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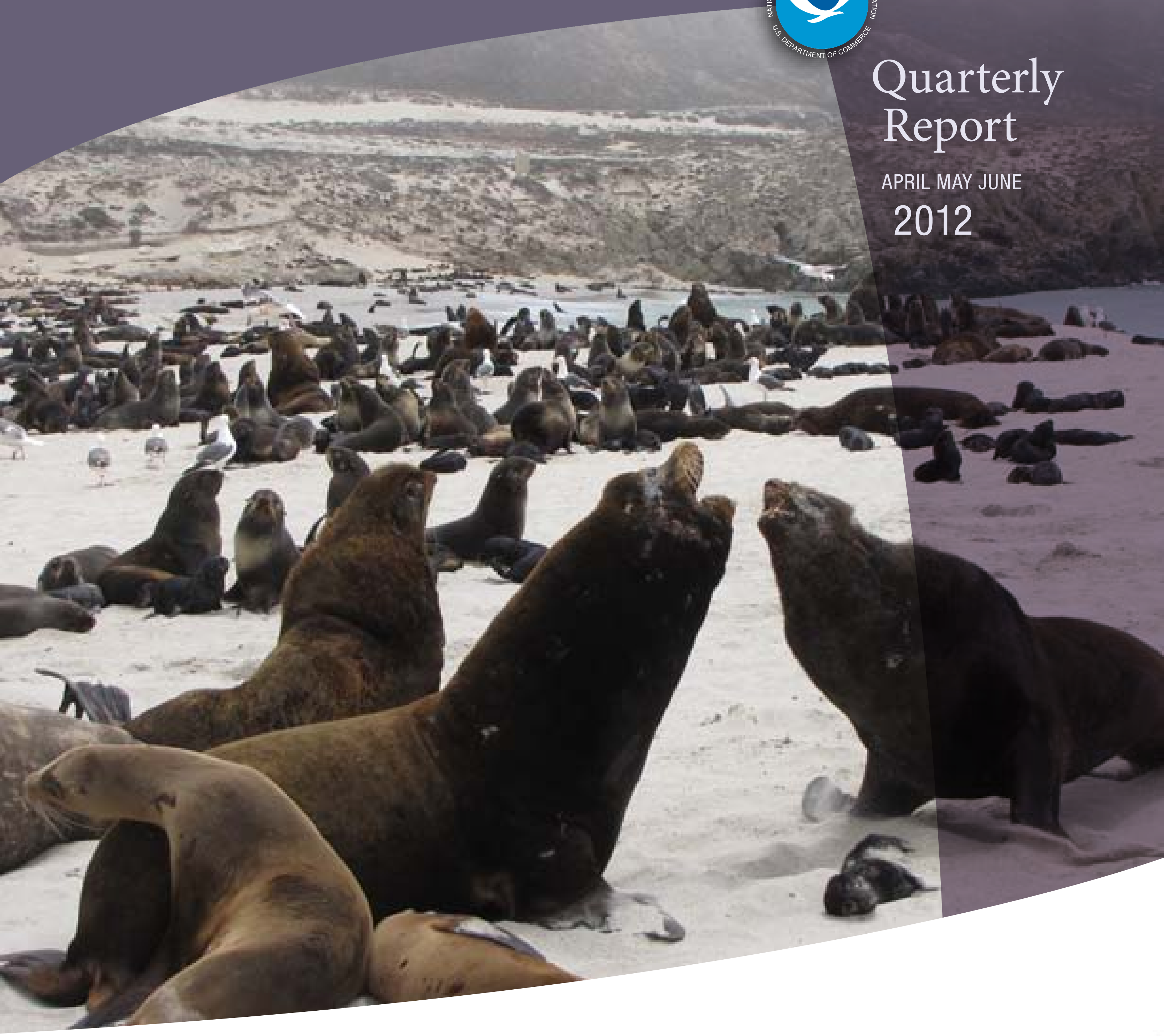

Studies of Northern Fur Seals Breeding at the Northern and Southern Extent of the Range

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A Tale of Two Stocks: Studies of Northern Fur Seals Breeding at the Northern and Southern Extent of the Range

Sharon R. Melin, Jeremy T. Sterling, Rolf R. Ream, Rod Towell, Tonya Zeppelin, Anthony J. Orr, Bobette Dickerson, Noel Pelland, and Carey Kuhn

This is a tale of two stocks of northern fur seals (*Callorhinus ursinus*): the Eastern Pacific stock and the San Miguel Island stock. The Eastern Pacific stock breeds mostly on the Pribilof Islands, Alaska, at the northern extent of the breeding range in the Bering Sea Large Marine Ecosystem (Fig. 1). This stock was listed as depleted in 1988 under the Marine Mammal Protection Act of 1972, but not all populations within the stock boundaries display similar population trends. Within the Eastern Pacific stock, the Pribilof Islands population, historically the largest breeding population in the world, has declined dramatically over the past 20 years, whereas a new breeding population at Bogoslof Island has increased exponentially since its discovery in 1980. In contrast, the San Miguel Island stock, which breeds mostly on San Miguel Island, California, at the southern extent of the breeding range in the California Current Large Marine Ecosystem (Fig. 1), is not listed as depleted because it has increased or been stable since its discovery in 1968.

Video 1. Learn more about the National Marine Mammal Laboratory's northern fur seal investigations. Visit the AFSC Multimedia Gallery.

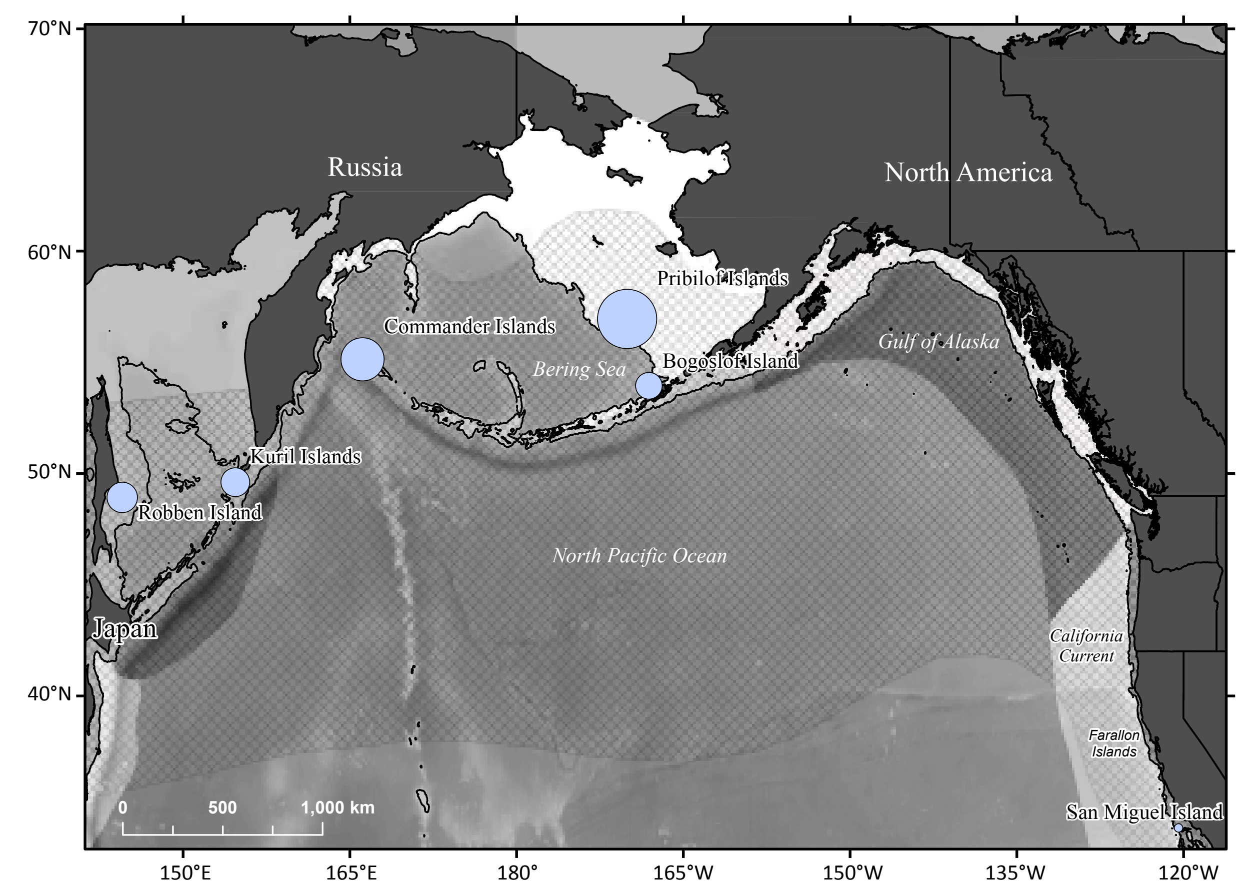


Figure 1. Breeding sites and range of northern fur seals. Breeding sites are indicated by circles and the size of the circles represents the relative size of the population. Range is depicted by hatching.

Photo 1. Northern fur seal breeding group at Bogoslof Island, Alaska. Adult male is in the center surrounded by smaller adult females and black pups.

Over the past 20 years, the San Miguel and Bogoslof Island fur seal populations have thrived while the Pribilof Island population has declined. It is unclear why annual pup production continues to decrease at the Pribilof Islands, but it is likely related to declines in the health, survival, or reproduction of fur seals breeding there. Survival and reproduction of Pribilof Islands fur seals may be affected by factors such as climate shifts in the North Pacific Ocean that alter migratory or foraging patterns, alterations in available prey, new or increased interactions with commercial fisheries that increase mortality rates, or an increase in predation levels. The increase in pup production at Bogoslof and San Miguel Islands is likely influenced by immigration of animals from the Pribilof Islands; however, the movement of animals to Bogoslof and San Miguel Islands cannot solely account for the magnitude of declines documented at the Pribilof Islands.

The U.S. Northern Fur Seal Conservation Plan describes research and actions to be taken to restore the Eastern Pacific stock to a healthy population level. One of its aims is to quantify environmental effects on foraging behaviors and identify essential habitat during the annual cycle of northern fur seals throughout the species' range. To do this, the National Marine Mammal Laboratory's (NMML) Alaska and California Current Ecosystem Programs have taken a collaborative approach in their investigations of the Eastern Pacific and San Miguel Island stocks since the 1970s. The goal is to better understand the interplay between the stocks' biophysical environment, diet, foraging behavior and, ultimately, population dynamics. Comparing the two stocks could help identify ecological drivers of the divergent population trends within and between stocks. This article compares the history of the two stocks and highlights NMML's research investigating population dynamics, foraging behaviors of adult females, and their diet.

Natural History of Northern Fur Seals

The expansive range of northern fur seals covers seven different marine ecosystems (Kuroshio Current, Oyashio Current, West Bering Sea, East Bering Sea, Gulf of Alaska, California Current, and North Pacific Ocean). For 6 months of the year (mid-November to mid-May) fur seals are usually solitary and remain at sea migrating throughout the North Pacific Ocean. Most fur seals return to land once a year for the summer reproductive season (mid-May to mid-November) and form dense breeding aggregations on islands in Russia, Alaska, and California (Fig. 1). Northern fur seals have a polygynous breeding system. Adult males compete for access to breeding females by defending land territories. This has given rise to pronounced sexual size dimorphism with males up to 5 times the size of females. Adult males arrive at the colonies and set up territories in mid-May or early June and remain on land and fast for up to 3 months while defending their territories. Females aggregate in the territories for protection from other males and often breed with the territorial male, though not always (Photo 1).

Pregnant adult females arrive throughout June or July and give birth to single pups within 2 days after arriving ashore. Females remain ashore with their pups for up to 8 days and then breed before beginning a series of feeding trips to sea, alternated with nursing visits ashore throughout the 4-month lactation period. Feeding trips may last more than 10 days and nursing visits up to 2 days. While the mother is away, the pup remains ashore and fasts. Weaning is relatively abrupt with the female or pup departing from the colony and not returning.

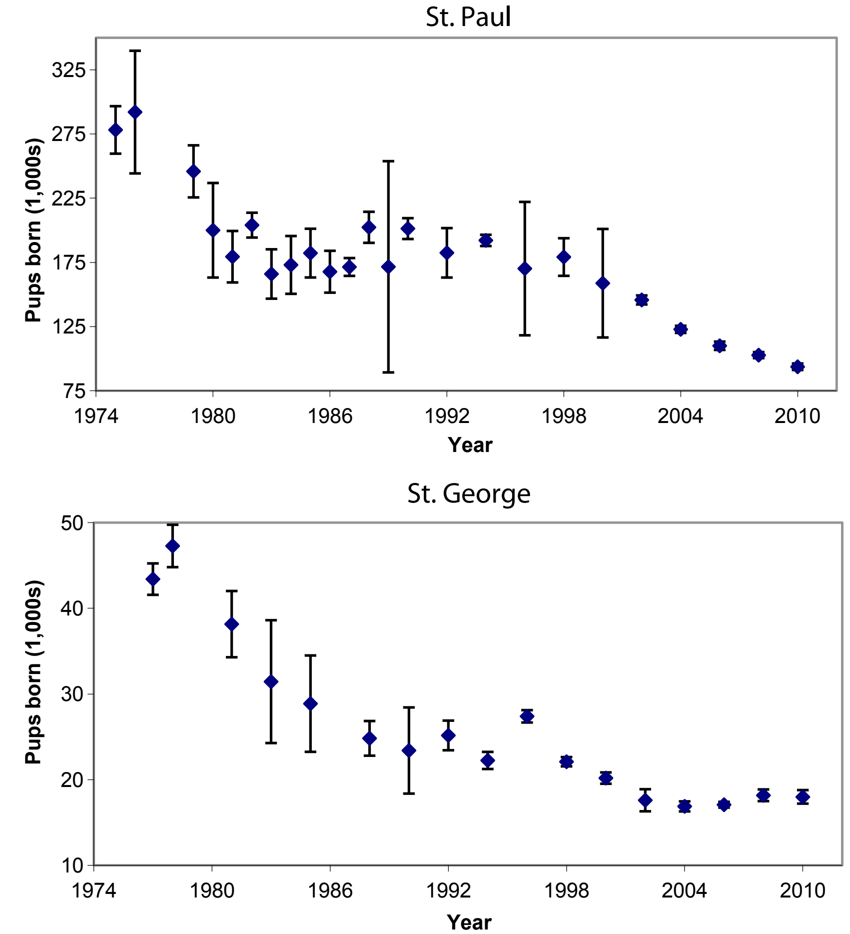


Figure 2. Estimated number (± 95% confidence intervals) of northern fur seal pups born on the Pribilof Islands (St. Paul and St. George), Alaska, 1975 to 2010.

Once weaned, the pups spend up to 3 years traveling the North Pacific Ocean, remaining almost exclusively at sea. Historically, about 50% of the pups have died in their first year. Some yearlings and 2-year-olds return to the colonies, but most remain at sea; thus, little is known about the juvenile life stage.

Females become reproductive at 3 or 4 years of age and are reproductive for most of their life span, which averages about 26 years. Males reach sexual maturity between 5 and 7 years of age and begin defending territories between 7 and 9 years of age. Breeding males have shorter life spans than females because of the energetic cost of fighting and fasting during the breeding season.

Despite a high affinity of both female and male northern fur seals to return to their natal sites to breed, there is very little genetic differentiation between stocks throughout their range. The only evidence of genetic differentiation is weak differences between the Russian populations and the Eastern Pacific stock. Northern fur seals from the San Miguel Island stock are not genetically distinct from those from either Russia or the Eastern Pacific stock. This is not surprising given that San Miguel Island was colonized by animals from throughout the range only 60 years ago – so only 12 generations have been born at San Miguel Island, leaving relatively little time for genetic differentiation to occur among the populations. In contrast, the Pribilof Islands were colonized by fur seals approximately 10,000 years ago following the Wisconsin glaciations. The genetic structure of the Pribilof Islands population indicates that it expanded initially but then experienced a dramatic decline, a result of intensive commercial harvesting between the late 18th and early 20th centuries. With the regulation of commercial harvesting after 1911, the Pribilof Islands population underwent another expansion, increasing to almost 2.0 million animals by the late 1940s. Interestingly, even with the dramatic decline from commercial harvesting, there is no evidence of reduced genetic diversity in the population, suggesting that the worldwide population level of northern fur seals has remained large enough to maintain genetic variability at high levels throughout the range.

The Fall of the Eastern Pacific Stock

The Eastern Pacific stock of northern fur seals has been exploited on and around the Pribilof Islands (St. George and St. Paul) since their discovery by Russian fur hunters in 1786. There have been three distinct periods of commercial exploitation and management of the Eastern Pacific stock: Russian harvest, U.S. government lease, and U.S. government management. Two periods of severe depletion in the Pribilof herds took place under Russian ownership, but restrictive killing and protection of females enabled the population to recover. Unregulated harvests commenced in 1867 immediately after the purchase of the Alaskan territory by the United States. The Alaska Commercial Company was granted a 20-year lease beginning in 1870 and harvested nearly 100,000 animals annually. During this period, pelagic sealing accelerated and, due to the high composition of females killed by this practice, severely depleted the Pribilof Islands population of northern fur seals by the early 20th century. The North Pacific Fur Seal Convention of 1911, a treaty agreed upon by England, Japan, Russia, and the United States, subsequently protected fur seals from pelagic sealing and raids on the breeding islands and led to the development of scientific research programs investigating the population dynamics and biology of the northern fur seal. Following the cessation of pelagic sealing and the commencement of restrictive harvest practices on the Pribilof Islands, fur seals recovered and numbered about 2.0 million animals during the late 1940s.

In 1956, the United States government implemented a northern fur seal herd reduction program which removed more than 300,000 females over a 10-year period. The purpose was to increase productivity of the herd by reducing the number of females; the reasoning for the reduction program was that females would reproduce at younger ages and produce more pups if there was less competition among fur seals for resources. However, pup production rates did not increase as expected but instead declined due to removals of females with the highest reproductive value. The program ceased in 1968. The signing of the Interim Convention on Conservation of North Pacific Fur Seals by the United States, Japan, England, and Russia in 1957 expanded scientific research programs that had been initiated under the 1911 treaty on the biology and life history of northern fur seals. Pelagic sampling of fur seals was conducted collaboratively by all treaty countries from 1958 through the 1970s to study northern fur seal distribution, feeding habits, reproduction, and survival. Juvenile male fur seals were commercially harvested on the Pribilof Islands until 1984 and currently are harvested in small numbers for subsistence needs of the Aleut people.

Despite cessation of the herd reduction program in 1968, pup production on the Pribilof Islands has exhibited an overall declining trend, with a period of stabilization in the late 1980s (Fig. 2). Pup production continues to decline in the absence of heavy commercial harvesting pressure.

Photo 2. Polovina Cliffs rookery on St. Paul Island, Alaska, in 1940 (top) and 2004 (bottom) taken from the same vantage point.

Specifically, from 1998 to 2010, pup production on St. Paul Island decreased 5.46% (SE = 0.32, P< 0.01) annually, while on St. George Island it declined 2.90% (SE = 0.69, P = 0.03) annually. Overall, pup production on the Pribilof Islands has decreased 4.90% (SE = 0.36, P < 0.01) annually since 1998 (Photo 2).

The recent decline in pup production at the Pribilof Islands decreased their contribution to the worldwide abundance of northern fur seals (Fig. 3). The Pribilof Islands population accounted for approximately 74% of the worldwide population in 1992. Since then, fur seal abundance at the Pribilof Islands dropped 46%, and recent estimates from other colonies indicate that the Pribilof Islands now account for approximately 45% of the worldwide population, with a decline in worldwide abundance of 10% to a total of roughly 1.18 million animals.

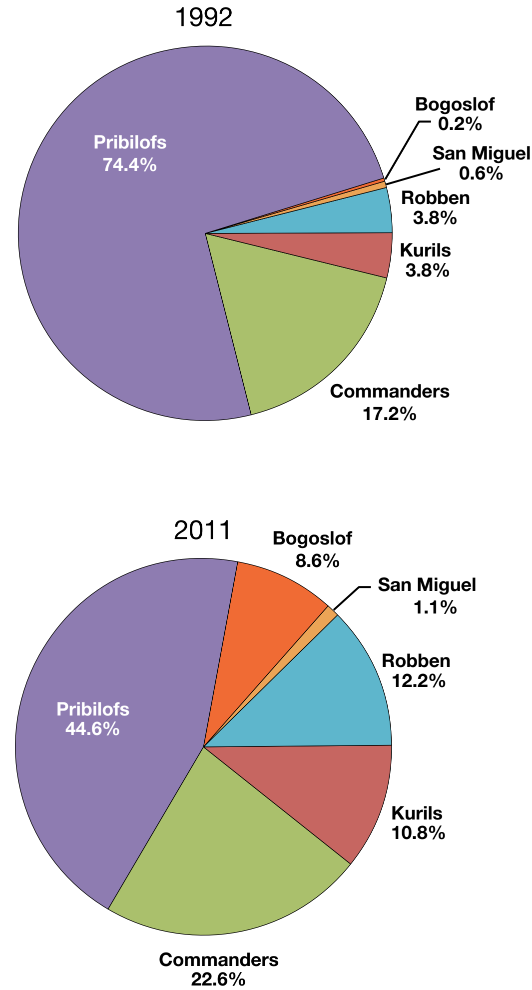


Figure 3. Estimated contribution of the breeding islands to worldwide abundance of northern fur seals in 1992 and 2011.

In contrast with the decline observed at the Pribilof Islands, fur seal numbers at a new location at Bogoslof Island have increased dramatically in recent years. Located approximately 74 km west of Dutch Harbor, Alaska, Bogoslof Island was formed by a series of volcanic eruptions in the late 18th century. Since pups were first observed there in 1980, pup production has increased at an annual rate of 38.2% (SE = 2.60, P < 0.01) through 2011, and at an annual rate of 11.7% (SE = 0.90, P < 0.01) from 1997 to 2011 (Fig. 4). Pup production on Bogoslof Island, estimated to be 22,905 (SE = 921.5) in 2011, has surpassed recent estimates for St. George Island.

The Rise of the San Miguel Island Stock

The San Miguel Island stock of northern fur seals has quite a different history from the Eastern Pacific stock. Once considered part of the Eastern Pacific stock, breeding fur seals at San Miguel Island and the Farallon Islands, California, were reclassified in 1992 as their own distinct stock due to their disparate population trends, continuous geographic distribution but geographic separation during the breeding season from the Eastern Pacific stock, and high natal site fidelity. Evidence of northern fur seals on San Miguel Island, located 46 km offshore in southern California, dates back to the island's occupation by Chumash Indians 12,000 years ago. Northern fur seal remains have been recovered from Chumash kitchen middens, but it is unknown if the animals bred on San Miguel Island or used it only as a hauling ground. There is some confusion about the history of commercial sealing of this stock because it was not considered distinct from the Guadalupe fur seal (*Arctocephalus townsendi*) until 1897, more than 40 years after most of the fur seals had been extirpated from the California Channel Islands. Furthermore, a large historical breeding population was likely located at the Farallon Islands, 43 km west of San Francisco Bay. Heavy commercial harvesting during the summer breeding season extirpated this population in the 1800s.

Northern fur seals recolonized San Miguel Island sometime in the 1950s and were first documented there in 1961 in photographs taken by George Silk, a photographer for Time-Life books. In 1968, biologists surveyed the northern fur seal population at San Miguel Island and identified 100 females, 36 pups, and 1 adult male at Adams Cove on the southwest end of the island where they shared space with California sea lions (*Zalophus californianus*) and northern elephant seals (*Mirounga angustirostris*) (Photo 3). In 1972, another breeding population was discovered on Castle Rock, a small offshore rock 2 km northeast of Adams Cove.

Evidence that the San Miguel population was founded by a mixture of animals from Pribilof Islands and Russian fur seals is based on identification of individuals by flipper tags deployed in these populations as part of the collaborative fur seal research that stemmed from the Interim Convention on Conservation of North Pacific Fur Seals of 1957. The tags uniquely identified individual animals to their birth or breeding sites. Tagging studies have been a cornerstone of fur seal population studies throughout the range; tagging studies of Russian and Pribilof Islands populations conducted from the 1940s to the 1970s provided the first comprehensive information on behavior, survival, reproduction, and movements of fur seals. Large-scale tagging programs conducted by NMML for the Eastern Pacific stock ceased in 1968. The need for recent information on survival and reproductive rates of the Eastern Pacific stock to better understand the current population decline led to the initiation of a new large-scale tagging program of pups and adult females in 2009. Fur seal pups at San Miguel Island have been tagged since 1975. Comparisons of the survival rates between the Eastern Pacific stock and the San Miguel Island stock determined from the tagging studies may provide insights into the role of survival and reproductive rates in the decline of the Pribilof Islands population.

