United States and has traditionally been touted as a prime example of overfishing (Hilborn and Walters, 1992).

The trends in abundance of sardine populations off Japan, California and Chile are synchronous - the collapse of the sardine stocks off the United States and Canada was concurrent with the collapse of the Japanese stocks (Kawasaki and Omori, 1988). This synchrony is strong evidence that the reason for the collapse had more to do with changes in ocean habitat than with fishing (McFarlane and Beamish, 1999). In the early 1980s, the sardine population off the coast of California began to recover and has been steadily increasing (Barnes et al., 1992). A recovery in British Columbia began in 1992 when sardines were reported in catches of Pacific hake (*Merluccius productus*) (McFarlane and Beamish, 1999). Furthermore, the behaviour of sardines changed. Their distribution shifted north, they moved into the Strait of Georgia, and they began spawning off the west coast of Vancouver Island (McFarlane and Beamish, 1999).

In addition to being a potentially important fishery resource, sardines may be important competitors of other species. Schweigert (1995), for example, found a significant difference in the survival rate of Pacific herring (*Clupea pallasi*) off the west coast of Vancouver Island before and after the disappearance of sardines in 1950. He speculates that the large herring recruitments that occurred off the west coast of Vancouver Island (WCVI hereafter) in the late 1930s and early 1940s were due to reduced competition from declining sardine stocks.

Ware (1991) examined the WCVI herring stock and found that herring growth rates were negatively influenced by warm ocean conditions and the associated lower zooplankton biomass. Recruitment was inversely related to sea surface temperature. Ware and McFarlane (1995) have shown that the abundance of Pacific hake (the key predator) increases along with ocean temperatures off the WCVI. This results in increased predation pressure on herring.

Schweigert (1995) studied environmental effects of the long-term dynamics of two major southern herring stocks – the WCVI (offshore) and the Strait of Georgia (SOG hereafter). He found that the two stocks exhibited similar biomass trends throughout 1937-1992, although the levels remained stable throughout the time series for WCVI and declined slightly in SOG. Schweigert also found that recruitment of both stocks was correlated under average conditions but not for the strongest year classes, which are associated with unusual oceanographic conditions in the form of very strong ENSO events. A possible explanation for these results might lie in the different recruitment processes of the stocks.

The offshore stock of herring spawns in Barkley Canyon on the WCVI while the SOG stock spawns in the Strait. The juveniles of the SOG stock do not move out onto the shelf to feed until they are around 2 years old while the WCVI juveniles move offshore in their first year (Hourston and Haegele, 1980 in Schweigert, 1995). This may be an indication that recruitment is determined by the time the SOG herring move offshore. Interestingly, Schweigert (1995) was unable to identify a change in the survival rate of SOG herring prior to and after 1950 when the sardine had disappeared. Sardines were a buffer to hake predation only for the WCVI stock.

Zebdi and Collie (1995) examined herring recruitment variability in Sitka Sound from 1972-1990 and found a positive relationship with sea surface temperature. Based on the match-mismatch hypothesis of Cushing (1975), they concluded that warmer temperatures lead to earlier spawning, which benefits herring survival because early hatched larvae will find conditions (plankton blooms) favorable to their survival. It is also possible that the increase that occurred in zooplankton biomass in the Gulf of Alaska (Brodeur and Ware, 1992) during the same period may have improved overall feeding conditions for larvae. In the same study, Zebdi and Collie noted that herring recruitment was synchronous within, but not between production domains, and that the northern and southern stocks were out of phase by one year. In addition, the recruitment response to sea surface temperature differs between production domains. Sitka Sound herring respond positively to warmer temperatures while the southern stocks respond negatively to warmer temperatures.

McFarlane et al. (2000a) studied the effects of the 1989 regime shift on the SOG and WCVI ecosystems and found the two systems had opposite responses to the change. Offshore, the distribution of Pacific hake shifted north (McFarlane and Beamish, 1999) which resulted in a greater total abundance off the WCVI (McFarlane et al. 2000a). Hake traditionally spawned offshore along the Californian coast. However, they have spawned off the WCVI since 1994 (McFarlane et al. 2000b). McFarlane et al. (2000a) point out that herring stock off the WCVI declined throughout the 1990s, presumably due to the increased predation pressure by migratory hake. Herring and the resident stock of hake in the SOG are now at high levels of abundance because of the elimination of herring in the diet of hake, which is a consequence of a decline in mean body size of the SOG hake (McFarlane et al. 2000a). Hake smaller than 40cm feed primarily on euphausiids (Tanasichuk et al., 1991). McFarlane et al (2000a) suggest that herring had opposite responses in the two ecosystems due to differing ecosystem organizations after the regime shift.

