Implications of Ecosystem Change on Fishery Management

HARVEST RATES MAY BE SUSTAINABLE FOR SINGLE SPECIES, YET MAY HAVE SIGNIFICANT IMPACTS ON THE OVERALL BIODIVERSITY OF THE OCEANS AT THE COMPLEX, SPECIES, STOCK, AND GENETIC LEVELS. FISH ARE NOT REMOVED EVENLY WITHIN THE POPULATION AND THE POTENTIAL EXISTS FOR COMPETITION BETWEEN FISHERIES AND OTHER SPECIES FOR RESOURCES.

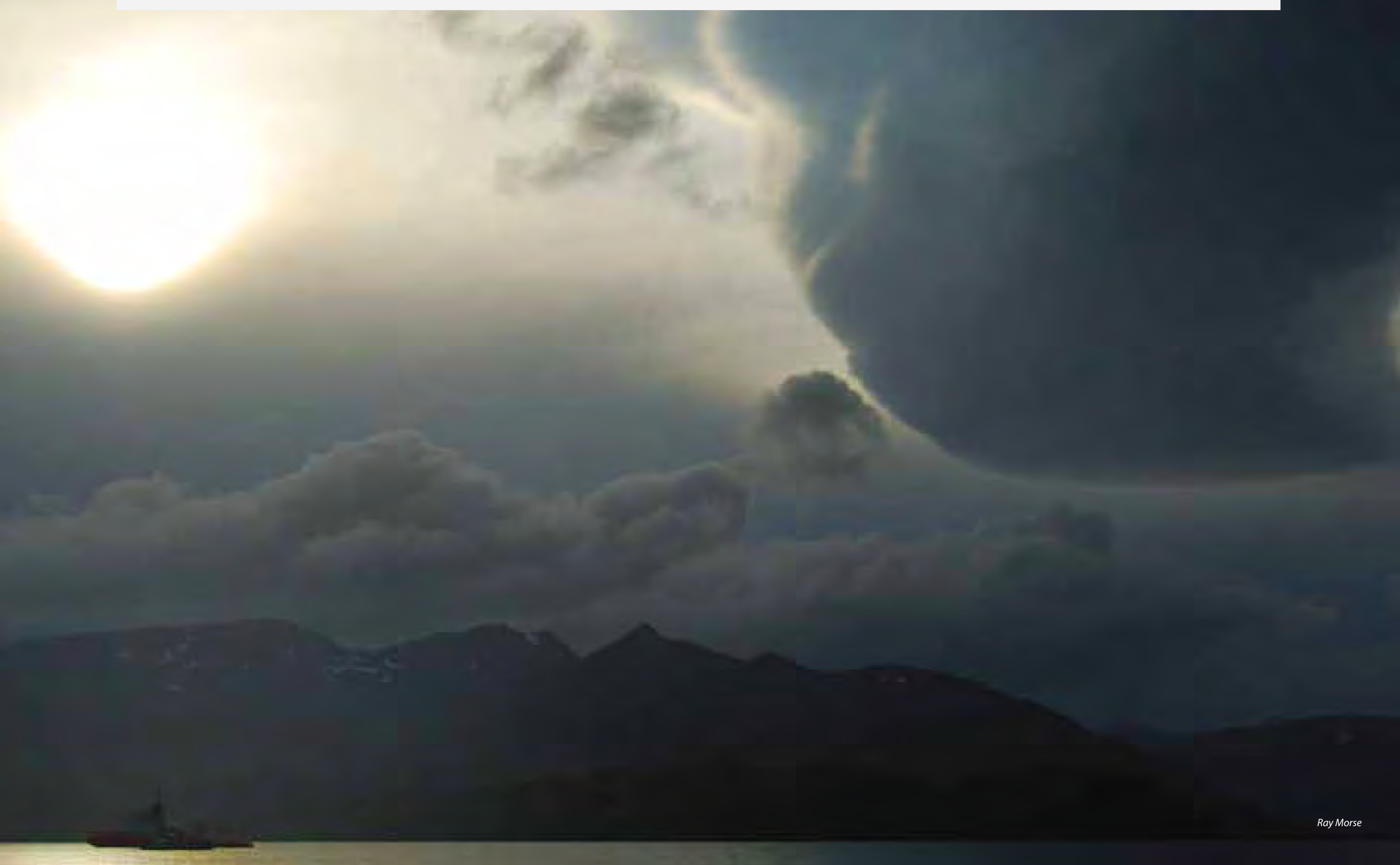
Changes in the ecosystem may at first only affect species and habitats not managed or harvested, yet eventually reverberate through the food web and have unexpected consequences for fishery management.

