NORTH PACIFIC UNIVERSITIES
MARINE MAMMAL
RESEARCH CONSORTIUM

ANNUAL REPORT 2007-2009

THE UNIVERSITY OF ALASKA
OREGON STATE UNIVERSITY
THE UNIVERSITY OF BRITISH COLUMBIA
THE UNIVERSITY OF WASHINGTON

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SUPPORTING MARINE SCIENCE

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FOREWORD

The North Pacific Ocean is unlike anywhere else on Earth. Wild and unpredictable, it is a place of extremes: light and darkness, tempest and calm, feast and famine, birth and death.

The coastal regions of the North Pacific are home to an unparalleled richness of marine life – thousands of known species with more still to be discovered – which collectively make an unfathomable contribution to global biodiversity.

But survival here is never guaranteed, even for the strong. Alarming and unexplained shifts in key predator populations in recent decades have snapped into focus the fragile nature of life in the North Pacific.

Can entire populations of northern fur seals and Steller sea lions, two of the ocean's most formidable predators, virtually disappear in less than 40 years? And if so, which of nature's mechanisms determine the success or failure of these populations? Is human activity to blame, or are they simply casualties of the ocean around them?

Dozens of scientists, working collaboratively under the **North Pacific Universities Marine Mammal Research Consortium**, are seeking the answers to these questions and many more.

This report represents two years of their work.

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OVERVIEW

STUDYING CHANGE IN THE NORTH PACIFIC OCEAN

Change is constant in the North Pacific Ocean, but the past 40 years have seen major shifts in the abundance of seals, sea lions, whales and seabirds. In Alaska, harbor seal populations are greatly reduced, northern fur seals are depleted, and Steller sea lions have been declared endangered in parts of their range. Similar declines have been reported in some seabird breeding colonies.

Meanwhile, populations of Steller sea lions and harbor seals have increased in British Columbia. Further south, striking increases are also being observed in the range and abundance of elephant seals and California sea lions.

Are these large-scale changes a natural phenomenon? Or are they connected to similar changes occurring simultaneously in a number of commercial fisheries? While their causes may remain unclear, their effects on key marine mammal species are evident: in 1990, the Steller sea lion was classified as a threatened species under the U.S. Endangered Species Act.

Then, in 1997, the Steller sea lion was divided into two distinct populations: those east of Prince William Sound were declared threatened, while those to the west were classified as endangered. These classifications forbid commercial or industrial activity that could 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 humans 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 catch by fishermen may also play significant roles.

The decline of northern fur seals on the Pribilof Islands is equally perplexing and is likely caused by whatever underlies the decline of Steller sea lions. However, whether the decline is caused by a single factor or a combination of the above is a matter of scientific debate: limited data has so far prevented the resolution of this question. However, research investigating the leading hypotheses of killer whale predation and nutritional stress is receiving ever-increasing attention. The interactions between fisheries and marine mammals are the subject of intensive research in many parts of the world and will continue to be a major focus of research in the North Pacific.

The North Pacific Universities Marine Mammal Research Consortium was formed in 1992 with four participating institutions: the University of Alaska, Oregon State University, the University of British Columbia and the University of Washington. Its mission is to undertake a long-term program of research on marine mammals and their interactions with fisheries, other species and oceanographic conditions in the North Pacific Ocean and Eastern Bering Sea.

The research program 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 integrated studies draw on the expertise of university-based physiologists, engineers, ecologists, marine mammalogists, fisheries specialists, oceanographers, and mathematical modelers. Only through a concerted effort and a commitment to long-term research can we hope to determine the causes of changes in the North Pacific.

Consortium researchers have completed their fifteenth full year of research. This report reviews their accomplishments from April 2007 to March 2009 and synthesizes some of the findings published during this period.

The Consortium's research program consists of four components:

1. **Field studies** contrasting healthy sea lion populations in Southeast Alaska, British Columbia and Oregon with declining populations in the Gulf of Alaska; and hands-on investigation of declining northern fur seal populations on the Pribilof Islands;
2. **Captive studies** on Steller sea lions and northern fur seals to enable the development and testing of new techniques and technologies for studying marine mammals in the wild; and to provide information that field studies cannot, including physiological data, nutritional requirements and how they use energy derived from food;
3. Developing **new measurement techniques** for processing biological samples; and
4. **Interdisciplinary studies** that analyze historical data sets, construct mathematical models and involve laboratory analysis.

ORGANIZATION & PERSONNEL

NORTH PACIFIC MARINE SCIENCE FOUNDATION

Implementing sound management policies governing human activities requires decision-makers to have a better understanding of the relationship between such activities and the surrounding ecosystems.

The North Pacific Marine Science Foundation, which funds the research program of the Consortium, was formed specifically for this purpose.

Contributions to the Foundation have come from other foundations, federal grants, coastal communities, businesses and a wide spectrum of donors representative of the fishing industry.

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The Consortium's research program is overseen by a Scientific Advisory Committee made up of representatives from universities, industry, and government agencies.

A Research Committee, composed of research leaders from the four universities and three government institutions, is responsible for preparing a proposal for research each year and for reporting on progress to the Scientific Advisory Committee.

The Consortium is administered by the Marine Mammal Research Unit of the Fisheries Center at the University of British Columbia. Core staff consists of a Research Director, Dr. Andrew W. Trites, and an Administrative Manager, Pamela Rosenbaum.

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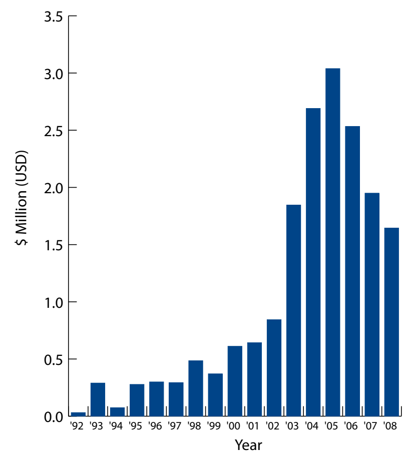


The Consortium received startup funding in late 1992 and full-year funding beginning in 1993. In 1994, our fiscal schedule changed from the calendar year to April 1 – March 31. As of the 1999–2000 year, federal grants were recorded in the year expenditures were made.

SURVEYING SEA LION DIETS IN SOUTHEAST ALASKA

FIELD STUDIES

By allowing scientists to observe wild animals in their changing natural environment, field studies provide information that captive studies often cannot. As such, field work is an essential component of the Consortium's research mandate. Field data is often compared, where appropriate, with data from captive studies; together they present Consortium scientists with as holistic and realistic a picture as possible of the North Pacific Ocean and its denizens.

In 2006–07, a legal dispute between the U.S. National Marine Fisheries Service and the Humane Society of the United States significantly hindered the Consortium's ongoing field research in the North Pacific. This lawsuit represented a 'lost opportunity' to collect field data, which may have a lasting impact on the research program. Field studies in 2007-09 continued following this interruption, but the loss of an entire season of data may have long-term implications.

Consortium field research in 2007-09 included a survey of sea lion haul-outs and rookeries based on scat samples collected from multiple locations over multiple seasons. Sea otter researchers also examined the relationship between otters, sea urchins and kelp in nearshore ecosystems.

Trites, A.W., D.G Calkins and A.J. Winship. 2007. **Diets of Steller sea lions *(Eumetopias jubatus)* in Southeast Alaska from 1993-1999.** *Fishery Bulletin* 105:234-248.

Steller sea lion populations in western Alaska mysteriously and dramatically declined through the 1980s and 1990s. During that same time, sea lion populations in Southeast Alaska increased. Although a number of factors may have contributed to these diverging population trends, a likely explanation may lie in dietary differences between these populations.

A shift in the quantity, quality, or availability of key prey has dramatic consequences for sea lions, which have a daily energy requirement for swimming, foraging, nursing, and breeding. Understanding dietary differences between sea lion populations in western Alaska and Southeast Alaska may help to explain why one population declined while the other increased.

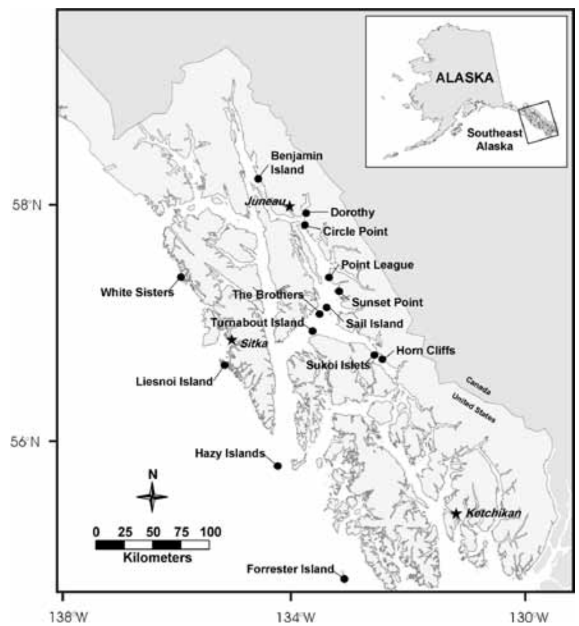
It may be, for example, that Steller sea lions in Southeast Alaska ate a wider range of prey and therefore had a more diverse diet. Or, perhaps their diet did not include a significant amount of low-calorie prey such as pollock. By collecting and analyzing fecal (scat) samples obtained from wild sea lions, scientists can determine the type and frequency of prey in the sea lion diet.

