The Alaska Predator Ecosystem Experiment (APEX): An integrated seabird and forage fish investigation sponsored by the *Exxon Valdez* Oil Spill Trustee Council

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Mr. Bruce Wright has been the Alaska Predator Ecosystem Experiment (APEX) Project Manager since its inception in 1994. At the time he was the Damage Assessment Program Manager for the Office of Oil Spill Damage Assessment and Restoration with the National Oceanic and Atmospheric Administration (NOAA), a position he accepted in 1991. Mr. Wright is now the Chief of that office, which works closely with the Exxon Valdez Oil Spill Trustee Council, and in 1997, he was assigned as the NOAA agency liaison to this Council. In 1998, he was selected as vice-chairman of the Jay Hammond Bald Eagle Research Institute, and was named the chairman in 1999. Having many years of teaching experience, he has helped develop six Wildlife Series correspondence courses on whales, eagles, and bears (1987), and continues to teach those courses as part-time visiting faculty at the University of Alaska Southeast. Bruce graduated from San Diego State University where he earned a B.S. degree in biological sciences (1975) and a M.S. degree in ecology (1977).

The Alaska Predator Ecosystem Experiment (APEX) project began in 1994, and arose as an effort to determine why some seabirds showed no sign of recovery from the *Exxon Valdez* oil spill. Such knowledge was seen as essential to undertaking biologically realistic recovery. The basic hypothesis of APEX, that food limits recovery, appears to have been confirmed by multiple approaches within APEX (www.uaa.alaska.edu/enri/apex/index.html). Historical data from long-running sampling of the Gulf of Alaska (GOA) indicate a major change in the marine ecosystem associated with increased water temperatures in the late 1970s. This led to a change from capelin *(Mallotus villosus)* and shrimp to flatfish and pollock *(Theragra chalcogramma)*. Seabird diets reflect this change: capelin and sand lance *(Ammodytes hexapterus)* were replaced by pollock. At-sea studies in Prince William Sound during APEX have demonstrated an abundance of pollock offshore, with schooling species such as herring *(Clupea harengus)* and sand lance inshore. Most seabird foraging has been concentrated inshore on these species. Capelin have been rare and limited to certain areas. APEX field studies in PWS and the GOA of Black-legged Kittiwake (*Rissa tridactyla)*, Marbled Murrelet (*Brachyramphus marmoratum*), and Pigeon Guillemot (*Cepphus columba*) have shown that they have better reproductive success when consuming high lipid schooling species: forage fish abundance and seabird breeding success have been positively linked. According to laboratory studies seabirds grow better and have heavier masses at fledging when fed high lipid schooling species. Nutritional studies have revealed that herring, sand lance, and capelin have higher lipid (and energy) levels than do pollock. Finally, models of populations and foraging have shown that certain colonies contribute disproportionately to the dynamics of a species.

Retrospective studies

Declines of APEX predator populations, murres, kittiwakes, harbor seals *(Phoca viyulina phocoena*), and Steller sea lions (*Eumetopias jubatus*), have occurred in the GOA since the 1970s. Changes in composition and abundance of forage species may be related to the decline of these predator populations and their chronic low population levels. A trophic regime shift resulting from a climatic forcing event in the last half of the 1970s was suggested as the driving mechanism for these observed trends. These data were collected in a similar manner, over widely dispersed regions of the GOA, and show massive reorganization of the marine ecosystem following the extreme environmental change, (*Figure 1*) as evidenced in long-term (1953-1998) small-mesh trawl surveys