Ideally, new multispecies fishery management strategies should consider the full range of ecosystem change implications to determine acceptable biological catch levels for a particular species based on an optimal harvest of a mix of species, rather than solely by the species biomass.

To provide critical information for such implementation, the Board has funded ten projects for just over $1.5 million, focused on the role of climate and forage species in fishery management, as well as on the development of ecosystem indicators.

ENVIRONMENTAL CHANGE

Most assessments of the potential role of climate and environmental conditions on fish and fisheries consider statistical relationships between various climate indices, such as the Pacific Decadal Oscillation, the Aleutian Low Pressure Index, and time-series of fish catches and recruitment. Although researchers speculate about cause and effect, explicit links between environmental conditions and species composition, fish survival and growth remain largely uncertain.



Ray Morse

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Environmental Factors in Herring Predictions for Bristol Bay

Project 208

Mike Miller

PROJECT 208 INVESTIGATED LINKS BETWEEN ENVIRONMENTAL factors and a variety of population parameters for Pacific herring in Bristol Bay. By analyzing historical catch data, the study surmised that after spawning, Togiak herring migrate clockwise around Bristol Bay and are harvested in a small food-and-bait fishery off of Dutch Harbor in July.

Herring then migrate northwest along the continental shelf break to the Pribilof Islands where they spend fall and winter. In completing their migration, herring may migrate over 1,000 miles annually, providing an important ecological link between primary production and upper-level predators, as well as between nearshore and offshore food webs in the Bering Sea.

The study found recruitment variability depends, in part, on the match between where and when herring larvae emerge with bio-physical conditions, such as the spring plankton bloom during March and April. Conditions along the herring migration corridor and in coastal spawning areas also affected the timing of both the arrival and spawning of herring in northern Bristol Bay. Researchers concluded that ocean temperature changes near the ice edge, which are controlled by atmospheric pressure gradients over the North Pacific Ocean, explain most of the interannual variability of herring spawning, and that placing new moorings in these areas to provide more accurate local information would likely further improve herring spawning predictions.

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Climate Change and Pacific Cod Productivity

Project 605

THROUGHOUT THE 1990s AND EARLY 2000s, REDUCED sea ice cover corresponded with a northward spread of commercially important species in the Bering Sea, including Pacific cod. Pacific cod have undergone significant shifts in their diet and in their abundance. Like other species in this family, Pacific cod are very productive, laying up to 5,000,000 semi-demersal eggs in one batch during the spring spawning season. This makes them particularly vulnerable to changing environmental conditions during this critical period.

Project 605 is investigating the responses of larval/juvenile stages exposed to varying temperature and food regimes. Investigators are designing models to make spatially explicit maps of survival probabilities at monthly and annual scales. They are using data taken from lab studies and coupling these with field data on larval and juvenile distributions, temperature and primary productivity to give insight into the link between climate change and Pacific cod productivity.