In a new dietary study, researchers sought to determine the diet of Steller sea lions in Southeast Alaska. They analyzed some 1,494 scat samples collected between 1993 and 1999 at 3 major breeding sites (rookeries) and 12 nonbreeding sites (haulouts).

Diversity in Diet

The authors report that a comparison of their dietary data from Southeast Alaska with dietary data collected from other regions of Alaska indicated that Steller sea lions consumed similar schooling species, most notably pollock, salmon, herring, sandlance, rockfish, and squid. However, in terms of frequency of occurrence, there were significant dietary differences between Southeast Alaska during the 1990s and regions where sea lions declined.

The researchers found that the sea lion diet was more diverse in Southeast Alaska during the 1990s than in any other region of Alaska, and may have had a higher energy content overall. They also discovered that the sea lions consumed the most diverse range of prey categories during the summer breeding season, and the least diverse in the fall.



Major rookeries (White Sisters, Hazy Island and Forrester Island) and haulouts (all other sites) of Steller sea lions in Southeast Alaska from 1993-99. Labeled sites indicate where scats were collected.

These findings support a previous study that discovered a positive relationship between the diversity of summer sea lion diets and the rate of population change in areas of decline in the early 1990s (i.e., the greater the diet diversity, the slower the rate of population decline). The authors suggest that sea lions enjoying a diverse, energy-rich diet may be less sensitive to the effects of ocean climate or human fisheries on any single prey population.

Another advantage of a diverse, energy-rich diet is that it should be easier to find enough prey to meet daily energy requirements. Sea lions with a less diverse or less energy-rich diet would have to forage longer to consume enough food to meet their energy needs. This, in turn, might increase their risk of encountering killer whales or sharks, contributing to a further decline in the population.

The Importance of Pollock

The scats collected during the 1990s revealed that pollock were the most frequently occurring food item at haulouts during the nonbreeding season, and were second in importance only to salmon at rookeries during the summer breeding season.

"Since the mid 1970s, pollock has been one of the most dominant species in the Bering Sea and Gulf of Alaska ecosystems," the authors write. "Unfortunately, little is known about the distribution and relative importance of pollock in the Southeast Alaska ecosystem. It is unclear what role pollock and Atka mackerel stocks alone have played in the different trajectories of Steller sea lion populations."

The authors note that pollock was not as dominant in the sea lion diet in Southeast Alaska as it was in other regions, and was usually part of a diverse diet that included energy-rich prey such as herring or salmon. This did not appear to be the case in areas of decline in the Gulf of Alaska, where pollock has dominated a much less diverse diet.

This study provides valuable insights into the composition of Steller sea lion diets in Southeast Alaska. In addition, it opens the door for future research into the relative importance of pollock in Southeast Alaska, and emphasizes the ongoing need to continue to assess and monitor sea lion diet as an indicator of population change.

GROOMING THE KELP FOREST

IS THERE A UNIVERSAL LINK BETWEEN OTTERS, URCHINS AND KELP?

Carter, S.K., G.R. VanBlaricom and B.L. Allen. 2007. **Testing the generality of the trophic cascade paradigm for sea otters: a case study with kelp forests in northern Washington, USA.** *Hydrobiolgia* 579:233-249.

Early in the twentieth century, a rampant fur trade devastated sea otter populations along the west coast of North America. Decades later, several of these populations were restored in an effort to conserve the species. This ecological 'disappearing act' has provided scientists with a unique opportunity to examine what happens to a marine ecosystem when the apex (top) predator is removed and later reintroduced.

One leading theory suggests that removing sea otters triggers a cascade of changes through lower levels of the food web; specifically, by allowing their key prey, sea urchins, to flourish. The herbivorous urchins graze on enormous amounts of seaweed, collapsing the kelp forest ecosystem and leaving behind only rocky 'urchin barrens'. Kelp forests have been observed to return following the reintroduction of sea otters, which seems to support the idea that sea otters are a keystone species that plays a critical role in kelp forest ecosystems.

A group of Consortium scientists sought to test the universality of the trophic cascade theory as it applies to sea otters and kelp forests. They wanted to know whether sea otters always reduce urchin populations and thus promote kelp growth. Is this theory of trophic cascade applicable to all kelp forests from Alaska to Washington? Or could other factors such as physical disturbance be equally important? What implications might this have for the way otter populations – and the lucrative commercial urchin fishery – are managed?

Analyzing urchins

At a sheltered study site within San Juan Channel, the scientists simulated three levels of experimental urchin harvest: a monthly removal that mimicked near-constant sea otter predation; an annual removal that simulated the commercial harvest of the largest specimens; and a control site in which no urchins were harvested.

The first objective of the study was to determine whether the real effects of sea otter predation (i.e., those previously observed along outer or unprotected coastlines) were the same as those simulated in the physically protected waters of San Juan Channel. Second, the scientists sought to clarify whether differences in the timing, duration and size-selectivity of otter predation (versus commercial harvesting) had an indirect bearing on the ecology of the kelp forest.

"The two experimental urchin removal treatments did not significantly increase the density of perennial or annual species of macroalgae [kelp] after two years, despite significant and persistent decreases in urchin densities," the authors write, pointing to other influential factors including: grazing by other invertebrates, the density of certain perennial kelp species such as *Agarum*, and the frequency at which kelp and invertebrate populations grow.

These factors, they note, may significantly influence community structure in San Juan Channel as well as other physically protected marine waters that feature sea otters. Thus, if the Washington sea otter population were to expand into San Juan Channel, the authors suggest it would likely not cause the same dramatic changes in kelp forest ecosystems that have been documented along exposed coastlines.

The critical difference between these habitats hinges on the relative composition of *Agarum*, a species of macroalgae. *Agarum* tends to form denser stands in sheltered areas than it does along turbulent, exposed coastlines. An established *Agarum* stand uses shading, abrasion and possibly chemical defenses to limit the growth of competing algae species and to resist grazing invertebrates, including urchins. Because of this chemical defense, a sheltered kelp forest (with dense *Agarum* stands) is less vulnerable to increases in urchin population than an exposed kelp forest, which is typically more diverse because of *Agarum*'s inability to tolerate heavy wave action. Thus the grazing of non-defended algae by urchins in these areas is more widespread and significant.

Conservation concerns

The results of this study support the suggestion that sea otters are only one of several factors that may regulate urchin populations in nearshore waters. They also refute the assertion that the sea otter–trophic cascade paradigm is universally applicable across locations or habitat types. From a conservation perspective, the authors encourage managers to ensure that any otter-urchin management policies are built on sound, reproducible science that is specific to the geographical region in question.

TREADING LIGHTLY

SCIENTISTS SEEK TO REDUCE DISTURBANCE ON ROOKERIES

Trites, A.W., and D.G. Calkins. 2008. **Diets of mature male and female Steller sea lions differ and cannot be used as proxies for each other**. *Aquatic Mammals* 34:25-34.

To better understand the diet of wild Steller sea lions populations, Consortium scientists visit haulouts and rookeries to collect fecal (scat) samples, which they then analyze for prey remains. However, scat collection often requires displacing the animals that are onshore, which can be disruptive in breeding areas (rookeries) at certain times of year.

To reduce disturbance on rookeries, scientists proposed using scats from adjoining bachelor male (non-breeding) haulouts as a proxy. If the scats of non-breeding males are similar enough in composition it may eliminate the need to disturb breeding females. Consortium researchers tested this hypothesis and published their findings in the journal *Aquatic Mammals*.

Sampling Protocol

"We sought to develop a scat-sampling protocol that would minimize disturbance to Steller sea lions during the breeding season yet would yield accurate data about what sea lions eat," the authors write. They compared scats from sexually mature Steller sea lions at one male haulout with those from three female-dominated rookeries at Forrester Island in southeast Alaska.

If the diet of bachelor bulls was similar enough to that of nearby breeding females, it could be useful as a proxy in future studies. That is, it could help to predict the diet of females without sampling the breeding population and with minimal intrusion on the nearby bachelor bulls. Further, if the scats indicated a similar diet among the females, samples collected from one rookery could help to further reduce disturbance by predicting the diets of all local breeding females.

Shared Diet

"We found that it is not necessary to sample scats from all of the breeding sites that make up the Forrester Island complex because females using these rookeries all have the same diet," the authors reported. Female diets contained gadids, salmon and small oily forage fish, with fewer rockfish, flatfish, cephalopods, and other fishes.

Compared to females, males consumed significantly fewer salmon and more pollock, flatfish, and rockfish. These dietary differences suggest that males and females may forage in separate areas, or that their relative physical size affects their ability to capture certain prey.

This study shows that female diets can be determined from samples collected at a single site within a rookery complex. Thus, a rotating schedule of scat collection from one breeding group could determine the diet of all local breeding females while reducing long-term disturbance in the population. Unfortunately, the male diet at Forrester Island differed sufficiently from that of breeding females to prevent its use as a proxy for female diet.

To ensure the long-term conservation of the species, scientists must balance the need to accurately determine what Steller sea lions eat with the cost of obtaining this information. Future comparisons of dietary information from other rookeries and haulouts in Alaska will help to determine how many rookeries and haulouts need to be sampled to accurately determine what Steller sea lions are eating.

A FEAST OF FUR SEALS

STUDYING KILLER WHALE PREDATION IN THE PRIBILOF ISLANDS

This past summer, a research team headed by veteran killer whale researcher Craig Matkin ventured to the Pribilof Islands, a cluster of five tiny islands in the heart of the Bering Sea that hosts the largest population of northern fur seals in the world. The team's goal was to investigate whether predation by mammal-eating transient killer whales is having an effect on the already-declining numbers of fur seals in the Pribilofs.