Unlike the Eastern Pacific stock, the primary factors influencing the population dynamics for the San Miguel Island stock are fairly well known. The small size of the Adams Cove and Castle Rock populations allows for all the pups to be counted; NMML

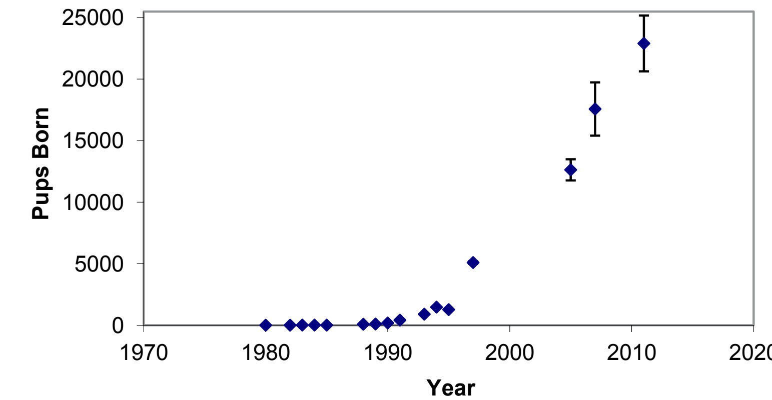


Figure 4. The numbers of northern fur seal pups born on Bogoslof Island, Alaska, 1980-2011. Error bars are approximate 95% confidence intervals.

Photo 3. Adams Cove northern fur seal herd at San Miguel Island, California, and an interaction between a northern fur seal bull (black) and California sea lion bull (brown). The fur seal herd is intermixed with a California sea lion breeding herd.

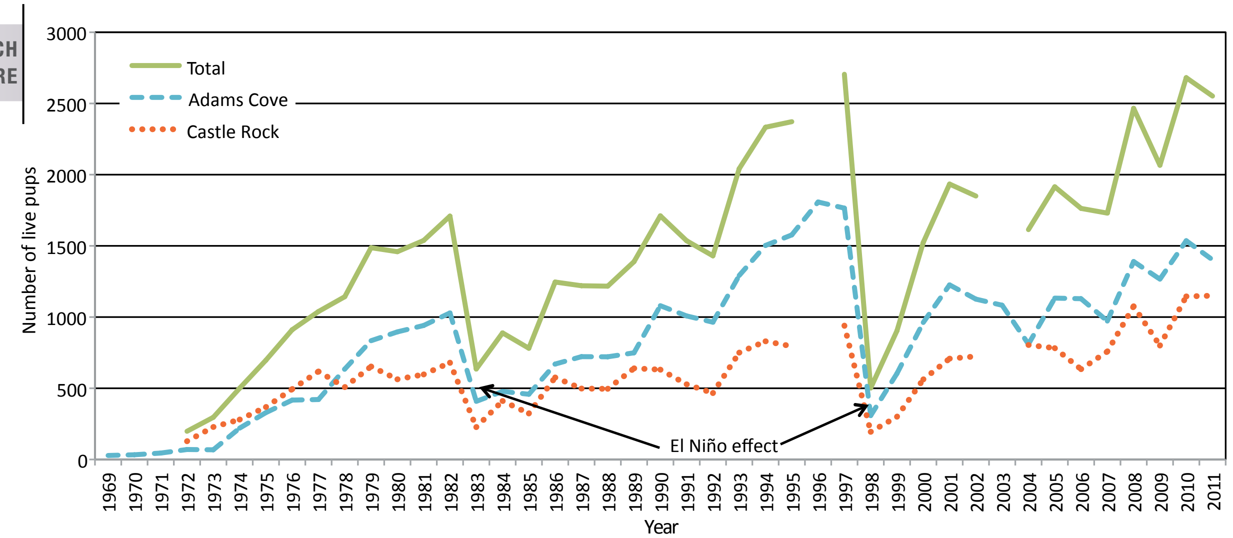


Figure 5. Number of live pups counted in July each year from 1969 to 2011 at Adams Cove (dashed blue), Castle Rock (dotted orange), and total for both rookeries (solid green).

biologists have counted live pups at San Miguel Island in July of each year and estimated the population size since 1968. The San Miguel pup counts cycle with periods of rapid increase followed by significant declines related to El Niño events (Fig. 5). In the California Current ecosystem, El Niño conditions produce changes in the marine environment that result in redistribution and reduced availability of prey to adult and juvenile fur seals that affect survival and reproduction. The strong El Niño events of 1982-83 and 1997-98 reduced the pup births on San Miguel Island by 63% and 81%, respectively. Over a 7-year period following 1983, the number of pup births slowly increased to reach pre-1983 levels in 1990. The slow recovery of pup production indicated that fewer animals were alive to produce pups following El Niño and, therefore, that a significant number of juveniles and adults also had died as a result of El Niño. The recovery from the 1998 decline has been even slower, but interpretation of the recovery is complicated by the emergence of <u>hookworm disease in the San Miguel Island stock</u> in the early 1990s. Hookworm disease has killed up to half of fur seal pups born since 1990 and in the early 2000s emerged as the primary cause of mortality for pups. Even so, the overall population trend for the San Miguel Island stock has generally increased or been stable throughout the last 20 years, likely due in part to immigration from populations from Alaska and Russia. The San Miguel stock, with a current population of about 10,000 animals, currently represents less than 1% of the worldwide northern fur seal population.

After more than a 150-year absence, northern fur seals returned to the Farallon Islands in the 1970s, and in 1996 the first pups were observed there. In 2011, a minimum of 180 live pups was counted in August. Many of the individuals recolonizing the Farallon Islands have tags that identify them as animals born at San Miguel Island, indicating that immigration from the San Miguel population is an important factor in the Farallon Islands population growth. However, not all the animals observed at the Farallon Islands are tagged, and it is possible that some are immigrants from Alaska or Russia.

Broad-scale Foraging Patterns

The National Marine Mammal Laboratory's approach to identifying essential habitat of northern fur seals and quantifying environmental effects on foraging behaviors includes describing age- and sex-specific broad-scale foraging patterns within the Eastern Pacific and San Miguel Island stocks as well as examining individual dive depths in relation to fine-scale biophysical measurements obtained from advanced oceanographic instruments. The research explores variability in foraging patterns within and among seasons (summer and winter) and among years. The goal is to identify environmental factors that influence foraging behavior and the possible consequences to population health, condition, reproduction, or survivorship.

In 2006, NMML researchers deployed satellite-linked telemetry instruments on lactating adult female fur seals at St. Paul, Bogoslof, and San Miguel Islands during the summer breeding season and prior to the winter migration to compare patterns in foraging behavior among the populations and relate them to divergent population trends. The foraging habitat surrounding each of the three islands consists of three oceanographic domains: continental shelf (<200 m), slope (200-1,000 m), and offshore (>1,000 m). Bogoslof and San Miguel Islands have little shelf habitat available around the islands, whereas St. Paul Island is located on the large Bering Sea continental shelf. The oceanographic domains support different prey assemblages and give rise to foraging behaviors that vary within and among the islands. Satellite telemetry instruments were glued to the fur between the shoulders (Photo 4) and provided location information on the animals while at sea or on land for up to 8 months. In addition, some of these satellite transmitters deployed on Alaska animals during the winter also provided information on the seals diving behavior, which can identify important foraging grounds.

Breeding Season

During the summer breeding season, average foraging trip durations (2.7 days) and average maximum foraging trip distances (51.6 km) were shortest for Bogoslof Island females (n=20), which primarily fed offshore, close to the island (Fig. 6). Females from St. Paul Island (n=20) mostly fed in geographically distinct areas from those at Bogoslof Island and exploited shelf and offshore habitats. Their average foraging trips were longer in duration (6.5 days) and in average maximum distance (293 km) than Bogoslof Island females'. Females at San Miguel Island (n=8) had the longest average foraging trip duration (12.5 days) and greatest average maximum distance (341 km) among the colonies.

Migration

Adult females departed the islands in November and began their winter migration. Thirteen of 19 females instrumented at Bogoslof (n=9) and St. Paul (n=10) Islands traveled from the Bering Sea, through the Aleutian passes, into the Gulf of Alaska, and into the North Pacific Ocean (Fig. 6). Of the 13 adult females that were tracked from Alaska, 5 were monitored for more than 90 days, and each ventured into the California Current ecosystem. They remained there and in the Gulf of Alaska ecosystem for 5-6 months foraging along the western slope of the continental shelf break and west into pelagic waters. By June, only one animal was still being tracked, and this female had departed the California Current and Gulf of Alaska ecosystems and was traveling towards her original departure site in Alaska. In contrast to the long distances traveled by the Alaska females, all nine females from San Miguel remained in the California Current and simply shifted their distribution farther offshore and northward compared to their summer foraging range but exploited similar continental shelf break and offshore habitats (Fig. 6). They spent little time in transit and spent most of their time feeding. None of the instruments on San Miguel animals functioned long enough to capture the full migration, but three females tracked into April began moving southward from northern California toward San Miguel Island and presumably returned to the island for breeding in June or July. There was considerable overlap between the San Miguel and Alaska female migration distributions in the California Current ecosystem – which highlights this region as an important winter foraging habitat for both the Eastern Pacific and San Miguel Island stocks.

Photo 4. Adult northern fur seal female with satellite telemetry device (yellow), dive recorder (yellow/green), and identification flipper tag. Instruments are glued to the fur and fall off when the animal molts in the autumn. Flipper tag is retained for several years.

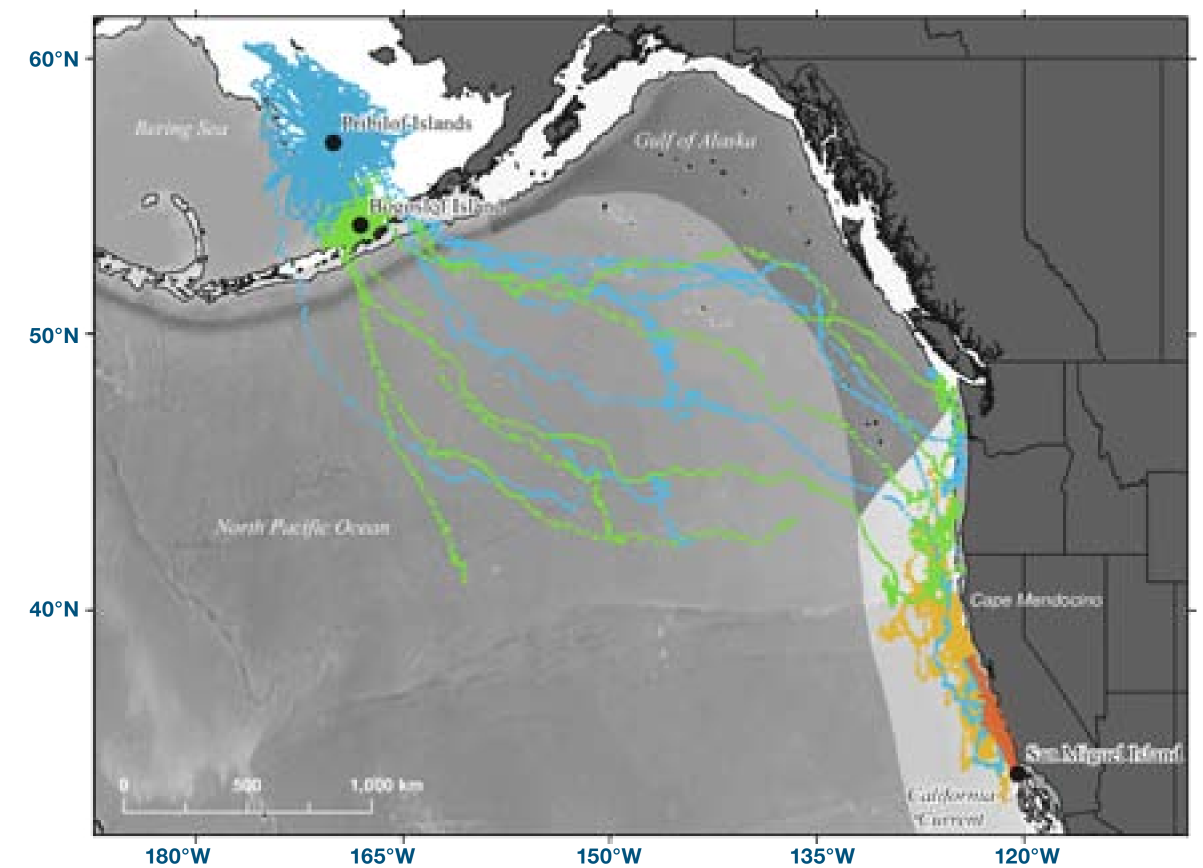


Figure 6. Foraging distribution of northern fur seals instrumented at St. Paul and Bogoslof Islands, Alaska, and San Miguel Island, California, in 2006. Summer movements were centered around the colonies at all sites with little overlap between St. Paul (blue) and Bogoslof (green) islands and no overlap between the Alaska sites and San Miguel Island (red). Alaskan animals migrated across the North Pacific Ocean during the winter, whereas San Miguel (yellow) animals remained in the California Current.

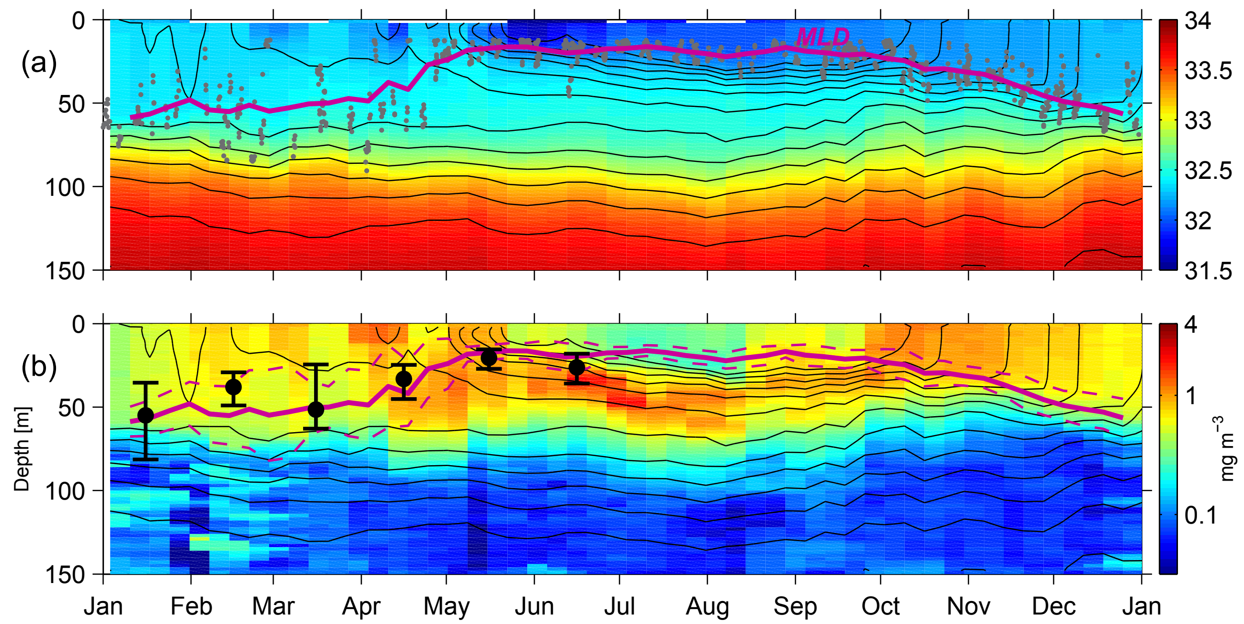


Figure 7. Average annual cycle of (a) salinity and (b) chlorophyll a, 60-80 km off the Washington coast shelf break, taken from 2003-09 Washington coast Seaglider observations (see Fig. 8 for region). In each panel, average annual cycle of density (σ_t) is contoured in intervals of 0.2 kg m^{-3}. Mixed Layer Depths (MLD) calculated from individual glider casts are indicated by grey dots in panel (a), with the mean in solid magenta; in panel (b), individual casts are not shown and instead dashed magenta lines indicate ±1 standard deviation of the MLD within each bin over all years. In panel (b), black circles plotted in the middle of each month indicate median adult female northern fur seal daytime diving depths during that month. Whiskers denote 1st and 3rd quartiles.

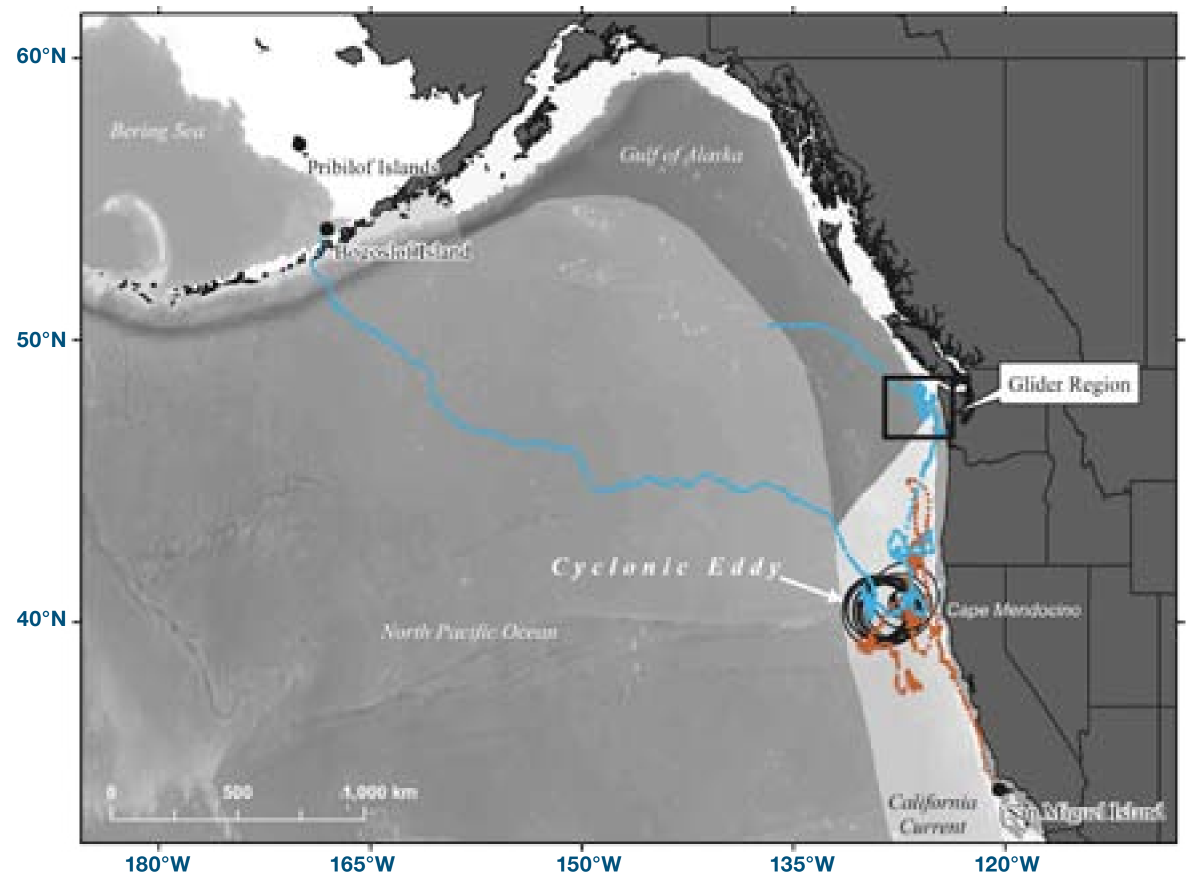


Figure 8. Satellite tracks of two adult female northern fur seals instrumented at Bogoslof Island (blue) and San Miguel Island (red) during winter migration 2006/2007, and the track of a cyclonic eddy present between January and March 2007 (black circles). Both females arrived at the eddy in January and were associated with it until March when the Bogoslof female began to move northward and the San Miguel female began moving southward. Box indicates area surveyed by Washington coast Seaglider Project (data presented in Figs. 7 and 9).

Small-scale Foraging Patterns

The National Marine Mammal Laboratory's collaboration with the University of Washington Applied Physics Laboratory and School of Oceanography also has described northern fur seal foraging patterns on a smaller spatial scale that reflect seasonal, mesoscale, and fine-scale oceanographic variability in the California Current ecosystem. The seasonal features of the California Current ecosystem are important factors affecting the density, distribution, and abundance of fur seal prey during the winter. Integration of remotely sensed oceanographic environmental data off the Washington coast, obtained from surveys conducted using an autonomous underwater vehicle (Washington Coast Seaglider survey), were combined with northern fur seal diving and movement patterns to demonstrate the interplay between northern fur seal behavior and the mixed-layer depth (MLD), eddies, wind-driven coastal upwelling, and seasonal ocean production. For example, seasonal changes in fur seal diving depths from deeper to shallower correspond well with seasonal shoaling of the surface MLD and initiation of the spring chlorophyll bloom (Fig. 7). As adult females from Alaska arrive to the California Current in January their diving depths are deeper and more variable compared to diving depths in May and June (Fig. 7).

Mesoscale variability such as coastal jets and eddies also affects the movement behavior of both San Miguel Island and Alaska fur seals. The animals' distributions overlap during the winter, and they tend to forage along steep oceanographic gradients both horizontally and vertically (Figs. 6 and 7). Eddies form in the California Current ecosystem and can persist for several months to a year and promote production and aggregation of zooplankton and northern fur seal prey species such as fish and squid. Biophysical interactions between eddies and fur seals generally occur along eddy edges (Fig. 8). Presumably, eddy physical structure promotes good foraging opportunities for northern fur seals, which may partially explain why the distant Alaska migrants travel to the California Current ecosystem during the winter months and why the San Miguel Island fur seals remain resident.

Furthermore, broad-scale wind patterns can cause alterations in fine-scale biophysical structure, which ultimately affects fur seal movement and diving behavior (Fig. 9). For example, a shift in the dominant wind direction (Fig. 9d) is associated with coastal upwelling and advection of nutrients westward and can promote a strong surface and subsurface chlorophyll bloom (Fig. 9a, b). Fur seals responded to increased ocean productivity with a shift in movement from transitory to searching behavior and remained within 50 km from the continental shelf break in an area of high production (Fig. 9a, c). Fine-scale vertical variability and the surface chlorophyll bloom indicate a shoaling of the MLD close to the continental shelf break (~ 20m depth; Fig. 9b). Fur seal diving depths, both during the daytime (white triangles; Fig. 9b) and nighttime (black triangles; Fig. 9b) were shallow and aggregated around the MLD, reflecting the depth and distribution of their prey. Thus, the spatial and temporal integration of fur seal behavior with seasonal, mesoscale, and fine-scale biophysical structures highlights important linkages between atmospheric patterns, ocean production, and fur seal prey.