The study by McFarlane et al. (2000a) is unusual in that it compares the response of two adjacent ecosystems within the same production domain. Much of the regime research has focused on comparing the response of stocks across production domains. For example, Hollowed and Wooster (1995) examined recruitment time series from 1950 to 1989 for six Pacific herring stocks, one northern anchovy stock and 16 groundfish stocks. They found parallel recruitment patterns in several groundfish species that related to switching between Type A and Type B conditions (Figure 6). They also found that strong year classes were infrequent in the northernmost regions (transitional and downwelling domains), while strong year classes were more common in the coastal upwelling domain. Most of the stocks that did exhibit strong year classes did so prior to 1977, but not after. Conversely, herring and widow rockfish in the Gulf of Alaska and off Prince Rupert had strong year classes only after 1977. This suggests that there was a shift in the production that differentially affected northern and southern stocks.

5.2 Pacific salmon

Pacific salmon (*Oncorhynchus spp.*) inhabit or pass through at least two production domains in th ir lifecycle. For example, Alaska pink (*O. gorbuscha*) and sockeye (*O. nerka*) spend most of their life in the Central Subarctic Domain (Ware and McFarlane, 1989), but on their seaward and return migrations they pass through the Coastal Downwelling Domain. Studies on the effects of climate on these species must therefore take into account oceanographic conditions in both areas (Hare and Francis, 1995). Fluctuations in Pacific salmon production trends, as they relate to large-scale climate variability, have been studied extensively (e.g. Beamish and Bouillon, 1993; Beamish and Bouillon, 1995; Francis and Hare, 1994; Hare and Francis, 1995; Mantua et al., 1997).

Evidence that large-scale salmon production is related to climate processes in the North Pacific is presented in the form of synchronous shifts in production among several species or stocks in response to a physical regime shift (Beamish and Bouillon, 1995; Hare and Francis, 1995; Hollowed and Wooster, 1995). There are indications that salmon abundance has varied with climate for centuries (Beamish et al., 1999) and that large-scale climate impacts occur in the oceanic, not the freshwater phase of the salmon lifecycle, at least for coho (*O. kisutch*) (Bradford, 1999). It should be noted that production has generally been estimated by catches or by abundance of recruits because salmon exploitation rates are high and are therefore considered to track abundance well (Beamish et al., 1999). However, use of these simple indices of production have been criticized because they can be confounded by changes in spawner abundance (Peterman et al. 1998).

Salmon production trends in Alaska are generally the opposite of those in the Pacific Northwest (Hare and Francis, 1995). Landings for the northern North Pacific and Alaskan salmon stocks were high in the 1930s and 1940s, low from the late 1940s through to the mid-1970s, and began to increase in the mid-1970s (Beamish and Bouillon, 1993; Hare and Francis, 1995). As the Alaskan landings increased in the 1970s, several North American west coast stocks, especially the Oregon coho salmon stock, began to decline (Pearcy, 1992). Beamish et al. (2000) point out that the 1989 regime shift was associated with some of the lowest catches in the history of the Canadian fishery and that this decline was most evident for the southern British Columbia stocks.

Two mechanisms have been proposed to explain the increased production in the northern stocks in the late 1970s. The first mechanism involves improved feeding conditions as a result of the regime shift. Beamish and Bouillon (1993) proposed that increased salmon productivity is linked with increased copepod production that is associated with periods of intense Aleutian Lows (McFarlane and Beamish, 1992). The other proposed mechanism relates to improved marine survival of migrating salmon in their last year at sea (Rogers, 1984). The improved survival is hypothesized to be a result of reduced vulnerability to predation by marine mammals because of an altered timing and route of migration due to warming of the surface waters in the Gulf of Alaska with the 1977 regime shift (Hare and Francis, 1995). Supporting evidence for both hypotheses is given by Brodeur and Ware (1995).

Brodeur and Ware (1995) compared catch data for five Pacific salmon species, two species of shark, three species of cephalopod and three nonsalmonid fishes (tuna, mackerel and pomfret) from the Gulf of Alaska for the late 1950s and 1980s. They showed that distribution patterns changed dramatically between the two periods. In the 1980s the distribution of most subarctic species was compressed to the northern and western side of the Gulf of Alaska. In addition, the catch rate for all species except Jack mackerel was substantially higher in the 1980s. The authors note that in their earlier study (Brodeur and Ware, 1992) they found a twofold increase in zooplankton biomass in the eastern subarctic Pacific from the 1950s to the 1980s, with the largest increases in biomass occurring along the northern boundary of the Gulf of Alaska. This would result in increased food availability for juvenile salmonids in the nearshore region and would lead to improved early ocean survival. Brodeur and Ware (1995) propose that the doubling of the zooplankton biomass in the area increased the carrying capacity for pelagic nekton by a factor of two.

5.3 Gulf of Alaska and the Bering Sea

The Gulf of Alaska and the Bering Sea have both exhibited changes in their environment and biota in recent decades (Livingston et al. 1999). Brodeur et al. (1999) surveyed catches of large medusae from the eastern Bering Sea from 1979 to 1997 and found a tenfold increase in medusae biomass that was gradual from 1979-1989 and increased dramatically after 1990. It is unknown whether this increase was due to human intervention or if it was due to environmental changes. However, the authors point out that there were concomitant changes in atmospheric and oceanographic variables in 1990, and that these changes are strong indications of a regime shift. Even though the biomass of medusae increased dramatically, no negative effects on recruitment of any fish species have been detected. However, walleye pollock (*Theragra chalcogramma*) has had only one strong year class since 1989 and summer zooplankton biomass on the south-east Bering Sea shelf has declined slightly in the 1990s (Brodeur et al. 1999).