"Since the 1920s there have been reports of killer whales attacking fur seals in the Pribilofs, but nobody had looked at it that closely," Matkin says. "We had no idea of when or how often it happens, or how serious an effect it has on the population."

Living aboard a 45-foot research boat for five-and-a-half weeks, the research team logged 35 research days between July 5 and August 13. With the help of a land-based sightings network set up by local biologists Bruce Robson and Phil Zavidil, Matkin and his research partner, John Durban, tallied a total of 22 kills or harassments of fur seals, 10 of which were certain kills.

"We identified 28 individual killer whales right away, and resighted them in various groups during the study," Matkin recalls. "We also tagged a couple of whales with satellite tags to track their movements, and we found a real pattern in the way they behaved."

Matkin and team found that the killer whales typically rested offshore during the day, as far as 15-20 nautical miles from St. Paul Island, the largest of the Pribilof Islands, and would return to the island to forage between midnight and 4 a.m. Most of the 22 predation events observed by the researchers lasted up to half and hour, and occurred late at night or very early in the morning.

Disappearing act

"The interesting thing, and what we didn't expect, is that it was quite lively until July 21, and after that most of the killer whales just left, even the tagged ones," Matkin says. "It was amazing."

The sudden disappearance of the killer whales, though perplexing, might be explained by the seasonal changes in their prey. Body condition (including body fat) of male and female fur seals likely declines after they arrive on land to breed, making fur seals less nutritious in late July and August. Matkin suspects that the fur seals' deteriorating body condition in late summer may make them less appealing prey to killer whales. "Apparently, the killer whales come back in late September when the newborn pups take to the water for the first time," he notes.

Further research

Matkin remarks that St. Paul provided him and his colleagues with a "wonderful natural laboratory" in which they could observe predation occurring within a limited area. The researchers collected excellent data on short-term movement, from which they hope to determine predation rates and the potential impact of killer whales on fur seal populations during the summer.

"We made good progress in understanding how many killer whales were around and when predation was occurring," Matkin says. "We also discovered something we didn't expect at all: that the animals leave in the middle of the summer. Now we need to find out what happens during the earlier and later parts of the season in order to get a full picture of predation rates."

To this end, Matkin is analyzing samples of killer whale blubber, which contains the unique lipid-fatty acid signatures of prey consumed up to 1.5 months earlier. Thus, the blubber samples obtained in mid July should reflect what the whales were eating in early June.

Another part of the research involves recording the killer whales' vocalizations with underwater microphones. Matkin will compare his own field data, which documents the time and location of 22 kills, with concurrent recordings of each event made from remote autonomous recorders placed on the sea floor and recovered by Kelly Newman, a graduate student at the University of Alaska Fairbanks.

"Transient killer whales vocalize loudly after kills," Matkin notes. "If we can consistently identify the number of kills just by listening, we can tally them remotely. This would allow us to study the whales year-round, not just in the summer when the seas are calm enough for field work."

AT HOME ON THE COAST

WHAT MAKES A GOOD SEA LION HOME?

Ban, S. and A.W. Trites. 2007. **Quantification of terrestrial haul-out and rookery characteristics of Steller sea lions.** *Marine Mammal Science* 23:496-507.

For thousands of years, Steller sea lions have occupied some of the most barren and remote coastlines in the North Pacific. A key to their survival has been the careful selection of terrestrial habitats – haulouts for resting, and rookeries for breeding – that offer some protection against wind, weather and predators.

Yet the rationale for selecting and inhabiting some locations, while ignoring others, remains a mystery to scientists. *How do sea lions judge a section of shoreline suitable or unsuitable for breeding or hauling out? Do sea lions in the declining western populations select different types of habitat than their thriving eastern counterparts?* In the hands of managers, this information could help conserve dwindling populations by identifying key shorelines or forecasting the effects of climate change.

To address this paucity of information, Consortium researchers quantified the types of terrestrial habitat used by Steller sea lions at rookeries and haulouts in British Columbia and Alaska.

Exposed Coastlines

By studying shoreline classification data – detailed descriptions of shorelines issued by the U.S. and Canadian governments to aid in oil spill response – the researchers assessed the general characteristics of some 294 known haulouts and 38 rookeries.

"Classifying and comparing the shoreline type of haulouts and rookeries against sites not used by Steller sea lions showed that they preferentially locate their haulouts and rookeries on exposed rocky shorelines and wave-cut platforms," they write. "Shoreline types used less frequently by sea lions included fine-to-medium-grained sand beaches, mixed sand and gravel beaches, gravel beaches, and sheltered rocky shores."

While there were differences in the distribution of haulouts and rookeries among shoreline types, the authors did not find rookeries on sheltered sites as expected, where pups would be better protected from storms.

Thus, the relative shelter offered by a site does not appear to be a consideration when colonizing a site. Instead, the researchers suggest that other factors may drive site selection, such as protection from predation by bears and wolves, or proximity to key foraging areas.

Range of Habitats

By surveying sites across the entire North American range, the researchers sought to better understand why western populations dwindled while eastern populations held relatively steady. Both populations had access to and utilized similar shoreline types; however, a higher proportion of sites in the western population favored wave-cut platforms, while eastern sites favored exposed rocky shorelines.

Overall, the authors conclude that site selection likely involves either an optimization or compromise of two factors: the nearness to favorable foraging areas, and the degree of difficulty in entering or exiting the water during different tidal heights.

INTERDISCIPLINARY STUDIES

To complement the established program of traditional field, captive and laboratory studies, Consortium researchers also engaged in a number of forward-thinking studies requiring innovative and interdisciplinary analytical techniques.

In 2007-09, these studies included a survey of shoreline classification data in Alaska and British Columbia, using available remote sensing data, to assess the general characteristics of hundreds of known haulouts and rookeries.

Another effort saw Consortium researchers undertake a complex ecosystem mapping exercise with the goal of presenting managers with a viable a new approach to classifying marine ecosystems.

Finally, Consortium researchers combined dietary and climactic data to analyze and refute the proposed Sequential Megafaunal Collapse hypothesis, which suggests that the legacy of commercial whaling has led to the decline of Steller sea lions in western Alaska.

CRITICAL HABITAT REVISITED

RESEARCHERS DEVELOP PREDICTIVE MODEL TO IMPROVE LEGISLATION

Gregr, E.J. and A.W. Trites. 2008. **A novel presence-only validation technique for improved Steller sea lion Eumetopias jubatus critical habitat descriptions.** *Marine Ecology Progress Series* 365:247-261.

Federal laws that designate so-called Critical Habitat for Steller sea lions have played a key role in driving marine mammal conservation policy in Alaska, but the information this designation was based on is now dated. Consortium researchers have used more recent knowledge to better predict the occurrence of sea lions at sea, providing policy makers with new tools to refine and update current legislation designating Critical Habitat.

Legislation such as the *US Endangered Species Act* (1972) plays an important role in designating and protecting habitat that is critical to the survival of a population or species. In the case of western Alaska's endangered Steller sea lion populations, areas designated as Critical Habitat currently include all major haulouts and rookeries and their associated aquatic zones extending 20nmi (37km) seaward, in addition to some larger presumed foraging areas in the Bering Sea (see Figure 1 below).

When this Critical Habitat was designated in 1993 it was likely based on the best available knowledge. This model of Critical Habitat has formed the basis for all subsequent protective legislation for Steller sea lions. However, the rationale for selecting these particular boundaries has never been fully explained or justified. *Do they accurately represent habitat that sea lions frequent and rely upon year-round? Or could knowledge gained in the intervening years be used to develop a more robust and defensible definition of Critical Habitat for this species?*

To answer these and other questions, Consortium researchers developed a series of habitat models to predict the probability of sea lions occurring on a fine scale within the Gulf of Alaska and Bering Sea.

Building a Predictive Model

"We used published information about foraging behavior, terrestrial resting sites, bathymetry, and seasonal ocean climate to develop hypotheses relating life history traits and physical variables to the at-sea habitat of Steller sea lions," the authors write. One hypothesis predicted, for example, that optimal foraging opportunities for Steller sea lions occur near depths of 200m (656ft), based on consistent reports that maximum densities of both bottom-dwelling and free-swimming fish also occur at that depth.

The researchers then divided the survey area – from Southeast Alaska to the end of the Aleutian Island chain – into grids of 3x3 km^2 (3.47 square miles). Applying the eight broad hypotheses, which considered both the accessibility and suitability of sea lion habitat, they developed a series of habitat models predicting the probability of sea lions occurring at sea within each grid (see Figure 2). These models were then compared with actual at-sea observations of sea lions (see Figure 3) using a skewness test to assess how the predicted probabilities related to the observations.

The results were encouraging. The habitat maps produced for adult female sea lions, for example, captured a higher proportion (43.7%) of actual at-sea observations than did the current Critical Habitat model (36.1%).