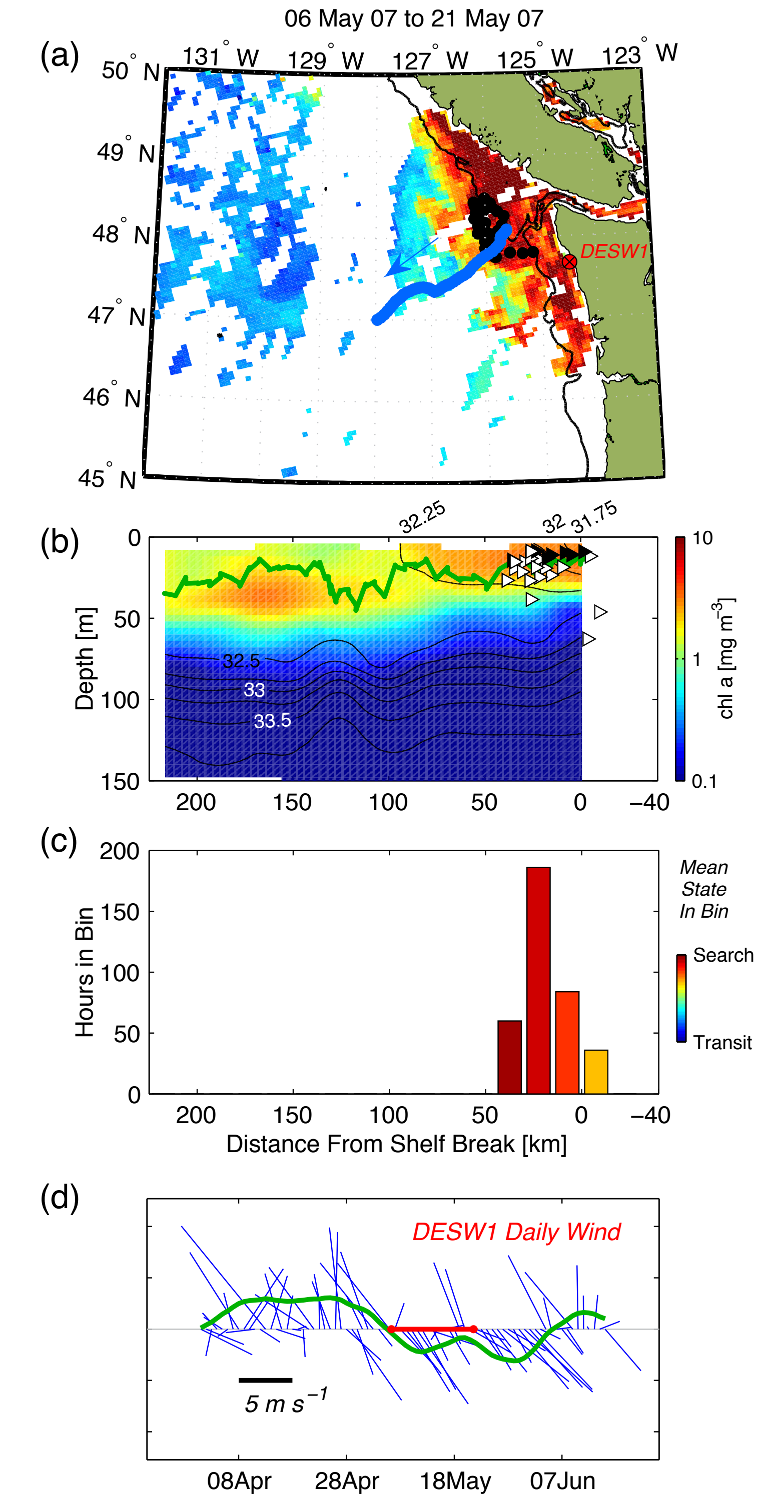


Figure 9. Movement and dive behavior of an adult female northern fur seal in relation to surface chlorophyll a (a), subsurface salinity and chlorophyll a (b), distance from the continental shelf break (c) and spring winds (d) in the California Current. Subsurface salinity and chlorophyll a measurements (b) were obtained along the Washington coast Seaglider survey line shown as blue dots in (a). Black dots in (a) indicate fur seal locations and the black and white triangles in (b) represent the average dive depth for each 6 hour period during nighttime and daytime periods, respectively. Movement behavior was determined as either searching or transitory and this behavior relative to the continental shelf break is shown in (c). The behavior of this fur seal switched to a searching behavior just as the spring winds switched to a northwesterly direction (d), causing upwelling and a chlorophyll bloom (a). In addition, the seal's dive behavior intensified and was aggregated at the mixed-layer depth (MLD) (b).

Diet Differences Within and Between Stocks

Diet samples are collected within each stock to monitor how diet changes over time in relation to the diverse prey and marine habitats available to northern fur seals during the summer breeding season and winter migration. The research employs multiple techniques including stable isotope analysis and scat (feces) collection, which provide a more comprehensive view of the diet by encapsulating both small and large spatial and temporal scales of seal foraging. The goal is to determine if seal diets can help explain the divergent population trends observed within and between the two stocks.

Scat analysis involves the identification of prey hard parts (e.g., fish bones and cephalopod beaks) found in samples and is useful for providing information on specific prey taxa consumed. Stable isotope analysis is based on the premise that the stable isotope composition of a consumer's diet is reflected in its tissues and that each tissue assimilates diet at different temporal scales due to dissimilar isotopic turnover rates within each tissue. For fur seals, plasma represents the diet integrated about 1-2 weeks prior to collection (i.e., foraging trip); red blood cells (RBCs) represent the previous month or two (i.e., breeding season); and fur represents diet from the breeding season and, to a lesser extent, the previous winter migration. The carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios of the fur seal tissues indicate foraging location and trophic level, respectively. Values of $\delta^{13}C$ increase from high to middle latitudes, offshore to nearshore, and pelagic to benthic environments; $\delta^{15}N$ values increase with each trophic level.

The goal is to determine if seal diets can help explain the divergent population trends observed within and between the two stocks.

Table 1. Percent frequency of occurrence (%FO > 5%) of prey taxa retrieved from northern fur seal fecal samples collected at Bogoslof Island (BI, 2007), San Miguel Island (SMI), and two rookeries on St. Paul Island (SPI) in 2006. n **represents the number of samples that had identifiable prey remains. Bold numbers indicate prey taxa with %FO > 10%.**

Prey taxa	SPI Reef	SPI Vostochni	BI	SMI
	(n = 28)	(n = 74)	(n = 41)	(n = 27)
Northern anchovy				**92.6**
Northern smoothtongue			**73.2**	
Walleye pollock	**89.3**	**68.9**	9.8	
Pacific hake				**55.6**
Pacific sardine				**51.9**
Market squid				**22.2**
Gonatid squid	3.6	5.4	**73.2**	3.7
Clupea harengus	**14.3**	27.0		
Pacific salmon	**17.9**	**18.9**		
Gadid spp.	3.6	**25.7**	2.4	
Myctophid spp.	**10.7**		**17.1**	3.7
Atka mackerel	**14.3**	6.8	2.4	
Rockfish				7.4
Pacific sand lance		5.4		
Three-spine stickleback		5.4		
Irish lord		5.4		
Sculpin				3.7

Diet studies were conducted at the same locations as the satellite telemetry studies: St. Paul Island in the Pribilof Islands, Bogoslof Island, and San Miguel Island. Scat analysis revealed that relatively few prey taxa had high occurrences (found in >10% of scats) at each location (Table 1). Prey identified from scats at each site was associated with a specific oceanographic domain. At St. Paul Island, scats from two different areas had different primary prey taxa; Vostochni Rookery on the northeast side of the island had highest occurrences of on-shelf species (e.g., walleye pollock, Pacific herring, Pacific sand lance) and Reef Rookery on the south side of the island had high occurrences of both on-shelf (e.g., walleye pollock, Pacific herring) and off-shelf (e.g., myctophids) species. Bogoslof Island was characterized by high occurrences of off-shelf prey (e.g., gonatid squid and northern smoothtongue), whereas San Miguel Island had high occurrences of on-shelf schooling prey (e.g., northern anchovy, Pacific hake, Pacific sardine, rockfishes, and market squid).

Plasma and RBC $\delta^{13}C$ values were different at each island (San Miguel Island > St. Paul Island > Bogoslof Island; Fig. 10). These results corresponded with scat analyses and reflected the geographic differences in the prey assemblages around each island during the breeding season. All tissues collected from animals at San Miguel Island were more $\delta^{13}C$-enriched than those collected from animals at Alaska locations, likely due to latitudinal isotopic differences (Fig. 10). There were some similarities (San Miguel Island and Vostochni Rookery at St. Paul Island) and differences (San Miguel Island and Vostochni Rookery, St. Paul>Reef Rookery, St. Paul Island >Bogoslof Island) in plasma and RBC $\delta^{15}N$ values among islands (Fig. 10). This pattern indicates that individuals that feed on prey in relatively nearshore or on-shelf waters were feeding at a higher trophic level compared to those feeding in off-shelf, pelagic areas. Fur $\delta^{15}N$ values followed this same pattern.

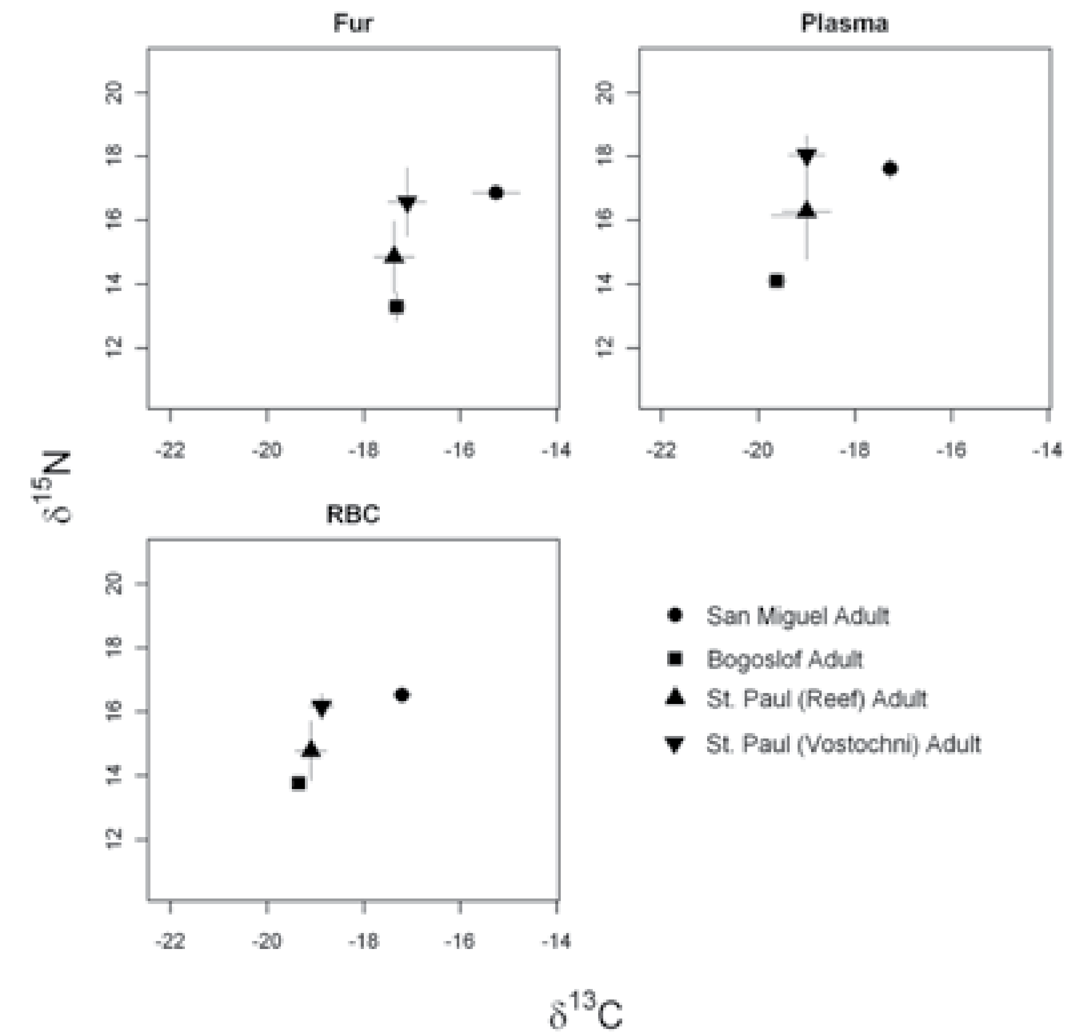


Figure 10. The relationship between mean $\delta^{13}C$ and $\delta^{15}N$ of tissues collected from adult female northern fur seals at Bogoslof Island (in 2007), San Miguel Island, and two rookeries on St. Paul Island (Vostochni, Reef) in 2006. Error bars represent ± 1 SD. RBC: red blood cells.

Apart from a few discrepancies (e.g., at San Miguel Island scat diet data indicated on-shelf foraging; however, telemetry data indicated slope/off-shore feeding), the diet data corroborate the movement patterns from our satellite telemetry studies. Fur $\delta^{13}C$ values were similar among the Alaska populations, suggesting that Alaska fur seals migrate to the same general areas during winter to feed. These individuals had lower $\delta^{13}C$ values compared to their counterparts at San Miguel Island, indicating that during part of the fur growth, these animals were feeding in different oceanic domains. The satellite data support this finding; between molting periods, San Miguel Island females feed exclusively in the California Current ecosystem whereas Alaska female fur seals only spend 3-4 months in this ecosystem and the rest of the year in the North Pacific Ocean and Bering Sea.

Future Directions

The Northern Fur Seal Conservation Plan describes the importance of comparative studies across the range of northern fur seals to better understand ecological processes that affect fur seal population dynamics. As our research demonstrates, there are similarities in foraging behavior among the populations in the two stocks, but it is the differences among them that should help to explain the divergent population trends. Future studies will focus on connecting foraging behavior and oceanographic features to demographic parameters throughout the range with the goal of identifying what is driving the decline of the Eastern Pacific stock.

Additional Reading:

National Marine Fisheries Service. 2007. Conservation Plan for the Eastern Pacific stock of Northern fur seal (*Callorhinus ursinus*). U.S. Dept. of Commerce, NMFS, Protected Resources Division, Alaska Region. Available at http://www.fakr.noaa.gov/protectedresources/seals/fur/cplan/final1207.pdf.

Zeppelin, T.K. and A.J. Orr. 2010. Stable isotope and scat analyses indicate diet and habitat partitioning in northern fur seals *Callorhinus ursinus* across the eastern Pacific. Marine Ecology Progress Series 409:241-253.

Arctic Fish Assessment in Near-shore and Lagoon Habitats

This summer the ABL Habitat and Marine Chemistry (HAMC) program commences a 3-year study to assess the fish assemblages in Arctic near-shore and lagoon habitats. The project is led by Johanna Vollenweider and Ron Heintz, with collaborators from University of Alaska Fairbanks (Professor Brenda Norcross) and Florida International University (Kevin Boswell). The Arctic shoreline is a matrix of shallow lagoons and barrier islands on the edge of an expansive shallow shelf and, with the prospect of oil development, is the most vulnerable habitat to chronic long-term contamination should oil come ashore. There is a dearth of knowledge about fisheries populations and productivity in the near-shore because these shallow habitats are relatively inaccessible to deep-draft vessel surveys. Near-shore fish assemblages are different from those offshore; hence, these near-shore surveys will complement the offshore fish assessment surveys.

The objective of the HAMC study is to describe and quantify the fish species in the shallow near-shore areas and lagoons along the Arctic coastline, providing information essential in environmental assessments associated with oil and gas development and damage assessments, should a spill occur. In addition, a variety of biological characteristics that are poorly documented for Arctic species will be measured, including nutritional content, diet, trophic position (isotope content), and size-at-age—information needed to understand the ecological value and use of these vulnerable habitats.

We will use novel technologies from small, shallow-draft vessels to work in these difficult areas, including an autonomous vehicle equipped with SIMRAD and DIDSON hydroacoustic gear. Fish identified with hydroacoustic methodology will be verified, and samples will be collected for laboratory analyses using small otter trawls and beach seines. In summer 2012, HAMC scientists will conduct a site visit and pilot study based in Barrow, Alaska. During summer 2013 and 2014, surveys will be expanded along the shoreline to areas such as Wainwright and Peard Bay.

Support for this study comes from several sources: the National Pacific Research Board (NPRB), Bureau of Ocean Energy Management, National Marine Fisheries Service, North Slope Borough, and student support provided by Florida International University (FIU) and University of Alaska Fairbanks. Results from the study will provide an understanding of the productivity of Arctic near-shore habitats and their overall importance and contribution to the Arctic ecosystem. Our evaluation of the importance of near-shore Arctic habitats is integral to management of areas considering the potential impacts and vulnerability to climate-induced changes and anthropogenic alterations.

By Johanna Vollenweider

Busy Outreach Season at ABL

Auke Bay Laboratories completed several major outreach efforts during the spring.

Science Fair Winners Advance: Winners of the Southeast Alaska Regional Science Fair (SARSF) advanced to several national and international competitions with the aid of ABL scientists. Dr. Lawrence Schaufler (ABL), the SARSF fair director, was selected to be a judge at the Intel International Science and Engineering Fair in Pittsburgh, Pennsylvania, 13-18 May and chaperoned four students. Another pair of students mentored by NOAA scientists in ABL's Nutritional Ecology Lab attended the International Sustainable World Energy Engineering Environment Project Olympiad (I-SWEEP) Science Fair in Houston, Texas, 2-7 May and won a third place prize. In June, ABL outreach coordinator Bonita Nelson accompanied a student she mentored to the national competition for the Stockholm Water Prize in Boston, Massachusetts.

Sea Week: In May, ABL hosted Sea Week, started at ABL 33 years ago, which has evolved now into the state's Alaska Rivers and Seas Curriculum. More than 1,000 kindergarteners, sixth-graders, and their adult chaperones toured ABL. Thirty percent of ABL scientists volunteered to introduce the visitors to local intertidal ecology, fish biology, and the research programs conducted at ABL. The biggest hit each year is holding the creatures in the touch tanks.

STAR Interns: Science Teacher and Researcher (STAR) interns arrived in June to begin their 8-week program. The STAR program is conducted in conjunction with California Polytechnical State University and is a new partner for NOAA. The teachers are engaged in research projects and, with the help of NOAA mentors, are learning how to translate "doing science" into "teaching science." Their teaching mentor, Kathleen Galau, is one of two NOAA "teachers-in-the-lab." During their residence the students interns will conduct fish feeding studies and develop energy budgets for rhinoceros aukelet seabirds. Both of these studies will contribute data to the NPRB-funded Gulf Project and will produce curriculum as part of their projects.

STAR interns Brielle Kemis and Dustin Taylor.

National Marine and Aquatic Educators Association (NMAEA): Also in June, Bonita Nelson, Kathleen Galau, and the STAR interns attended the national NMAEA meeting in Anchorage. Nelson was on the steering committee and gave two presentations. The first was on the value of science fairs. The second was on how ABL is getting at-risk students involved in science, technology, engineering, and math through a program developed in conjunction with our second NOAA teacher in-the-lab, Laura Dzinich. Galau used her experiences at ABL to discuss the value of science teachers collaborating with scientists.

Sun to Sea Marine Science Camp: ABL scientists Nelson and Tom Rutecki teamed up with NOAA Weather Service and the Juneau Economic Development Council to sponsor the annual Sun to Sea Marine Science Camp targeted for middle school students. For the week of 4-9 June, 13 students participated in hands-on activities designed to introduce the principles of marine science and weather. A representative of the Weather Service described how climate influences ocean currents. Students subsequently helped map currents in Auke Bay. Dave Csepp and John Karinen accompanied students on chartered vessels to demonstrate ROV (remotely operated vessels) technology.Cindy Tribuzio and Alex Andrews led campers in dogfish dissections. The camp explored sampling for invertebrates, fish, plankton, and algae, as well as ocean acidification, oil spills, acoustics, and art in science.

Campers Jenae Kesey, Sabrina Jones, Cale Jenkins, and Arlo Handley test for paralytic shellfish poisoning as part of the Sun to Sea Marine Science Camp activities.

By Bonita Nelson

Finding Nemo is Easier Than Identifying Hydrocarbon Sources

Past oil spills (*Exxon Valdez*, *Selendang Ayu*, and *Deepwater Horizon*) have taught us that oil spills will occur, that oil will linger (approaching 25 years with the *Exxon Valdez* spill), and that identification of the source oil will be complicated and controversial. Oil spills in the Arctic will be no different. An increasing number of vessel operations, discovery wells, and natural oil seeps ensure there will plenty of contaminated material to analyze, and source identification in those oil spills will likely be contested.

Auke Bay Laboratories has made strides in the forensic chemistry of identifying hydrocarbon sources, and much of that progress depends on mathematical modeling. Chemistry provides the primary data; we now have five analytical "streams" that quantify 100 different hydrocarbons that include polynuclear aromatic hydrocarbons (PAH), alkane hydrocarbons, and biomarkers such as hopanes, terpanes, and steranes. Recent progress has been in the mathematical modeling that follows chemical analysis. Together these analytical and mathematical measures are required to separate multiple anthropomorphic and natural organic sources.

Principal components analysis (PCA) is a mathematical strategy proving useful in source identification. Applied to the 2004 *Selendang Ayu* spill in the Aleutian Islands, PCA of hopanes and steranes distinguished all known oil sources and provided evidence of the environmental stability of these compounds. For PAHs, and separately alkanes, PCA analysis provided evidence of weathering (thermodynamically controlled shifts in composition) and clearly distinguished oiled sediment from reference sediment.

A second mathematical approach proving useful is direct comparison of the composition of stable compounds (those highly resistant to degradation) from known sources to composition of unknown samples. For example, hopane composition can be quantitatively compared between known sources and field samples and has allowed definitive identification of hydrocarbon sources in sediment.

A third mathematical approach useful in understanding sample conditions is a pattern-recognition algorithm designed to distinguish petrogenic (oil) and pyrogenic (fire) sources. This model works despite weathering and has been used on samples from *Exxon Valdez* and *Deepwater Horizon* spills.

It is not enough to measure the quantities of hydrocarbons in environmental samples; their source must also be identified. Collectively, chemical analysis followed by the mathematical modeling allows us to identify the source that contributes hydrocarbons to an unknown sample. In the Arctic we have the luxury of collecting and archiving near-shore samples before development proceeds. In the future, these samples will allow us to place a numerical value on what is meant by the term "pristine" and point to the naturally-occurring sources of environmental hydrocarbons.

By Mark Carls

ABL DIVISION/ LABORATORY REPORTS

NOAA scientists surveying the beaches of Southeast Alaska for marine debris found this fragment of trawl web entangled with beach logs, along with two single-use water bottles and a dishwashing soap bottle in Veta Bay on Baker Island. Photo credit NOAA Fisheries.

First Phase of Alaska Marine Debris Survey Completed

ABL scientists have completed the first phase of several planned surveys of Alaska's coast for marine debris. In June ABL completed surveys in southeastern Alaska, covering 36 sites along the 600 km of the outer coast. This year's survey adds to a series of surveys ABL has conducted over the last 40 years. There is the added factor of possible debris from Japan's March 2011 tsunami. ABL scientist Jacek Maselko is leading the field effort, which also includes Jason Rolfe, acting Deputy Chief of the NOAA Marine Debris Program, and three others.

Styrofoam fragments larger than softballs (smaller size pieces are essentially innumerable) and plastic single-use water bottles are the most prevalent debris. The amount and types of marine debris on Southeast Alaskan shores was not unusual, but 27 large black oval floats were observed at 11 of the 36 sites. Floats like these have been reported to NOAA by residents of Washington, Oregon, and Alaska in the last few months. Are these floats from the tsunami? Marine debris from Japan and other Asian countries has been seen over the years, so the trick is determining whether a particular item of debris is, in fact, from the Japan tsunami or just typical marine debris seen most years. Our 40-year time series of surveys provides a good baseline for comparison, and the results from this summer's work should provide a more complete picture. Surveys to the north and west will occur later this summer.

By Jacek Maselko

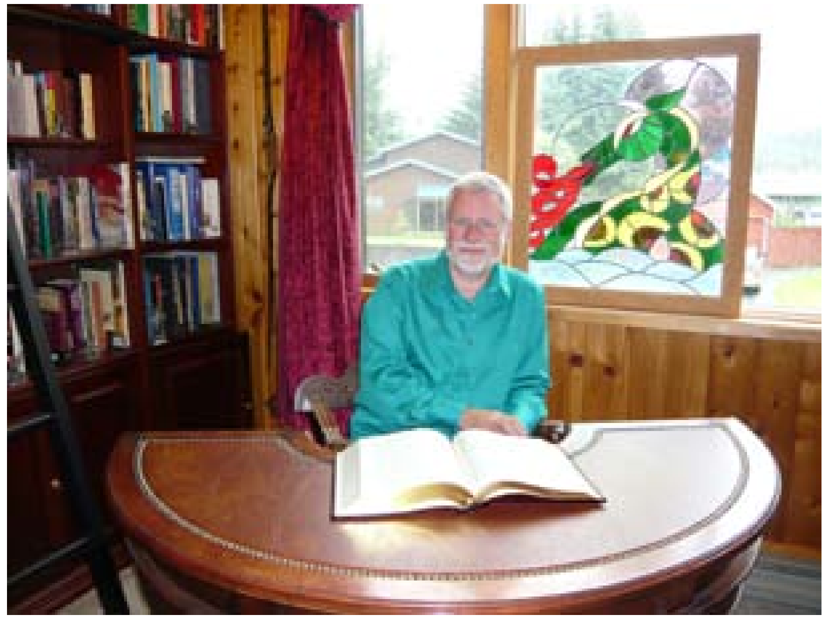
Hjort's Match/Mismatch Hypothesis Revisited; Prey Quality Can Mismatch Consumer Needs

Most work on climate change and trophodynamics has focused on temporal match and mismatches between prey and predators, but it is more complicated than just "quantity." The HAMC program is working to understand how the nutritional content of walleye pollock, Pacific ocean perch, and Pacific herring diets varies with climatic conditions and how those differences subsequently influence production. Up until now we have tended to think that prey abundance drove production. However, NOAA's work under the auspices of the Bering Sea Integrated Ecosystem Project has demonstrated that the modes by which climate affects fish production may be more nuanced than previously appreciated.

Typically the assumption is that climate alters the phenology of prey production and, if fish larvae are feeding when prey are scarce, the larvae fail to survive. However, another sort of mismatch occurs when the prey available to fish do not match their nutritional needs. Just because humans can eat celery does not mean that a diet of celery will meet our nutritional needs. Similarly, there is growing evidence that climate influences on prey quality can have demonstrable effects on fish production. For example, warm and cold conditions in the Bering Sea result in differences in the prey field available to juvenile walleye pollock. These differences result in variations in amount of lipid in the diets of young-of-the-year pollock. In turn, reductions in the rate of lipid ingestion have a direct effect on their survival, as measured by the number of age-1 recruits per female spawner. This latter relationship is likely related to resource depletion in winter.