Some confusion appears to exist regarding the status of walleye pollock stocks. Bulatov (1995) reports substantial declines in the catches of pollock in the western and central Bering Sea since 1989, but points out that Russian and United States scientists have different views of the state of the stock. Bulatov notes that the Russians say the abundance is declining in the eastern Bering Sea while Americans say the abundance is increasing. Merrick et al. (1997) point out that pollock abundance decreased through most of the central and western Aleutian Islands in the 1980s and 1990s, and declined through 1993 in the Gulf of Alaska. Nevertheless, according to Wepestad et al. (2000), walleye pollock is still the single most abundant fish species in the eastern Bering Sea and is of great commercial importance. Due to its large biomass, variations in the abundance of pollock are felt throughout the food web (Livingston, 1991).

The distribution of Bering Sea fish is affected by variations in ice cover. As mentioned previously, the extent of ice cover in the Bering Sea was reduced beginning in 1976 (Niebauer, 1988). Northward blowing winds associated with an intense Aleutian Low pushed the ice northward and resulted in reduced ice cover in warm years (Wyllie-Echeverria, 1995). Wyllie-Echeverria (1995) notes that pollock were not reported north of Bering Strait before 1976. Since then pollock have been present north of the Strait in years of light ice cover. Additionally, larval pollock were found in the Chukchi Sea, north of Bering Strait in 1988, which suggests a change in the spawning distribution, at least for a portion of the population. It is interesting to note that, as mentioned previously, Pacific hake are also spawning north of their traditional spawning grounds (McFarlane et al., 2000b). In addition to the presence of winter sea ice, the other dominant physical feature in the Bering Sea is the presence of a cold (< 2°C) mass of subsurface (between 50m and 100m) water in the summer that extends across the middle shelf domain from Russia to Alaska (Wyllie-Echeverria and Wooster, 1998). This cold pool of water is most developed in summers following an extensive winter ice cover.

Wyllie-Echeverria and Wooster (1998) proposed that the distribution of fish stocks that are sensitive to temperatures around 2°C should reflect ocean conditions. They found that Arctic cod (*Boreogadus saida*) are present only within the cold pool while the distribution of pollock, a subarctic species, is more variable. Pollock were rarely found in the cold pool of water but were more abundant on the outer continental shelf in cold years and dispersed across the entire shelf in warm years. Therefore, during the warmer regimes, the distribution of pollock expands while the distribution of Arctic cod contracts.

Wyllie-Echeverria and Wooster (1998) also noted that changes in fish distribution involve changes in predator-prey relationships, given that shifts in prey distributions can affect predators that are limited in their foraging range. The presence of cold water at depth could restrict the distribution of young pollock to the surface layer and to the warmer waters of the outer shelf where they could be more easily taken by predators (Decker et al., 1995). Francis et al (1998) note that the proportion of age-1 pollock in the diets of seabirds declined between the 1970s and the 1980s near the Pribilof Islands, and that they were less common in bottom trawl surveys at the same time. This was most likely due to a change in their distribution.

Quinn and Niebauer (1995) found consistent relationships between pollock recruitment at age 2 and environmental variables on a one year lag, and suggested that age 2 pollock recruitment is related to above normal air and sea temperatures and reduced sea ice extent 6-18 months earlier. They also found that environmental effects are "felt" more strongly at the juvenile stage than at the larval or egg stage. Another factor that affects recruitment is density dependent (biological) regulation (Livingston, 1993).

The roles of environment and density dependence need not be considered separately. For example, Wepestad et al. (2000) proposed that water mass transport due to wind forcing was the important regulating factor in pollock recruitment because transport is the mechanism that separates juvenile and adult pollock. They showed that strong year classes occur in warm years when juvenile pollock are transported inshore and away from the highly cannibalistic adults. In cold years, transport is reduced and the distributions of juvenile and adult pollock overlap, which can result in weak year classes due to cannibalism.

Margalef (1963) hypothesized that a sudden, prolonged external disturbance could reset or reorganize community structure and succession. Building on this, Bailey (2000) proposed that a regime shift could trigger community restructuring. He further suggested that immature (less structured) ecosystems could be more vulnerable to environmental influence acting on plankton, and that biological control might emerge as a dominant effect in more mature systems. Beamish (1993) found a majority of commercially important salmon and nonsalmon species ranging from California to the Bering Sea had exceptionally strong year classes between 1976 and 1978, immediately after the shift from cool to warm ocean conditions. This appears to support Bailey's hypothesis.

Bailey (2000) examined the impacts of changes in the Gulf of Alaska community on pollock recruitment. He found that recruitment was related to larval mortality immediately following the 1977 regime shift. However, 5-10 years after the shift, as the abundance of large predators built up, predation by flatfishes and cod on juvenile pollock had an increasing effect on recruitment. Bailey showed that the dependence of recruitment on environmental conditions that lead to high larval survival appears to have decreased in recent years, but not completely as a few relatively strong year classes appeared in the population in the 1990s. According to Bailey, these strong year classes may be attributed to reduced overlap of larvae and predators as a result of environmental conditions.