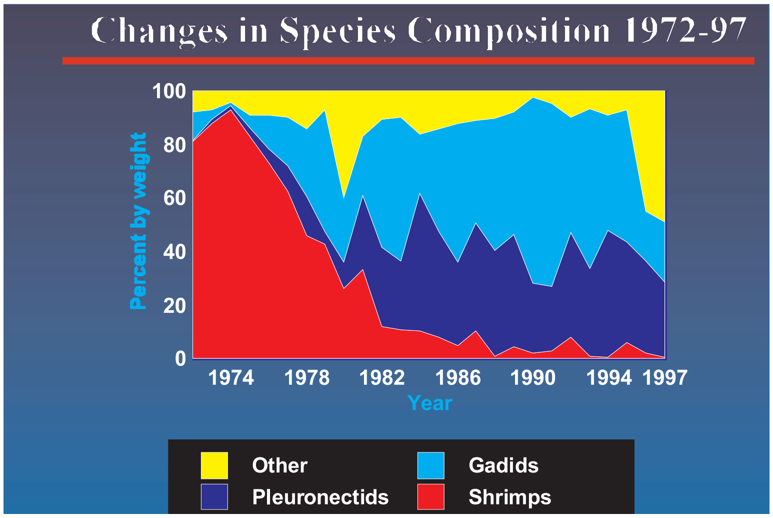

Fig. 1 *Changes in species composition in the Gulf of Alaska, 1972-1997, from small-mesh mid-water trawl surveys (from Anderson, P. J., J. E. Blackburn, and B. A. Johnson. 1997. Forage Fish and Marine Ecosystems. Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program No. 97-01. University of Alaska Fairbanks, 1997.)*

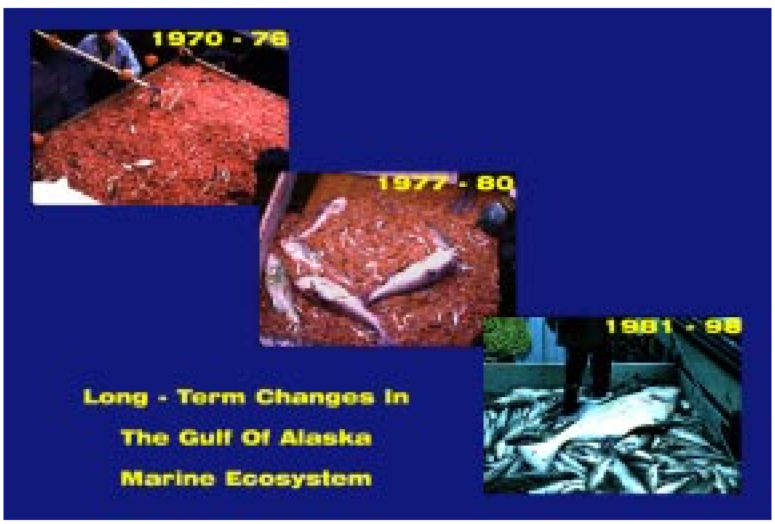

Fig. 2 *Long-term changes in the Gulf of Alaska Marine Ecosystem (from Botsford, L. W., J. C. Castilla, and C. H. Peterson. 1997. The Management of Fisheries and Marine Ecosystems. Science 277: pp 509-515)*

(www.fakr.noaa.gov/trawl/index.htm). Nearly 10,000 individual sampling tows are in the current project database. Recent analysis of the 1996-1998 survey data has indicated that the groundfish-dominant trophic structure still exists with no signs of reversal (*Figure 2*). Thus, the current system exhibits a high degree of stability. Long-term monitoring is needed to determine what drives and maintains these GOA marine ecosystem changes, particularly the effects on APEX predators.

Scale

Factors affecting food availability of seabirds occur at many spatial scales ranging from tens of meters to thousands of kilometers. While broad-scale oceanic processes (e.g., circulation and temperature) may affect general food abundance, it is often small-scale events (e.g., local currents and upwelling) that have an impact on how and where individual seabirds choose to forage. By observing individual seabirds and schools of fishes the APEX study has found several factors that influence how seabirds forage. In summer, the waters of PWS are stratified with little mixing and the near-surface fish schools (herring, sand lance, and capelin) are small, occur in low density, and are located close to shore. Seabirds in PWS respond by foraging singly or in small flocks close to shore. This is in contrast to lower Cook Inlet where there is strong tidal mixing of the water column, the fish are in larger and more dense schools than in PWS, and the fish occur offshore (capelin and pollock) as well as near shore (capelin and sand lance). When prey are predictable, seabirds learn and remember where prey can be found and individual birds return to the same area repeatedly. In this case, they do not always forage on fish that are closest to the colony; rather, they pass by fish schools to return to the area where they have successfully foraged in the past. When prey availability changes daily due to tidal cycles, birds respond by adjusting their foraging activities. Seabirds also change their foraging strategy in respect to prey abundance: when prey are scarce seabirds generally forage in flocks, but when prey are abundant they often forage alone. This behavior change likely increases their efficiency by using other birds to find food when it is scarce, and decreasing risk of kleptoparasitism by foraging alone when prey are abundant. At intermediate spatial scales of tens to thousands of km, the distribution of seabirds at colonies and at sea in the northern GOA reflects regional patterns of productivity and forage fish abundance. Seabird productivity varies with overall forage fish abundance in a nonlinear fashion, and in some areas and years, productivity is clearly limited by food availability. Decadal changes in forage fish stocks have altered the diets of many seabirds in the GOA, and influenced trends in productivity and population dynamics.