Similar effects may occur with more specific nutritional components. Much of the aquaculture literature from the 1980s and 1990s aimed at identifying essential macronutrients that fish larvae cannot synthesize *de novo*. Among these were essential fatty acids. The availability of many of these fatty acids varies in the Strait of Georgia in response to the relative abundance of diatoms and dinoflagellates in the spring bloom. Certain climatic conditions can produce a phytoplankton bloom that does not supply sufficient levels of nutrients to upper trophic levels. This may have important implications for larval groundfish such as Pacific cod whose growth rates and survival can be maximized by offering them diets replete with specific fatty acids. Thiamine deficiencies offer yet another example of how nutrient limitations can affect fish production. Populations of adult salmonids with thiamine deficiencies can experience complete year-class failure.

By Ron Heintz



Adam Moles

Adam Moles Retires

With an impressive 75 publications during his 40-year career, Dr. Adam Moles retired from Federal service on 1 July. Adam's research at Auke Bay Laboratories (ABL) focused on the interactions of contaminants, habitat alteration, and disease for dozens of marine and freshwater species. He also served as scientific editor for the National Marine Fisheries Service from 2005 to 2008, overseeing the scientific content for the *Fishery Bulletin* and NOAA Professional Paper series. In recent years, he stepped away from research to take a more active role in planning and administration for ABL.

Starting as a bottle washer with ABL in 1972, Adam's assigned tasks were to prepare hydrocarbon solutions for other scientists and clean up the oil-soaked apparatus between trials. Many of the hydrocarbon studies done by Adam and others at ABL from 1972 to 1988 provided a basis for the Center's successful response to the *Exxon Valdez* oil spill in 1989.

The *Exxon Valdez* oil spill proved to be a watershed event for Adam. Laboratory experiments were superseded by field studies. Adam took this opportunity to pursue a Ph.D. and to focus on a wide variety of laboratory-based growth and behavior studies, often with limited funding. In particular, Adam pioneered the use of parasites as indicators of oil pollution. Some of his methods for monitoring water quality were adopted worldwide, most notably by the city of Venice, Italy. Adam also proved adept at administrative tasks and took on many of the administrative chores at ABL. Adam enjoyed mentoring writers and served part time as ABL editor. His favorite saying was "done climbing ladder, now lifting others."

For many years, Adam taught English classes at the University of Alaska, as well as classes in fish diseases and microbiology. His hobby has always been medieval literature, going so far as to pick up a master's degree in literature in 2003 at Oxford University, where his tutor, Douglas Gray, held the Tolkien Chair for Languages and Literature.

In retirement, Adam hopes to do some part-time teaching in English literature in Bellingham, Washington. After a lifetime in Alaska, he and his wife Terri are looking forward to seeing a bit more of the world. They've heard rumors about something called "sunshine."

FMA Observer Program Activities

During the second quarter of 2012 a total of 209 observers were trained, briefed, and equipped for deployment to vessels and processing facilities operating in the Bering Sea and Gulf of Alaska groundfish fisheries. Observers collected data onboard 207 vessels and at 17 processing facilities for a total of 11,158 observer days over this 3-month period.

New observer candidates are required to complete a 3-week training class with 120 hours of scheduled class time and additional training by staff as necessary. Returning observers are required to attend an annual 4-day briefing class prior to their next deployment in order to provide observers with necessary updates regarding their responsibilities. Prior to subsequent deployments throughout the year, all observers must attend a 1-day, 2-day, or 4-day briefing in Seattle; the length of the briefing is dependent on individual observer's needs. During the second quarter of 2012, FMA staff in Seattle provided training for 56 new observers and briefed 143 observers in Seattle.

The Observer Training Center at the University of Alaska Anchorage was closed in March of this year; as a result, most observer training activities as well as safety and sampling gear disbursements are conducted now in Seattle. To accommodate observers deploying from and returning to Alaska, FMA field office staff in Anchorage now provide 1-day briefings and issue gear to observers who are rapidly redeploying. During this last quarter, 10 observers attended the 1-day briefing we now offer at our Anchorage field office.

After each deployment, observers meet with a staff member for debriefing to finalize the data collected. There were 21 debriefings in Anchorage and, due to a larger debriefing staff, 192 debriefings in Seattle. Note that the values for the numbers of briefings and debriefings do not represent a count of individual observers as many observers deploy multiple times throughout the year.

A highlight for our Division during this quarter was the addition of a new staff member, Gwynne Schnaittacher, who will represent FMA as the North Pacific Groundfish Observer Provider Liaison in Seattle. Gwynne serves as the primary point of contact for observer providers and for observers with provider concerns. As such, in coordination with supervisors and observer providers, Gwynne resolves operational problems; develops policies and procedures to manage the pool of observer providers; and monitors observer provider compliance with regulations and policies. Gwynne is the primary point of contact for all training and briefing registration issues, and she schedules all debriefing requests and reviews and maintains observer files.

Gwynne joins us with extensive experience from the East Coast where, for over 6 years, she worked as the direct observer provider liaison between A.I.S., Inc. and the NMFS Northeast Fisheries Observer Program. In that role, her primary responsibility was to work closely with NMFS to ensure A.I.S. contractual parameters were achieved, such as data quality monitoring, sea day requirements, and scheduling debriefings and trainings. Gwynne was the supervisor of senior management staff at A.I.S. and was ultimately responsible for 70 observers. While in her position with A.I.S., Gwynne also maintained her certification as a NMFS Northeast Fisheries Observer by deploying on several commercial trips each year.

Gwynne received both her bachelor's and master's degree from the University of New Hampshire in zoology. In addition to her observer program involvement, Gwynne has conducted bycatch reduction studies on the East Coast in collaboration with local commercial fishermen. Outside of the work environment, she actively pursues adventure through international travel, hiking with her dog Moxie, kayaking, mountain biking, and gardening.

The FMA Division is extremely pleased that Gwynne brings her skills, experience, and enthusiasm to this important position. Please join us in welcoming Gwynne to our team.

By Allison Barns and Patti Nelson

FMA North Pacific Groundfish Observer Provider Liason Gynne Schnaittacher.

First Special Issue of the Bering Sea Project Published

Hot off the press this summer are 23 research articles from the Bering Sea Project (aka BEST-BSIERP). Published in *Deep Sea Research II*, the special issue represents findings of a partnership of the National Science Foundation, North Pacific Research Board, NOAA, and several other academic and federal partners.

About 100 researchers studied Bering Sea ice and ecosystem conditions over 6-years to understand the processes that influence the eastern Bering Sea marine ecosystem. The special journal issue features multiple papers describing the changes in sea-ice, the distribution of important nutrients, and how fish, seabirds, fur seals, and whales are responding.

NOAA, through the AFSC and Pacific Marine Environmental Lab (PMEL), played a key role in the study of this important large marine ecosystem and how it responds to climate variability. NOAA and its partners contributed a combined amount of $52 million during the 4 years of field research (2007-10). NOAA scientists comprised about one-third of the approximately one hundred experts from universities and other institutions working on this special project. Critical to the results of this study and the special issue were measurements made by NOAA scientists in the decades before the recent study began. For example, the AFSC is the only institution with long time series of observations of zooplankton, larval fish, adult and juvenile fish, fur seals, and whales. These observations allowed Bering Sea Project participants to put the most recent measurements in context.

To give you a flavor of their findings, here are short summaries of the articles with NOAA (either AFSC or our neighbor PMEL) senior authors.

About 100 researchers studied Bering Sea ice and ecosystem conditions over 6-years to understand the processes that influence the eastern Bering Sea marine ecosystem.

Recent Bering Sea warm and cold events in a 95-year context.
Overland J.E., Wang M., Wood K.R., Percival D.B., Bond N.A.

In the past decade, Bering Sea shelf waters experienced a multi-year, very warm spell followed by a very cold spell. These events were compared to a 95-year long weather record. Such extreme events were rare but not unique. We found that while modest long-term warming due to climate change is expected in the North Pacific Ocean and southeastern Bering Sea, the historical records suggest that the most important climate feature over the next few decades will be large random variability.

A comparison of the physics of the northern and southern shelves of the eastern Bering Sea and some implications for the ecosystem.
Stabeno P.J., Farley E.V. Jr, Kachel N.B., Moore S., Mordy C.W., Napp J.M., Overland J.E., Pinchuk A.I., Sigler M.F.

Measurements made during the 6-year study show a potential impact of climate change on species from zooplankton to whales living on the Bering Sea shelf, a relatively shallow portion of the sea directly off the Alaskan coast. The study projects warming of southern shelf waters will limit the distribution of Arctic species such as snow crab, while the distribution and abundance of whales will change as their food source moves.

Comparison of warm and cold years on the southeastern Bering Sea shelf and some implications for the ecosystem.
Stabeno P.J., Kachel N.B., Moore S., Napp J.M., Sigler M.F., Yamaguchi A., Zerbini A.N.

From 1972 to 2000, there was high interannual variability of areal extent of sea ice during spring (March–April). In 2000, this shifted to a 5-year period (2001–05) of low ice extent during spring, which transitioned to a 4-year period (2007–10) of extensive sea ice. During the warm period, there was a lack of large copepods and euphausiids over the shelf; however, their populations rebounded during the cold period. Small crustacean zooplankton taxa did not appear to vary between warm and cold years.

Stratification on the eastern Bering Sea shelf, revisited.
Ladd C., Stabeno P.J.

NOAA historical data demonstrated that stratification of the water was not simply a matter of whether or not the water column was warm or cold. Strong stratification during the summer prevents the refertilization of the surface waters and decreases the amount of production.

Net community production on the middle shelf of the eastern Bering Sea.
Mordy C.W., Cokelet E.D., Ladd C., Menzia F.A., Proctor P., Stabeno P.J., Wisegarver E.

The presence or absence of sea-ice was previously thought to have a large impact on the production of microscopic plant life (phytoplankton). We found that the wind accounts for a larger piece of the phytoplankton production puzzle, and this finding can be implemented for future models of the Bering Sea ecosystem.

Developing an acoustic index of euphausiid abundance to understand trophic interactions in the Bering Sea ecosystem.
Ressler P.H., De Robertis A., Warren J.D., Smith J.N., Kotwicki S.

We developed a new time series of euphausiid zooplankton (or krill) biomass and distribution and documented 1) a recent increase coinciding with the end of a warm period and the beginnings of a cold period in the eastern Bering Sea and 2) an inverse relationship with adult walleye pollock biomass.

Influence of environment on walleye pollock eggs, larvae, and juveniles in the southeastern Bering Sea.
Smart T.I., Duffy-Anderson J.T., Horne J.K., Farley E.V., Wilson C.D., Napp J.M.

Using historical data collected on larval fish surveys conducted by the AFSC, we documented a shift in the location of larval fish between warm and cold years. In cold years they were much closer to the edge of the shelf, while in warm years they were closer to the middle of the shelf. This has important implications for their transport and survival.

Distribution of fish and macrozooplankton in ice-covered and open-water areas of the eastern Bering Sea.
De Robertis A., Cokelet E.D.

Using sonar installed on an icebreaker, we made the first comprehensive observations of fish in the ice-covered Bering Sea. During winter periods of ice cover, the cold and icy Arctic-like conditions force fish southeastward, out of their summer habitat.

Effects of climate variations on pelagic ocean habitats and their role in structuring forage fish distributions in the Bering Sea.
Hollowed A.B., Barbeaux S.J., Cokelet E.D., Farley E., Kotwicki S., Ressler P.H., Spital C., Wilson C.D.

The distributions of forage fish (fish used as food by other fish, seabirds, and marine mammals) are affected by the warm and cold cycles in the eastern Bering Sea. We examined historical survey data collected by the AFSC in warm and cold years and described how they differ and the consequences of these shifts in spatial distribution.

Latitudinal trends and temporal shifts in the catch composition of bottom trawls conducted on the eastern Bering Sea shelf.
Stevenson D.E., Lauth R.R.

Overall biomass of the epibenthic community declines with increasing latitude in the eastern Bering Sea, which is primarily driven by declining fish catches in the northern Bering Sea. The fish fauna in northern latitudes is increasingly dominated by gadids, with smaller species becoming more common in the north. The biomass of the invertebrate megafauna remains relatively consistent throughout the eastern Bering Sea, but invertebrates make up a larger proportion of the catch in bottom trawls conducted at higher latitudes.

Cetacean distribution and abundance in relation to oceanographic domains on the eastern Bering Sea shelf: 1999 to 2004.
Friday N.A., Waite J.M., Zerbini A.N., Moore S.E.

Visual line transect surveys for cetaceans were conducted on the eastern Bering Sea shelf in association with pollock stock assessment surveys aboard the NOAA ship *Miller Freeman* in June and July of 1999, 2000, 2002, and 2004. Fin whales were the most common large whale in all years except 2004 when humpback whales were more abundant. Dall's porpoise were the most common small cetacean in all years.

Marine predators and persistent prey in the southeast Bering Sea.
Sigler M.F., Kuletz K.J., Ressler P.H., Friday N.A., Wilson C.D., Zerbini A.N.

A predator's foraging mode and their restrictions during breeding affect their response to prey persistence. We examined whether this association with ecologically important prey (euphausiids, age-1 pollock) is influenced by differences among predator species (baleen whales, seabirds) in foraging modes (travel cost, surface feeder or diver) or whether the predator species is a central place forager or not.

A second special issue received 29 submissions with reviews now underway. To date, 58 peer-reviewed journal articles have been published by the Bering Sea Project.

Mike Sigler, HEPR
Jeff Napp, RACE

Figure 1. Satellite-tag deployment on a humpback whale off Dutch Harbor, Alaska.

Cetacean Assessment & Ecology Program

Eastern Aleutian Islands Humpback Whale (*Megaptera novaeangliae*) Satellite-Tagging Project

North Pacific humpback whales (*Megaptera novaeangliae*) migrate from temperate low-latitude breeding grounds to high-latitude feeding grounds each summer. The waters surrounding the eastern Aleutian Islands are dominated by strong tidal currents, water-column mixing, and unique bathymetry; these factors are thought to concentrate the small fish and zooplankton that comprise the typical humpback diet in Alaska, creating a reliable and abundant food source for whales in the Bering Sea. While humpbacks are probably the most studied large whales in the world, individual fine-scale habitat use and movement are still poorly understood, particularly in remote regions like the Bering Sea and the eastern Aleutian Islands. Most of what we know about humpback distribution and habitat use has been from analyses of historical whaling data and from modern photo-identification and genetic studies, yet these types of studies reveal only a small fraction of a whale's behavior.

This study clearly shows that humpbacks are a highly mobile, multi-national species, both within and between seasons.

Satellite telemetry is being used worldwide to create detailed, fine-scale tracks of whale movement, revealing behaviors that were previously unknown. During summer 2007-11, members of the Cetacean Assessment and Ecology Program deployed satellite-telemetry tags on humpbacks off the coast of Unalaska Island (Fig. 1). These tags are designed to record the animal's position while at the surface, 12 hours a day for up to several months. The tag data we collected during this study revealed the first fine-scale movement information for humpback whales in a North Pacific feeding ground. Ten satellite transmitters were deployed, yet only eight tags transmitted long enough to be evaluated. The whales were tracked for an average of 28 days (range = 7-67 days). Although all of our study whales were tagged in Unalaska Bay, they showed remarkable variation in speed, direction, and overall distance travelled, both within and between years. In 2007, one of the two tagged whales (21810 2007) made a trip to the Island of Four Mountains and returned to the northern side of Umnak Island, while the other (21809 2007) explored presumed feeding areas to the east of the tagging location between Unalaska Bay and Unimak Pass (Fig. 2). Of the two whales tagged in 2008, one (21809 2008) remained within 50 km of Unalaska Bay for the duration of the tag and the other (21810 2008) travelled nearly three times farther that year, between Unimak Pass and the Pacific side of Umnak Pass (Fig. 2). The single whale tagged in 2009 (87769 2009) remained within Unalaska Bay during the 7 days of tag transmission (Fig. 2).

The two whales tagged in 2010 showed the most surprising variation from any other year. One whale (88720 2010) travelled from Unalaska Bay west to northeastern Umnak Island, then through Umnak Pass, presumably to forage on the Pacific side of the island (Fig. 2). The other animal tagged that year (88721 2010) left Unalaska Bay 3 days after it was tagged and moved at least 1,500 km (in 12 days) along the outer Bering Sea shelf to southern Chukotka, Russia (Fig. 3). After 4 days off the Russian coast, this whale moved east across the Bering Sea basin to Navarin Canyon (60°30'N, 179°20'W), where it remained until transmissions ceased. In all, whale 88721 2010 travelled over 3,000 km, roughly the equivalent of swimming from Seattle, Washington, to Houston, Texas, in 26 days! The animal tagged in 2011 (87771 2011) remained nearshore between Unimak Pass and Umnak Pass (Fig. 2) for the duration of the tag transmission.

These results support the findings of historical and current studies that humpbacks frequently congregate in shallow, highly productive coastal areas of the North Pacific Ocean and Bering Sea. However, these tracks also make it clear that individual whales are making independent decisions about movement and that these decisions can lead to surprisingly long-distance travel within a feeding season. This movement variation is difficult to predict or describe but could potentially have a major impact on stock structure definitions. Ironically, whale 88721 2010's trip to the Chukotka coast occurred about a week after a NMFS Biological Review Team, charged with assessing the population structure of humpback whales, had decided that there was population separation between the eastern Aleutian Islands and Russia.

Fishing gear entanglement, a well-known cause of injury or death in the North Atlantic humpback population, has already been documented in nearly a quarter of the humpbacks photographed in Alaskan waters. Ship strikes, involving a wide range of vessels, are also increasing in Alaska. Impacts on humpbacks in the eastern Aleutians region and Bering Sea will likely increase with the influx of human activity from newly opened oil and gas lease areas in the Chukchi and Beaufort Seas. This study clearly shows that humpbacks are a highly mobile, multinational species, both within and between seasons. These data should highlight the need for cooperation between North Pacific coastal nations in creating effective research and management strategies that mitigate the known threats to humpbacks throughout all stages of their life cycle. Continued research involving satellite telemetry will help describe how these whales overlap with human activity throughout the North Pacific and will provide domestic and international governments with the information they need to take effective action against those threats.

By Amy Kennedy

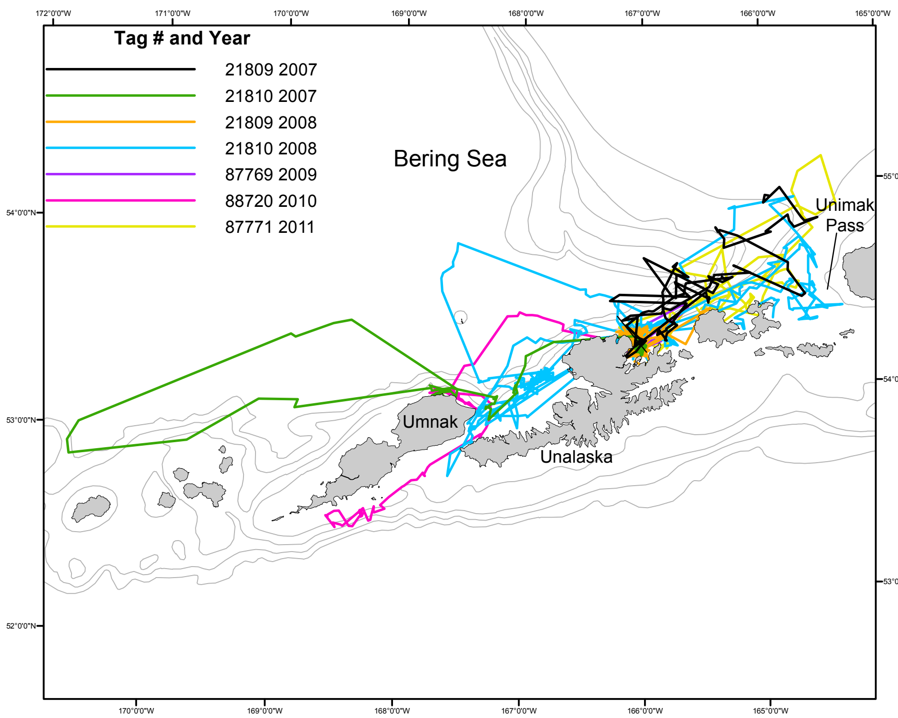


Figure 2. Telemetry tracks for seven humpback whales tagged during summer 2007-11.

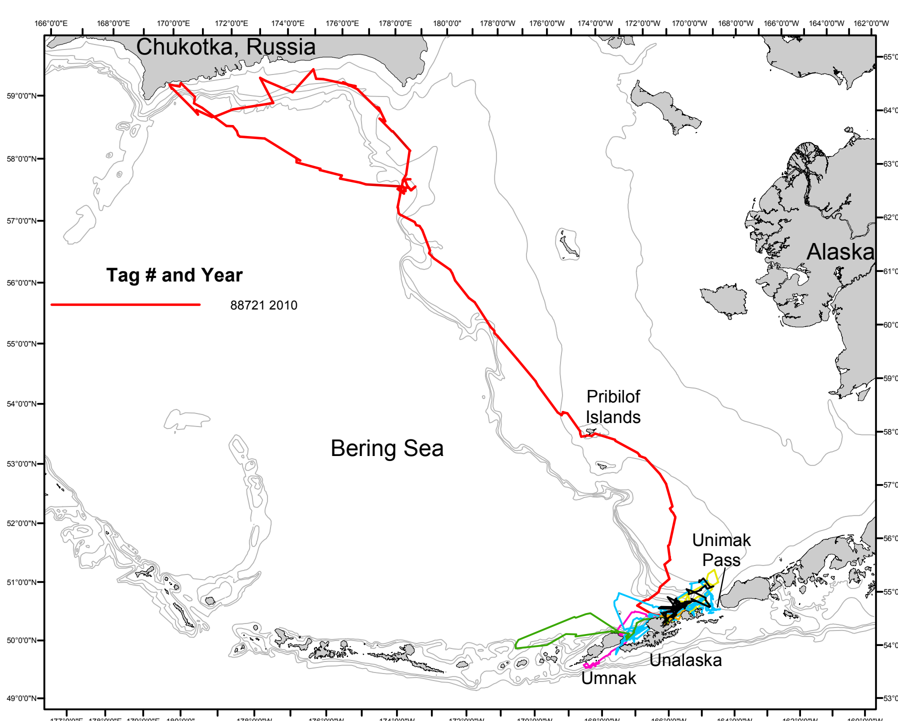


Figure 3. Telemetry tracks for all whales tagged during this study. Note that whale 88721 2010 travelled along the shelf break to coastal Russia before looping back, covering approximately 3,000 km in 26 days.

Polar Ecosystems Program

Bering Okhotsk Seal Surveys (BOSS): Joint U.S.-Russian Aerial Surveys, 1 April – 23 May 2012

Researchers from the National Marine Mammal Laboratory's (NMML) Polar Ecosystems Program (PEP), in collaboration with Russian colleagues, conducted synoptic abundance and distribution surveys for the four species of ice-associated seals (bearded, spotted, ribbon, and ringed seals) which are known to occupy and breed in the Bering Sea during the spring and summer (Fig. 4). The fieldwork was conducted using digital cameras and thermal imagers mounted in the belly ports of two U.S. and one Russian fixed-wing aircraft from 1 April to 23 May 2012.

The U.S. surveys consisted of flights originating from airports in Nome, Bethel, and Dillingham, Alaska. The U.S. team utilized airstrips in Gambell, on St. Lawrence Island, and St. Paul, in the Pribilof Islands, to reach the most remote areas of sea ice in the central Bering Sea. The Russian team began western Bering Sea surveys in mid-April from Ossora, Russia, on the Kamchatka Peninsula and worked their way north to the Bering Strait.

Most U.S. flights lasted 4-9 hours and were flown at an altitude of 1,000 ft (300 m) to maximize the area surveyed and minimize the chance of disturbance to seals and other wildlife. A NOAA Twin Otter (N56RF) housed three FLIR SC645 thermal imagers, which recorded continuous data in the 7.5-13.0 µm wavelength. Each thermal imager was paired with a Canon Mark III 1Ds digital single-lens reflex (SLR) camera with a 100-mm Zeiss lens. All six instruments were mounted in an open-air belly port (Fig. 5). The combined thermal swath width was approximately 1,500 ft (470 m) at an altitude of 1,000 ft. A contracted Aero Commander aircraft carried two sets of paired thermal imagers (SC645) and digital SLR cameras (Nikon D3X) and surveyed a maximum swath width of approximately 900 ft (280 m). The two aircraft flew a total of 39 surveys, which covered over 14,000 nautical miles (27,000 km) of trackline and collected more than 885,600 images.