FEATURE PROJECT

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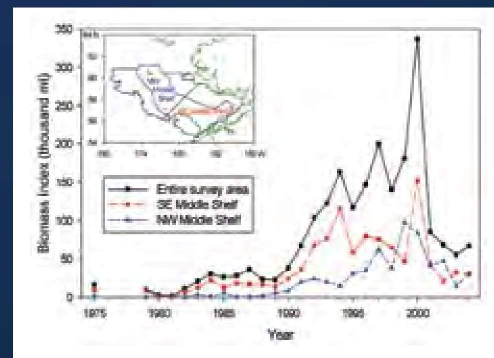
Jellyfish Fluctuations

Project 606

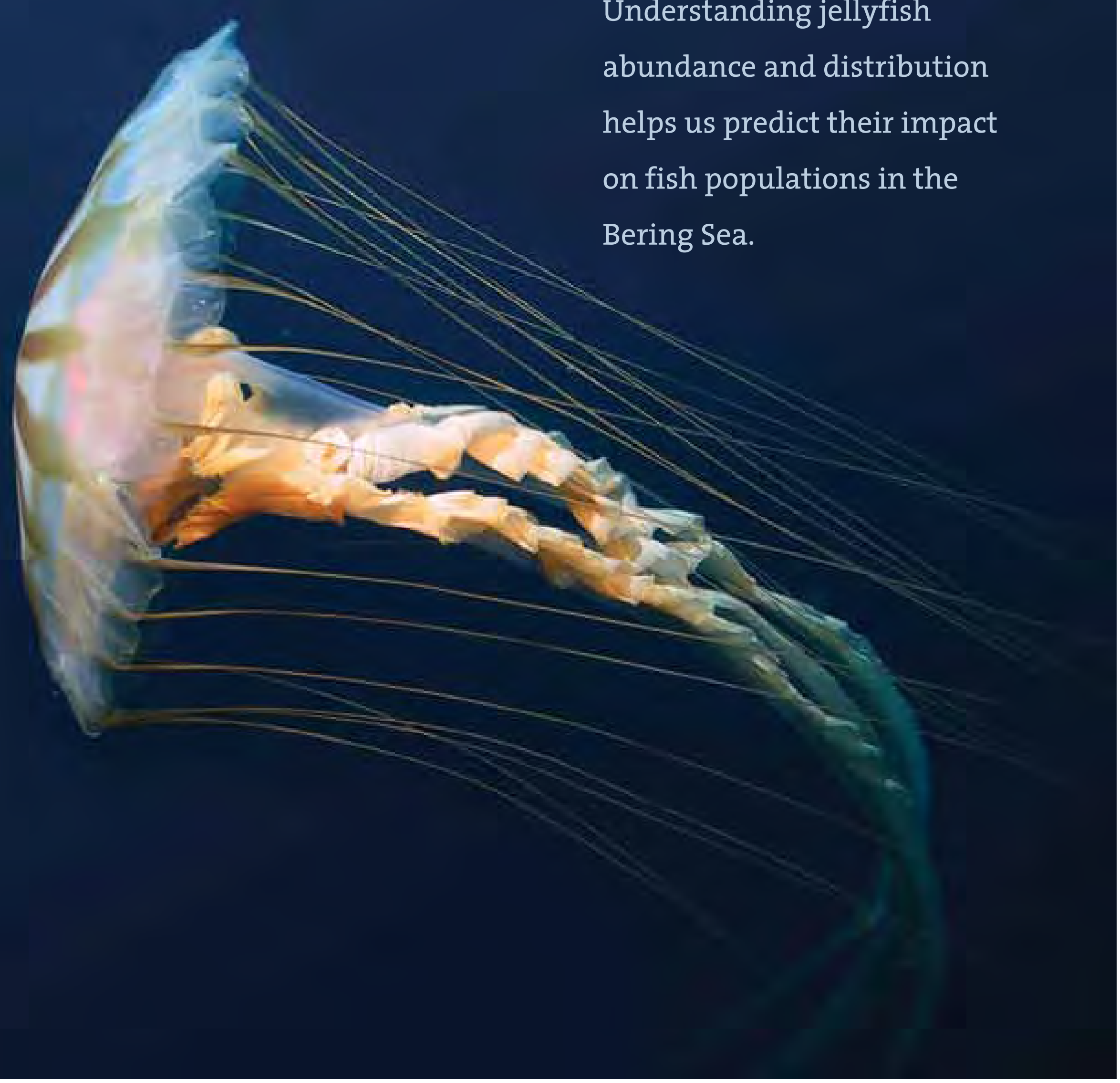
A LINK BETWEEN CLIMATE CHANGE AND PRODUCTIVITY IS SOUGHT IN Project 606 for jellyfish, which have undergone dramatic fluctuations in biomass in the Bering Sea. Jellyfish can adversely affect commercial fisheries by clogging nets, by feeding on young fish, and by competing with fish for zooplankton prey.