The Gulf of Alaska nekton community structure changed after the 1977 regime shift from one that was dominated by forage species such as shrimp and capelin to one dominated by piscivorous gadids and flatfish (Anderson et al., 1997; Anderson and Piatt, 1999; Mueter and Norcross, 2000). Mueter and Norcross (2000) point out that the observed decline in shrimp can be attributed more to increased predation by the large piscivorous fish rather than to fishing, because the decline followed, rather than preceded, the increase in large piscivores. It is also possible that the shrimp population may have been initially depressed by fishing and therefore more vulnerable to predation by the increasing population of piscivores (Orensanz et al., 1998). Anderson and Piatt (1999) point out that most of the declining species were pelagic while the species on the rise tended to be benthic or demersal (cod and flatfish).

Decker et al. (1995) note that the diet composition of seabirds reflects the distribution, abundance and availability of their prey. They examined the diets of black-legged kittiwakes (*Rissa tridactyla*), red-legged kittiwakes (*R. brevirostris*) and thick-billed murres (*Uria lomvia*) from the Pribilof Islands in the southeastern Bering Sea, and found that the diet composition changed after 1978. There was an overall decline in the presence of capelin (*Mallotus villosus*) and an increase of sandlance (*Ammodytes hexapterus*) in the diets in certain areas for some species after 1978. The use of gadids showed no consistent change though the period.

Decker et al. (1995) suggest that the reduction of capelin in the diets could be attributable to an altered distribution in response to warmer temperatures, as capelin are commonly associated with cold, ice-covered waters. They may have either moved deeper in the water column where they were unavailable to surface foraging sea birds, or they may have retreated to colder northern waters. In either case, the abundance of capelin decreased in the area around the Pribilof Islands in the late 1970s.

Livingston (1993) assessed the relative importance of pollock and herring in the diets of marine mammals, birds and groundfish in the eastern Bering Sea in 1985-1988. Cannibalism by pollock was determined to be the most important source of predation on age-0 pollock, while consumption of age-1 (10-19cm) fish was spread evenly between fish, pinnipeds and birds. The fishery took most pollock > 40cm. In terms of removals from the total biomass of pollock, groundfish (primarily cannibalism by pollock) were the most important source, followed by the fishery and then by marine mammals. Northern fur seals were the most important marine mammal predator, while common and thick-billed murres were the main sea bird predators.

Livingston (1993) compared her results with those of Kajimura and Fowler (1984), who examined the diets of marine mammals prior to 1980. She found that pollock biomass consumption by marine mammals in the 1980s was about half of the pre-1980 estimate. The higher consumption prior to the 1980s was a function of a larger pinniped population and a higher proportion of pollock in their diet (Livingston 1983). These results are contrary to diet studies that found Steller sea lions ate more pollock in the 1980s than in the 1970s (Alverson, 1992; Merrick et al., 1997).

Livingston (1993) found that Pacific cod was the most consistent groundfish predator of herring, and that groundfish predation was more a function of school encounter rates than of absolute abundance. Marine mammal and bird predation on herring was as important as groundfish predation, while the primary source of herring biomass removals was the fishery. The majority of herring biomass removed by the fishery, pinnipeds and fish was composed of fish greater than 20cm (age 3+ biomass), although groundfish tended to consume herring less than 20cm.

6. Marine Mammals and Sea Birds

Francis et al. (1998) acknowledge that the responses of top predators to climate change are difficult to interpret due to the confounding effects of natural responses and human influences (e.g., the 1989 Exxon Valdez oil spill, commercial pinniped harvest). In addition, climatic impacts may indirectly or directly affect birds and mammals, which will affect the time scale of response. For example, York (1995) correlated northern fur seal (*Callorhinus ursinus*) survival with environmental indices on time lags ranging from months to years before the birth of a cohort. Shorter time lags were used to relate direct effects of temperature on growth while longer lags were used to account for possible changes in production that would affect the food supply of a growing cohort.

Piatt and Anderson (1995) found significant declines in the piscivorous marine bird population in the Bering Sea between the 1970s and the 1990s concurrent with a shift in diet, from one dominated by capelin to one where capelin was essentially absent. Decker et al. (1995) found the diets of marine birds nesting on the Pribilof Islands changed beginning in 1978 (as previously noted). They also found reproductive performance declined.

Declines in the Bering Sea and Gulf of Alaska populations of Steller sea lions, fur and harbor seals have been observed since the mid-1970s (Springer, 1992; Francis et al., 1998; Trites, 1992; Trites and Larkin, 1996; Rosen and Trites, 2000). At the same time, the portion of the Steller sea lion population breeding between southeast Alaska and Oregon has been increasing (Calkins et al., 1999). The magnitude of the sea lion decline is equivalent to a 30-60% reduction in juvenile survival or to a 70-100% decline in female fecundity (Pascual and Adkinson, 1994). Different responses of separate segments of a pinniped population have been shown to be related to the extent of influence of concluded that Steller sea lions would have to eat 35-80% more pollock than herring to maintain similar energy intakes, which is consistent with the junk food hypothesis. It should be noted that Rosen and Trites did not observe an increase in food intake in response to the lower calorie diet. It appears that once physically satiated, the sea lions will not continue to feed.