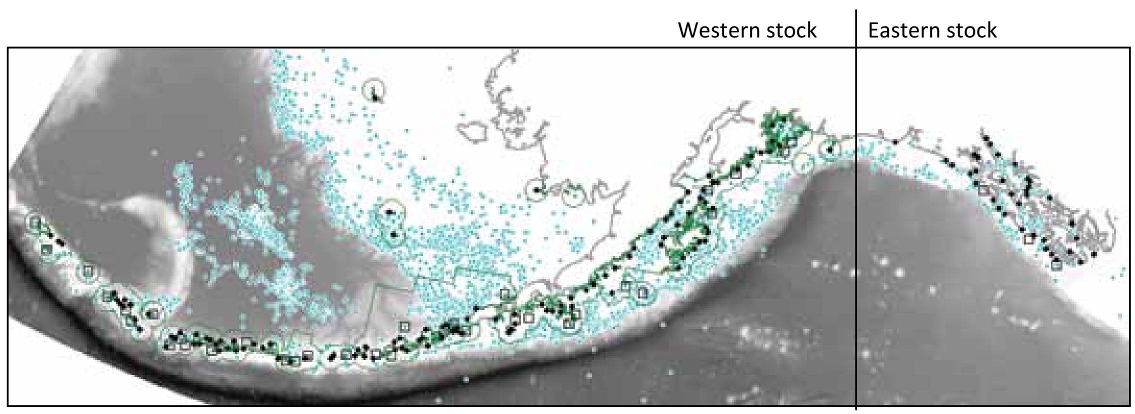


Figure 1: The spatial extents of the study area showing major Steller sea lion terrestrial sites (black symbols), platform of opportunity (POP) sightings of Steller sea lions (green symbols), and designated Critical Habitat (black line). The coastline is in gray and the marine portion is shaded from light to dark in increasing depth.

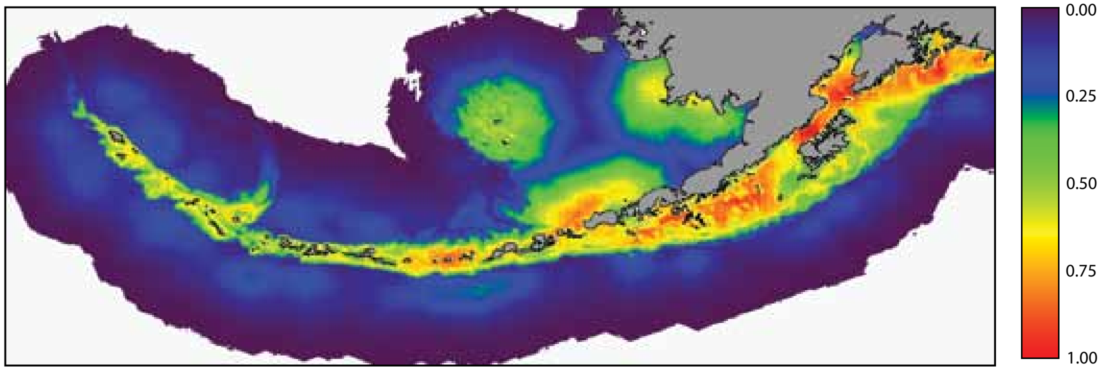


Figure 2: The best performing habitat prediction for adult females during winter (non-breeding season). The model was based on depth and sea surface height variability. Model predictions of 0.0 are shown as white to clearly delimit the spatial extent of non-zero values.

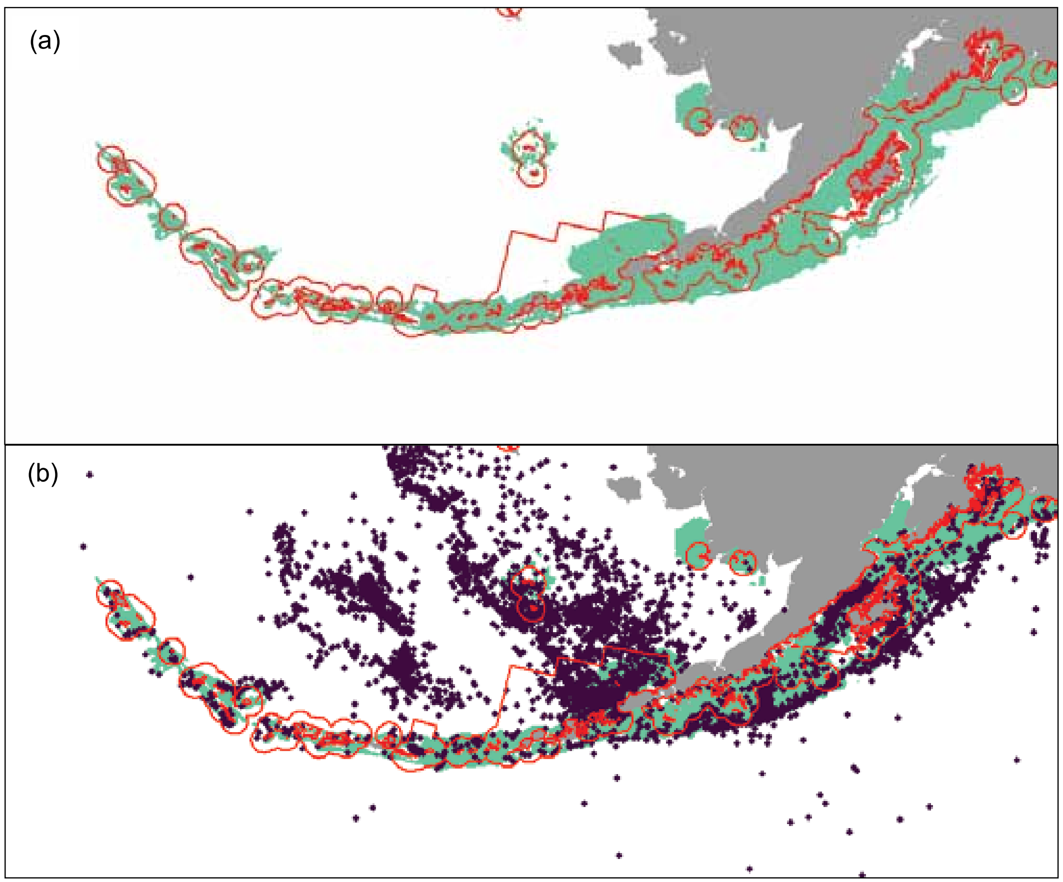


Figure 3: A comparison of the designated model for Steller sea lions (red line) to the best performing predictive model based on hypothesized depth and front suitability. The HS1 model captured 43.7% of the POP observations, while the designated model captured 36.1%. The POP data are overlaid in (b) to support comparisons of the relative model performance.

A Novel Technique

Many studies have described pinniped foraging behavior, but few have used the information gleaned from such studies to develop predictions of where sea lions will occur. The quantitative approach used by the current study to describe fine-scale, at-sea distributions of Steller sea lions across their Alaskan range has not been previously attempted, but the authors maintain that such a prediction is necessary to effectively design, implement and evaluate any measures intended to protect Steller sea lion populations.

"Our results show that explicitly stating *a priori* hypotheses about the relationships between species distributions and physical and biological factors, and subsequently validating the resulting predictions, moves conservation biology and resource management closer to understanding ecosystem function, and places the debate of delineating habitat where it should be—on the state of available knowledge and how the animals are believed to be distributed."

The skewness test played a key role in the model development. Developed by the authors, this test allows presence-only data to be used as a measure of model performance. The authors write "Our goal was to demonstrate that a deductive model could be built with some quantitative rigor in the absence of range-wide survey data. Skewness provides both a quantitative and visual interpretation of how well the predictive models achieve this."

This study opens the door for future habitat models with higher resolutions and smaller spatial extents to address more local movements of sea lions, and eventually, of other wide-ranging marine predators. However, the authors note that a more comprehensive habitat-based definition of Critical Habitat will require developing hypotheses for other age and sex classes, such as juveniles, but this will require more complex at-sea data than is currently available.

APPETITE FOR DESTRUCTION?

RESEARCH PUTS KILLER WHALE PREDATION IN CONTEXT

Trites, A. W., V. B. Deecke, E. J. Gregr, J. K. B. Ford, and P. F. Olesiuk. 2007. **Killer whales, whaling and sequential megafaunal collapse in the North Pacific: a comparative analysis of the dynamics of marine mammals in Alaska and British Columbia following commercial whaling.** *Marine Mammal Sci.* 23:751-765.

There is little doubt that killer whales worldwide have earned their position atop the marine food chain. In the North Pacific Ocean alone, killer whales hunt either fish or marine mammals with a prowess worthy of legend. Some researchers have even suggested that killer whale predation could be responsible for the dramatic decline in western Alaska's seal and sea lion populations in the post-industrial whaling era.

The proposed Sequential Megafaunal Collapse (SMC) hypothesis suggests that commercial whaling robbed western Alaska's transient (mammal-eating) killer whales of their usual diet of large whales, forcing them to prey on smaller mammals such as seals and sea lions. Like all good science, the SMC hypothesis is subject to peer review and was recently critiqued by Consortium researchers.

Are hungry whales to blame for western Alaska's sea lion woes? To find out, the researchers began by reconstructing the "compelling and eloquently simple" SMC hypothesis.

Trophic Cascade

It seems logical to assume that widespread commercial whaling in the North Pacific should have had similar impacts on all coastal ecosystems in the area. On this premise, Trites and colleagues sought to test the Alaskan SMC hypothesis by constructing an identical model for British Columbia. Both models calculated the biomass of whales removed by whaling, and each limited their analysis to similar-sized areas during the post-World War II period of commercial whaling.

Both B.C. and Alaska lost similar amounts of whale biomass to commercial whaling. But contrary to the SMC hypothesis, the authors found that populations of harbor seals, sea lions and sea otters actually increased in B.C. following the end of whaling, while declining in western Alaska.