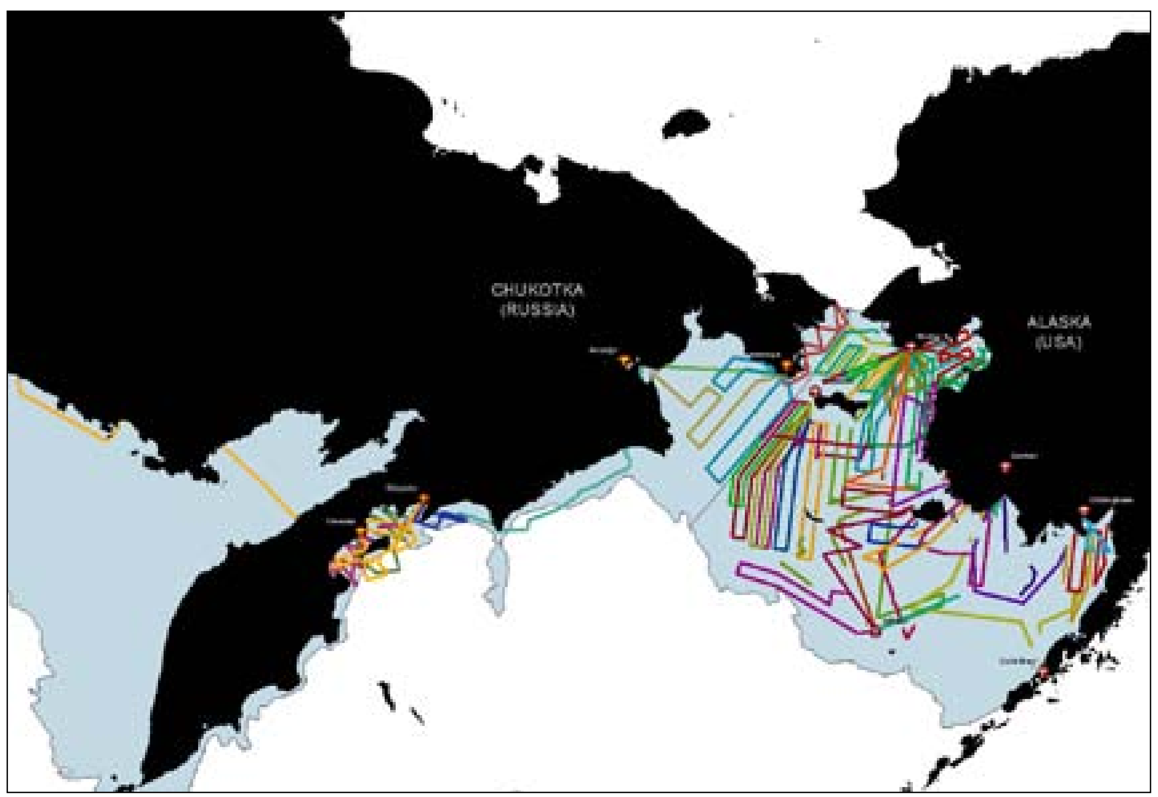


Figure 4. Map showing on-effort U.S. survey tracks and Russian flight tracks during the 2012 Bering Sea survey.

Figure 5. Paired Canon Mark III 1Ds digital SLR cameras and FLIR SC645 thermal imagers mounted in the belly port of a NOAA Twin Otter (N56RF) aircraft.

Figure 6. Paired thermal and visual images of a bearded seal on Bering Sea pack ice, collected during the 2012 survey. The images were collected using a Canon Mark III 1Ds digital SLR camera with a 100-mm Zeiss lens and an FLIR SC645 thermal imager mounted in the belly port of a fixed-wing aircraft flying at an altitude of 1,000 feet.

Advanced thermal-imaging technology was used on both the U.S. and Russian survey aircraft to detect the warm bodies of seals against the background of the cold sea ice. High-resolution digital images will be used to identify the species of seals detected by the thermal imagers (Fig. 6). Novel statistical approaches will also be used to tackle the unique challenges presented by the moving and melting sea-ice habitat. A second survey in spring 2013 will complete the coverage and increase the precision of the population numbers. Ultimately, this project will provide the first comprehensive estimates of abundance for the four species of ice-associated seals found in the Okhotsk and Bering Seas.

By Erin Moreland, Michael Cameron, and Peter Boveng

Recruitment Processes Program

A Collaborative Effort to Improve Assessment of the Early Life History Stages of Important Commercial Fish Species in the Bering Sea

The effort will provide seasonal fisheries information, environmental and biological indices, and annual syntheses necessary to apply an ecosystem approach to management.

The Fisheries Oceanography Coordinated Investigations (FOCI), the Ecosystem Monitoring and Assessment (EMA), and the Midwater Assessment and Conservation Engineering (MACE) Programs have begun a comprehensive, collaborative effort to improve assessment of the early life history stages of important commercial fish species in the Bering Sea. The effort will provide seasonal fisheries information, environmental and biological indices, and annual syntheses necessary to apply an ecosystem approach to management. Specifically, the coordinated research focuses on studying processes during the first year of life, a time when climate variation has a large affect on survival.

This spring, the first two in a series of collaborative seasonal cruises were completed. Scientists departed Kodiak, Alaska, aboard the NOAA ship *Oscar Dyson* for the Bering Sea on 26 April 2012 (cruise DY-12-04). Along the way they deployed long-term oceanographic moorings in Chiniak and Pavlov Bays and accomplished ichthyoplankton and CTD (conductivity-temperature-depth) sampling in Shelikof Strait (Gulf of Alaska). However, sea ice in the eastern Bering Sea covered the mooring sites and precluded retrieval of FOCI's sentinel moorings there. Scientists quickly adapted and began an ichthyoplankton survey over the southwest Bering Sea shelf, which was originally scheduled for the second cruise (DY-12-05). The objectives of this survey were to assess the distribution and abundance of eggs and larvae of walleye pollock (*Theragra chalcogramma*), examine the interactions among climate, oceanography, and ichthyoplankton, and determine how physical and biological factors affect the transport and survival of fish larvae. At the end of the first cruise, the moorings were still covered with ice (see The Bering Sea: Current Status and Recent Events in PICES Press v. 20 no. 2, in press for an explanation). The survey was resumed at the beginning of the second cruise (DY-12-05) which began on 15 May. Scientists were able to survey two known spawning grounds of walleye pollock over the shelf, the Unimak Island vicinity of the Alaska Peninsula and the Pribilof Islands. They also were able to begin surveying presumed spawning areas north of Pribilof Canyon but ran out of time and were unable to complete the survey as far as Zhemchug Canyon. This coverage was over a much larger geographic area than scientists were previously able to search. Most of the ice-free portions of the survey area were successfully sampled for ichthyoplankton (Fig. 1) and other zooplankton, along with temperature and salinity profiles at each bongo station. Data on distribution and abundance of zooplankton will provide information on prey fields for developing larvae. Throughout the cruise, walleye pollock larvae were collected to assess condition and study bioenergetics, work which will be conducted in the laboratory by AFSC scientists Ron Heintz and by Steve Porter. This work is central to understanding climate-mediated variation in condition of young walleye pollock in the spring and summer of the first year of life. Scientists were also able to complete mooring recoveries and redeployments for the two southern Bering Sea mooring sites (M2 and M4, Fig. 2). This will continue the long-term physical observations collected by the Pacific Marine Environmental Laboratory side of the FOCI program. These measurements are critical to studying climate change and oceanographic variability.

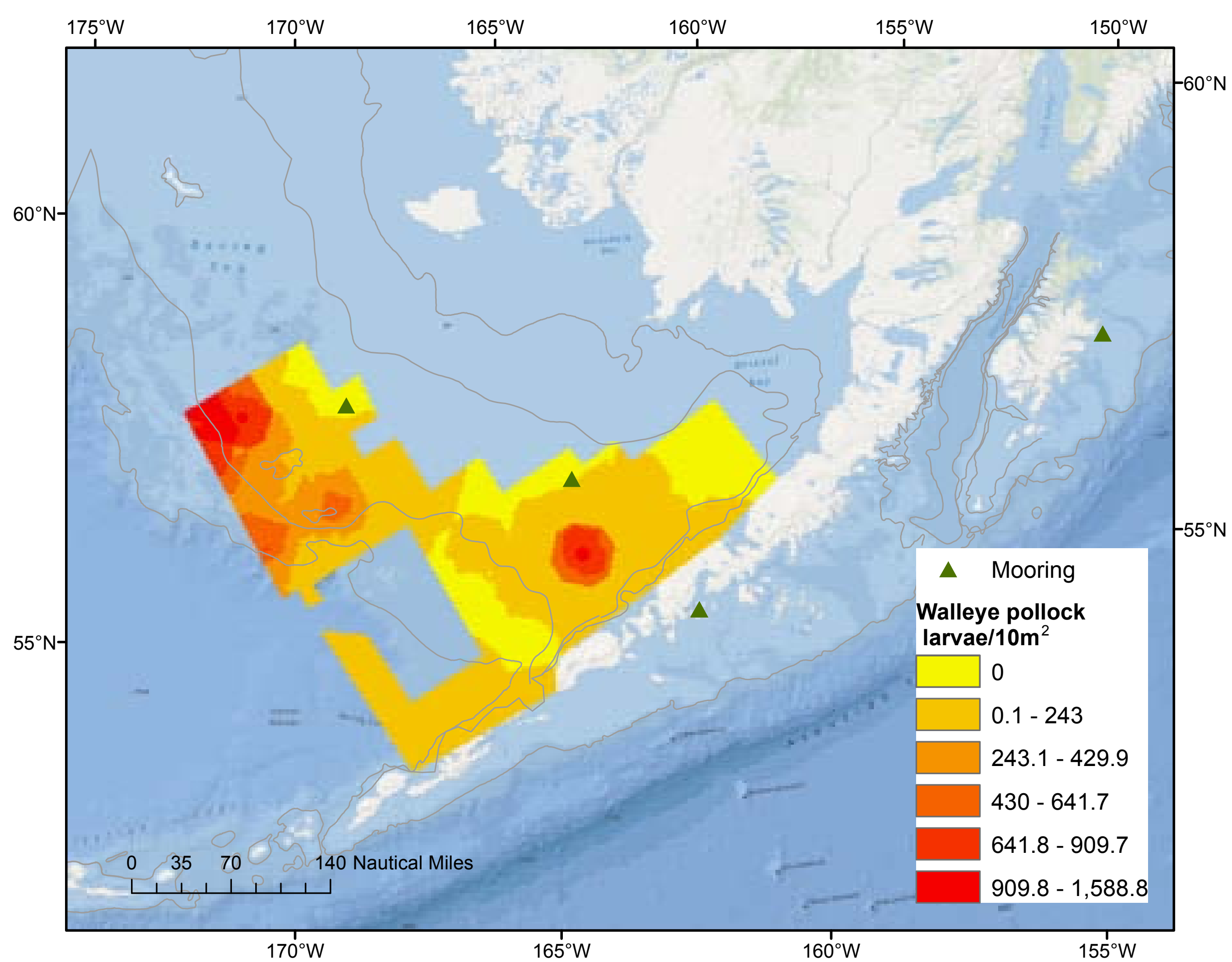


Figure 1. Preliminary densities (also known as rough counts) of walleye pollock larvae and locations of mooring deployments and recoveries from two FOCI cruises April 26 – June 2, 2012. Note that many walleye pollock eggs were collected along the Alaska Peninsula in the early part of the cruise, however eggs were not rough counted at sea. The timing of sampling may explain, in part, the difference in larval abundance between the southern and more northern areas.

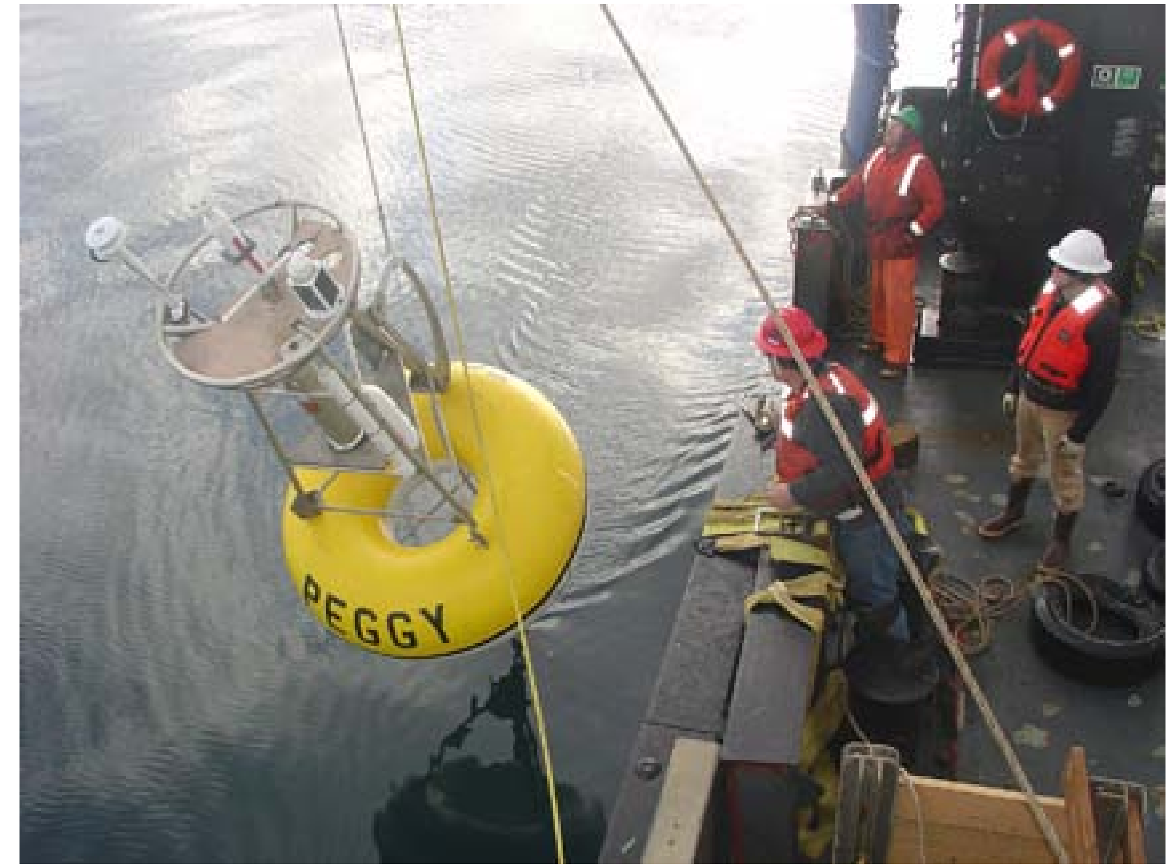


Figure 2. Bill Floering (AFSC/PMEL), Dave Hermanson and Brian Kibler (NOAA Marine Operations) deploy a surface mooring at Bering Sea mooring site M2. Photo taken by Kathy Hough (Marine Operations).

This work is central to understanding climate-mediated variation in condition of young walleye pollock in the spring and summer of the first year of life.

Stay tuned for the next article examining this first year of life study when the three programs collect late summer/early fall data on the *Oscar Dyson* (August – October) to see how the fish have been growing since last spring and whether or not they have managed to store enough energy to survive their first winter.

By Daniel Cooper and Janet Duffy-Anderson

Resource Ecology & Ecosystem Modeling Program

Fish Stomach Collection and Lab Analysis

During the second quarter of 2012, Resource Ecology and Ecosystem Modeling (REEM) program staff made preparations for summer surveys in addition to analyzing stomach samples. Stomach sampling has begun on the trawl surveys of the Aleutian Islands, eastern Bering Sea continental shelf, and eastern Bering Sea continental slope. Preparations for collecting stomach samples during both surface and bottom trawl surveys of the Chukchi Sea also have been made. Stomach Content ANalysis at sea (SCAN) is being conducted on both Aleutian Islands trawl survey vessels, and collection of all visually unidentifiable fishes will be returned to the lab for microscopic or genetic examination. Genetic examination of fish specimens collected from SCANned stomachs in previous years have shown that the accurate visual identification by current laboratory personnel is very robust, even for very digested fish specimens. However, genetic identification of the small percentage of fishes that are not identifiable to at least the genus level suggests that the species composition of these fishes is not well represented by the visually identified portion of the stomach contents. Stomach samples are currently being collected and preserved from the eastern Bering Sea trawl surveys. Total survey collections will be reported at the end of the third quarter.

Laboratory analysis of groundfish stomach contents has continued. During this quarter, 3,582 stomachs from 14 predators species were analyzed from the eastern Bering Sea, and 101 stomachs from three predator species were analyzed from the Gulf of Alaska. This resulted in 15,868 records being added to the AFSC Groundfish Food Habits database. Observers collected 221 stomachs during this quarter.

By Troy Buckley, Geoff Lang, Mei-Sun Yang, Richard Hibpshman, Caroline Robinson, Sean Rohan, and Kimberly Sawyer

Multispecies Stock-Assessment (MSM) and Bioenergetic Modeling

Multispecies Stock-Assessment Modeling (MSM) is a three-species model of some of the most productive fish stocks and key predators in the Bering Sea – walleye pollock, Pacific cod, and arrowtooth flounder. Their biological interactions may influence natural mortality estimates and subsequent harvest recommendations. Thus MSM is a first-cut approach for implementing ecosystem-based management of fisheries resources in the Bering Sea. MSM combines traditional catch-at-age stock assessment models with multispecies virtual population analysis models (MSVPA) in a statistical framework and uses abundance and diet data to estimate fishing mortality, recruitment, stock size, and predation mortality. MSM typically models the latter as a series of functional bioenergetics responses to derive temperature-dependent predator rations. Because MSM can capture critical threshold effects that characterize many ecological interactions, such an approach also provides a statistical framework to evaluate and manage both the direct and indirect effects of fisheries harvest on multiple species. Additionally, we used projections of the model to derive biological reference points (BRPs) for various harvest control rule approaches under variable climatic conditions.

As part of the MSM modeling effort we have continued to update the bioenergetic parameters used in MSM. In particular, we recently completed a comparative analysis of field-based daily ration values (corrected for digestion) to bioenergetic-based ration estimates for the eastern Bering Sea (EBS), Gulf of Alaska (GOA), and Aleutian Islands (AI) regions for walleye pollock, Pacific cod, and arrowtooth flounder. This comparative analysis is currently summarized in a draft manuscript tentatively titled "Field- and bioenergetic-based daily ration estimates for walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), and arrowtooth flounder (*Atheresthes stomias*) from Alaska (USA)." For this we refit Wisconsin bioenergetic parameters to published consumption data for the three (or similar) species and compared bioenergetic rations to digestion corrected field-based ration estimates (using two different methods) and von Bertalanffy derived estimates of consumption (Fig. 1).

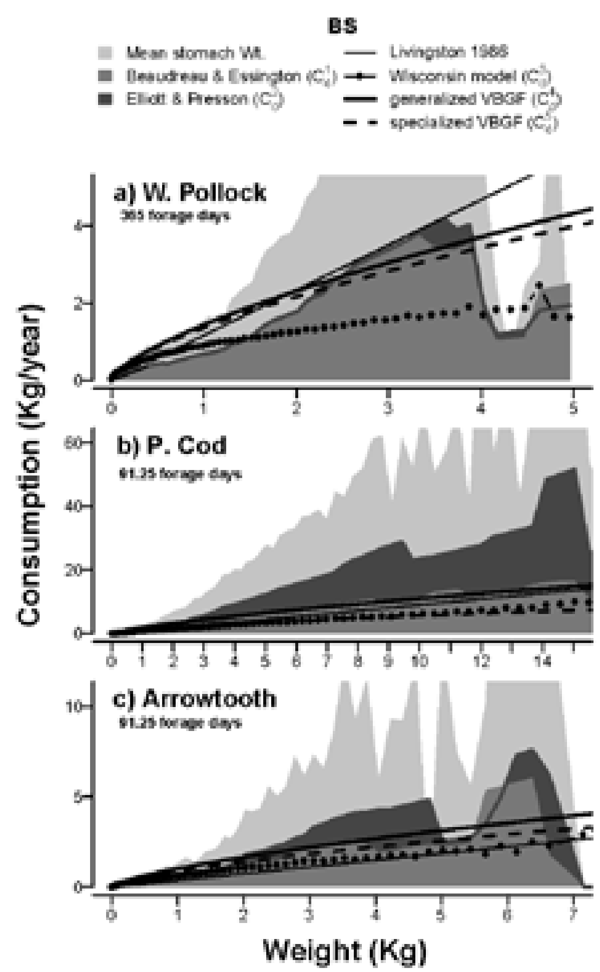


Figure 1. Weight-dependent annual ration estimates for walleye pollock, Pacific cod, and arrowtooth flounder from the eastern Bering Sea. Shaded polygons represent field-based rations estimated from three different methods: Mean. stomach Wt. (i.e., no correction; light gray), Beaudreau & Essington (digestion correction using prey condition; medium gray); Elliott & Presson (digestion correction using mean stomach weights; dark gray). The thin line shows values reported in Livingston et al. 1986. The remaining lines represent bioenergetic based estimates of consumption from the Wisconsin model (dotted line), the generalized von Bertalanffy growth equation (solid thick line) and the specialized von Bertalanffy (dashed line).

This allowed us to derive consumption parameters that can now be used to update regional MSM models.

Additionally we have conducted a detailed analysis of allometric patterns in predation risk and prey selectivity (Fig. 2). These analyses have allowed us to parameterize the size-based foraging model used in MSM. We have applied the updated bioenergetic and foraging model parameters to the MSM model for the EBS. In particular, we have generated projections for the three species under various target harvest rates including (i) no fishing, and (ii) fishing to 40% of the unfished spawning biomass. Model predictions were compared to single species assessments from 2011 as well as Ecosim predictions for the Bering sea (Fig. 3). We now are in the processes of generalizing the MSM model code to accommodate additional species, initially anticipated to include Steller sea lions and Bering Sea flatfish species. The updated model and initial model results are being compiled in a draft manuscript titled "Incorporating bioenergetics into multi-species statistical catch-at-age models: an example from the Bering Sea."

By Kirstin Holsman, Kerim Aydin, Jim Ianelli

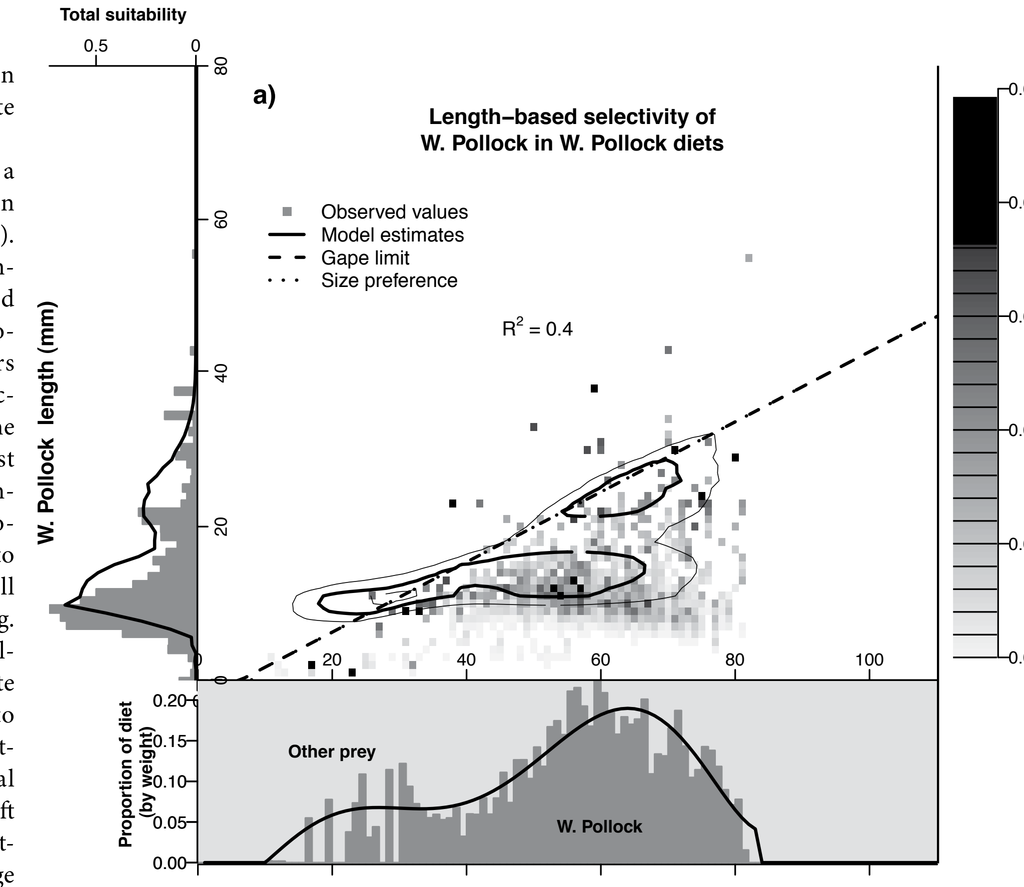


Figure 2. Length-based prey selectivity for cannibalistic walleye pollock predators consuming walleye pollock prey of various sizes (shaded squares), and model estimates of selectivity (contour lines). The horizontal and vertical bar graphs represent the row (i.e., suitability) or column (i.e., proportion of diet by weight) totals, respectively; solid lines represented foraging model estimates.