The change in sea lion diets reflects a combination of changes in diversity and abundance of prey species and an apparent preference of sea lions for small (< 30cm) schooling fish (Merrick et al., 1997). In the Gulf of Alaska, the Atka mackerel population has remained low since the 1980s while pollock populations also declined but were still more abundant than Atka mackerel. However, the pollock that were present in the Gulf of Alaska in 1990-1993 were the larger, older fish. Sea lions in the eastern Aleutian Islands were the only ones examined by Merrick et al. that had a significant amount of herring and sandlance in the diets. Although there is little supporting evidence, this suggests these species were more available here than elsewhere in the Gulf of Alaska and Aleutian Islands.

7. Summary

Environmental variability occurs across many spatial and temporal scales (Francis et al., 1998). The research we reviewed focused on decadal or longer-term variability in both physical and biological time series, although some (e.g., York, 1995) has concentrated on interannual variability. The intent of our review was to identify the timing of the regime shifts that occurred in the 20th century, and to characterize the nature of the biological responses from primary producers through to the top predators in the food chain.

We presented evidence that large-scale changes in atmosphere-ocean climate conditions should not be considered as random variations. Instead, they should be thought of as long term, stable conditions that can sometimes abruptly change state, as occurred over the north Pacific in 1925, 1947, 1977 and 1989 (Beamish et al., 1999; Mantua et al., 1997; Minobe, 1997; Overland, 1999). Changes in atmospheric pressure result in altered wind patterns that affect oceanic circulation and physical properties such as salinity and depth of the halo- and thermoclines. Phytoplankton productivity is directly affected by these physical oceanographic conditions, as shown by the near doubling of the chlorophyll *a* biomass around the time of the 1977 regime shift (Venrick et al., 1987; Venrick, 1994). This doubling was due to a deepening of the mixed layer that resulted from the intensification of the Aleutian Low in 1977 (Polovina et al., 1995). Such direct effects are manifest more quickly than indirect responses.

Regime shifts, such as those that occurred in the north Pacific, can have opposite effects on species living in different domains, or can affect different species living within a single domain in opposite ways. For example, the zooplankton biomass in the central north Pacific more than doubled between the 1950s and the 1980s (Brodeur and Ware, 1992), while off the coast of California the biomass of zooplankton declined by more than 80% (Roemmich and McGowan, 1995). Another example is how the trajectories of salmon populations in the California Current and Gulf of Alaska regions have gone in opposite directions (Francis et al., 1998). Even within the same production domain, groups of species, such as hake and herring in the SOG and off the WCVI, can respond differently (McFarlane et al., 2000a). The opposite response of populations in different regions is also observed for the top predators in the system. For example, Steller sea lion populations have been declining since the mid-1970s in the Bering Sea and Gulf of Alaska (Springer, 1992; Francis et al., 1998; Trites and Larkin, 1996), while populations off south-eastern Alaska to Oregon have been increasing (Calkins et al., 1999).

The effects of climatic forcing on fish are not necessarily easy to predict. Climate may indirectly affect fish populations through changes in predator distribution and abundance. Examples of indirect effects on fishes include the previously mentioned hake-herring interaction and the overlap of adult and juvenile walleye pollock distributions (Bailey, 2000). Climate is also more likely to affect sea birds and mammals in the North Pacific and Bering Sea through indirect means. There are indications that the Steller sea lion decline since the mid-1970s in the Gulf of Alaska and the Aleutian Islands is the result of a change in the relative abundance of different types of prey that are available to Steller sea lions. This change, from a diet dominated by herring and other fatty fishes to one dominated by gadids, may have adversely affected the health of Steller sea lions (Rosen and Trites, 2000).

Fisheries stock assessment has traditionally focused on controlling and limiting the effects of fishing in order to maintain fish populations at fixed viable levels. In addition, the yields from such populations are considered to be indefinitely sustainable. The key inputs required by traditional stock assessment models are the stock-recruitment relationship and the virgin unfished biomass, both of which are assumed to be constant. However, there is a considerable body of scientific literature indicating that the productivity of fish stocks varies naturally in association with climate, and that the effects of fishing are superimposed on this natural regulation. This indicates that a new approach to managing fisheries, one that incorporates climatic as well as fisheries effects, is required.

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Congressional Response/Appropriations Language

- Conference Report (106-1005) – 25 October
- Senate Report (106-404) - 18 July
- "Stevens Rider" *in* Conference Report (106-1033) – 15 December
- Congressional Record (Senate) – 15 December

Meeting Jan. 24-25
Alaska Fisheries Science Center
NMFS / NOAA

Conference Report (HR106-1005)
(25 October 2000)
referenced in
Commerce Appropriations Bill (HR5548)
(18 December 2000)

"The conference agreement includes **$12.3 million** for Steller sea lion recovery, to be allocated according to the direction in the Senate report. The Senate language regarding the Administration's reduction of funding for Steller sea lion recovery is included by reference.