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the possibility of additional experiments, for example in the Gulf of Alaska, was considered.

The Panel was informed of the development of the FAO Fisheries Global Information System, FIGIS, which could do much to answer the Panel's concern about the need to bring together national and regional analyses of fisheries data in order to assess population changes in the upper trophic levels of marine ecosystems.

Pilot experiments have been proposed in order to demonstrate the concept of monitoring from the living marine resource point of view. Those in connection with the GEF-funded Large Marine Ecosystem (LME) monitoring and assessment projects and with large-scale GLOBEC projects, such as those concerned with small pelagics and with the Southern Ocean, seemed promising. In the PICES region, Professor Takashige Sugimoto (Japan) described work in the northwest Pacific that could constitute an LMR pilot project, and Professor Warren Wooster (USA) proposed that a northeast Pacific plan for use of the Continuous Plankton Recorder (CPR) be adopted.

The full report of the meeting should be completed in the next month and distributed in early summer. Comments and suggestions from the PICES community will be welcome. These can be considered at a third meeting, anticipated by the end of 1999, when an implementation plan should be completed.

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APEX mesoscale studies of seabird populations in the northern GOA reveal a high degree of local, short-term variability in population parameters, but a pervasive influence of mesoscale phenomena on populations in discrete oceanographic domains.

Energetics

APEX research also addresses whether shifts in diet quality may constrain reproduction of Pigeon Guillemots, Black-legged Kittiwakes, and other piscivorous seabirds nesting within the *Exxon Valdez* oil spill area. Researchers measured lipid content of forage fishes because it is the primary factor determining energy density. Lipid content of seabird prey ranged from 2% to 61% of dry mass, resulting in a fivefold difference in energy density (2.0 to 10.8 kJ/g wet mass). Most of this variation was due to among-species differences, but intraspecific variation in lipid content was related to age, sex, location, and reproductive status of fish. Of the main fishes consumed by seabirds, juvenile herring, pre-spawning capelin, and sand lance had the highest energy densities. Kittiwake diets were dominated by these high-lipid forage fishes at all study sites, and the dates of energy provisioning to nests were correlated with nestling growth and survival. The trend established in the earlier part of this decade of higher kittiwake productivity associated with increasing availability of sand lance, capelin, and herring was broken in 1997, a poor year at most kittiwake study colonies. For guillemots, the proportion of high-lipid schooling fish (sand lance, herring) in the diet was associated with higher growth rates, and productivity, compared with those consuming mostly nearshore demersal fishes or gadids. These results support the hypothesis that productivity of kittiwakes and guillemots in the northeast Pacific area is strongly linked to the availability of three species of forage fishes: Pacific sand lance, Pacific herring, and capelin. These three species form schools near shore and have high energy densities compared with most other forage fishes. Recovery of seabird populations injured by the *Exxon Valdez* oil spill will depend on recovery of these key fish stocks.

Modeling

The population dynamics of kittiwakes and other seabirds in PWS are usually in a state of flux. At any given time, some colonies are growing and some are declining. Although there is strong evidence that variation in food supply underlies much of the fluctuation in colony size, the mechanism by which food supply influences colony dynamics needs to be more clearly defined. Analysis of demographic data indicates that the rate of population change for a given colony is closely related to the breeding success of that colony. Breeding success in turn is related to the rate at which food is delivered to chicks and the quality of that food. Using detailed data on the movement patterns and foraging behavior of radio-tagged kittiwakes coupled with extensive concurrent aerial surveys of fish schools, APEX researchers have constructed a computer model designed to mimic the behavior of a foraging kittiwake. This model can be used to simulate the response of a foraging kittiwake to various patterns of food distribution and abundance. These simulated foraging behaviors can then be used to predict the distance that adults must travel in order to forage, and the rate and nature of food deliveries to the chicks. Since chick survivorship is known to be strongly influenced by these factors, we believe that it will be possible to make predictions about the performance of individual colonies based on hypothetical fluctuations in the distribution and abundance of the forage fish.

Summary

Changes in the marine ecosystem of the GOA led to a low-fat "lean cuisine" on which seabirds had difficulty raising young. APEX researchers are still exploring why this shift occurred and the mechanism through which it affects seabirds. The main implication for management is that recovery will continue to be inhibited as long as present ecological conditions exist. APEX studies have also identified key colonies and foraging areas that should be protected during future oil spills and during development of infrastructure in the GOA.