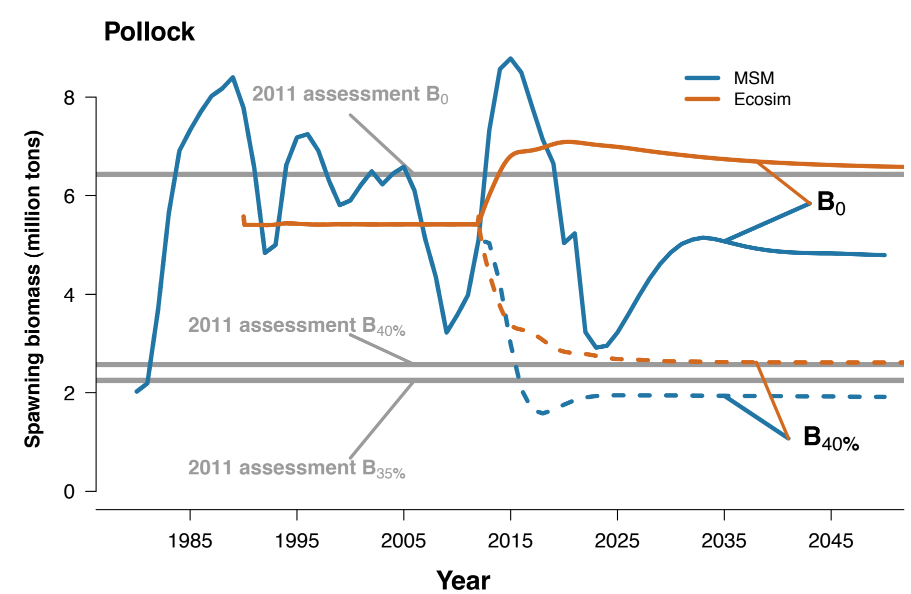


Figure 3. MSM estimates of spawning biomass of walleye pollock from the eastern Bering sea (blue line) and projections of unfished and 40% unfished biomass from MSM (solid and dashed blue lines, respectively), Ecosim (orange lines), and the 2011 stock assessment (horizontal gray bar).

Forage Euphausiids Abundance in Space and Time (FEAST)

More and more, high resolution end-to-end models have started incorporating fish as one of their components. Such exercises are usually restricted to a few years, and do not include fisheries removals. FEAST is a length-based, spatially explicit bioenergetics model that comprises the fish portion of the vertically integrated model of the Bering Sea Integrated Ecosystem Program (BSIERP). The vertical model itself contains five modules: 1) climate; 2) oceanography (ROMS); 3) lower trophic levels (NPZ); 4) fish; and 5) fisheries (FAMINE). FEAST models 14 fish species linked to five zooplankton groups (Fig. 4) and 20 fisheries specified by sector, gear, and target species. Species include walleye pollock, Pacific cod, arrowtooth flounder, Pacific salmon, capelin, Pacific herring, eulachon, sandlance, myctophids, squids, shrimp, crab, epifauna, and amphipods; these have a two-way interaction with six groups from the Nutrient - Phytoplankton - Zooplankton (NPZ) module: small copepods, oceanic/shelf copepods, oceanic/shelf euphausiids, and benthos. Temperature and advection estimates from the physical oceanography portion (ROMS) are used in the fish bioenergetics and movement components. The model has a spatial resolution of approximately 10 km and will be run both with past climate (1970-2010 hindcast) and three different climate projections stemming from three different climate models. In addition, FEAST is the "real world" model to be used in a management strategy evaluation (MSE) for walleye pollock and Pacific cod, two of the main commercial groundfish in the Bering Sea.

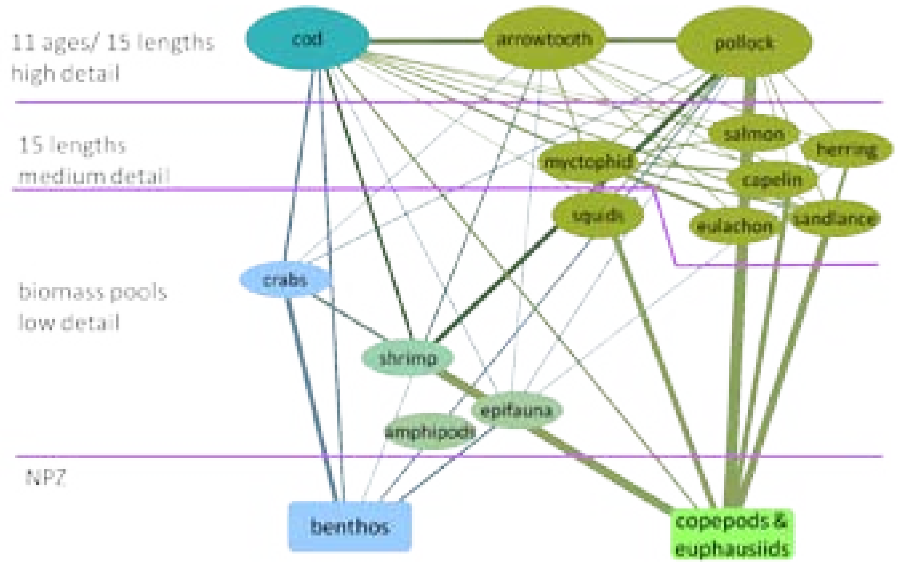


Figure 4. The food-web underlying FEAST, showing level of detail for the groups modeled. Lines depict trophic flows, line thickness is proportional to magnitude of flow and color represents pelagic (green) or benthic (blue) routes.

We have made several substantial changes at different levels: improved the temperature estimates in the oceanography module (ROMS), added the length-only and biomass pool species, and added predation as a component of fish movement. Early in April a review of the temperature showed the model was still estimating temperatures about 2 degrees higher on average, which prompted a re-parameterization that lowered the bias by 1 degree. The addition of the rest of the species decreased the predation mortality on pollock (via prey switching) and the fish movement, previously based on maximizing individual potential growth, is now based on maximizing fish biomass. The net improvement has been on better fits of estimated diet composition to stomach content data from the Food Habits Database across different regions of the Bering Sea shelf. Current work is focused on adjusting for low winter production in the zooplankton module and excessive mortality of the age-0 pollock. The background work to parameterize fish growth, predation, and movement in FEAST is being summarized in three draft manuscripts for the upcoming third special issue of BSIERP in *Deep Sea Research Part II*. Working titles are: "A length-based, spatially explicit bioenergetics model for walleye pollock, Pacific cod, and arrowtooth flounder;" "Extension of a three to fourteen species dynamic prey selectivity model based on lengths and prey preferences;" and "Modeling fish movement for walleye pollock, Pacific cod, and arrowtooth flounder in the Bering Sea."

In addition to the parameterization of FEAST, we have also streamlined the supply of key model output to the management strategy evaluation routine, so that all the data included in the stock assessments for Bering Sea pollock, Pacific cod, and arrowtooth flounder can be extracted seamlessly from FEAST and incorporated into the stock assessments, e.g., length frequency, diet composition, and CPUE of each species by station. Regular updates of FEAST-MSE are presented to the North Pacific Fisheries Management Council for informational as well as feedback purposes. Also, results from FEAST were presented in May at the Second International Symposium on Effects of Climate Change on the World's Oceans in Yeosu, Korea.

By Ivonne Ortiz and Kerim Aydin

Tern in Southeast Alaska. Photo by Dave Withrow

Coordinated Seabird Studies

Core operations supporting AFSC seabird studies continued throughout the last quarter. With the March closure of the Anchorage Observer Training Center, the number of observers trained by the Coastal Observation and Seabird Survey Team has increased. Seabird necropsy work continues as does the marine bird food habits project. Processing of specimens continues in support of collaborative work among the Alaska and Pacific Islands Regions and with the U.S. Fish and Wildlife Service. In addition to this core work we have been coordinating with the Freezer Longline Coalition to address further reductions to seabird bycatch. Past work completed by the AFSC Seabird Studies group illustrated the vessel-specific nature of seabird bycatch rates. We participated in the May skippers meeting held by the Freezer Longline Coalition and have been working with them and Washington Sea Grant on a joint effort to visit vessels with higher bycatch rates and provide advice on streamer line configurations and activities. Two vessel visits were completed in June.

By Shannon Fitzgerald

Economics & Social Sciences Research Program

Regional Impacts and Bioeconomics of North Pacific Crab Stocks

The Economics and Social Science Research (ESSR) program, the AFSC Kodiak Lab, and Dr. André Punt at the University of Washington School of Fishery and Aquatic Sciences are collaborating in the development of bioeconomic models for North Pacific crab stocks to evaluate the biological and economic impacts of ocean acidification and other issues relevant to management. These models separate life-history stages for growth and mortality of juveniles and adults, include fishery impacts by analyzing catch and effort in both biological and economic terms, and can integrate predictions for trends in ocean pH or other environmental factors. These models were originally designed to estimate maximum economic yield (MEY) with uncertain recruitments and population dynamics that are based on simplified versions of the full assessment models for each crab stock. Currently, bioeconomic models for Bristol Bay red king crab and eastern Bering Sea snow crab are operational. Figure 5 shows a hypothetical example with dynamic MEY paths for fishing mortality rates that start from a range of initial conditions and model parameters set to converge to the maximum sustainable yield proxy $F_{35\%}$ from the 2010 stock assessment model for EBS snow crab. Economic parameters in the bioeconomic model for EBS snow crab were calibrated using catch, effort, revenue, and cost data for the post-rationalization period 2006-10 from fish tickets, and the Bering Sea Aleutian Islands Crab Economic Data Report database. Based on these bioeconomic models, ESSRP has begun developing a joint crab bioeconomic/regional economic model in order to calculate the economic impacts on employment, factor income, and household income of ocean acidification and the resulting consequences on Bristol Bay red king crab and eastern Bering Sea snow crab.

By Michael Dalton and Chang Seung

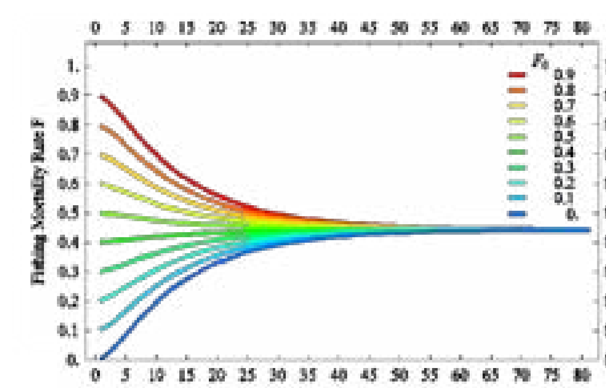


Figure 5. MEY fishing mortality rates converge to F35% for a range of starting points.

Status of Stocks & Multispecies Assessment Program

Atka Mackerel Tag Recovery Cruise in the Aleutian Islands and Examination of Tagged Steller Sea Lion Prey Field *In Situ*

The objective of the Fisheries Interaction Team's (FIT) tag release-recovery studies is to determine the efficacy of trawl exclusion zones as a management tool to maintain prey abundance/availability for Steller sea lions at local scales. Trawl exclusion zones were established around sea lion rookeries as a precautionary measure to protect critical sea lion habitat, including local populations of prey such as Atka mackerel. Localized fishing may affect Atka mackerel abundance and distribution near sea lion rookeries. Tagging experiments are being used to estimate abundance and movement of Atka mackerel between areas open and closed to the Atka mackerel fishery.

This study is an ongoing research effort. From 1999 to 2006, approximately 80,000 tagged fish were released during AFSC chartered tag release cruises near Seguam Pass, Tanaga Pass, Amchitka Island, and Kiska Island. In May to June of 2011, a cooperative venture between the North Pacific Fisheries Foundation and the AFSC released approximately 8,500 fish near the Seguam Pass area, 9,000 fish at Tanaga Pass, and 10,000 at Petrel Bank. In August 2011, we conducted a summer recovery cruise in the same area (Fig. 6). The recent winter recovery cruise was conducted from 27 March to 17 April 2012.

The cruise had three objectives. The first objective was to recover previously tagged fish in the open areas outside the trawl exclusion zones during the winter months. Even though tags were released inside the closed areas, during the recent 2011 recovery cruise, recoveries were not conducted inside the trawl exclusion zones to minimize potential negative impacts of Atka mackerel removal to the Steller sea lion prey fields inside the closed areas. The second objective of this study was to use catch composition data from the tows to estimate relative abundance indexes (CPUEs) for all major fish and invertebrate species present in the study areas. The third objective of this study was to characterize Atka mackerel habitat and develop methods for estimating indices of abundance of sea lion prey species with non-extractive methods such as camera tows.

During the 2012 cruise we conducted 54 hauls and examined 1,529 metric tons (t) of Atka mackerel for tags, equivalent to approximately 2.6 million individual fish. We recovered 49 tags: 13 at Seguam pass, 25 at Tanaga pass, and 11 at Petrel Bank, all of which were released during the 2011 tag release charter. All hauls were sampled for species composition and sexed length frequencies. In addition, we collected 420 biological samples such as stomachs, gonads, and age structures and obtained sexed length frequencies from 4,697 individual fish. Length distribution of Atka mackerel differed by area with the smallest fish at Petrel Bank, medium sized fish at Tanaga Pass, and the largest fish at Seguam Pass (Fig. 7).

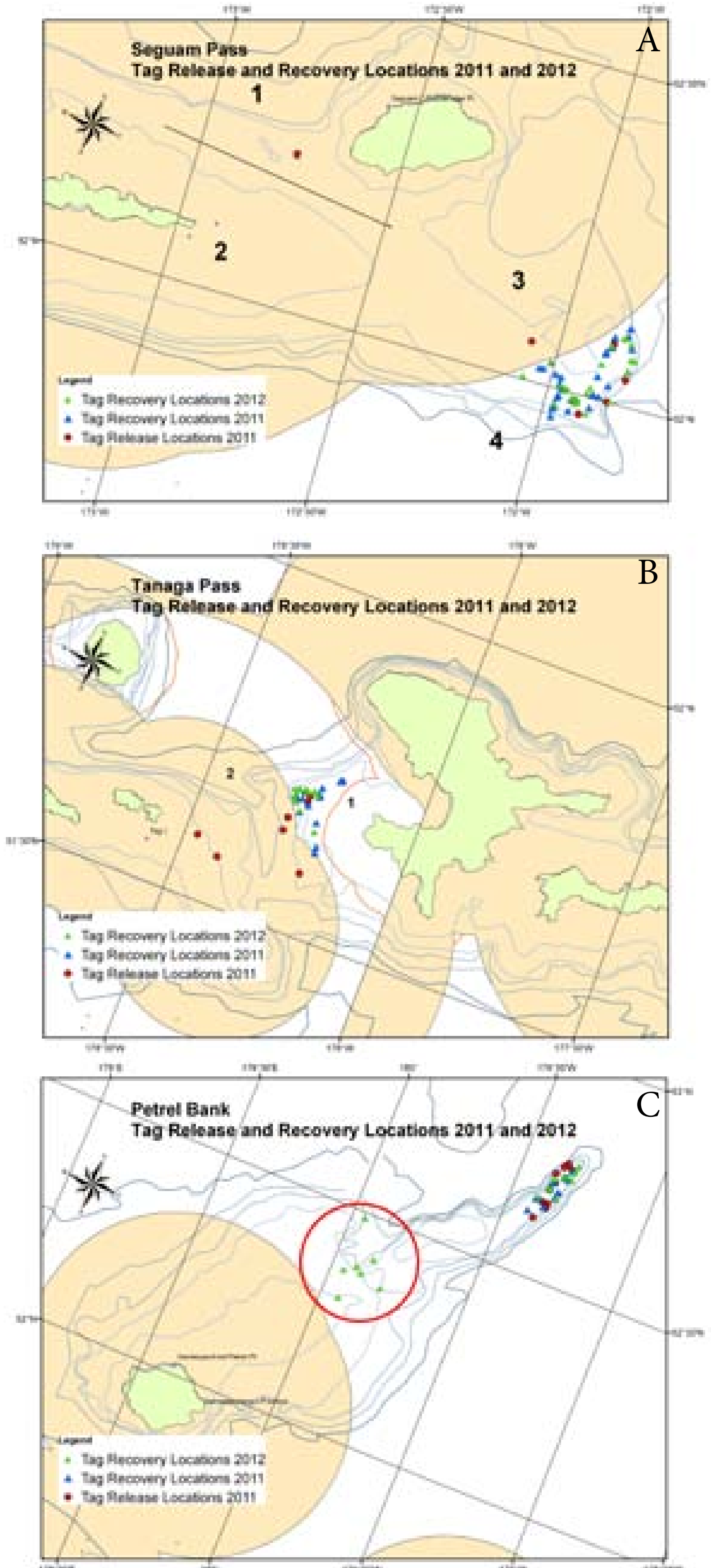


Figure 6. Atka mackerel tag release and recovery locations, 1a) Seguam Pass, 1b) Tanaga Island, 1c) Petrel Bank. Tags release in May-June 2011 and recovery locations in August 2011 and March-April 2012 are shown. The area circled in red at Petrel bank shows the tows made for the Steller sea lion prey field study.

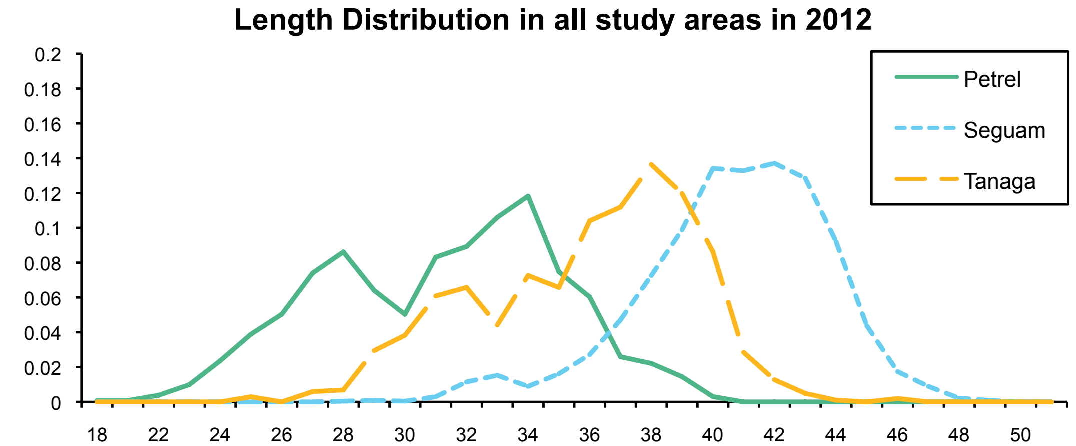


Figure 7. Length Frequency distribution in the three study areas. Solid line: Petrel Bank; large stippled line: Tanaga Island; small stippled line: Seguam Pass.

In order to examine the habitat and develop indices of abundance, we conducted 12 underwater tows with a portable underwater camera. We conducted the camera tows at the same locations as the tag recovery hauls. We were able to conduct five camera tows at Seguam Pass, four camera tows at Tanaga Island, and three camera tows at Petrel Bank.

Further analysis will be conducted to estimate population sizes of Atka mackerel in these study areas and understand relative abundance of other Steller sea lion prey species, invertebrates, and habitat types associated with those populations.

Satellite tagged Steller Sea Lion prey study

During November 2011, the AFSC's National Marine Mammal Laboratory tagged a female adult Steller sea lion with a satellite tag. The female was also branded with the brand '=24', hence for the purposes of this report we will refer to her under this name.

The female =24 had been transmitting location data since November 2011. She was located at Semisnopochnoi Island and travelled to the southern part of Petrel Bank at regular intervals, presumably to feed. FIT staff took the opportunity during this recovery cruise to run a hydroacoustic transect at the southern end of Petrel Bank. We conducted five tows in areas where the sea lion was frequently observed and where we found fish signal during the transects. We also conducted two camera tows in the vicinity of one of the feeding 'hot spots' of =24. The location of the transect, bottom, and camera tows are presented in Figure 8.

It appeared that the sea lion was diving consistently in two locations— one close to the canyon edge (haul 21) and one in the flat area to the south of the edge (haul 16). Future analysis of the hydroacoustic data will give further insight of the size of the fish aggregations in this area.

We conducted two tows in the vicinity of the canyon; at the canyon edge we found mostly Pacific ocean perch (78%) and sponges (15%) with a trace of Atka mackerel (2%). In the canyon itself we found a mix of adult walleye pollock (59%) and Pacific ocean perch (31%). We conducted two tows in the flat area to the south of the canyon. In haul 16 we found mostly northern rockfish (50%) and Pacific cod (30%) and in haul 20 we found mostly northern rockfish (65%) and Atka mackerel (18%). We also conducted a tow along the eastern edge of the shelf (haul 22) where we found mostly Atka mackerel (75%) and Pacific cod (12%).

By Susanne McDermott

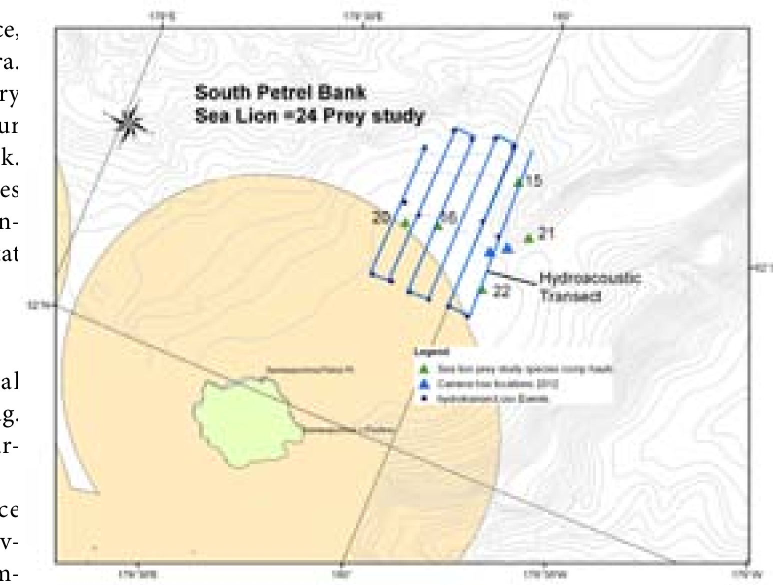
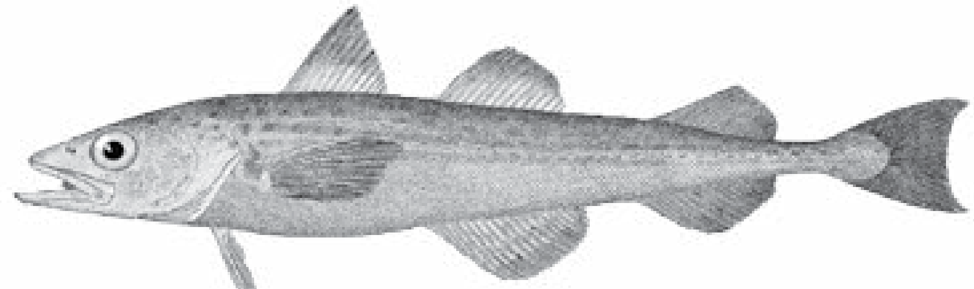


Figure 8. South Petrel Bank Steller sea lion prey study. Hydroacoustic transect in blue solid lines, camera tows in blue triangles and species composition bottom trawls in green triangles. Haul numbers of the species composition hauls are indicated in black numbers next to haul locations.

Tagging experiments are being used to estimate abundance and movement of Atka mackerel between areas open and closed to the Atka mackerel fishery.



Scientific Acoustic Data from Commercial Fishing Vessels: Eastern Bering Sea Walleye Pollock (*Theragra chalcogramma*)

The International Council on the Exploration of the Sea (ICES) Working Group on Fisheries Acoustics, Science and Technology has provided guidance on using commercial fishing vessels for collecting opportunistic acoustic data (OAD). However, an explicit approach for working with these non-traditional datasets has not been addressed. A scientific study was designed and conducted to test the feasibility of collecting and utilizing acoustic data from commercial fishing vessels fishing walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea as part of a Ph.D. dissertation project. This study demonstrated methods for processing and analyzing acoustic data collected from commercial fishing vessels to investigate current issues in fisheries management. Although the opportunistic acoustic data in this study were uncalibrated and, therefore, could not be used for biomass estimates, it was found to be suited to investigating fisheries issues where an index of abundance proportional to biomass could be substituted. This study demonstrates the scientific application of opportunistically collected acoustic data from commercial fishing vessels operating in the winter eastern Bering Sea (EBS) walleye pollock fishery (Fig. 9). Due to their high resolution and wide spatial and temporal range, opportunistic acoustic data provided an excellent data source for investigating population spatial and temporal dynamics during the winter. These data were used to identify spatio-temporal dynamics of pollock aggregations over scales ranging from hundreds of meters to hundreds of kilometers and from minutes to months. Spatial analyses identified three levels of pollock aggregation (Fig. 10), and time series analysis identified diel changes in pollock distribution in both the vertical and horizontal planes and an overall decline in pollock density over the study period.

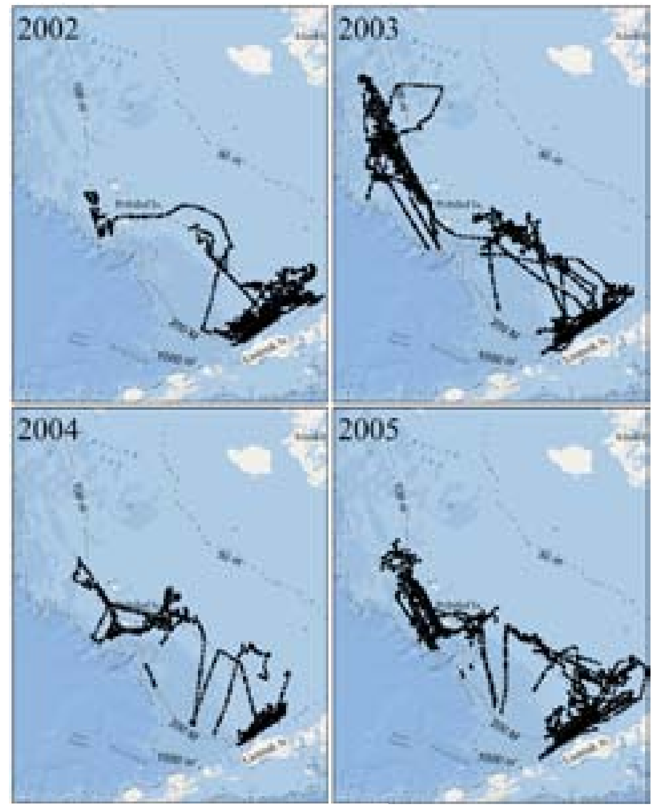


Figure 9. Location of observations from opportunistic acoustic data collection for 2002 through 2005.

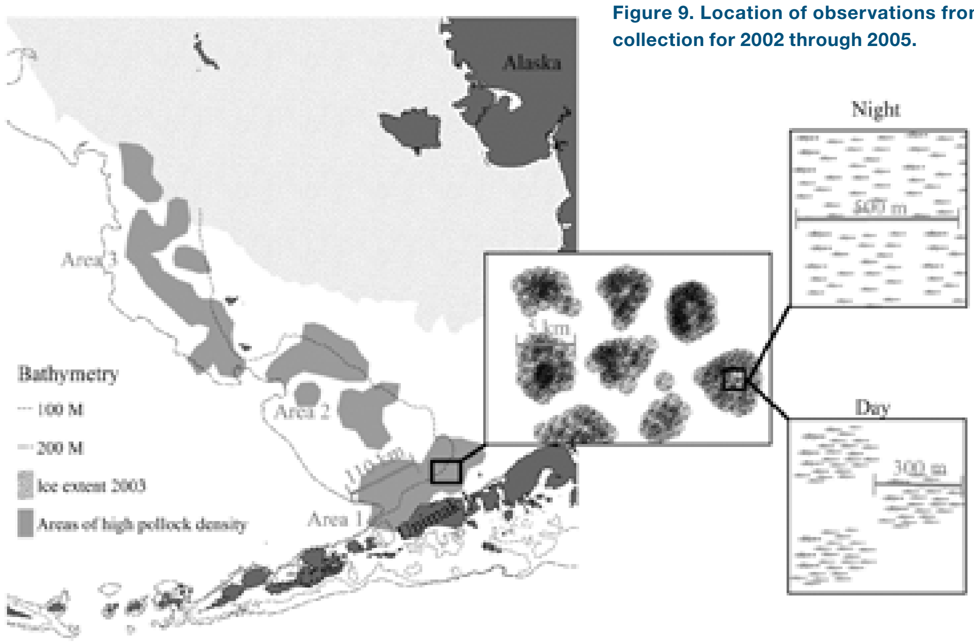


Figure 10. The distribution of pollock aggregations at the three spatial and temporal resolutions observed in the spatial cross-correlogram analyses with a diel pattern at the finest resolution. At the lowest resolution and highest extent pollock distribution is shown to be consistent with the three traditional fishing areas on the eastern Bering Sea shelf.

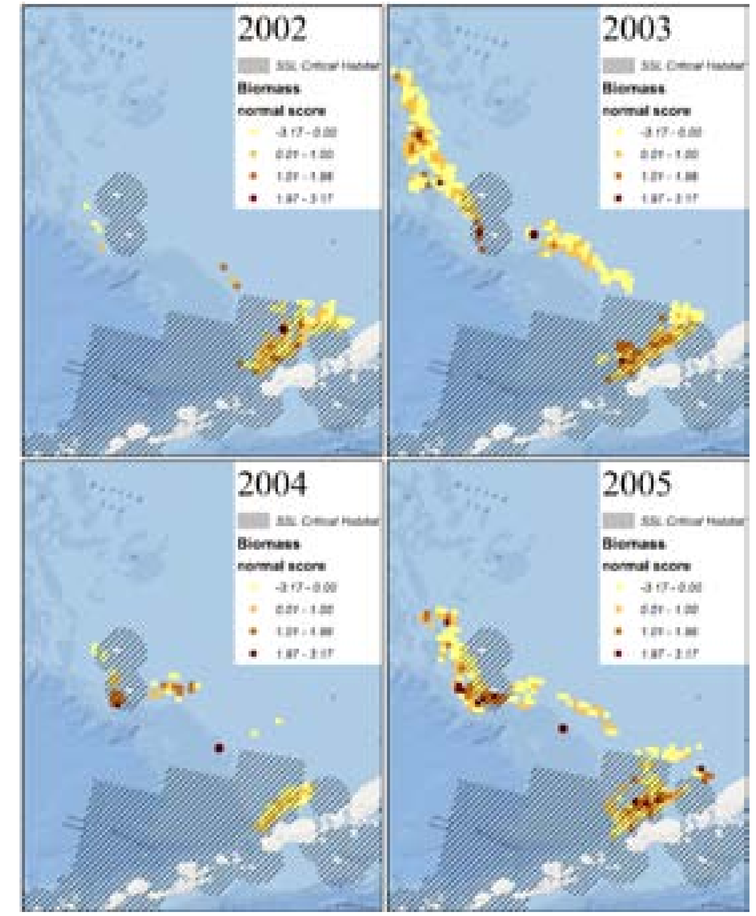


Figure 11. Maps of the posterior median pollock biomass (normal score of tons) by year at the 100 km² model spatial resolution. Crossed circles (⊕) are the posterior median centroids for each resolution and year.

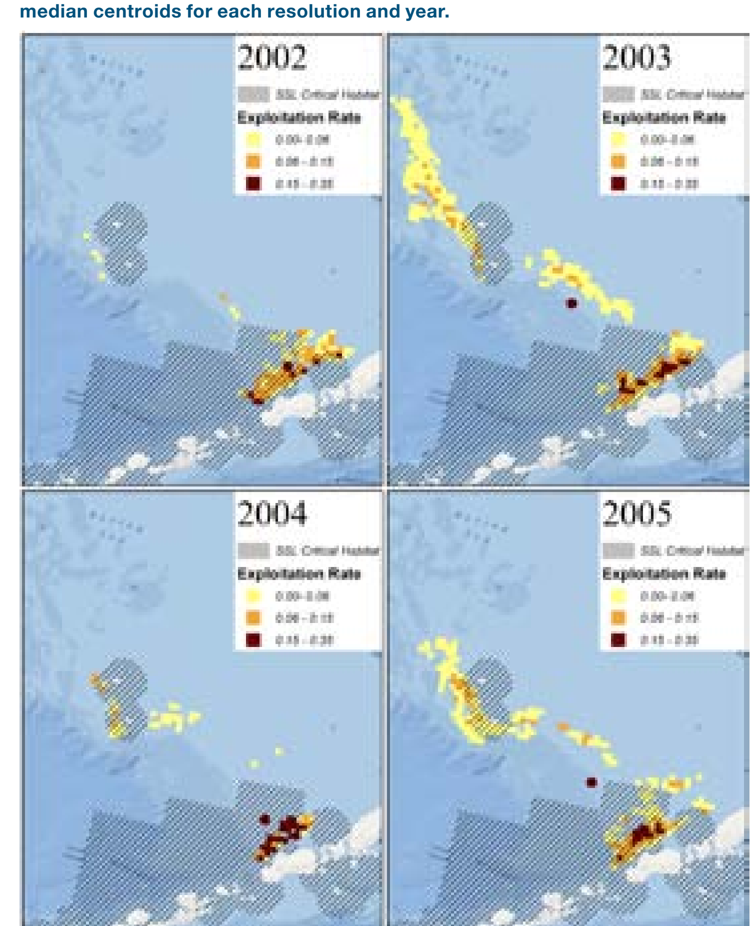


Figure 12. Maps of posterior median fishing exploitation rates by year at the 100 km² model spatial resolution. Crossed circles (⊕) are the posterior median centroids of fishing exploitation for each resolution and year.

Although the opportunistic acoustic data in this study were uncalibrated and, therefore, could not be used for biomass estimates, it was found to be suited to investigating fisheries issues where an index of abundance proportional to biomass could be substituted.

Table 1. Posterior median of mean fishing exploitation rates by year and combined for inside ($\widetilde{\widetilde{F}}{}^{inside}_{90y}$) and outside ($\widetilde{\widetilde{F}}{}^{outside}_{90y}$) of Steller sea lion critical habitat (SSLCH) with lower and upper 95% credible intervals (CI) generated by MCMC. Mean fishing exploitation were generated for each MCMC draw separately for inside and outside SSLCH as the sum of catch on day 90 divided by the sum of biomass for each year and for all four years.

Year	$\widetilde{\widetilde{F}}{}^{inside}_{90y}$	Lower CI	Upper CI	$\widetilde{\widetilde{F}}{}^{outside}_{90y}$	Lower CI	Upper CI
2002	0.0763	0.0757	0.0769	0.0609	0.0605	0.0614
2003	0.0903	0.0896	0.0910	0.0339	0.0337	0.0342
2004	0.1456	0.1445	0.1468	0.0394	0.0391	0.0397
2005	0.0745	0.0740	0.0751	0.0332	0.0330	0.0335
All Years	0.0900	0.0893	0.0907	0.0365	0.0362	0.0367

Questions on the intensity of the EBS pollock fishery arising from the decline of Steller sea lion (*Eumetopias jubatus*) populations have been a focus of many studies, but a lack of informative data on winter pollock distributions has hindered these efforts. This data provided an abundance index that was used in a spatially-explicit depletion model to examine possible differences in fishery exploitation rates inside and outside of Steller sea lion critical habitat areas. Findings suggested that exploitation rates were relatively low (~6%), but that fishing inside SSL critical habitat was more than twice that observed outside critical habitat (Fig. 11, Fig. 12, and Table 1).

The lack of comprehensive survey data on pollock distribution in the EBS during the spawning season is problematic for predicting possible effects of climate change in the EBS. The opportunistic acoustic data were used as an index of abundance to develop and evaluate a generalized additive model for projecting winter EBS pollock distributions using available data and oceanographic conditions. Sea surface temperature, bottom depth, distance to the ice edge, and cumulative catch were all found to be significant predictors of pollock density in the winter (Fig. 13, Fig. 14, and Fig. 15). Functional relationships between temperature, bottom depth, and pollock density were also found to overlap between summer and winter. These studies show the utility of opportunistic acoustic data for gaining insight into the spatial and temporal dynamics of winter pollock aggregations which have previously not been examined by fisheries scientists due to the lack of scientific quality data at the appropriate resolutions and ranges.

By Steve Barbeaux

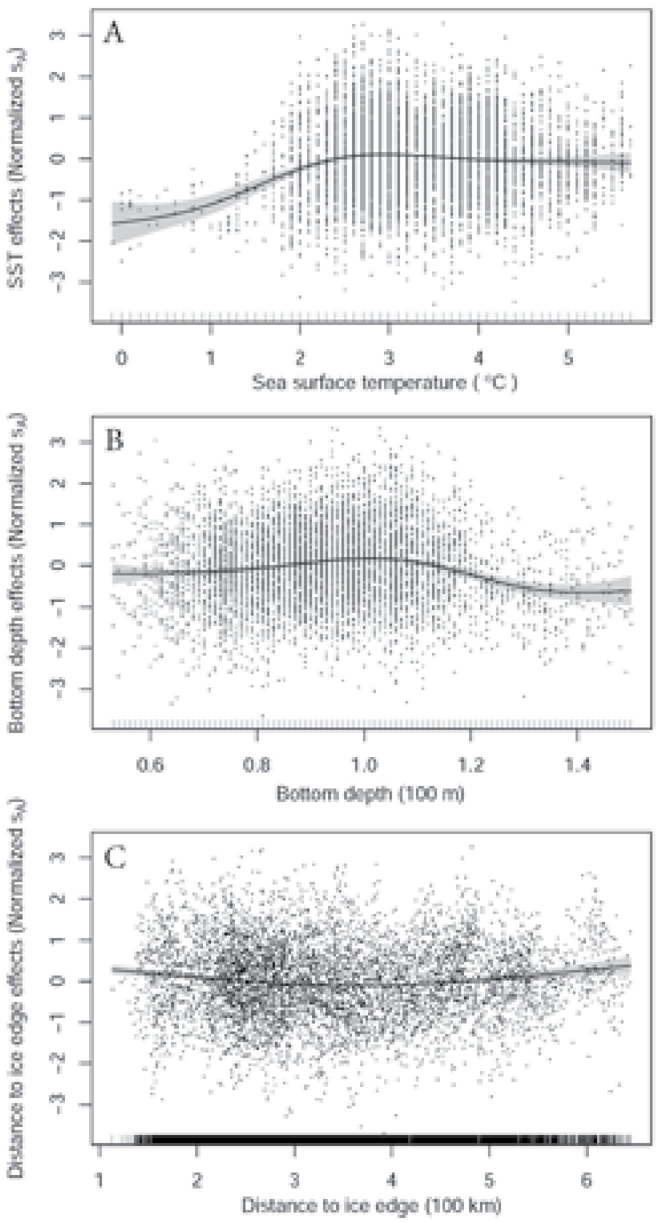


Figure 13. Effects of A) sea surface temperature, B) bottom depth, and C) distance to ice edge on the normalized backscatter (sA) from the optimum projection model (OPM). Shaded areas are 2 standard errors around estimated effects.

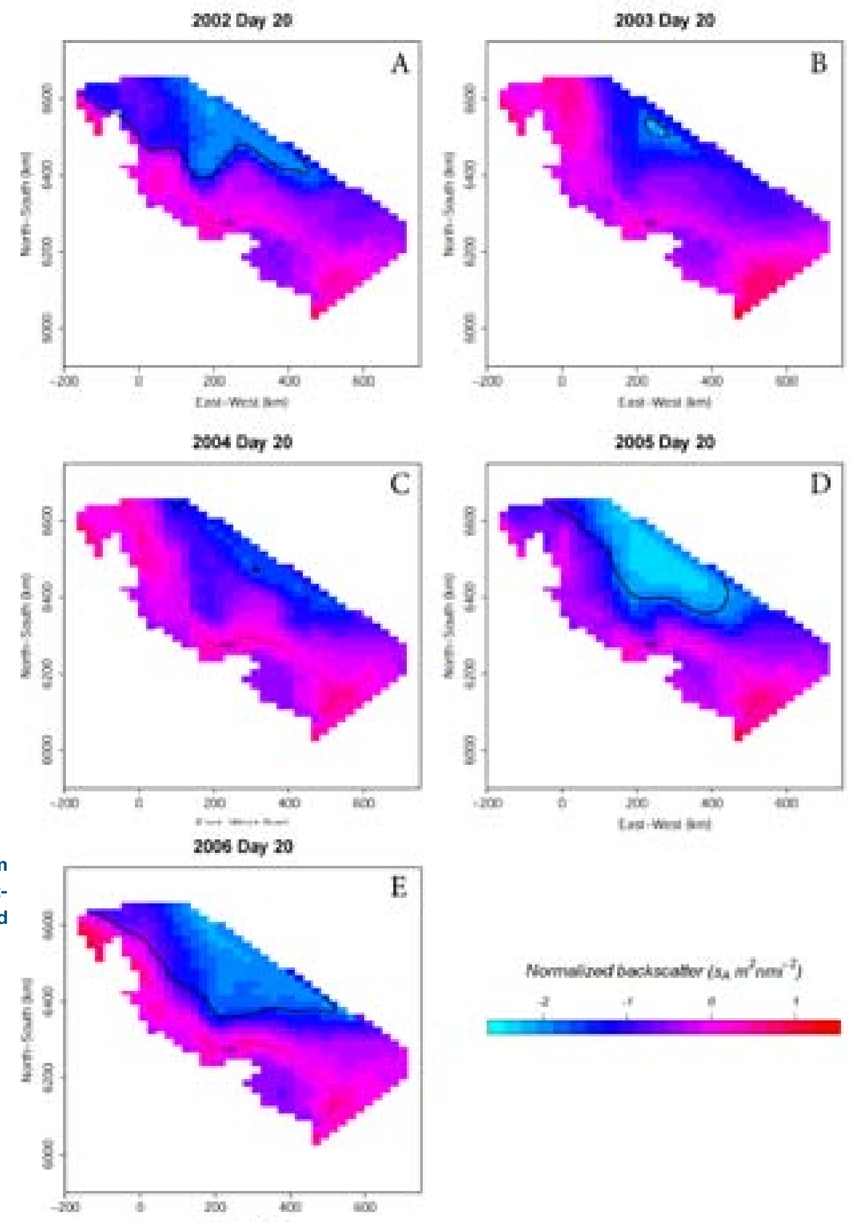


Figure 14. Projections of EBS pollock preferred habitat on January 20 for A) 2002, B) 2003, C) 2004, D) 2005, and E) 2006. The 1 °C isotherm is indicated in the solid black line, the 100 m isobath by a dotted black line.

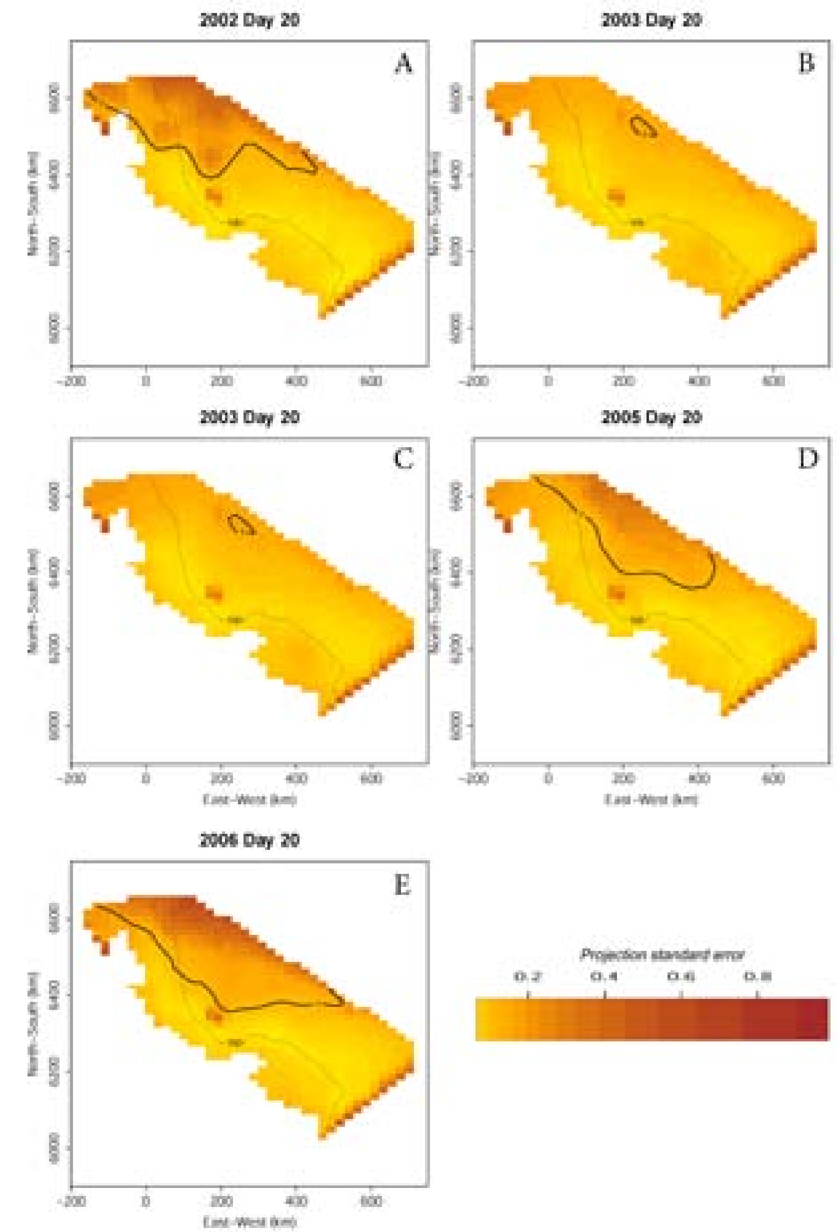


Figure 15. Prediction error from projections of EBS pollock preferred habitat on January 20 for A) 2002, B) 2003, C) 2004, D) 2005, and E) 2006. The 1 °C isotherm is indicated in the solid black line, the 100 m isobath by a dotted black line.

Age & Growth Program

Age and Growth Program Production Numbers

Estimated production figures for 1 January – 30 June 2012. Total production figures were 17,841 with 3,729 test ages and 172 examined and determined to be unageable.

Species	Specimens Aged
Alaska plaice	565
Atka mackerel	899
Bering flounder	864
Blackspotted rockfish	585
Dusky rockfish	47
Flathead sole	1,237
Great sculpin	51
Kamchatka flounder	1,058
Northern rock sole	906
Pacific cod	2,009
Pacific ocean perch	415
Rougheye rockfish	249
Walleye pollock	7,672
Yellowfin sole	1,284

By Jon Short

2012 Yeosu Workshop (W7) on "Beyond Dispersion"

William Stockhausen (AFSC representative on U.S.- Republic of Korea Fisheries Science Panel) Sukyung Kang (Korea, National Fisheries Research and Development Institute (NFRDI)), and Carolina Parada (Chile, Fisheries Research Institute (INPESCA)), co-convened a 1-day workshop entitled "Beyond Dispersion: Integrating Individual-based Models for Bioenergetics and Behavior with Biophysical Transport Models to Predict Influences of Climate Change on Recruitment Processes in Marine Species" on 20 May 2012, immediately following the 2nd International Symposium on Effects of Climate Change on the World's Oceans held in Yeosu, Korea.

Future climate change is expected to influence the abundance and distribution of marine fish species in complex ways, including changes in the local environmental characteristics and transport pathways experienced by early life stages that are typically pelagic, such as eggs and larvae.

Future climate change is expected to influence the abundance and distribution of marine fish species in complex ways, including changes in the local environmental characteristics and transport pathways experienced by early life stages that are typically pelagic, such as eggs and larvae. To date, numerous coupled biophysical models (CBPMs) with individual-based model (IBM) subcomponents have been developed to study the influence of oceanographic transport patterns on dispersion of early life stages and recruitment variability in marine fish species. In many of these models, advective oceanographic processes are hypothesized to be the main determinant of recruitment variability; simulated individuals in the models are regarded primarily as passive particles or drifters, and "success" is judged by the relative number of simulated particles that end up being advected to suitable juvenile nursery grounds. While these models represent a significant step in our ability to understand and predict the effects of climate change on recruitment, they ignore important effects (temperature/salinity stress, food availability, etc.) on growth and survival associated with the environmental conditions encountered by (simulated) individuals along their drift trajectories. Although bioenergetics models typically include such effects and can be used to address the impact of local environmental variation on the growth and survival of eggs and larvae, few bioenergetics models have been targeted toward early marine life stages, few CBPMs incorporate bioenergetic considerations, and fewer still have been used to address the potential impact of climate change on marine species. The workshop was intended to discuss the state-of-the-art for incorporating individual-based bioenergetics models within coupled biophysical models, together with current challenges and future directions.