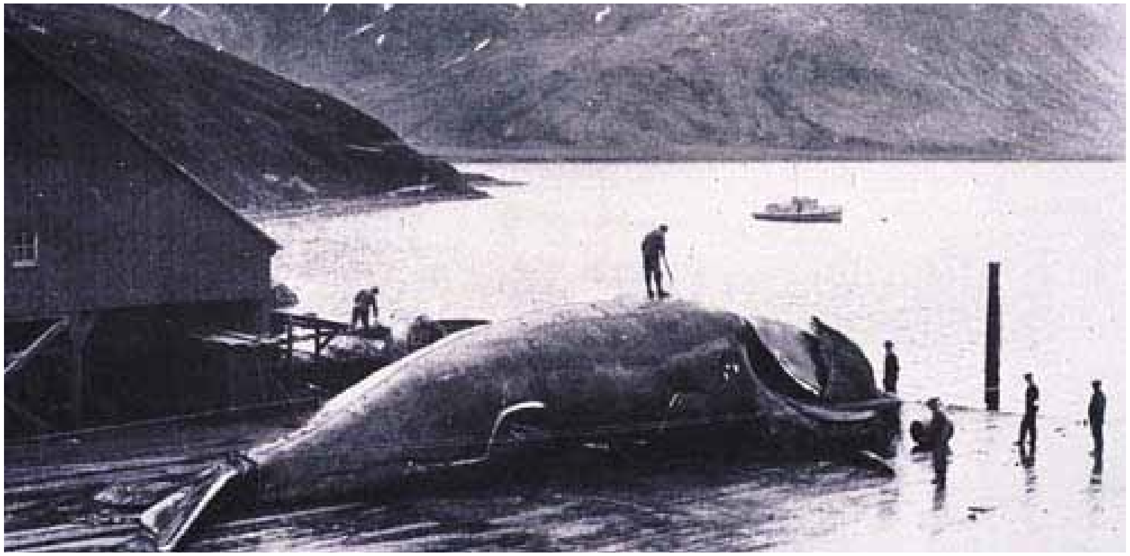
"In theory, the abundance of seals, sea lions and sea otters in British Columbia should have also declined, or remained at low numbers, if killer whales that once depended on eating large whales were forced to switch to alternative prey," the authors write. "Instead, the positive response of otters, seals and sea lions in the 1980s and 1990s shows that they were not limited by killer whale predation."

The relative success of British Columbia's sea lions, harbor seals and sea otters might be largely due to protection from culling and hunting that began in the mid-1970s. But if killer whale predation was on the increase at that time, as the SMC hypothesis suggests, these depleted populations should not have recovered, much less flourished. Furthermore, this sequential decline of marine mammal populations – called a *trophic cascade* – was not recorded in the southern hemisphere following the end of commercial whaling. The situation in western Alaska, it seems, is unique.

Dietary Dilemma

Furthering their defence of killer whales, Trites and colleagues offer a deluge of dietary data showing that gray whale calves and minke whales are the only large whale species known to be regularly preyed upon by North Pacific killer whales—and minke whales were never commercially hunted. Even gray whales, which were once targeted by whalers, have recovered to historic levels while seals and sea lions have declined. These population trends show no historical shortage of mid-sized whale prey.

Moreover, it is unlikely that killer whales would even attempt to feed on larger whales, much less



A right whale on the flensing platform of the former whaling station at Akutan in the Aleutian Islands (Alaska (Historical Photography Collection, University of Washington Libraries, Seattle).

be impacted by their dwindling numbers. The effort and danger involved in subduing larger, migratory whales such as fin and sei whales may be unprofitable, especially if the carcass sinks too quickly to eat. It would seem more sensible for killer whales to target smaller, easier-to-kill species (such as seals, sea lions, dolphins and porpoises) that are available year-round.

"Pinnipeds [seals and sea lions] and small cetaceans [whales, dolphins and porpoises] appear to represent a profitable food source for transient killer whales in British Columbia and southeastern Alaska," the authors write. "This is supported by the observations that killer whales focus on pinnipeds and small cetaceans in areas where large whales are locally abundant, suggesting that the preferred and profitable sources of food for transients are the smaller species of marine mammals."

Contrary to the SMC theory, the researchers submit that these smaller species formed the historic core of the transient killer whale diet in western Alaska, and that their dramatic decline is likely due to mechanisms that are larger and more insidious than marauding killer whales.

Tip of the Iceberg

"The declines of seals and sea lions in Alaska represent the tip of an iceberg of documented changes in the Gulf of Alaska and Bering Sea ecosystems that began around 1977," the authors write. At that time, a basin-wide regime shift in ocean climate began to impact all marine life in the North Pacific, causing long-term changes in prey availability that are still evident today. For western Alaska's sea lions, this translated to a shift in diet from energy-rich prey to energy-poor prey that left them weak, hungry, unable to breed successfully and vulnerable to disease and killer whales. Steep declines in these pinniped populations were evident shortly after the regime shift which, due to climatic and oceanographic variables, severely depleted western Alaskan populations but boosted those in southeastern Alaska and British Columbia.

Unlike the SMC hypothesis, this ocean climate hypothesis does not discount other leading hypotheses that propose to explain the decline of Steller sea lions, such as nutritional stress, fishing, disease and even killer whale predation. Instead, the authors believe it provides a holistic framework to align and associate the other hypotheses.

While acknowledging that more research is necessary to fully understand the subtleties of killer whale prey selection, the authors present a clear 'not guilty' verdict for killer whales supported by substantial dietary and climatic data. The rigors of peer-reviewed science occasionally send researchers back to the drawing board, but this process only advances the collective understanding of the oceans.

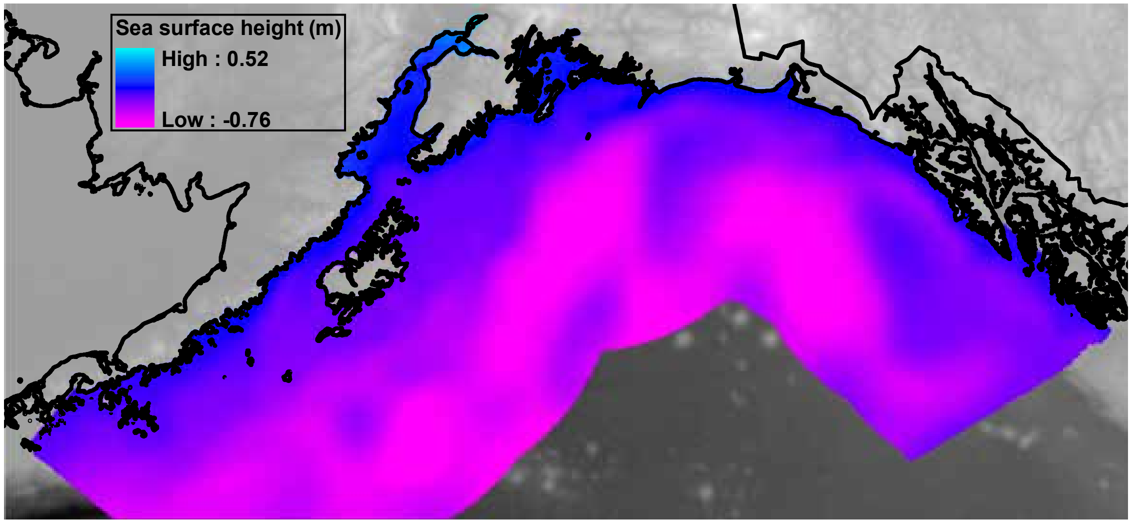
Testing the Data

While Consortium researchers tested the SMC hypothesis by modeling whaling impacts in British Columbia, another group of researchers critically examined the data and assumptions that form the basis for the original SMC hypothesis. Douglas DeMaster, Phillip Clapham, Sally Mizroch, Paul Wade and Jay Ver Hoef (of NOAA Fisheries) and Robert Small (of the Alaska Department of Fish & Game), along with Andrew Trites, concluded the following:

1. The best available data shows that killer whales did not depend on commercially-hunted fin and sperm whales as prey;
2. While some whale species were impacted by whaling, the total biomass of large whales in the North Pacific did not in decline in the 1960s and 1970s; and
3. Pinniped declines in western Alaska in the 1970s and 1980s were not sequential; they began a minimum of 15 years after the end of commercial whaling.

TOWARD A COMMON GOAL

SCIENTISTS SHARE DATA SETS TO ADVANCE RESEARCH



Gregr, E.J. and R. Coatta. 2008. **Environmental data for the eastern North Pacific and Bering Sea**. *Fisheries Centre Research Reports*, Vol 16(6), pp. 79.

The eastern North Pacific Ocean is home to a staggering diversity of marine life, built upon a rich ocean climate and an abundance of available nutrients. These "bottom-up" processes – the set of environmental conditions that make life possible – are countered by "top-down" processes, in which predators of all sizes control prey populations.

In the complex eastern North Pacific system, top-down and bottom-up processes act simultaneously and with different intensities on all species. The detailed study of these processes is constrained both by scale – the relative size of the study area and the duration of the study – and by poor, often incomplete descriptions of the state of the ocean. Consortium researchers have published several datasets of spatial information on temperature, chlorophyll-a and other environmental parameters for the eastern North Pacific. Their goal: sharing data to enable their own work and that of fellow researchers studying the same region.

Building the Dataset

"We conducted a series of analyses investigating the relationship between Steller sea lions, their prey, and various indicators of their physical habitat," the authors write. "We conducted these studies for two different spatial extents, at two spatial resolutions, and three temporal scales."

The areas studied included the Gulf of Alaska, which was divided into grid cells of 3x3 km^2 (3.5 sq mi), and a larger study area encompassing the range of the western stock of Steller sea lions within U.S. waters using grid cells measuring 9x9 km^2 (31.6 sq mi). The researchers built a collection of physical oceanographic data from satellite-borne remote sensors and output from an ocean circulation model, developed by Al Hermann and colleagues at the Pacific Marine Environmental Laboratory in Seattle Washington.