Jellyfish populations respond promptly to changes in physical and biological conditions, both by changes in the rates of production of young jellyfish, and by increased feeding and growth in good conditions. To explore the effects of climate change on jellyfish populations in the Bering Sea, this study is using a 27-year time series of jellyfish catches, which extends through two major regime shifts. Researchers are exploring links between current flow and jellyfish distribution and abundance, and determining the effects of variations in physical (sea ice, temperature, atmospheric variables, currents) and biological conditions (zooplankton, forage fish) on where jellyfish occur. Our increased understanding of how environmental changes influence jellyfish abundance and distribution will help us understand and predict their potential impacts on fish populations in the Bering Sea.



Trend in jellyfish biomass from standardized trawl surveys in the Bering Sea since 1975. Shown are the total biomass (black line) and subsets for the SE (red) and NW (blue) Middle Shelf Domains. The inset shows the sampling areas on the Bering Sea shelf.

> Understanding jellyfish abundance and distribution helps us predict their impact on fish populations in the Bering Sea.



Russell Hopcroft

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Growth Rates of Snow Crab

Project 713

SNOW CRAB DISTRIBUTION IN THE BERING SEA HAS shifted north from Bristol Bay to northwest of St. Matthew Island, with evidence of decreasing body size from south to north. The commercial importance of snow crab, and investigations into their stock dynamics in the Bering Sea was previously described under projects 508, 624, 812, and 813.

Project 713 expands on some of this work and links to Project 624, but specifically aims at understanding the relationship between temperature and the growth rate and diets of settled juveniles and adults around St. Lawrence Island. The study will provide a critical piece of information in the life cycle of this species by predicting when and where snow crabs may reach marketable size in more northern areas as the climate warms.

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Genetic Differences in Walleye Pollock

Project 610

SCIENTISTS KNOW OR INFER RELATIONSHIPS BETWEEN environmental factors like temperature, currents, or primary productivity and fish year-class strength for many species. Yet they are uncertain whether larval and juvenile mortality is random as a consequence of varying environmental parameters, or whether specific genotypes are favored under certain conditions.

Project 610 is using population genomics to estimate genetic differences in space and time for walleye pollock in the Bering Sea for two years with contrasting environmental conditions, in particular, temperature. Scientists are also identifying molecular markers that undergo selective evolutionary pressure and assessing the scope for adaptation to changing climate conditions.

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Impacts of Grazers on Kelp

Project 407

KELP BEDS ARE HIGHLY PRODUCTIVE SYSTEMS THAT play an important role in nearshore carbon fixation. Many different kinds of invertebrates live in kelp beds, and are prey for other species. Greenlings, ronquils, pricklebacks, and sculpins all use kelp beds as feeding grounds, nurseries, refuges and spawning grounds. Several commercially important fish species, including herring and halibut, depend on nearshore kelp beds during different parts of their life cycle. Finally, marine mammals, especially sea otters, forage in kelp for sea urchins, clams and other invertebrates, and wrap themselves in large blades of bull kelp during resting periods. Such biological diversity and cascading trophic systems depend on the abundance, health, and stability of the kelp beds. The persistence and abundance of these living habitats are at the mercy of changing environmental conditions and grazing pressure.