Senate Report (106-404)
(18 July 2000)

"The Committee is greatly concerned by the administration's proposed reduction of spending for Steller sea lion recovery off Alaska. The cause of the Steller sea lion decline is still unknown, and costly limitations which could seriously impede the Nation's most productive fisheries are being implemented. Lawsuits are being filed which challenge the agency's data on the Steller sea lion, and **more resources are needed to enable the agency to produce the science and data to keep these fisheries open while protecting the sea lion population...**"

Senate Report (106-404)
(18 July 2000)

"The Committee, therefore, has provided a total of **$12,300,000** including **$7,000,000** for the National Marine Fisheries Service, **$2,500,000** for the State of Alaska, **$1,000,000** for the Alaska SeaLife Center, **$1,000,000** for the Gulf Apex Predator study at the University of Alaska, and **$800,000** for the North Pacific Marine Mammal Consortium, to address this pressing concern."

Conference Report (HR106-1033)
(15 December 2000)
referenced in
Commerce Appropriations Bill (HR5548)
(18 December 2000)

Section 209 (d) SEA LION PROTECTION MEASURES
$20,000,000 is hereby appropriated to the Secretary of Commerce to remain available until expended to develop and implement a coordinated, comprehensive research and recovery program for the Steller sea lion, which shall be designated to study–

(12 items)

Conference Report (HR106-1033)
(15 December 2000)
referenced in
Commerce Appropriations Bill (HR5548)
(15 December 2000)

Section 208

- $10,000,000 "shall be available only for research regarding litigation concerning the Alaska Steller sea lion and Bering Sea/Gulf of Alaska groundfish fisheries of which..."
- $6,000,000 ~ OAR – "to study the impact of ocean climate shifts on the North Pacific and Bering Sea fish and marine mammal species composition"
- $2,000,000 ~ NOS – "to study predator/prey relationships as they relate to the decline of the western population of Steller sea lions"
- $2,000,000 ~ NPFMC – "for an independent analysis of Steller sea lion science and other work related to such litigation"

(1) available prey species;
(2) predator/prey relationships;
(3) predation by other marine mammals;
(4) interactions between fisheries and Steller sea lions, including the localized depletion theory;
(5) regime shift, climate change, and other impacts associated with changing environmental conditions in the North Pacific and Bering Sea;
(6) disease;
(7) juvenile and pup survival rates;
(8) population counts;
(9) nutritional stress;
(10) foreign commercial harvest of sea lions outside the exclusive economic zone;
(11) the residual impacts of former government-authorized Steller sea lion eradication bounty programs; and
(12) the residual impacts of intentional lethal takes of Steller sea lions

Within available funds the Secretary shall implement on a pilot basis innovative non-lethal measures to protect Steller sea lions from marine mammal predators including killer whales

Congressional Record (Senate)
(15 December 2000)

Section-by-Section Analysis (page S11857):

"Subsection (d) appropriates $20,000,000 to the Secretary of Commerce..."

"...The Alaska SeaLife Center should receive **$5,000,000** of these funds to continue their important work on Steller sea lion science."

Funding Landscape

FY02 Steller Sea Lion Research and Management: **$43.15 million**

$850 K - NMFS

$12.3 million:

$7.0 million – NMFS

$2.5 million – State of Alaska

$1.0 million – University of Alaska

$1.0 million – Alaska SeaLife Center

$0.8 million - NPUMMRC

$10.0 million:

$6.0 million – OAR

$2.0 million – NOS

$2.0 million – NPFMC

$20.0 million:

$5.00 million – ASLC

$5.44 million – NMFS mgt. (Region/HQ)

$5.00 million – FY02 Contingency Fund

$4.56 million – Unspecified research and management that the Commerce Department has proven, let alone adequately tested, its hypothesis that fishing contributes to the sea lions' decline. A few minutes spent skimming the biological opinion reveals the lack of science underlying the proposed actions it contains. For example, the Commerce Department states in its biological opinion that it does not know if fishing impacts sea lions, or that sea lions would likely continue to decline even if all fishing were halted.

Nonetheless, the lives of our fishermen will continue to be affected by this opinion. Our agreement provides a three-step phase-in process for fishery restrictions proposed to be implemented by the National Marine Fisheries Service (NMFS) in the Alaska groundfish fisheries under Endangered Species Act (ESA) requirements. This section is intended to lessen the negative economic consequences to the fishing community caused by the restrictions and to ensure that any Steller sea lion protective measures do not create negative consequences for the conservation of the fisheries and ecosystem. This is accomplished by requiring the Secretary to rely on the fishery management provisions in the Magnuson-Stevens Act, including the regional council processes, when implementing reasonable and prudent alternatives under the Endangered Species Act.