"This collection of monthly, physical oceanographic data is suitable for a range of oceanographic analyses at the temporal scale of months and seasons," the authors advise. "The spatial scale of 9x9 km^2 is suitable for monthly studies, and could be aggregated if seasonal or long-term temporal averages were desired."

Further, the researchers note that the data collection for the 3x3 km^2 northern Gulf of Alaska study area, by integrating remote sensing data with water column properties, represents one of the best physical data sets ever assembled for this region. Although the circulation model output limits the data to a single year (2001), the data offers a breadth of variables that should provide a fertile background for further research into relationships between species and their habitat.

Enabling Marine Research

The scientists also comment on the recent development of general distribution maps of marine species, based on average ocean conditions. They note that such analyses are suitable for tracking population trends and managing fisheries. However, studies at this broad scale do not necessarily reflect the ecology of a particular species, which responds to subtle interactions between species and to environmental changes from season to season and year to year. Data applicable to a variety of scales is essential to grasp the nuances of ecology.

"These data can thus support analyses in the North Pacific and Bering Sea across a range of temporal and spatial scales," the authors conclude. "We hope this collection will be useful to marine scientists interested in species distributions, habitat description, marine classification, and protected area designation."

RECONSTRUCTING THE PAST

PREHISTORIC DATA HELPS TO ASSESS MODERN COD FISHERY

Maschner, H. D. G., M. W. Betts, K. L. Reedy-Maschner and A. W. Trites. 2008. **A 4500-year time series of Pacific cod *(Gadus macrocephalus)* size and abundance: archaeology, regime shifts, and sustainable fisheries**. *Fishery Bulletin* 106:386-394.

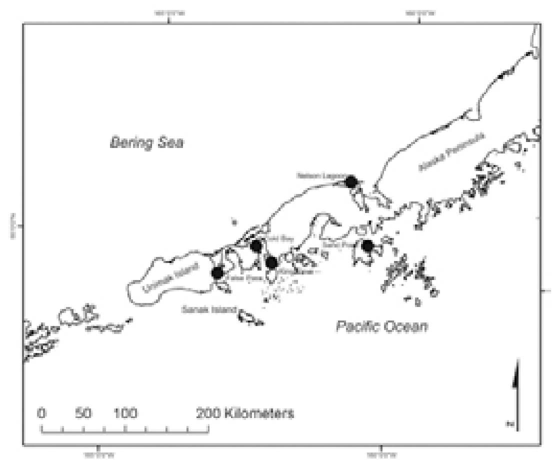
Pacific cod are among the most heavily fished species in the Northern Hemisphere, and once-thriving populations have significantly declined in many parts of the world. In the Gulf of Alaska, the Pacific cod fishery is generally thought to be sustainable, but managers have limited resources and only a few decades of recorded data from which to base their conclusions.

Researchers addressed this problem using a new interdisciplinary approach that reconstructed the past. By combining palaeoecological data with biological data, they extended limited data sets from a half-century to several thousand years, giving scientists and fisheries managers a better idea of how current trends fit into the bigger picture.

In order to assess the general sustainability of the modern fishery in the Gulf of Alaska, researchers sought to determine whether industrialized fishing has affected the size of Pacific cod and whether climate change affects cod size and abundance.

"The fish that stops"

The study took place on Sanak Island, in the western Gulf of Alaska, where the Aleut people have lived and fished for thousands of years, and where well-preserved shell mounds (or "middens")



The North Pacific and the western Gulf of Alaska region showing Alaska and the location of Sanak Island where bones were collected at archeological sites, to determine whether a change in fish size was evident over the 4500 archeological record.

now offer windows into their ancient ways and the conditions they faced. The researchers chose eight such sites spanning the period between 2550 B.C. and 1540 A.D. They excavated and measured the size and abundance of large numbers of fish bones from all sites, comparing these sizes to those of modern cod. They also looked into the effects of climatic changes over that time span.

The findings showed that although the size and relative abundance of Pacific cod fluctuated over the years, modern cod are fairly similar in size to their ancient ancestors. They also showed that Pacific cod tend to periodically vanish in great numbers, only to reappear in greater numbers later (which explains why the Aleut word for Pacific cod translates to "the fish that stops").

This disappearing act seems to be linked to natural changes in ocean climate called regime shifts. While periods of warming seem to cause cod numbers to fall, the researchers found that Pacific cod populations do appear to recover quickly when the climate cools again. According to the study, regime shifts do not appear to affect cod body size.

A sign of sustainability

The palaeoecological data led the research team to conclude: "The changes in fish length between the prehistoric and modern eras in the Gulf of Alaska are more consistent with natural fluctuations than with harvesting pressure," indicating that "current Pacific cod fisheries management and harvesting techniques in the western Gulf of Alaska are working."

The palaeoecological data also points to an association between low ocean temperatures and low cod abundance, leading the authors to conclude that global warming may well become a complicating factor in the ability of fisheries managers to sustain abundant cod populations.

PUTTING A PRICE TAG ON HABITAT CONSERVATION

NEW METHODS TO ESTIMATE THE VALUE OF OCEAN FISHERIES

Berman, M., E.J. Gregr, G. Ishimura, R. Coatta, R. Flinn, U.R. Sumaila and A.W. Trites. 2008. **Economic valuation of critical habitat closures.** *In* Fisheries Centre Research Reports, Vol 16(8), pp. 102.

Protecting natural habitats rarely occurs without sparking controversies—usually among those whose livelihoods depend on resources within the protected areas. Conservation can thus come at a significant economic cost.

In the Gulf of Alaska and Bering Sea, restricting fisheries within areas deemed to be critical habitat for Steller sea lions may or may not have resulted in serious financial losses for the fishing industry. This uncertainty reflects the fact that there has been no reliable method to estimate the opportunity costs, or the costs of not fishing in protected areas.

To address this obvious need, Consortium researchers sought to develop a "scientifically defensible" method of valuing habitat-driven fishery closures, and to apply this method to a relevant issue, namely the effects of the 2001 Steller sea lion habitat closures on groundfish trawl fisheries in the North Pacific. Their findings were published in *Fisheries Centre Research Reports*.

Considering Space

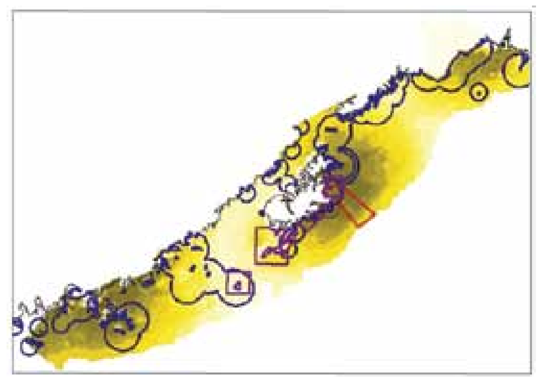
According to the researchers, there is a growing consensus that management of fisheries needs to consider spatial differences in habitat and the resources they provide at different times of the year. Past economic analyses of habitat closures have attempted to account for spatial considerations, but have not addressed the variations and complexities of the ocean environment. Berman's team designed a new method to differentiate habitat among a large number of small areas within the Gulf of Alaska and Bering Sea, and among different fisheries (at-sea and shore-based trawl fleets).

The researchers hypothesized that environmental variables would play important roles in their analysis—that conditions such as surface temperature, wave height, and salinity can explain and predict the spatial distribution of fish, which in turn influences the distribution of fishing effort. They analyzed environmental variables using satellite images, oceanographic modeling, and bathymetry techniques (to measure sea floor and depth) at 3-km and 9-km spatial scales and two-week and one-month intervals—and used these data to predict fish biomass and fisheries catch per unit of effort (CPUE), which, combined with spatial regulatory and cost factors, could explain the spatial distribution of fishing effort over time.

A Crucial Tool for the Future

Through an extensive statistical analysis of the variables, Berman's team found that the 2001 Critical Habitat Closures cost the North Pacific groundfish trawl fisheries 5-40 percent of their total potential net earnings, although cost estimates varied widely between at-sea and shore-based trawl fleets. They also found strong empirical support for their hypotheses—that environmental conditions can predict the spatial distribution of fish, which can in turn predict the distribution of fishing effort.

The researchers report that the new set of methods they developed to estimate the value of ocean fisheries can easily be generalized to evaluate fishery closures in time and space for any protected species or for marine conservation generally. Certainly, with pending proposals to close additional areas to fishing in the North Pacific, this is potentially a crucial tool to ensure that responsible decisions are made to manage fisheries, protect people's livelihoods, and safeguard species at risk.



Estimated spatial economic values of shore-based Pacific cod fisheries in the Gulf of Alaska during the summer-fall 2001, showing higher value areas in darker colors. Circles surrounding sea lion haulouts and rookeries identify Steller sea lion critical habitat, while the rectangles show other areas closed to fisheries. The red rectangle shows the Chiniak Gully Research Area, which was closed to commercial fishing to allow the Alaska Fisheries Science Center to conduct research on the effects of the pollock fishery on pollock abundance and distribution.

IN PURSUIT OF PREY

FORAGING BEHAVIOR IN TRAINED SEA LIONS

***Do sea lions forage** at an optimal depth? Do they prefer a specific density and type of prey? How long will a sea lion stay down and how much food does it need to capture to make it worthwhile? Is there an optimum feeding depth and a depth beyond which sea lions cannot feed?* These are some of the questions Consortium research at the Open Water Research Station is answering.