To better understand the environmental and biological dynamics controlling the health of kelp beds and implications on fisheries, Project 407 specifically investigated the grazer-kelp relationship between the gastropod, *Lacuna vincta*, and four common kelp species (*Nereocystis luetkeana, Agarum clathratum, Saccharina latissima, S. subsimplex*) in Kachemak Bay, Alaska. The study showed that *L. vincta*, which is only a few millimeters long, is seasonally abundant in the shallow subtidal zone and reaches densities of 70 snails per square meter in summer. This snail appears to be a driving force in the spatial and temporal

Heloise Chenelot,

variability of canopy kelp beds in Kachemak Bay, especially of the dominant, canopy-forming species *N. luetkeana*, which has very limited defense mechanisms against this grazer.

Considering the multitude of factors and their variability from year to year that likely control kelp recruitment and growth as well as grazer recruitment in Kachemak Bay, it is extremely difficult to predict where and when *L. vincta* will decimate kelp beds. While at present the researchers found that kelp beds are reasonably resilient and can re-establish a few years after decimation, it is unclear how this resilience may change with changing environmental conditions. A small but abundant species like *L. vincta* is difficult to monitor and manage. Learning from terrestrial examples of ecological pest control, the authors concluded that a next step would be to identify natural predators of *L. vincta* within the system to better understand the level of natural control of the grazer within the system.

THE ROLE OF FORAGE SPECIES

While capelin, eulachon, sand lance, myctophids, and other forage fish are an important component of the North Pacific ecosystem, many aspects of their ecology and population dynamics remain unknown. We understand some of the effects of changes in local availability of forage fish to some seabird colonies, and have estimates of their importance as prey for several commercially important fish species. Yet ecosystem-wide implications of forage fish changes on other ecosystem components remain speculative.

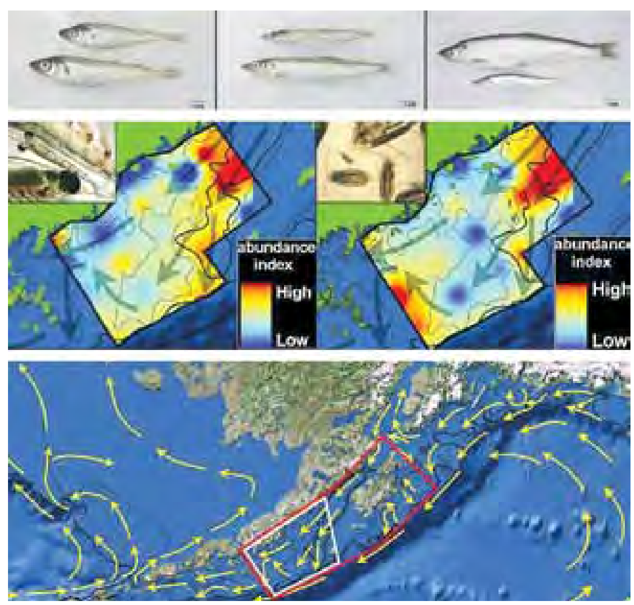
Little is also known about the effects of large fluctuations of crab, shrimp, flatfish, and sharks on other ecosystem components through competition and predation. As intermediaries in the food web, all of these species are important conveyors of trophic energy through the food web and variation in their productivity impacts many other predators, such as fish, seabirds, and marine mammals.

John Piatt

Forage Fish Productivity Nearshore in the Gulf of Alaska

Project 308

IN LATE SUMMER, LARGE NUMBERS OF SMALL, SILVER-colored smelts (capelin and eulachon) and brass-colored young-of-the-year walleye pollock, search the coastal waters of the Gulf of Alaska for zooplankton. Project 308 examined the effects of coastal hydrography and seasonality on forage fish productivity as mediated through bottom-up processes in the western Gulf of Alaska.



Researchers found that the offshore flow near the Shelikof sea valley had high concentrations of krill and large copepods. Fish in regions of high krill and large copepod densities ate more of these prey, were larger and in better condition, had more growth potential, and/or more fish per volume than areas with lower concentrations of prey. Climate-related forcing on hydrographic dynamics in the Gulf of Alaska most affected forage fish growth potentials by altering how much food is available. Also, nursery areas, especially for pollock, near Kodiak Island appeared to provide environmental conditions that tempered wintertime adversity, implying that regional differences in wintertime nursery habitat for this species could be relevant for juvenile walleye pollock survival and subsequent recruitment of individuals to spawning populations.

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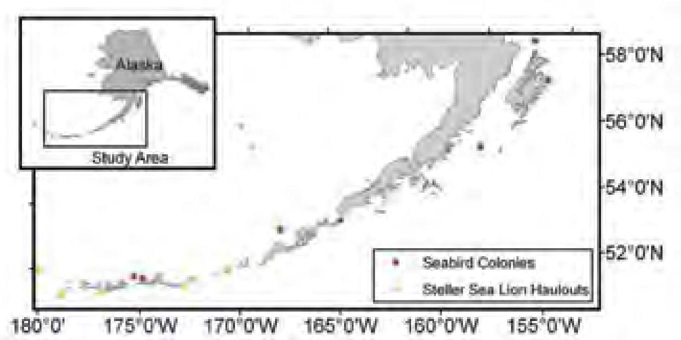
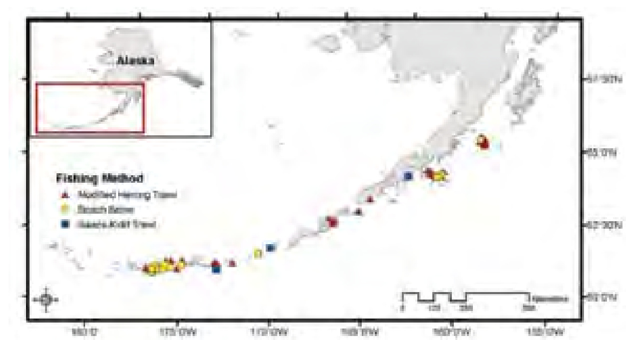
Characterizing Forage Resources of the Aleutian Islands

Project 630



Location of study area and major predator core areas routinely visited by the *Tiĝlax̂*.



Map of fishing effort by method during summer 2006.

OUR LACK OF KNOWLEDGE ABOUT FORAGE FISH biology or links to predator distribution and abundance extends to the Aleutian Islands. Relatively few studies have described the regional distribution and abundance of non-commercial nearshore and offshore forage resources in the Aleutian archipelago, in part, because surveying such a large area is expensive and difficult, and abundance estimates are difficult due to the patchiness of schooling fish and invertebrates.

Nevertheless, Project 630 opportunistically used established research platforms to sample prey and quantify ocean climate conditions to gain a better understanding of the ecological relationships between marine predators, prey resources, and marine habitat. Using the U.S. Fish and Wildlife Service M/V *Tiĝlax̂*, a vessel that routinely travels throughout the Alaska Maritime National Wildlife Refuge along the Alaska Peninsula and Aleutian archipelago, researchers recorded acoustic backscatter and measured sea surface temperature and salinity using haul-mounted equipment.

Midwater trawls sampled pelagic forage species and beach seines captured nearshore forage species. Twenty-four species of pelagic fishes and 30 species of nearshore fishes were documented throughout the study area. Walleye pollock, Pacific sand lance and spawning capelin dominated the pelagic catch, and young-of-the-year gadids, Pacific sand lance and pink salmon dominated the nearshore catch.

A longitudinal gradient of physical oceanography suggested cooler, more saline, and nutrient rich conditions in the west (central Aleutians) compared to the east (Alaska Peninsula). Researchers found that automated data collection using equipment permanently installed on the vessel is an efficient and cost-effective way to sample the marine environment during travel of the *Tiĝlax̂*. Opportunistic sampling of station data—CTD, plankton tows, beach seines—was moderately efficient, while trawling was least efficient of all sampling procedures. However, during normal operations the refuge bore the cost of transit time, leading to great efficiency in spatial sampling. This research platform has enormous potential for monitoring key ecosystem components in the Gulf of Alaska and Aleutian archipelago on seasonal, annual, and decadal time-scales.