The workshop consisted of five oral presentations in the morning, including talks by invited speakers Myron Peck (University of Hamburg, Germany) and Shin-ichi Ito (Tohoku National Fisheries Research Institute, Japan), followed by a productive afternoon discussion period. Altogether, 19 people participated in the workshop. In addition, it featured what had to be the largest banner of all sessions and workshops (Fig. 1).

Following initial remarks by workshop co-conveners Sukyung Kang and William Stockhausen, invited speaker Myron Peck discussed recent advances in, and future challenges to, integrating physiology, behavior, and physical constraints into coupled IBMs/CBPMs for the early life stages of marine fish. In a wide-ranging talk, Dr. Peck highlighted the diverse physiological mechanisms and responses to environmental conditions that need to be accounted for in modeling the growth and survival of early (and later) life stages of marine fishes on an individual basis. These include direct effects of temperature and size on growth and survival through egg development rates, hatching success, size-at-hatch, yolk sac utilization rates, routine metabolism rates, and swimming speed. Parental effects on egg survival, environmental effects on success of first feeding success, changes in diet composition and prey energy content, flexibility in foraging behavior, and species interactions were also discussed. Among his recommendations, Dr. Peck stressed the importance of increased knowledge of the growth physiology of target species and the need for modelers to conduct sensitivity studies to identify critical model parameters.

Shin-Ichi Ito, the second invited speaker, discussed the importance of incorporating feeding and spawning migrations in models for growth and survival of marine fishes. He presented results from a comparison of such models for Japanese sardine (*Sardinops melanostictus*) in the western North Pacific. Dr. Ito's talk highlighted the importance of confronting observed spatial patterns (based on field data) with multiple alternative models because different behavioral mechanisms can give rise to similar spatial patterns. In the study that he recounted, Dr. Ito and colleagues were able to eliminate two of four hypothesized behavioral mechanisms for observed sardine feeding migrations from further consideration; however, they were unable to discriminate between the remaining two mechanisms, even though the behavioral bases for these models were quite different (predator avoidance vs. extended kinesis). Dr. Ito also presented a rather novel approach, based on artificial neural networks, to "forcing" a spawning migration pattern when hypothesized behavioral mechanisms were inadequate to reproduce observed movement patterns.

Fittingly, (given the venue), the other speakers presented talks featuring models and data relevant to Korean marine systems. Jung-Jin Kim (Ph.D. student, Pukyong National University, Korea) used a coupled IBM/CBPM to infer current seasonal spawning grounds for Korean common squid (*Todarodes pacificus*) in the western Pacific from field data for larval occurrence. He then used IPCC model runs to drive a regional ocean model to predict changes in spawning grounds under future climate change. Dr. Sukgeun Jung (Jeju National University, Korea) presented preliminary results for a coupled IBM/CBPM for Pacific anchovy (*Engraulis japonicus*) in Korean waters. And finally, Min-Jung Kim (NFRDI) presented results from diet studies on Pacific anchovy in the southern coastal waters of Korea. Ms. Kim's talk highlighted the spatiotemporal and ontogenetic variability in anchovy diets in southern Korean waters due to variability in prey species composition and abundance, plasticity in feeding strategies, and ontogenetic differences.

A key outcome from discussions following the presentations was the recognition that one aspect of the impact of future climate change on species abundance and distribution patterns will occur through changes in the growth rates and subsequent survival of individuals. However, these changes may not be predictable from simple statistical relationships based upon (current) growth rates and expected changes in temperature. Instead, it is likely that future changes will be due to the dynamic interaction of several factors, including indirect effects on the abundance, composition, and relative energy content of key prey species. These indirect effects will act in concert with direct effects, such as changes in water circulation patterns and temperature, which will influence the spatial overlap and metabolic processes of predators and prey.

A key outcome from discussions following the presentations was the recognition that one aspect of the impact of future climate change on species abundance and distribution patterns will occur through changes in the growth rates, and subsequent survival, of individuals.

Thus, one important recommendation stemming from the discussions was that IBMs used to predict the impact of future climate change on species abundance and distribution should incorporate mechanistic bioenergetics models that account for effects of changes in prey abundance, energetic content, and species composition on individual growth rates. Workshop participants also acknowledged a general lack of data on the physiology of many fish and shellfish species, even for commercially- and/or ecologically-important ones, as well as a scarcity of marine physiologists who could potentially address these issues.

A list of additional recommendations from the workshop include:

1) Incorporating life-cycle closure within physiologically-based models to capture climate impacts on various life stages (and identify potential climate-driven bottlenecks to recruitment), with a recognition of stage-specific differences in growth physiology, diets, and tolerance to environmental factors;

2) Increasing process-level understanding of the factors controlling fish migration patterns, particularly spawning migrations, and the environmental factors that regulate behaviorally-mediated movements or the evolution of observed behaviors of different life stages; and

3) Conducting more basic, controlled laboratory experiments on the growth physiology of species, including experiments designed to capture the interactive effects of multiple factors (e.g., temperature *x* prey species *x* pH).

By William Stockhausen

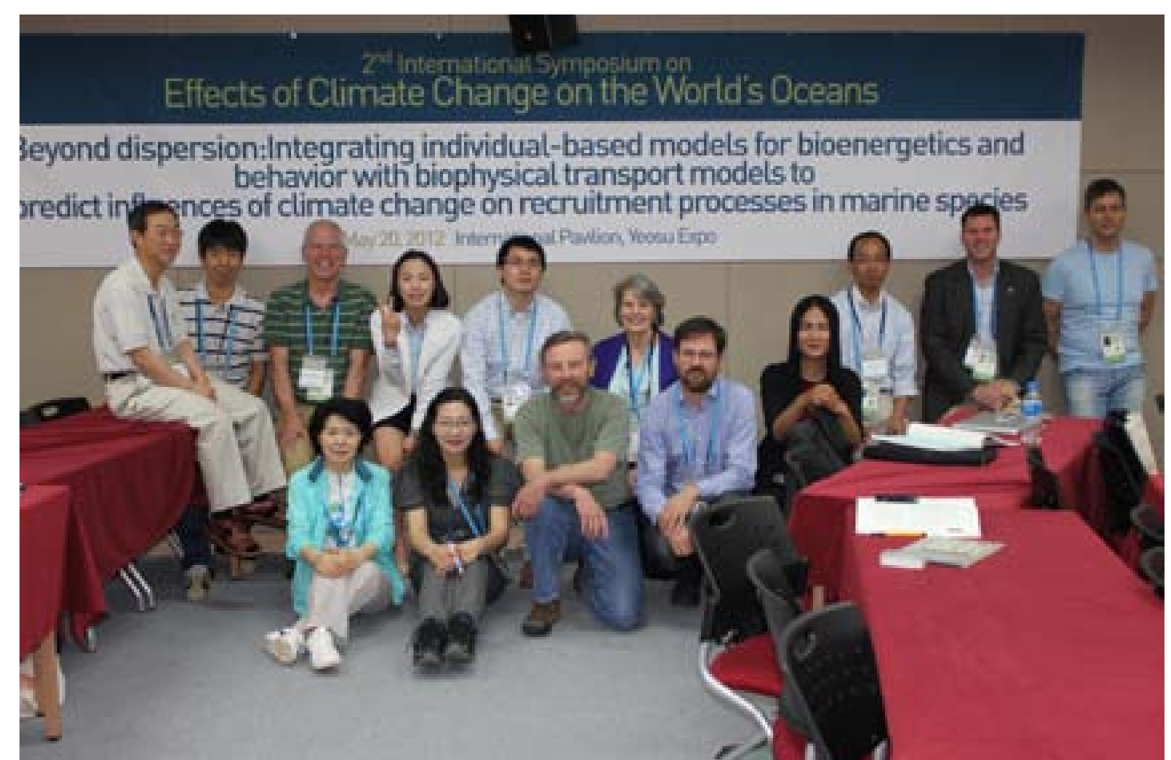


Figure 1. The W7 workshop participants and banner. Photo by Sukgeun Jung

2nd ICES/PICES Conference for Early Career Scientists — Oceans of Change

The 2012 Second ICES/PICES Conference for Early Career Scientists

The International Council for the Exploration of the Sea (ICES) and North Pacific Marine Science Organization (PICES), in conjunction with NOAA, sponsored the Second ICES/PICES "Conference for Early Career Scientists" 24-27 April in Majorca, Spain. The objective of the meeting was to encourage greater involvement of young scientists in international scientific investigations and to foster their involvement in the management of marine ecosystems. The meeting builds on the success of the ICES/PICES Early Career Scientists Meeting held in Baltimore, Maryland, in 2007 and the ICES Young Scientist Conference in Denmark in 1999. Interested early career marine scientists applied for an invitation from the Scientific Steering Committee. Applicants were required to be under 35 years in age or have completed a Ph.D. after 2007. Applicants were evaluated on their productivity, potential for novel science, and relevance of their research to the session themes.

Steven Barbeaux and Ingrid Spies of the Status of Stocks and Multispecies Assessment (SSMA) program and Matt Baker, a postdoctoral researcher with Anne Hollowed, were accepted to attend. Anne Hollowed, SSMA program manager, was an invited key note speaker for the Theme 2 Session: Human Interactions with the Marine Environment. Steve Barbeaux gave an oral presentation and Ingrid Spies presented a poster in the Theme 2 Session. Matt Baker's poster was presented *in absentia* by Anne Hollowed in the Theme 1 Session: Impact of Change on Marine Ecosystems. Their abstracts follow:

Climate change effects on fish and fisheries: current outlooks and a roadmap for interdisciplinary research *Anne B. Hollowed*

Recent global assessment reports provide compelling evidence that climate change is occurring. In response to these reports, the marine science community has endeavored to provide new science to improve our ability to understand and predict these impacts on fish and fisheries. This presentation will examine the expected effects of climate change on ecosystem productivity, habitat quality and quantity, and how these changes will impact the spatial distribution, predator-prey interactions, and vital rates of marine biota. Case studies from around the world will be used to demonstrate how these expected changes will influence the quantity, quality, and availability of marine resources for human use. These case studies will demonstrate how members of the marine science community have united in an effort to develop mechanistic scenarios that are incorporated into stock projection models for use in evaluating the performance of management strategies under a changing climate. These examples fostered plans for new initiatives between ICES and PICES that are designed to provide credible, objective, and innovative scientific advice on the effects of climate change on marine ecosystems. The success of these initiatives will challenge the next generation of young scientists to form global partnerships to communicate advancements in scientific understanding to improve our capability to more accurately project the implications of changing climate on marine systems.

Monitoring on a shoestring: the use of commercial fishing vessels as inexpensive sampling platforms for long-term biological and oceanographic monitoring

Steven J. Barbeaux

Long-term monitoring is a key component of an ecosystem-based approach to fishery management. Data time series enable the examination of changes in oceanographic and community metrics. Government funding for long-term monitoring of biological and oceanographic processes has dwindled in recent years, while the mandate for this type of information has increased. If data-driven ecosystem-based management continues to be the goal, then methods for reducing the costs of data collection must be found while data quality is maintained. An example of this type of innovative approach can be found in the Alaska walleye pollock fishery where researchers have teamed with commercial fishers to deploy inexpensive temperature and depth data storage tags on trawl nets. At the same time, data on fish density and distribution are being collected using the fishing vessels' own acoustic systems. These data are being used to validate oceanographic models, to assess the effects of oceanographic conditions on bycatch in the walleye pollock fishery, monitor the impacts of the fishery on the stock across a wide range of temporal and spatial scales, and evaluate the effects of oceanographic conditions on walleye pollock density and distribution. This project demonstrates a cooperative monitoring program in which researchers work with other seagoing stakeholders to inexpensively collect biological and oceanographic data that can be integrated into a long-term ocean observing system.

The hidden story: what are the potential genetic effects of different types of fisheries management? *Ingrid Spies and André Punt*

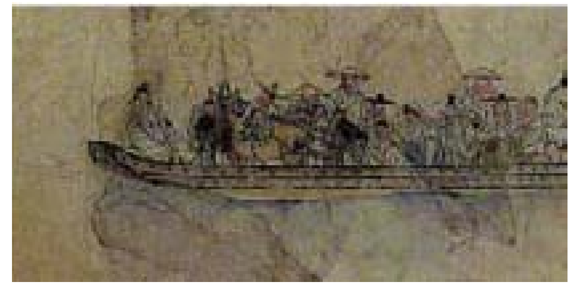
Under a precautionary approach to fisheries management, management units should correspond with a single genetic population or stock. Such an approach is intended to preserve individual populations, biodiversity, and the overall resilience of the stock complex. Although genetic population structure has been documented in many marine fish species, no clear method exists to translate this information into a meaningful management strategy. Here, we simulate marine fish populations with two types of genetic population structure: panmixia and discrete populations. Panmixia occurs when individuals in a population move about freely within their habitat, possibly over a range of hundreds to thousands of miles, and thus breed with other members of the population, as opposed to discrete populations between which interbreeding does not occur. Fish are partitioned into a linear array of spatial units, and fishing pressure is modeled with effort proportional to the distance from the fishing port. A population study is simulated by randomly selecting 100 individuals from each unit, and standard genetic methods are used to determine where a boundary (or boundaries) should be drawn to form management areas. Two types of management are simulated: combined management (all subpopulations are managed as one unit) and separated management (subpopulations are managed individually with boundaries selected using population genetic methods). Population dynamics and genetic population structure are then projected under both management plans with annual stock assessments and fishing pressure for 100 years. Performance measures such as total catch and population size are compared under both management scenarios, as well as any genetic population structure changes. This project is loosely based on the dynamics of Pacific cod in the Bering Sea and Aleutian Islands area of Alaska. Initial results show that fishing can result in loss of genetic diversity and depletion in population size of the more proximate population, and that smaller populations are more susceptible to loss of genetic diversity.

Role of habitat in moderating species distributions and interactions *Matt Baker, Anne Hollowed, M. Elizabeth Clarke, and Ray Hilborn*

Several mechanisms drive ecosystem structure and stability in marine systems, including competition between species, climate, and fisheries extraction. Many systems subject to perturbation show stability in total biomass and structure, despite shifts in relative species abundance. This suggests sequential replacement related to compensatory dynamics. We examine species dynamics within and between functional guilds in the eastern Bering Sea to weigh evidence for compensation, resource partitioning, and common forcing via external drivers and examine how habitat governs species interactions. We applied random forests to determine the importance of environmental variables on individual species distributions. We then extended these methods to species assemblages, synthesizing cross-validated coefficient of determination and accuracy importance measures from univariate analyses to quantify compositional turnover along environmental gradients. These outputs were applied to define distinct regions within large marine ecosystems based on unique aggregations of community composition and physical habitat. We also applied centroid-based clustering methods to time series trends of species abundance to explore evidence for sub-structure in exploited stocks within this system. We are currently integrating these methods to inform approaches to examining relative effects of various drivers of species abundance and community composition through multivariate autoregressive state-space models.

By Anne Hollowed, Steve Barbeaux, Ingrid Spies, and Matt Baker

Yeosu, Korea
May 15–19, 2012



2nd International Symposium on Effects Of Climate Change on the World's Oceans

The earth's oceans influence the fundamental processes of our planet and provide the living resources and services upon which humans depend. They play a critical role in the global carbon cycle and provide the habitats that sustain marine biodiversity. Humans are changing the world oceans to an extent that is unprecedented. Greenhouse gas emissions are warming the planet, affecting the global carbon cycle, and changing the chemical composition of the ocean. Marine ecosystems are being disrupted by overfishing and pollution. These fundamental changes can have serious consequences for oceanic productivity and species composition.

The International Council for the Exploration of the Sea (ICES), the North Pacific Marine Science Organization (PICES), and the Intergovernmental Oceanographic Commission of UNESCO (IOC) joined forces in 2008 for the first global ocean symposium in Gijón, Spain, to provide a comprehensive view of the current state of the global ocean and comparison between regions. The 2008 symposium in Gijón, Spain, attracted 400 scientists from 48 countries. The 2nd International Symposium on Effects of Climate Change on the World's Oceans covered many issues of the role of climate change on the oceans: sea level rise, changes in thermo-haline ocean circulation, acidification, oligotrophy of temperate seas, changes in species abundance, distribution and phenology, loss of biodiversity, all of which will have serious implications for marine living resources and the humans that depend on them. The symposium's aim was to bring together experts from different disciplines to exchange observations, results, models, and ideas at a global scale and to discuss the opportunities to mitigate and protect the marine environment and its living resources.

Anne Hollowed (co-chair of the ICES/PICES Strategic Initiative on Climate Change Effects on Marine Ecosystems, SICCME), Miguel Bernal (Spain, ICES Working Group on Integrative Physical-Biological and Ecosystem Modeling, WGIPEM) and Keith Criddle (University of Alaska Fairbanks, PICES Section on Human Dimensions, SHD) co-convened Session 4: Climate Change Effects on Living Marine Resources: from Physics to Fish, Marine Mammals, and Seabirds, to Fishermen and Fishery Dependent Communities. This session was the largest and most well attended session of the symposium, with 55 oral presentations from scientists from 17 countries. The SICCME co-chair Manuel Barange (United Kingdom) was the keynote plenary speaker, gave a presentation titled "Quantifying the Impacts of Climate Change on Marine Shelf Ecosystems and Their Resources: Feeding the World in 2050." This talk focused on the recent findings of the Quest-Fish program. Dr. Shin-ichi Ito (Japan) was the theme session invited speaker; he gave a presentation titled "Climate-induced Fluctuation of Japanese Sardine; Its Influence on Marine Ecosystem and Human Being."

The theme session spanned a 4 days. Day 1 started with a series of synthesis talks followed by presentations that focused on climate change impacts on high latitude and middle latitude ecosystems. The morning of Day 2 highlighted new analytical approaches to understanding how climate change and ocean acidification will impact the spatial distribution of marine species and how these shifts in distribution will impact marine ecosystems. Speakers for the afternoon session targeted social and economic impacts of climate change on fishery dependent communities. Day 3 speakers presented studies of ecosystem level impacts of climate change and results from regional assessments of climate change. Day 4 focused on studies that formally linked climate change projections to assessments of the performance of management strategies. These 4 days provided a global view of the implications of climate change on marine ecosystems.

Anne Hollowed gave an oral presentation titled "Modeling Fish and Shellfish Responses to Climate Change: Trade-offs in Model Complexity**."** She recognized that the marine science community has applied numerous techniques to project the effects of climate change on marine ecosystems and the responses of fishery dependent communities to these ecosystem changes. Considerable progress has already been made in coupling nutrient, phytoplankton and zooplankton into physical models using the existing Global Climate Model and Earth System Models. There is considerable interest in extending this capability to include commercially exploited fish and shellfish. Fish and shellfish exhibit complex responses to changes in the distribution and abundance of prey, competitors, and predators. Incorporation of these complex processes will come at a high computational cost. She compared the costs and benefits of different methods for modeling fish and shellfish responses to climate change on a global scale. A variety of different modeling approaches were considered including: minimally realistic trophic energy transfers, size spectrum models, single species and multispecies stock assessment models, whole ecosystem food web models, spatially explicit coupled-bio-physical models (*e.g.* NEMURO-FISH), and spatially explicit gradient tracking models.

Paul Spencer and Teresa A'mar also gave oral presentations in Session 4. Their abstracts follow:

Management strategy evaluation for the Gulf of Alaska walleye pollock (*Theragra chalcogramma*) fishery: how persistent are the environmental-recruitment links?

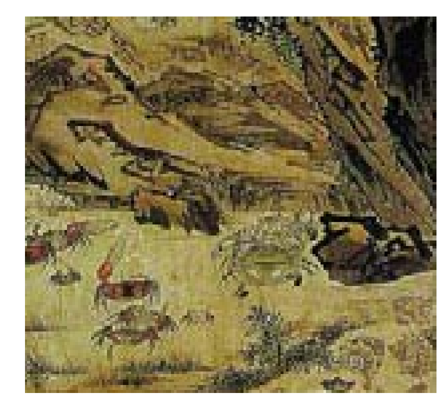
Z. Teresa A'mar and Martin W. Dorn

A management strategy evaluation for the Gulf of Alaska walleye pollock fishery was performed based on data through 2005. One of the sources of error and uncertainty in the previous analysis included links between environmental indices and age-1 recruitment. The results suggested that winter precipitation and summer sea surface temperature (SST) had a positive impact and spring and autumn SST had a negative impact on recruitment when the normalized indices were included to account for some recruitment variability; these findings matched results from other studies. It is useful to reexamine these environmental recruitment relationships after new data have been collected to assess how robust they are. This study includes six additional years of stock assessment and environmental data and examines whether the environmental recruitment links, suggested previously, have persisted. This study also extends the previous operating model configurations by considering additional local- and basin-scale environmental covariates which were available for the historical period and can be obtained or calculated from downscaled IPCC model output. Environmental recruitment relationships were evaluated with cross-validation outside of the operating model, and a set of parsimonious models which explained a considerable amount of the recruitment variance were included in the operating model to generate future recruitment based on IPCC model output.

Projected spatial distributions for eastern Bering Sea arrowtooth flounder under simulated climate scenarios, with implications for predation

Paul D. Spencer, Nicholas A. Bond, Anne B. Hollowed and Franz J. Mueter

Empirical relationships between the extent of the eastern Bering Sea shelf summer "cold pool" (bottom water ≤ 2°C) and maximum sea ice extent and sea level pressure allow projections of cold pool area from global climate model simulations. The present study uses these projections to predict future spatial distributions of arrowtooth flounder in the Bering Sea, assuming these distributions are controlled primarily by the cold pool. An inverse relationship between the area occupied by arrowtooth flounder and the cold pool area has been observed from 1982 to 2010. Small cold pool areas and large arrowtooth flounder areas were observed in the warm years of 2003-05, whereas the colder years of 2006-10 have exhibited larger cold pool areas and smaller arrowtooth flounder areas. Projections of cold pool area from 2010 to 2050 based upon 15 International Panel on Climate Change (IPCC) model runs show a wide range of variability but an overall decreasing trend, resulting in the median arrowtooth flounder area across the 15 IPCC models increasing from 140,000 km2 in 2010 to 160,000 km^2 in 2050. Changes in the spatial distribution of arrowtooth flounder relative to other species can affect their consumption of prey, of which age-1 and -2 walleye pollock comprise a large portion. The relationship between the area occupied within various EBS subareas and cold pool extent will be examined for arrowtooth flounder and walleye pollock in order to project future spatial distributions and assess the potential impact of arrowtooth predation on pollock.



By Anne Hollowed, Teresa A'mar, and Paul Spencer

Workshop on Strategies for Implementing Management Strategy Evaluations

During the first week of June, colleagues from the Alaska and Northwest Fisheries Science Centers, the University of Washington, and the Chilean fisheries agency INPESCA (Instituto de Investigación Pesquera) convened an informal technical workshop on methods for developing management strategies evaluations (MSEs). The activities centered on a variety of case studies including Bering Sea yellowfin sole and Chilean hake. Additional overviews on methods used for Pacific sardine and Gulf of Alaska pollock were also presented. Approaches for modifying current models within an MSE context were reviewed and developed. This included converting "estimation models" into "operating models" that can be tested over a broad range of alternative hypotheses and sources of estimation uncertainty. In particular, the workshop participants developed code to generically call operating models which will then provide output that can be processed and evaluated with estimation models (and by extension catch specification/control rules). A side benefit of this exercise was honing skills in simulating data from known population dynamics parameters to test assessment model estimation performance.

Activities focused on two main topics: 1) Ways to condition an operating model that reflects (to the extent practical) uncertainty in the resource dynamics with the ability to generate new data (given a future catch level) and 2) testing the robustness of control rules (quota specification processes) given new data sequences arising from the operating model. Ideally, operating models should reflect the uncertainty of processes and measurement errors for the stock in question. One method is to "grid" over different structural models (and use the point estimates obtained). This was contrasted with a separate technique in which operating model simulations are derived from Markov chain Monte Carlo (MCMC) estimates of the posterior probability densities. The group also developed and reviewed a hybrid approach which used MCMC-derived posterior distributions for different model configurations (fixed values of stock recruitment steepness). With the generous assistance and expertise from NWFSC scientists, methods for simulating data using the stock synthesis program (using the R package *r4ss*) were developed. For further details and technical documentation, contact James Ianelli (*Jim.Ianelli@noaa.gov*).

By James Ianelli

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[1] The NOAA Technical Memorandum series NMFS AFSC (formerly F/NWC) is a Center publication which has a high level of peer review and editing. The Technical Memorandum series reflects sound professional work and may be cited as publications. Copies may be ordered from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161 or at *www.ntis.gov*.

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Alaska Fisheries Science Center
7600 Sand Point Way N.E.
Seattle, Washington 98115

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