By observing the foraging decisions made by trained sea lions, scientists are working to better understand the metabolic requirements and foraging behavior of sea lions in the wild. One ongoing research project at the Consortium's Open Water Research Station is designed to estimate how much food Steller sea lions need to search and catch prey while underwater. This is accomplished by measuring how many calories they burn during a dive.

Energy used by Steller sea lions is estimated by measuring the amount of oxygen that is breathed in before a dive and the amount of carbon dioxide that is breathed out afterward. The sea lions are trained to dive and capture fish at different depths, then resurface and breathe inside a plexiglass dome. Scientists measure the concentration of oxygen and carbon dioxide inside the dome to determine how much energy the sea lions used in each dive.

Another study uses an underwater feeding tube that provides the sea lions with 'prey' at depths of as much as 50 metres. The goal of this particular study is to determine how changes in depth and density of fish affect sea lions. Patches of prey at different densities are simulated by delivering fish through the feeding tube at different rates and different depths.

CAPTIVE STUDIES

Studies on captive Steller sea lions are a key part of the Consortium's scientific program. By working with sea lions housed at the Vancouver Aquarium and the Open Water Research Station, Consortium researchers can investigate a number of hypotheses explaining the decline of their wild counterparts. This research forms a scientific bridge between observations made in the wild and inferences generated by computer models of animal physiology and behavior.

There are 15 animals in the captive research program, ranging in age from 1–14 years old; the focus continues to be on younger animals as this is the portion of the wild population deemed to be most at risk.

Consortium studies on captive sea lions and fur seals are roughly divided into three categories: basic physiology, bioenergetics and nutrition. Additionally, the animals are used to develop and test various techniques and technologies that can be applied to studying animals in the wild. These opportunities enable scientists to evaluate the usefulness of proposed field studies before they are undertaken, and to help interpret their data.

Captive studies on Steller sea lions in 2007–2009 included studies of seasonal variability in nutritional stress, and the diving physiology and foraging decisions of sea lions in an open water environment.

THE OFF-ISLAND NORTHERN FUR SEAL RESEARCH PROGRAM

Consortium Researchers and the Vancouver Aquarium have worked together since 1993 to understand the population decline of Steller sea lions. This partnership and research program has created a world center of excellence for laboratory-based studies of marine mammals. The success of the sea lion research program has led to the creation of the Off-Island Northern Fur Seal Research Program that seeks to determine why fur seals are declining in the North Pacific on the Pribilof Islands.

Most of the world's population of northern fur seals breeds in Alaska in summer and migrates and feeds along the west coast of North America in the spring. The Pribilof population declined by over 75% since the mid 1950s and have been declining at a rate of approximately 6% per year since 1998. They are listed as a depleted species under the *U.S. Marine Mammal Protection Act*, and as a threatened species by the Committee on the Status of Endangered Wildlife in Canada — but the reason for their decline is unknown.

Six female fur seal pups have joined the Steller sea lions at the Vancouver Aquarium for this important research program. Researchers transferred the animals on a flight by PenAir from the Pribilof Islands in the Bering Sea to Vancouver, British Columbia. The pups will participate in long-term physiological studies critical to understanding their decline in the wild.

"We know their numbers are getting smaller and smaller each year, but we don't have the data to determine why. Is their decline related to nutrition or is it associated with changes in the North Pacific as the oceans have become warmer?" asks Dr. Andrew Trites, Consortium Research Director. "We believe the six fur seal pups that have joined our Steller sea lions hold the key to unlocking this ecological mystery. The pups are vital to the conservation of fur seals and will participate in studies that can only be accomplished with trained animals in a controlled setting."

The six female pups are now at the Vancouver Aquarium where they receive the highest standards of veterinary care, husbandry and support.

"All six pups have acclimated very well to their new surroundings", notes Dr. Trites. "They are active, grooming and interacting well with our researchers and marine mammal husbandry staff. Everyone is very excited to have this unique opportunity to work so closely with such a rare and beautiful species."

Consortium researchers are determining the amount of food they require, the effects of food shortages, and their ability to contend with changing ocean temperatures.

INVESTIGATING METABOLIC MYSTERIES

SURVIVING LEAN TIMES

Rea, L.D., D.A.S. Rosen and A.W Trites. 2007. **Utilization of stored energy reserves during fasting varies by age and season in Steller sea lions.** *Canadian Journal of Zoology* 85:190-200.

Just as humans fast periodically for physical or spiritual purification, natural fasting also occurs frequently in wildlife. Adult male Steller sea lions fast for weeks during the summer breeding season; reproductive females fast for up to two weeks directly after giving birth; even newborn pups fast at an early age while nursing mothers forage at sea.

Steller sea lions display a natural tolerance for periodic fasting, but the metabolic cost of fasting is still unclear. *How is weight loss minimized? How is body fat stored and metabolized? How do age and season affect a sea lion's tolerance for periodic fasting?* Consortium scientists studying captive Steller sea lions at the Vancouver Aquarium are answering these and other questions.

During controlled fasts of 7-14 days, researchers monitored changes in the sea lions' body masses and body conditions (measured by percent total body lipid content, or %TBL). The trials were repeated during the summer breeding season and the nonbreeding season.

Juveniles lost more mass per day than subadults, at a significantly higher rate during the breeding season than during the nonbreeding season, suggesting that the impact of fasting is greatest among juveniles during the breeding season.

Seasonal Variation

In the wild, juveniles and subadults typically fast for shorter periods than adults. The researchers point out that the ability to withstand prolonged fasting may simply be physiologically limited in younger sea lions until they become adults, when it is needed (e.g., during breeding season). Juveniles may also have difficulty depressing their metabolism while fasting to conserve body mass because they have higher metabolic demands to grow and develop.

The results of the study suggest that juvenile sea lions would be more affected by a food shortage during the breeding season than would subadults, who are more capable of adapting to fasting during the breeding season by slowing their metabolism to prevent undue weight loss. During the nonbreeding season, both juveniles and subadults would be equally affected by food limitation.

The authors conclude that a sea lion's body condition prior to fasting likely plays a significant role in determining its ability to adapt to fasting. Lean animals will likely use more protein reserves for energy during fasting, while animals with a higher %TBL will likely preferentially metabolize body lipids before depleting tissue and other proteins.

DECISIONS AT DEPTH

Rosen, D.A.S., A.J. Winship, and L.A. Hoopes. 2007. **Thermal and digestive constraints to foraging behavior in marine mammals.** *Philosophical Transactions, Royal Society of London B* 362:2151-2168.

Marine mammal scientists often describe an animal as behaving or performing in an *optimal* manner, but life in the open ocean is rarely optimal: compromise is fundamental to survival. For example, the high energetic cost of foraging must be balanced with the chances of catching prey. If an animal catches enough prey to recoup the energy it invested in foraging, all is well. But if no prey is caught the animal incurs an *energy deficit*, having spent more energy than it gained.

Marine mammals face a constant compromise between expending energy to forage, energy to digest food, and energy to stay warm. In examining the ways in which prey acquisition, prey processing and thermoregulation limit foraging, Consortium researchers sought to refine the standard predictive models of foraging behavior.

Competing Priorities

A marine mammal's ability to find enough food to meet its energy requirements – and hence stay warm and survive – is determined by three key factors. First is the ability to find and acquire prey, which is limited by the amount of time and energy spent foraging, as well as its diving capabilities.

The second constraint to foraging is the ability to digest prey and generate metabolic energy from the meal. This is limited by the size of the stomach and the amount of time required for digestion. As an obvious example, time spent ashore (to nurse, mate, or keep warm) decreases potential foraging time.

The third factor is *thermoregulation*, or the cost of generating body heat. Hauling out on land can help regulate body temperature, but thermoregulation is chiefly fuelled by energy gained from prey.

Downward Spiral

An animal that is unsuccessful in foragaging will begin to break down its own tissues to meet its energy deficit, leaving it colder, less agile and less likely to catch prey. Its chances of survival decrease as it spends more energy on each trip, with less likelihood of recouping that energy—a metabolic downward spiral. The blubber layer's dual role as insulator and energy source is especially significant in younger animals, who have a higher surface-area-to-volume ratio than adults, suggesting they would lose heat more quickly when the blubber layer is depleted.

This research presents a novel framework of interconnecting process that together form the physiological constraints to foraging behavior.

HORMONE CHANGES AND NUTRITIONAL STRESS

WHAT TIME OF YEAR ARE SEA LIONS MOST SENSITIVE TO FOOD SHORTAGES?

Rosen, D.A.S. and S. Kumagai, 2008. **Hormone changes indicate that winter is a critical period for food shortages in Steller sea lions.** *Journal of Comparative Physiology B* 178:573-583.

Like most mammals, Steller sea lions require varying amounts of food throughout the year, according to such appetite-influencing factors as age, sex, and the reproductive cycle. Yet the availability of sufficient food in any given season is beyond their control, and a shortage of prey in a time of great energetic need can lead to long-term health effects.

This raises questions about how changes in the availability of key prey such as walleye pollock, a major winter food source for Steller sea lions in western Alaska, might affect the sea lion populations that depend on them. Could the seasonal pollock fishery play an exacerbating role? Little is known about how critical prey shortages affect the physiology of individual sea lions in each season.

Consortium researchers worked with captive Steller sea lions to study hormonal levels, which mediate seasonal changes in physiology, in response to periods of food restriction across all seasons.

The Role of Hormones

A previous study by the authors found that when captive Steller sea lions were subjected to short-term periods of food restriction, they lost more body mass in winter than in other seasons. The current study examines the seasonal relationship between key hormones and physiological changes (in body mass, body composition, and metabolism) during periods of food restriction.