Carrie Eischens

ECOSYSTEM INDICATORS

As we move toward ecosystem-based fishery management, discussions focus on identifying ecosystem indicators that will monitor trends in the ecosystem and help evaluate whether current management measures are achieving their objectives. On a smaller level, fish quality expressed as energy density could be an index for the health of individual fish. Project 210 supported the purchase of the equipment necessary to carry out such analyses. Many other species-specific and region-wide environmental parameters have been suggested as indicators of ecosystem status. But even though such indicators are reported, and fisheries in the Gulf of Alaska, Bering Sea, and Aleutian Islands are managed very progressively under a suite of ecosystem considerations, we still need to develop a more integrated, formalized approach.

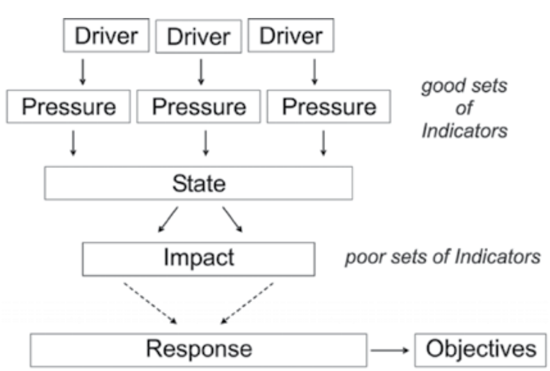
Using Ecosystem Indicators in Resource Management

Project 502

THE BOARD FUNDED PROJECT 502 TO HELP DEFINE a framework within which to choose and implement the use of ecosystem indicators for management. Ecosystem indicators are part of a larger process that considers policy-level goals for an ecosystem, and so should be linked to operational objectives and performance criteria. Although the project focused on the Bering Sea, the intent was to provide insights, findings, and recommendations more broadly applicable to the North Pacific and adjacent seas.

Using a workshop approach, the lead investigators involved the Bering Sea and international community to discuss a variety of topics, including:

- development of operational objectives for the southeastern Bering Sea ecosystem
- evaluation of the Ecosystem Consideration chapter of the SAFE report and the PICES Marine Ecosystems of the North Pacific publication
- investigation of methodologies to monitor system-wide structural changes within the marine ecosystem
- identification of steps to validate indicator performance, improve the monitoring network, and integrate indicators into predictive models



Schematic that matches indicators to objectives using a Driver-Pressure-State-Impact-Response approach.

Although this project was ambitious and no specific indicators were chosen, substantial progress was made, and a series of recommendations was brought forward.

Participants noted that ecosystem-level and community-level conservation thresholds are relatively new ideas in marine conservation, and they need further research. Existing indicators need to be synthesized into a usable set of parameters, linked to operational objectives, and evaluated using a formal evaluation and selection process available from other disciplines.

While the workshop did not address socio-economic operational objectives for the Bering Sea and North Pacific, investigators noted that links between the well-being of people and healthy marine ecosystems require a level of attention comparable to those for ecosystem conservation objectives. They concluded that the North Pacific Fishery Management Council should play a central role in shepherding the development of these socio-economic objectives and indicators for the southeastern Bering Sea and Gulf of Alaska ecosystems.

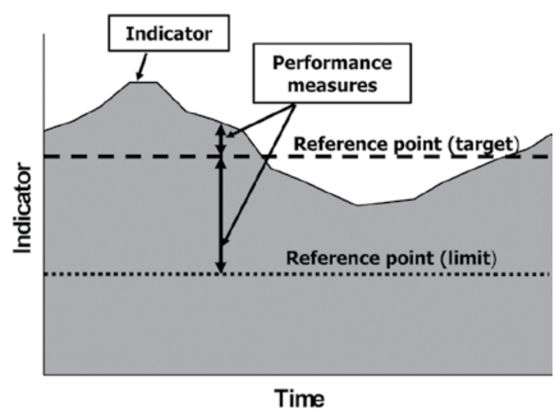


Illustration of an indicator, reference points, and performance measures relative to an ecosystem operational objective. Modified after FAO (2003).