Unfortunately, work on this provision was not completed until shortly before the conference agreement was filed on the final day of this session. I ask unanimous consent that the section-by-section analysis of this provision be printed in the RECORD.

There being no objection, the material was ordered to be printed in the RECORD, as follows:

SECTION-BY-SECTION ANALYSIS

Subsection (a) includes findings by Congress concerning the decline of the Steller sea lion and need for scientists to study the relationship between commercial fisheries and sea lions. It also includes findings confirming that the authority to manage federal fisheries lies with the regional councils created under the Magnuson-Stevens Act. It clarifies that the Secretary is required to comply with, and use the procedures established under, the Magnuson-Stevens Act when implementing measures to comply with the Endangered Species Act. This finding recognizes that the Administration should not use the Endangered Species Act to implement fishery management measures without respect to the Magnuson-Stevens Act, particularly the processes by which the councils develop, review, and promulgate fishery management measures. The appropriate forum to develop fishery management measures, including those measures necessary to protect threatened and endangered species, are the regional councils.

Subsection (b) requires the North Pacific Fishery Management Council to conduct an independent scientific review of the November 30, 2000 biological opinion (hereafter the "Opinion") issued by NMFS for the Bering Sea/Aleutian Islands and Gulf of Alaska groundfish fisheries, drawing upon the expertise of the National Academy of Sciences. This subsection reflects the Congress's deep concerns over the validity and objectivity of the science relied on in the biological opinion and the process by which the Commerce Department developed this opinion. It directs the Secretary of Commerce to cooperate with the North Pacific Council's scientific review, and requests the National Academy of Sciences to give the review its highest priority.

Subsection (c)(1) directs the Secretary to submit proposed Magnuson-Stevens Act fishery conservation and management measures to implement the reasonable and prudent alternatives (RPAs) to the North Pacific Council immediately or as soon as possible, and then tasks the Council with preparing a fishery management amendment or amendments under the Magnuson-Stevens Act to implement such conservation and management measures. While the amendments must implement the measures necessary to protect sea lions and, it is equally important that such measures provide for the conservation and safe conduct of the fisheries, as required in the Magnuson-Stevens Act. Congress remains concerned that the proposed closures would have forced small vessels to fish in dangerous waters during the winter storm season, a prospect specifically commented upon by our Coast Guard.

Subsection (c)(2) requires the RPAs, as developed by the North Pacific Council under subsection (c)(1), to become effective on January 1, 2002. To address Congress' concerns about the objectivity and validity of the scientific conclusions of this opinion the opinion must incorporate changes warranted by the scientific review required under subsection (b) or other new information that comes to the Secretary or Council's attention. The Council and Secretary are directed to jointly develop a schedule for the development of FMP amendment or amendments to implement the RPAs beginning in the 2002 fisheries. Subsection (c)(2) specifies that the RPAs shall not go into effect immediately, but shall be phased in according to subsection (c)(3) during the 2001 fisheries.

Subsection (c)(3) requires the 2001 Bering Sea/Aleutian Island and Gulf of Alaska groundfish fisheries to be managed in accordance with the regulations promulgated for the 2000 fisheries prior to the issuance of the July 19, 2000 court injunction in those fisheries (which has since been lifted). The 2000 regulations provide substantial protections for Steller sea lions, while maintaining the comprehensive and proven framework that has protected the marine resources of the North Pacific and been fine-tuned for more than two decades. These regulations for the first months of the 2001 fisheries are to be implemented by emergency rule so that the fisheries can begin by January 20, 2001.

Subsection (c)(4) requires the Secretary of Commerce to amend regulations based on the 2000 regulations, but which are consistent to the extent practicable with the RPA's, by January 20, 2001. The Secretary is to consult with the North Pacific Council in preparing these draft regulations, with the goal of incorporating some of the protective concepts in the RPAs for these regulations, in time for the fisheries to open no later than January 20, 2001. Under paragraph (7) of subsection (c), the draft regulations amended upon the recommendation of the North Pacific Council until March 15, 2001. As soon after March 15, 2001 as possible, the Secretary of Commerce will publish and implement the regulations, and these regulations shall then govern the Bering Sea/Aleutian Island and Gulf of Alaska fisheries for the remainder of 2001, consistent with all the requirements of the Magnuson-Stevens Act. It is our intent that the Secretary provide ample opportunity for the public to comment on these regulations before the regulations take effect.

Subsection (c)(5) requires that the "Global Control Rule" from the RPA's take effect immediately in the fisheries, this is particularly important during the period during the Spring and/or early summer of 2001 when the fisheries are being managed under the 2000 regulations. Paragraph (5) modifies the Global Control Rule during 2001 to limit any reduction to not more than ten percent of the total allowable catch in any of the fisheries.

Subsection (c)(6) provides the North Pacific Council with the authority to recommend, and the Secretary of Commerce with the authority to approve, modifications to the RPAs contained in the regulations that will take effect in the Spring or early-summer of the 2001 fisheries. These modifications may include the opening of additional designated Steller sea lion critical habitat for fishing by small boats, the postponement of seasonal catch levels inside critical habitat for small boats, or other measures to ensure that small boat fishermen and on-shore processors in Alaska are not adversely affected during 2001 as compared to the fisheries before the July 19, 2000 injunction. This was specifically agreed to by both the Congressional and Administration negotiators to allow coastal Alaskan fishermen to fish in the safer waters closer to shore.