The researchers studied seasonal differences in initial levels of three hormones (triiodothyronine or T3, thyroxine or T4, and cortisol) and one blood metabolite (blood urea nitrogen, or BUN) in captive Steller sea lions. Cortisol is usually elevated in response to stresses such as a restricted diet or increased mass loss. Similarly, elevated BUN levels have traditionally been used as an indicator of nutritional stress in wildlife management. The principal thyroid hormones, T3 and T4, affect metabolism in mammals and can alter growth rates.

Competition for Prey

The sea lions were fed restricted diets for up to nine days in each season and lost an average of ten percent of their initial body mass.

"Overall, restricted energy intake during the winter resulted in the greatest decreases in T3 and body mass and the greatest increases in cortisol and BUN, and the opposite results in summer," the authors write. "This suggests that the Steller sea lions had a greater physiological reaction to food restriction during colder seasons (non-breeding seasons), and that they were probably less impacted in warmer seasons (breeding seasons)."

Importantly, the study suggests that sea lions may be more physiologically susceptible to short, severe reductions in prey during the winter, which coincides with the timing of the Alaskan pollock roe fishery. This also corresponds to the time of year when pollock densities may require sea lions to forage for longer and to consume more pollock prey to meet their higer seasonal energetic needs.

"Thus, while competition between fisheries and sea lions is still a contentious hypothesis, the potential effects of such interactions would appear to be greater in the winter," the authors note.

These results serve several important purposes. They provide a clearer understanding of the underlying physiological responses and bioenergetic priorities of Steller sea lions at different times of year, and they also test the ability of certain blood parameters to be used as indicators of nutritional stress. Finally, they can be used to help refine current fisheries legislation by offering empirical experimental results. Together, this represents a valuable contribution toward measuring and identifying nutritional stress and its underlying causes among populations of wild Steller sea lions.

TO THE DEPTHS ON A BREATH

EXPLORING DIVE METABOLISM IN SEA LIONS

Hastie, G.D., D.A.S. Rosen and A.W. Trites. 2007. **Reductions in oxygen consumption during dives and estimated submergence limitations of Steller sea lions *(Eumetopias jubatus)*.** *Marine Mammal Science* 23:272-286.

When a sea lion dives below the ocean's surface in search of food, its foraging success largely depends on how long it can hold its breath. A complex metabolic reaction called a *dive response* helps the animal to use a single breath as efficiently as possible, to maximize its dive time.

By gathering information on the rate at which diving sea lions consume the oxygen in a single breath, scientists seek to predict the energy needs of individual animals and entire populations. This information also helps to explain the physiological constraints that drive the foraging decisions a sea lion makes – such as when to end the dive – and how a shift in prey type may affect those decisions.

Metabolic Depression

Using sea lions trained to dive to specific depths in an open water environment and remain there for short periods, Consortium scientists measured oxygen consumption at the surface and at varying depths. The sea lions cooperated with all data collection and were never restrained or confined during any of the trials.

The sea lions showed a marked decrease in oxygen consumption while diving – as much as 45% lower than the corresponding surface rates – suggesting that a diving sea lion can automatically depress its metabolism to efficiently use a single breath. The study provides the first estimates of diving oxygen consumption for Steller sea lions, and is the first study to demonstrate metabolic depression in an otariid (an 'eared' seal or sea lion) while freely diving in the open ocean.

The results were combined with existing information on oxygen storage capacity among sea lions to estimate the aerobic dive limit (ADL), or the maximum length of time a Steller sea lion may remain submerged on one breath. The ADL is a theoretical calculation; seals and sea lions have been observed to approach or exceed the expected ADL during a dive.

"Recent work suggests that there is a concise link between foraging ecology and the tendency to approach physiological limitations during dives," the authors write. "Given that Steller sea lions generally feed at or near the seabed, we might expect that they regularly approach or exceed their aerobic limitations in the wild."

Foraging Strategies

The authors note that the physiological mechanisms for efficiently using oxygen – which vary between species of pinniped – likely arise from the fundamental link between foraging strategy and aerobic limitations while diving. In other words, the techniques used by each pinniped species to capture its key prey will determine its dive limits and the physiological mechanisms that enable it to approach those limits while foraging.

The authors note that further work is required to assess how active foraging influences diving metabolism (the sea lions in the current study were stationary at depth), and how the energetic costs of diving by wild animals vary under a range of realistic diving scenarios.

DNA ANALYSIS PROVIDES DIETARY CLUES

Deagle, B.E. and D.J. Tollit. 2007. **Quantitative analysis of prey DNA in pinniped faeces: potential to estimate diet composition?** *Conservation Genetics* 8:743-747.

Scientists are exploring a number of theories explaining the mysterious decline of Steller sea lion populations in Western Alaska. One possibility suggests that a long-term change in the distribution of fish stocks might be depriving sea lions of high-quality prey such as Pacific herring.

Testing this theory requires some gastric sleuthing, and the easiest way to determine a sea lion's most recent meal is to examine its feces. By analyzing undigested bones and other "hard parts" in fecal samples, scientists can identify the types of prey that have been consumed, indicating possible dietary trends.

This method, while useful, may not accurately show how much of a particular prey has been eaten relative to other types of prey. Some scientists have suggested that analyzing the mitochondrial DNA (mtDNA) of soft tissue remains in feces may provide a more complete dietary picture.

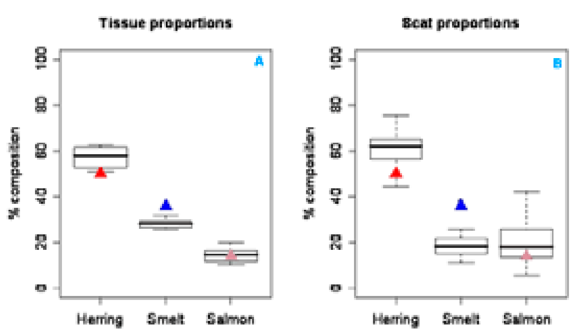
A new study by Consortium researchers assesses whether a quantitative real-time PCR approach could be useful on a broad scale.

Differential Digestion

Scientists assessed the use of quantitative real-time PCR by testing levels of mtDNA in a ground up sample of undigested fish tissue. They also tested the levels of mtDNA present in actual fecal samples (collected from two captive Steller sea lions fed known amounts of different fish at the Vancouver Aquarium). The researchers found that the mtDNA in the undigested tissue sample corresponded reasonably well to the actual amounts of fish fed to the sea lions (50% Pacific herring, 36% surf smelt and 14% sockeye salmon by mass — see Figure). However, Real-time PCR results based on the fecal samples did a poorer job of replicating the sea lions' actual diet (see Figure above), suggesting the flesh of certain prey types are digested at different rates than others.

The authors report that the DNA analysis overestimated the proportion of salmon and underestimated the proportion of smelt mtDNA in the fecal samples, and highlighted that measuring prey DNA recovery rates in captive feeding trials may be useful in reducing this bias. Despite this bias in DNA recovery, the authors feel that quantifying DNA amounts in fecal samples can still provide some informative data.

"For example, based on our results, herring was correctly predicted as dominant prey in 21 of 23 samples," they write. "Therefore, in situations where large uncertainties surround conventional hard-part fecal analysis, measuring prey DNA amounts in feces may be a useful approach for determining pinniped diet composition."



Box plots showing a summary of the percentage DNA composition data (median, range and upper/lower quartiles) based on quantitative real-time PCR estimates: (A) results from tissue mixture (n=10); (B) results from faecal samples (n=23). Closed triangles show percentage of each fish prey species (by mass) in the diet. Data for two independent replicate runs and the mean values are shown.

LABORATORY STUDIES

Laboratory-based studies provide an important analytical tool for biological samples collected from animals in the field or in a captive setting. The most common sample collected is scat, the analysis of which yields substantial insights into the recent diet of an individual or population.

Future for Feces?

The authors note that their quantitative DNA-based fecal analysis method could also be used to examine the diet of species whose feces do not contain hard parts (such as seabirds or cetaceans) and could be modified to quantify prey DNA in stomachs of invertebrates where few conventional approaches to studying diet have been explored.

DNA analysis remains costly and technically challenging, and the authors acknowledge that its use may likely be restricted to situations where traditional methods of diet analysis have proven inadequate. The approach also requires a basic knowledge of the diet under study, and particularly the prey of interest. Finally, they note that a large number of fecal samples would help to produce the most accurate results.

Based on the results of this feasibility study, the authors are optimistic, noting that this technique for studying predator diet is likely to increase because of its ability to improve taxonomic identification of prey and to address questions beyond the scope of traditional methods of diet analysis.

SUMMARY

Understanding the causes of change in the North Pacific requires a commitment to long-term research: solutions need a concerted effort and are unlikely to come quickly. With this understanding, the Consortium was formed to address issues concerning interactions between marine mammals and fisheries in the North Pacific.

In 2007–2009, Consortium-funded research resulted in 45 peer-reviewed publications, book chapters, and dissertations. In addition, Consortium researchers were engaged in a wide range of studies, many of which are ongoing.

We have undertaken a solid field program, a strong captive research program and major analytical research initiatives. Specifically, a multi-disciplinary research program has been mounted to elucidate the factors responsible for the decline of Steller sea lions and northern fur seals in Alaska. Our studies also account for issues related to harbor seals and whales, which we believe will attract greater attention in the years to come.

Research in 2009–2011 will continue with a balance of short-term and long-term projects. These are designed to address and draw conclusions about changes occurring in the North Pacific and the role that commercial fisheries and other factors may have played.

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PUBLICATIONS AVAILABLE FOR DOWNLOAD AT *www.marinemammal.org*

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