Subsection (d) appropriates $20 million to the Secretary of Commerce to develop and implement a comprehensive research and recovery program for the Steller sea lion, and to study the myriad of factors which may be causing the decline of the Steller sea lion. Subsection (d) specifically requires that the theories of nutritional stress, localized depletion, and food competition with the fisheries be tested to determine their validity. This subsection also directs the Secretary of Commerce to implement non-lethal measures on a pilot basis to protect Steller sea lions from marine mammal predation, including killer whales, and to determine the extent to which predation may be causing the decline or preventing recovery. The Secretary is strongly encouraged to cooperate with the Alaska SeaLife Center, the North Pacific Universities Marine Mammal Consortium, the University of Alaska, and the North Pacific Council in the development and use of these funds. The Alaska SeaLife Center should receive $5,000,000 of these funds to continue their important work on Steller sea lion science.

Subsection (e) provides $30 million as a direct payment to the Southwest Alaska Municipal Conference to distribute to the fishing communities, businesses, western Alaska community development quota program groups, individuals, and other entities that have been hurt by the economic losses already inflicted as a result of Steller sea lion restrictions. The President of SWAMC is required to submit a written report to the Secretary of Commerce and the U.S. Senate and House appropriations committees within six months after receiving the funds to indicate how they have been distributed.

Mr. BYRD. Mr. President, in these waning days and hours of the 106th Congress, the focus in Washington is naturally on what action is taking place to resolve the remaining fiscal year 2001 appropriations bills and concluding the business of this Congress. However, all around us, life goes on. Our constituents in the steel industry must be among the few in America who will not be happy to see the 106th Congress adjourn sine die. Our constituents in the steel industry will see Congress's adjournment as a thinning of the bucket brigade that has spent the last two years trying to bail out an including--

(A) conservative total allowable catch levels;

(B) no entry zones within three miles of rookeries;

(C) restricted harvest levels near rookeries and haul-outs;

(D) federally-trained observers;

(E) spatial and temporal harvest restrictions;

(F) federally-mandated bycatch reduction programs; and

(G) additional conservation benefits provided through cooperative fishing arrangements,

and said regulations are hereby restored to full force and effect.

(4) The Secretary shall amend these regulations by January 20, 2001, after consultation with the North Pacific Council and in
a manner consistent with all law, including the Magnuson-Stevens Act, and consistent with the Alternatives to the maximum
extent practicable, subject to the other provisions of this subsection.

(5) The harvest reduction requirement (``Global Control Rule'') shall take effect immediately in any 2001 groundfish fishery in
which it applies, but shall not cause a reduction in the total allowable catch of any fishery of more than ten percent.

(6) In enforcing regulations for the 2001 fisheries, the Secretary, upon recommendation of the North Pacific Council, may
open critical habitat where needed, adjust seasonal catch levels, and take other measures as needed to ensure that harvest
levels are sufficient to provide income from these fisheries for small boats and Alaskan on-shore processors that is no less than
in 1999.

(7) The regulations that are promulgated pursuant to paragraph (4) shall not be modified in any way other than upon
recommendation of the North Pacific Council, before March 15, 2001.

(d) SEA LION PROTECTION MEASURES.--$20,000,000 is hereby appropriated to the Secretary of Commerce to
remain available until expended to develop and implement a coordinated, comprehensive research and recovery program for
the Steller sea lion, which shall be designed to study--

(1) available prey species;

(2) predator/prey relationships;

(3) predation by other marine mammals;

(4) interactions between fisheries and Steller sea lions, including the localized depletion theory;

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(5) regime shift, climate change, and other impacts associated with changing environmental conditions in the North Pacific
and Bering Sea;

(6) disease;

(7) juvenile and pup survival rates;

(8) population counts;

(9) nutritional stress;

(10) foreign commercial harvest of sealions outside the exclusive economic zone;

(11) the residual impacts of former government-authorized Steller sea lion eradication bounty programs; and

(12) the residual impacts of intentional lethal takes of Steller sea lions. Within available funds the Secretary shall implement
on a pilot basis innovative non-lethal measures to protect Steller sea lions from marine mammal predators including killer
whales,

(e) ECONOMIC DISASTER RELIEF.--$30,000,000 is hereby appropriated to the Secretary of Commerce to make
available as a direct payment to the Southwest Alaska Municipal Conference to distribute to fishing communities, businesses,
community development quota groups, individuals, and other entities to mitigate the economic losses caused by Steller sea lion
protection measures heretofore incurred; provided that the President of such organization shall provide a written report to the
Secretary and the House and Senate Appropriations Committee within six months of receipt of these funds.

GENERAL PROVISION--THIS CHAPTER

SEC. 213. (a) The provisions of H.R. 5548 (as enacted into law by H.R. 4942 of the 106th Congress) are amended as
follows: