North Pacific Climate Regimes and Ecosystem Productivity

NPCREP

SCIENCE PLAN

Climate has direct, discernible and predictable impacts on marine ecosystems.

October 2004

NOAA FISHERIES
NATIONAL MARINE FISHERIES SERVICE

Revised March 2006

CONTENTS

Science Plan

1. EXECUTIVE SUMMARY

Climate has direct, discernible and predictable impacts on marine ecosystems. North Pacific Climate Regimes and Ecosystem Productivity (NPCREP) will help the United States understand how varying climate conditions affect marine ecosystems of the North Pacific Ocean. Subarctic seas such as the Bering Sea and Gulf of Alaska are particularly sensitive to climate change. Climate variability affects the productivity, community structure and assemblage of harvested species and impacts the ability of endangered and threatened species to recover. Climate influences the physical and biological habitats of managed and protected species. Scientists and resource managers need additional information to manage our nation's ecosystems and their living marine resources under changing environmental conditions. Presently, there is little understanding of the mechanistic basis for these ecosystem responses, and there is limited ability to predict them.

Climate has direct, discernible and predictable impacts on marine ecosystems.

NPCREP will work within the exclusive economic zone (EEZ) of Alaska (the source of 50% of the nation's seafood), focusing on the Bering Sea. NOAA scientists will observe ecosystem variables and conduct process studies to understand how climate influences the structure and functioning of marine ecosystems. To detect and measure ecosystem changes, NPCREP will expand existing, and initiate new, long-term observing sites on the Bering Sea shelf and in the Gulf of Alaska. Analyses of observations from these sites, coupled with results from studies designed to reveal processes linking climate forcing to ecosystem change, will build a new comprehension of climate-ecosystem dynamics. From that will come new and more accurate predictive

Ecosystems within Alaska's EEZ produce about half of the nation's supply of fish and shellfish, by weight.

NPCREP will develop tools to assist the North Pacific Fishery Management Council apply an ecosystem approach to management.

methods that utilize environmental variables linked to climate. These new and more accurate methods will improve predictions of annual fish production, distribution and key vital rates. This improved information will enable us to initiate an ecosystem approach to management by improving our ability to forecast the effects of changing climate regimes on North Pacific Ocean ecosystems. Knowledge of likely ecosystem responses will enable the North Pacific Fishery Management Council, the State of Alaska and other stakeholders to establish harvest policies that are robust to change. The outcomes of NPCREP will be healthy and productive ecosystems that benefit society, and a well-informed public that acts as an effective steward of marine ecosystems.

2. VISION

We envision productive, ecologically diverse ecosystems that provide long-term, sustained benefits to local communities, the nation and the world. Responsible, efficient stewardship uses accurately measured environmental data and state-of-the-art management tools for guidance. An ecosystem approach to management permits optimum, sustained utilization of marine resources in ecosystems affected by climate and human activity. Nations cooperate by monitoring, regulating, and promoting ecosystem health in national and international waters. Observations are shared with the Global Ocean Observing System. North Pacific Climate Regimes and Ecosystem Productivity (NPCREP) is a springboard for attaining this vision.

3. MISSION

It is NOAA's mission to protect and manage U.S. marine resources through sound ecosystem management. Understanding how ecosystems respond to changing climate through atmospheric, oceanic and biological processes is a necessary step to providing an ecosystem approach to management.

It is NPCREP's mission to conduct research on climate variability and ecosystem response in the North Pacific, focusing initially on the productive waters of the eastern Bering Sea and western Gulf of Alaska (Fig. 1). Research will improve scientific understanding and guidance for resource managers.

4. INTRODUCTION

The United States must be prepared to deal with changing climate and its effects. Global climate models predict that high latitudes are most sensitive to climate change and variability. The recent Arctic Impact Assessment Report (Anon, 2004) concluded that "average annual temperatures [in the arctic] have increased at twice the rate of the rest of the world over the past few decades," and that reductions in arctic sea ice will push some species to extinction. We need to know how climate will change and how ecosystems will respond to that change. Knowledge must span not only the commercially important and endangered species, but also the interdependencies these species have with others. NPCREP will address national needs (NOAA, 2004) to help:

- Prevent collapse of commercial fisheries and sustain optimum yields of marine resources.
- Protect species and reduce economic impacts of natural climate fluctuations.
- Develop indices of climate and ecosystem status.
- Forecast extreme events.
- Promote international stewardship of shared marine resources.
- Complete an Integrated Ocean Observing System.

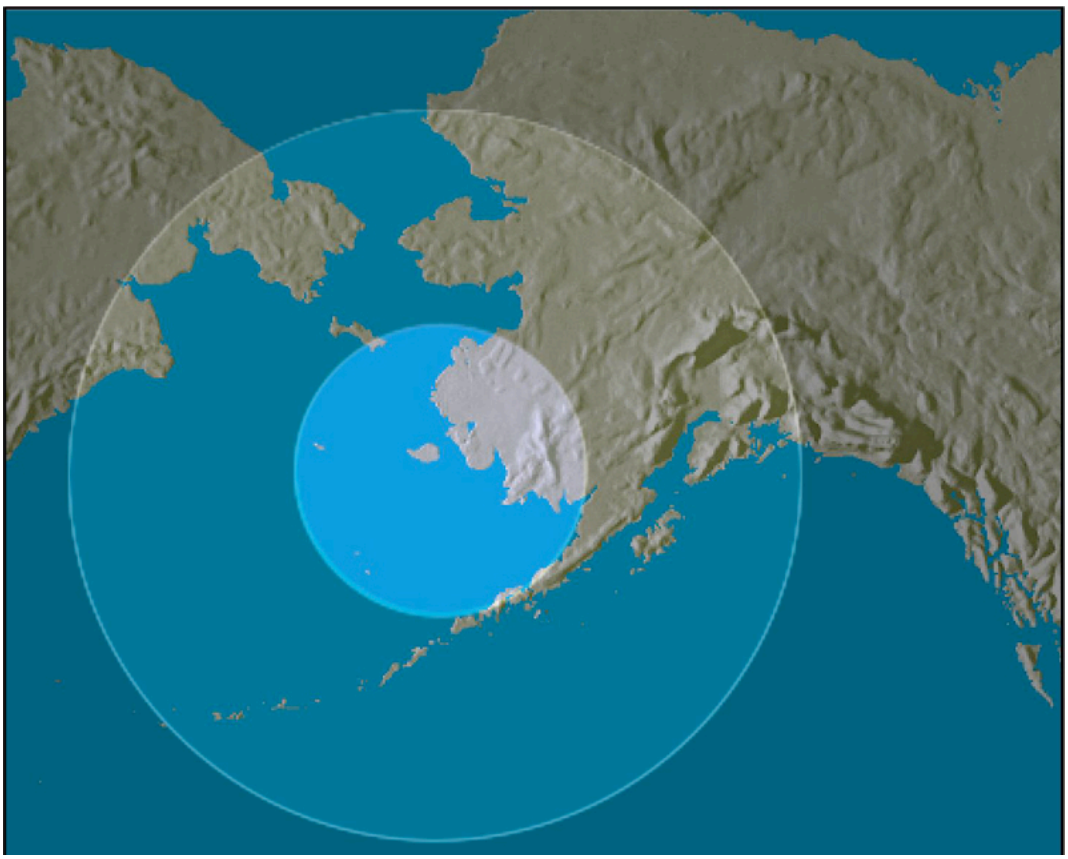

Fig. 1. NPCREP study area focused on the eastern Bering Sea. Secondary effort is aimed at the western Gulf of Alaska, Aleutian Islands and other neighboring regions.

5. BACKGROUND

5.1. DEFINITIONS

Climate change is the change in average behavior of the land-ocean-atmosphere-cryosphere system over a region over relatively long periods (relative to daily fluctuations of "weather") (Global Learning Resource Network, 2004). Climate change includes changes in temperature, wind patterns, ocean currents, sea ice and precipitation.

An *ecosystem* is a geographically specified system of organisms, the environment, and the processes that control its dynamics (NOAA, 2004). Humans are an integral part of an ecosystem.

The *environment* is the biological, chemical, physical, and social conditions that surround organisms (NOAA, 2004).

An *ecosystem approach to management* is management that is adaptive, specified geographically, takes into account ecosystem knowledge and uncertainties, considers multiple external influences, and strives to balance diverse social objectives (NOAA, 2004).

A *regime* is a period of several sequential years (often a decade or more) in which the state or characteristic behavior of the climate, the ocean conditions and/or an ecosystem is steady (North Pacific Marine Science Organization, 2004).

A *regime shift* refers to a relatively rapid change (occurring within a year or two) from one decadal-scale period of a persistent state (regime) to another decadal-scale period of a persistent state (regime) (North Pacific Marine Science Organization, 2004). Regime shifts often demark a fundamental change in the structure and function of a marine ecosystem and its components. The causes of regime shifts are not well understood and are an active research area. A regime shift may result from atmospheric and oceanic forcing and feedback, strong anthropogenic forcing (harvest), or a combination of natural and anthropogenic forcing.

Top-down and *bottom-up control* stipulate whether the fate of a species is dependent on its predators or its prey, respectively.

5.2. NORTH PACIFIC CLIMATE

Climate forcing on ecosystems occurs on many temporal and spatial scales. Climate oscillations affect the ecosystems of the ocean basins, shelves, and local coastal waters through many mechanisms.

5.2.1. Atmosphere

The climate of the North Pacific reflects the weather caused by spatial and temporal variations in the thermal contrast between air masses of low latitude, sub-tropical origin and those of high-latitude, arctic or continental origin. This contrast is much more marked in winter and results in a series of baroclinic disturbances (cyclones and anticyclones) moving generally from west to east. Cyclones are especially favored south of the Aleutian Islands (AI); their combined effect is responsible for the seasonal statistical center of low sea level pressure (SLP) known as the Aleutian Low. The latitudinal temperature gradient in the atmosphere is weaker and situated farther north in summer. Associated storms are also weaker and track farther north, typically across the Bering Sea. As a consequence, the North Pacific High located roughly halfway between Hawaii and Vancouver Island dominates the seasonal mean SLP distribution in summer.

The seasonal differences in the weather of the North Pacific have profound impacts on air-sea interactions. In the northern portion of the basin, i.e., the Bering Sea and Gulf of Alaska, the seasonal cycle of SLP implies mean winds from the east in winter and from the west in summer. The winds are typically much stronger in the winter than in the summer, transferring more momentum to the ocean and mixing the upper oceanic layer more. The heat exchange at the air-sea interface is dominated by the upward flux of sensible and latent heat (evaporation) during winter and the net downward flux of shortwave (solar) radiation in summer.

The weather of the North Pacific is prone to fluctuations on time scales of years to decades and longer. These fluctuations are of interest and importance because of linkages to the marine ecosystem (e.g., Hare and Mantua, 2000). The causes of climate variability, and their implications, are not well understood, but progress is being made. The wintertime atmospheric circulation over the North Pacific is influenced significantly and systematically by the remote effects of the El Niño/Southern Oscillation (ENSO) phenomenon in the tropical Pacific. Notably, during winters with a warm ENSO event (an El Niño), the Aleutian Low is often deeper than normal. This results in warmer than normal sea surface temperature (SST) in the coastal Gulf of Alaska and a tendency for an enhanced Alaska Coastal Current (see Sec. 5.2.2). The effects of El Niño on the Bering Sea are less consistent. Both the atmosphere and ocean of the North Pacific are subject to substantial multi-year variability in association with the Pacific Decadal Oscillation (PDO; Mantua *et al.*, 1997) and the Arctic Oscillation (AO; Thompson and Wallace, 1998). The PDO appears to be related to decadal variations in ENSO; it is unclear how sensitive the atmosphere is to the SST anomalies themselves. The AO involves the strength of the polar vortex of the Northern Hemisphere and is the result of complicated interactions between the mean flow and transient eddies and between the stratosphere and troposphere. The PDO and AO may be responsible for the physical and biological shifts seen in the North Pacific around 1977 and 1989, respectively.

Unresolved but potentially significant issues are emerging regarding the climate variability of the North Pacific. For example, the local atmospheric forcing in key locations such as the coastal Gulf of Alaska is not strongly correlated with the basin-scale variability (Stabeno *et al.*, 2004), and so exactly how these basin-scale variations impact marine ecosystems over the shelf is obscure. Much more attention has been paid to wintertime climate variability, yet other times of year are apt to be crucial to many elements of the system. In general, the pathways from the physical forcing through geochemical properties to biological effects are not well understood. Understanding these pathways will enable society to anticipate changes in the marine ecosystem in association with climate variability.

5.2.2. Ocean

Ecosystems of the North Pacific Ocean respond to the North Pacific Current or West Wind Drift (Fig. 2) that flows generally eastward across the ocean from Japan to North American. There, the current splits into the southward flowing California Current and the northward flowing Alaska

Current, forming the eastern boundaries of the subtropical and subarctic gyres, respectively. The Alaska Current flows northward along the North American coast, turning southwestward at the head of the Gulf of Alaska to form the Alaskan Stream, which flows southwestward along the south side of the Aleutian Islands. The Alaskan Stream supplies the northward flow through the deeper Aleutian passes into the Bering Sea. The passes permit the introduction of relatively warm, saline water to the Bering Sea, and also are a conduit for plankton, fish and mammals. In the Bering Sea, the eastward flowing Aleutian North Slope Current combines the water flowing through the eastern passes to form the Bering Slope Current, the eastern boundary of the cyclonic Bering Sea gyre.

The shelves have flow distinct from that of the basin. Along the shelf of the Gulf of Alaska is the westward flowing Alaska Coastal Current, which dominates shelf currents in the Gulf of Alaska. This buoyancy and wind-driven current flows westward to the Aleutian Islands, with a portion flowing through Unimak Pass onto the Bering Sea shelf. Flow on the Bering shelf is weak, but there is a general northward flow along the 50-m and 100-m isobaths. Water from the Bering Sea flows northward through Bering Strait, providing the Arctic with warm water and either freshwater from Alaskan rivers during summer or high-salinity water from brine rejection during sea ice formation in winter. This water is important to the water properties and structure of the Arctic Ocean.

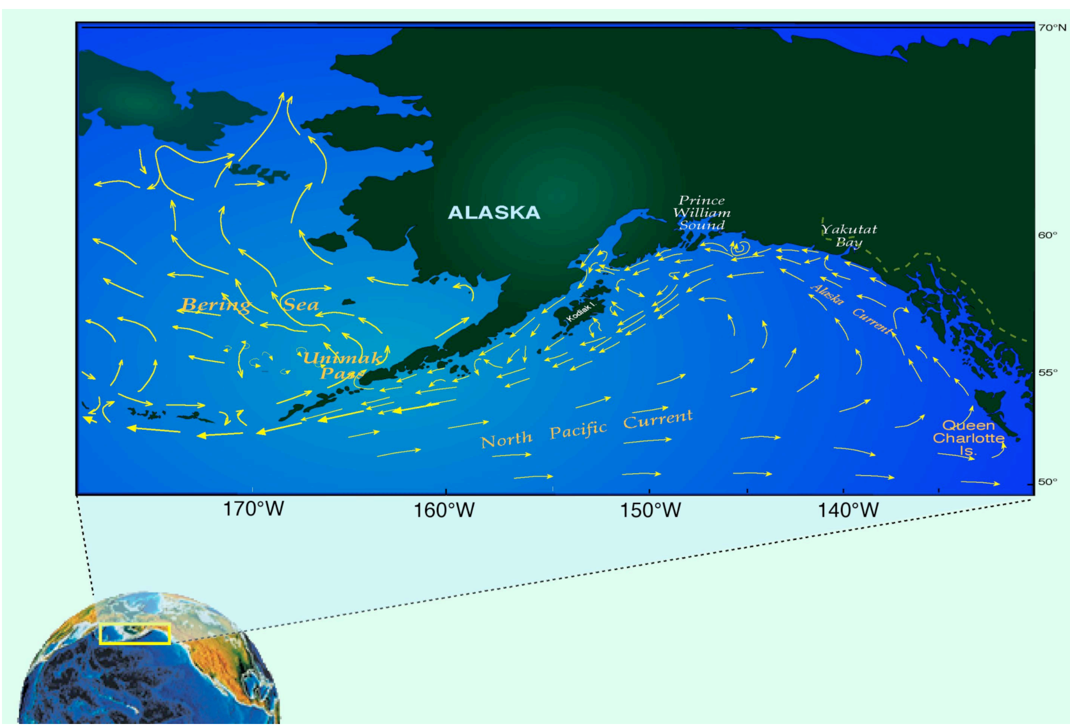

Fig. 2. Major currents and geographic features of the study area.

5.2.3. Cryosphere

The eastern Bering Sea ecosystem is a marginal ice zone (Fig. 3), with sea ice generally present to some degree from December through May. Sea ice produced in the lees of headlands and islands in the northern Bering Sea is advected to the south by cold winds. Its range is highly variable. At maximum extent, it can cover most of the eastern shelf. During years of minimal coverage, sea ice may not extend south of St. Matthew Island. Even though the annual variability is large, sea ice conditions tend to occur in decadal cycles.

Fig. 3. (left) Mooring site 2 in the eastern Bering Sea can be covered by sea ice as in this photograph from the late 1990s. (right) Walrus are threatened by the shrinking ice pack over the continental shelf.

Sea ice has a large and visible impact on local conditions. It cools the water column; when it melts, it adds freshwater that stratifies the water column; it leaves behind a "cold pool" of <2° C water at the bottom that may persist through the summer. Long-lasting temperature effects of sea ice affect biological processes in the region. For example, the presence of sea ice over the southeastern shelf after mid March results in an early phytoplankton bloom. The timing of this bloom is critical to the zooplankton providing secondary productivity for the region (Stabeno and Hunt, 2002).

5.3. NORTH PACIFIC ECOSYSTEMS

The ecosystems of the Gulf of Alaska and Bering Sea are rich and varied, supporting vast populations of birds, mammals, fish and shellfish. In 2003, commercial species in this region accounted for 51% of the U.S. seafood catch by weight and 18% by ex-vessel value. The value of the 2003 catch after primary processing was about $1.5 billion (Hiatt *et al*., 2004). Coastal communities of Alaska are dependent on the harvest of marine resources (Package and Sepez, 2004). A sound ecosystem approach to management of the Gulf of Alaska and Bering Sea/Aleutian Islands fisheries must consider the impacts of climate fluctuations on the ecosystem.

Until modern times, North Pacific ecosystems supported mostly indigenous subsistence populations and were not heavily exploited except possibly in localized areas. During this period of minimal anthropogenic exploitation, changes to the ecosystem occurred principally through natural forcing on a continuum of scales. During the past several centuries, however, human influence on marine ecosystems of the North Pacific Ocean has increased greatly. Present changes can be attributed to a combination of natural and anthropogenic forcing with no systematic way of distinguishing between the two. Because there are few baseline measures of most marine ecosystems, there is no way of knowing the "base" or original state of the ecosystems.

5.3.1. Large Marine Ecosystems

Large Marine Ecosystems (LMEs) are extensive oceanic areas (≥200,000 $km^{2)}$ characterized by distinct hydrographic regimes, submarine topography, productivity, and trophically-dependent populations (Sherman, 1991). The NOAA Ecosystem Goal Team recommended adoption of the LME concept for study of ecosystems. In the Alaska region, there are at least three recognized LMEs: the Gulf of Alaska, the eastern Bering Sea/Aleutian Islands region and the Chukchi-Beaufort Seas. Alaska Fisheries Science Center (AFSC) and Pacific Marine Environmental Laboratory (PMEL) investigators have previously published on the application of the LME concept to the Bering Sea (Incze and Schumacher, 1986; Livingston *et al.*, 1999), and its sensitivity to climate forcing (Schumacher *et al.*, 2003).

5.3.2. Biological environment and managed resources

The Bering Sea and Gulf of Alaska are home to many indigenous and migratory marine species. Relatively cold and nutrient-rich waters foster high regional productivity. During the last few decades, populations within Bering Sea and Gulf of Alaska ecosystems have undergone large fluctuations in numbers and extent of range (e.g., Hollowed and Wooster, 1995). For instance, shrimp in the Gulf of Alaska have fallen from high abundance in the 1960s and 1970s to very low abundance now (Anderson and Piatt, 1999). The red king crab fishery has undergone a similar decrease resulting in the fishery being closed in 1984 (Kruse *et al.*, 1996). Alaska salmon have undergone the opposite change, with a marked increase in catch during the last few decades (Hare and Mantua, 2000). The marked decrease in the Steller sea lion population beginning in the 1970s has caused it to be declared endangered and resulted in closure of fishing in and around rookeries (McBeath, 2004). Other mammal species (e.g., harbor seals and fur seals) have undergone similar decreases, while some mammal populations (e.g., elephant seals) have increased during the 1990s. As a society dependent in myriad ways on these ecosystems, we must ask: What are the causes of this variability? The two likely driving forces of these large fluctuations are climate variability and human impacts. To manage resources effectively, it is critical to understand how climate affects the ecosystem, so that human impacts such as fishing can be regulated appropriately for present and future levels of production.

> ***It is critical to understand how climate affects the ecosystem, so that human impacts such as fishing can be adjusted to levels appropriate to present and projected productivity.***

5.4. CLIMATE-ECOSYSTEM INTERACTIONS

There is emerging evidence of climate-induced change in Alaska for both the terrestrial and marine ecosystems. For example, in the terrestrial environment, the shoaling of the permafrost layer, the shortening of the spring freshet, and the receding of glaciers are all caused by changing climate (Anon, 2004). In the marine environment, thinning of arctic ice, decreased occurrence of sea ice in the southeastern Bering Sea and an increase in heat content of the water signal significant change (Overland and Stabeno, 2004). If the waters of the North Pacific and Bering Sea continue to warm, then one would predict an expansion of subarctic species to the north and a contraction of arctic species northward out of the Bering. This could have a tremendous impact on the trophic structure of the Bering Sea and on the coastal communities that depend on marine resources for survival.

Sea ice and ocean temperature affect ecosystems through:

- *The timing of the spring phytoplankton bloom (Stabeno* et al.*, 1996 and 2002),*
- *The partitioning of primary production between the benthic and pelagic communities (Walsh and McRoy, 1986),*
- *Secondary production and species composition (e.g., Brodeur* et al.*, 2000; Baier and Napp, 2003; Coyle and Pinchuk, 2002),*
- *Fish distributions, including contact between cannibalistic adult pollock and juvenile pollock (Wyllie-Echeverria and Wooster, 1998) and cod and capelin (Ciannelli and Bailey, in press),*
- *Production and temporal overlap of fish larvae and their prey (Napp* et al.*, 2000),*
- *Distribution of prey for migratory grey whales (Moore* et al.*, 2003),*
- *Suitable habitat for ice-dependent seals and walrus (e.g., Tynan and DeMaster, 1997).*

The subarctic region of Alaskan waters is sensitive to climate variability on many scales. Temperatures in the Bering Sea, which have been in a warm phase since the regime shift of the late 1970s, continue to increase despite recent shifts (1998-1999) in the PDO and AO (Overland and Stabeno, 2004). Examples of species that are not doing well under the present warm regime are snow crab (*Chionoecetes opilio*), an economically important shellfish species now considered overfished (Rugolo *et al*., 2003); Greenland turbot (*Reinhardtius hippoglossoides*), a commercial groundfish of moderate to low importance; and ampeliscid amphipods, food for grey whales. The reasons for these declines are not entirely known, but may involve reduced recruitment due to a combination of warming and high fishing pressure or predation by species that have been favored during the warm regime. In recent history, some of the best examples of fish stock "collapse" resulted from heavy fishing pressure during a period when the population was responding to environmental stress.

The Bering Sea ecosystem is particularly sensitive to changing atmospheric forcing (e.g., Napp and Hunt, 2001; Schumacher *et al*., 2003). Climate variability determines the amount of sea ice in the region. The extent and duration of seasonal sea ice on the shelf determines the temperature of the bottom layer over the middle shelf, i.e., the “cold pool.” Climate, too, modulates wind speed and direction.

Winds affect ecosystem productivity and structure through:

- *Wintertime re-supply of nutrients to the continental shelves (Stabeno* et al.*, 2002; Stabeno* et al.*, 2004)*
- *Vertical mixing and injection of nutrients into the euphotic zone (Sambrotto* et al.*, 1986; Mueter* et al.*, submitted)*
- In situ *ocean turbulence and larval foraging (Bailey and Macklin, 1994; Porter* et al.*, submitted)*
- *Ocean basin and shelf transport of heat, salts, nutrients and plankton (Reed, 2003; Mordy* et al.*, submitted)*
- *Horizontal separation of predator and prey (larvae) (Wespestad* et al.*, 2000)*
- *Transport of larvae to favorable habitat (Kendall and Schumacher, 1986; Wilderbuer* et al.*, 2002; Rosenkranz* et al.*, 2001).*

Ecosystem effects of shifts in climate are readily detected in the temporal and spatial distribution patterns of marine fish. Shifts in suitable habitats for fish directly influence predator prey overlap and thus the energy flow within the system. Similarly, shifts in fish distributions can influence bycatch rates by changing the likelihood that a species would be incidentally captured in a target fishery. Shifts in fish distributions can impact the accuracy of abundance estimates if survey grids do not encompass the geographic range of animals assessed. When fish move away from established shoreside processing plants, it impacts the cost of fishing and the expected revenues to coastal communities.

Recently, a new hypothesis (Oscillating Control Hypothesis) was presented to explain, in a mechanistic way, how climate, oscillating between "cold" and "warm" regimes, affects top trophic levels in the Bering Sea ecosystem (Hunt *et al*., 2002). The hypothesis (Fig. 4) predicts that in cold regimes, recruitment of pelagic fish such as pollock is limited by survival of larvae. During cold springs when ice covers the Bering Sea, there is a temporal mismatch between pollock larvae and their zooplankton prey reducing larval survival. In addition, the early phytoplankton bloom in large part is not consumed by zooplankton. It falls to the bottom, feeding the benthic food web. In warm regimes, there is a much better match between fish larvae and their preferred prey, and larval survival is enhanced. During warm regimes, the spring phytoplankton bloom occurs much later, after the water column becomes thermally stratified. In this case, a majority of the primary production is utilized in the water column, feeding the pelagic food web. After a few good warm years, the biomass of adult pollock and other piscivores increases. At some point, the large biomass of piscivores begins to inflict heavy mortality on juvenile fishes causing the critical period to switch to the juvenile stage. The system remains “locked” in this phase until the biomass of predators is reduced. It is possible to test parts of the Oscillating Control Hypothesis. If the hypothesis is valid, it will provide new predictive capability for some components of the ecosystem.

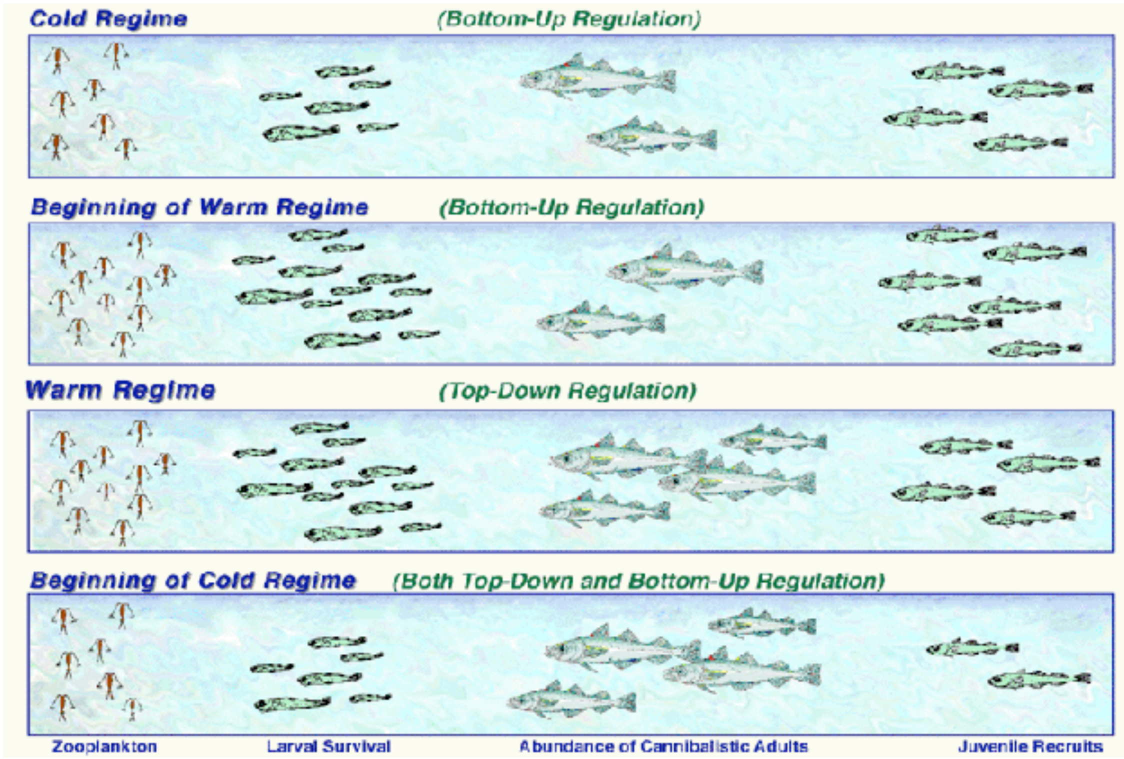

Fig. 4. The Oscillating Control Hypothesis relates climate regimes and their transitions to ecosystem productivity. [from Hunt *et al.*, 2002]

On a broader scale, it is still not understood why salmon production of the U.S. west coast and Alaska appear to be out of phase, and vary with the PDO. It may relate to the splitting of the West Wind Drift into the California Current and Alaska Current. The mechanisms of how this impacts the ecosystem are not understood and are just beginning to be examined as part of the North Pacific component of the U.S. Global Ecosystems Dynamics program (GLOBEC).

5.4.1. Regime shifts

In the last decade, evidence of associated decadal ecosystem variability has been documented for the NE Pacific (e.g., Brodeur and Ware, 1992; Mantua *et al.*, 1997; Brodeur *et al.*, 2000; Hare and Mantua, 2000; McGowan *et al.*, 1998; Mackas *et al.*, 2001). From phytoplankton (e.g., Sugimoto and Tadokoro, 1997; Venrick *et al.*, 1987) through zooplankton (Brodeur *et al.*, 2000; Sugimoto and Tadokoro, 1997; McGowan *et al.* 2003, Mackas *et al.*, 2004) to fish (Hare and Mantua, 2000; Hollowed *et al.*, 2001), there have been large changes in the Pacific marine ecosystem structure and function that are coincident with changes in the atmosphere. The exact time and nature of regime shifts (climatological or biological) are not always agreed upon. For example, within the NE Pacific, scientists have tentatively identified regime shifts occurring around 1978, 1987, and 1998 (PICES, 2004). Of these, the late 1970s shift was the largest and most often recognized.

In 1978, Unalaska/Dutch Harbor in the Aleutian Islands was the highest ranked fishing port in the nation because of the king crab fishery in the Bering Sea. At about the same time, there was a climate regime shift in the North Pacific from a cold to a warmer regime (King, 2005; Hare and Mantua, 2000). Sea ice intrusions into the eastern Bering Sea became less prevalent, the cold pool receded, and summer storms occurred less often. Species assemblages and abundances began to change, and by 1982, the king crab fishery had collapsed. A fishery on long-lived rockfish known as Pacific Ocean perch, which had already been hit hard by foreign fishing in the 1960s, continued to decline after 1977, reaching a minimum harvest in 1983 (NPFMC, 2004). The 1977 year class of walleye pollock recruited in exceptionally high numbers and continues to have enough good year classes to sustain the world's largest single-species commercial fishery. However, in the post-1977 regime, pollock stopped having high recruitment in the Gulf of Alaska (ca. 1981). Other groundfish species, for example, arrowtooth flounder (*Atheresthes stomias*), began to increase in the Gulf of Alaska and eventually were recognized as a major predator of pollock juveniles. The critical period for survival and recruitment in the Gulf of Alaska changed from the larval to the juvenile stage (Bailey, 2000).

The increase in predatory groundfish may also have resulted in a shortage of more nutritious forage fish for marine mammals and seabirds. Forced to feed on less nutritious food, many marine mammals and birds had poorer reproductive success, and their stocks went into decline (National Research Council, 1996). By 1990, Steller sea lions were placed on the threatened species list and the western population was listed as endangered in 1997. These listings have affected the fishing industry. Managers were required to balance between two potentially conflicting objectives: protecting and aiding the recovery of the Steller sea lion under the Endangered Species Act while at the same time providing for sustainable and economically viable fisheries under the Magnuson-Stevens Fishery Conservation and Management Act (MSA). This was, in effect, an ecosystem approach to management.

It is difficult to assess the economic impact of the regime shift of the late 1970s. As shrimp declined in the Gulf of Alaska, many fishers switched to the crab fishery. Then, as the Gulf of Alaska crab fishery declined, fishers migrated to the Bering Sea where larger boats were advantageous. As Gulf of Alaska and Bering Sea pollock increased and whiting decreased along the west coast, joint venture fishermen also migrated to the Bering Sea and joined others for midwater trawling of pollock (Gary Stauffer, AFSC, pers. comm.). Changes in target species involved changes in gear, types of fishing vessels, changes in processing and distance from homeports. With each change and the associated uncertainty, there were substantial economic costs.

Understanding and predicting ecosystem change at decadal time scales, then, is particularly important for industry and resource planning. Ecosystem forecasts will bring new efficiency to marine resource management and industry by anticipating changes in commercial fish populations and their interaction with threatened and endangered species.

5.5. ECOSYSTEM APPROACH TO MANAGEMENT

The North Pacific Fishery Management Council (NPFMC) is the principal management body for the study region. The council is adopting an ecosystem approach to management. The NPFMC is one of eight regional councils established by the Magnuson Fishery Conservation and Management Act in 1976 (now renamed the Magnuson-Stevens Fishery Conservation and Management Act) to oversee management of the nation's fisheries. With jurisdiction over the 900,000 square mile EEZ off Alaska, the Council has primary responsibility for groundfish management in the Gulf of Alaska and Bering Sea/Aleutian Islands, including cod, pollock, flatfish, mackerel, sablefish, and rockfish species harvested mainly by trawlers, hook and line longliners and pot fishermen. The Council also makes allocation and limited-entry decisions for halibut, though the US-Canada International Pacific Halibut Commission is responsible for conservation of halibut. Other large Alaska fisheries such as salmon, crab and herring are managed primarily by the Alaska Department of Fish and Game with Council oversight (for Bering Sea/Aleutian Island crab and Alaskan scallop).

Many council decisions are based on present and projected status of marine resources relative to an overall cap on fish removals. Status determinations can be improved by incorporating functional responses to ecosystem change into forecast models. Functional responses can include shifts in growth, reproduction or distribution of fish in response to changes in environmental conditions. Bycatch estimates can be improved by incorporating expectations of changes in the spatial and temporal distribution of target and non-target species under different climatic conditions. Whole ecosystem models can be used to forecast bottom-up impacts of shifts in climate on the overall productivity of the system. In the context of the National Environmental Protection Act, ecosystem status indicators are already used to define the significance of change and may alter management decisions, albeit in a more *ad hoc* fashion than those that are made with respect to single species reference points.

Application of prediction for ecosystem-based management is a developing science. Prediction can take one of two forms: qualitative and quantitative. Qualitative predictions can indicate trends (increasing or decreasing), status (healthy or stressed) or magnitude (high, medium, low). For the North Pacific, qualitative predictions and indicators of ecosystem status and trends are reported in the NPFMC annual Stock Assessment and Fishery Evaluation (SAFE) report's Ecosystem Considerations chapter and in the new PICES Report on Marine Ecosystems of the North Pacific. Although many of these indicators are not yet linked through stock assessments to single-species reference points, they presently serve as an early warning system for patterns of change and may aid in the development of ecosystem-level reference points.

Quantitative predictions can take one of three temporal forms: hindcasts (estimating what happened in the past), nowcasts (estimating the current state), and forecasts (predicting what will happen next year or during subsequent years). Mid-term and long-term predictions, even though very uncertain, are nevertheless important to managers for long-range contingency planning. Predictions of events or population levels often are made without estimates of precision or reliability. Some types of models (e.g., multi-species) may have such large confidence limits on their predictions of abundance that they may communicate a false sense of security (or doom) depending on the prediction and its impact on society. One useful approach (sometimes used in meteorology) entails Monte Carlo simulations based on the probability of a particular future regime. These and other methods can be used to generate probability distribution functions of model output.

5.5.1. Types of models

Below is a brief list of models that may be useful for now- and forecasts. These and others are depicted in Fig. 5. Forecast time horizons for different types of models are shown in Table 1.

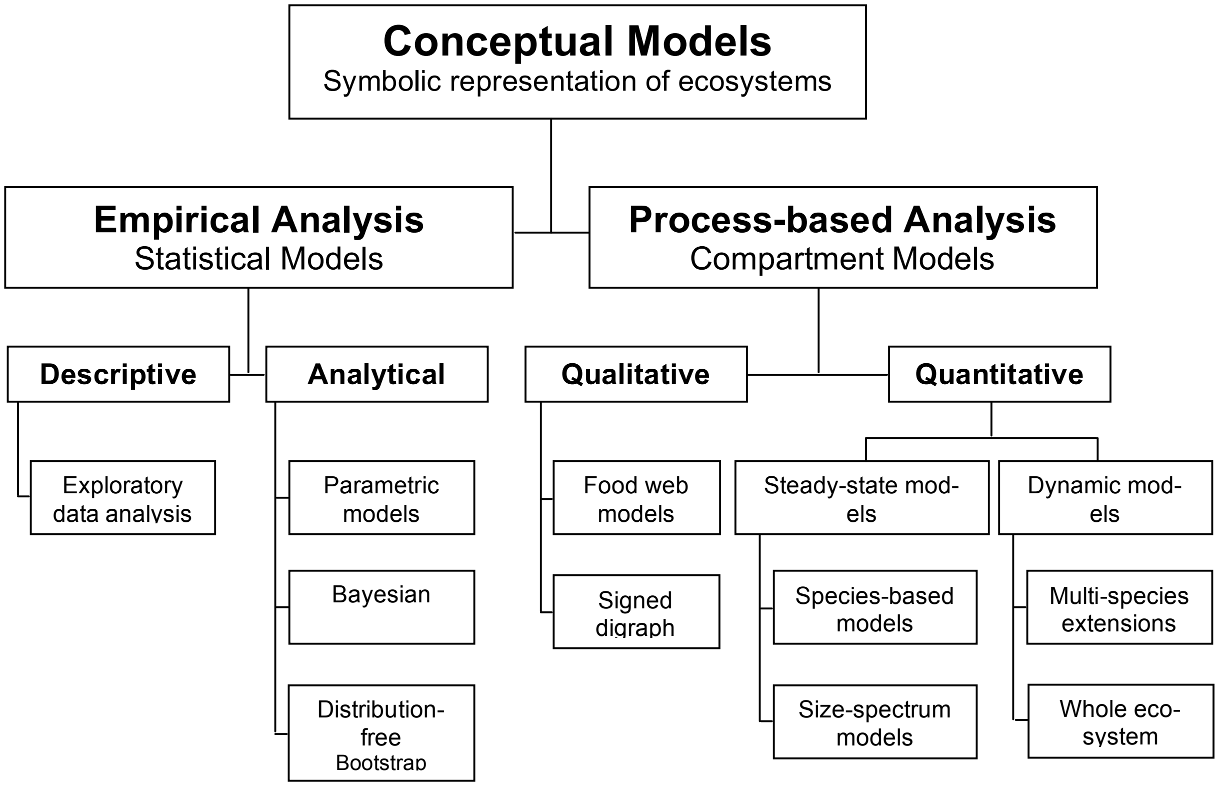

Fig. 5. Diagram of model classifications [from Whipple *et al*. 2000].

5.5.1.1 Statistical (heuristic) models

Econometric models and neural network (genetic algorithms) models that use long time series may be helpful within climate regimes as persistence is an important ecosystem attribute. The neural network approach is a form of pattern recognition; it finds repeating sequences of events in the data that can be used to predict a future outcome when that sequence is next observed. As mentioned above, this method is not robust in the face of dramatic change, for example, a climate regime shift.

Table 1. Forecast time horizons for different types of models.

	Short (1 yr)	Medium (2-5 yrs)	Long (>5 yrs)
Empirical	X		
Process		X	X
Food Web Dynamics		X	X
Single Species	X		

5.5.1.2 Process models

Process or mechanistic models are valuable tools in ecosystem and fisheries management. They provide a test of conceptual models, tell which variables are most important to measure, and provide quantitative predictions of abundance. Most assume bottom-up control of ecosystem processes, but they are not restricted to that assumption. One example is the biophysical Nutrient-Phytoplankton-Zooplankton (NPZ) models that are linked to Individual-Based Models (IBMs) of commercial populations (e.g., Hermann *et al.*, 2001; Hinckley *et al.*, 2001).

5.5.1.3 Multi-species ecosystem, food-web, mass-balance models

These models use functional guilds and size classes to define production and consumption (or growth) of populations in an ecosystem. They are most often employed to examine higher trophic levels within an ecosystem and can be driven by processes models (control from below) to calculate the amount of carbon (or number of animals) contained in a population of apex predators. The ECOPATH family of models is a good example of food-web modeling. They have been constructed and applied to resource use problems in the Bering Sea (Aydin 2002). They are also valuable in indicating gaps in knowledge.

5.5.1.4 Single-species models

Statistical age-structured models (SAMs) and IBMs are two examples of single-species models. SAMs can be run in hindcast mode or forecast mode. In hindcast mode, historical data on catch statistics, life history, and survey indices of abundance are combined to reconstruct the exploited population starting from the present and working back into time. Annual recruitment, spawning biomass, numbers-at-age, fishing mortalities by age and year and other biological parameters are typically estimated from the hindcast SAM using complicated statistical algorithms. In forecast mode, SAM results from the most recent year are used as a starting point to project or forecast the exploited population forward in time to explore the consequences of alternative assumptions, such as different harvest and recruitment scenarios or productivity regimes. IBMs are combinations of probabilistic and deterministic equations that predict the number of animals of particular age or stages resulting for a given set of growth and predation conditions. As mentioned above, one of the biggest challenges will be to incorporate environmental data into these models in a meaningful way.

5.5.1.5 Stock recruitment models

Stock recruitment (SR) models attempt to relate recruitment abundance to spawning biomass levels that gave rise to them. Empirical relationships between spawning stock and recruitment show extreme annual variability. Yet, it is clear that there must be some fundamental underlying relationship (i.e., there can be no recruits if there are no spawners), and there must be some limits on recruitment due to known limits imposed during early life history (i.e., food, spawning area, rearing areas, cannibalism). There is a long history of attempts to use SR models in fisheries science, and the basic models have remained unchanged since the 1950s. Work continues to explore the effects of density dependence, the influence of biological and environmental factors on recruitment and ways to construct meaningful management metrics and harvest guidelines from the basic data and estimated parameters.

5.5.1.6 Multispecies Models

Multispecies models (e.g., Livingston and Jurado-Molina, 2000) are a compromise between single-species models and ECOPATH-type, whole-system models. They include more than one species or functional group but, because they require a large number of parameters, cannot adequately represent the complexity and food web interconnections known to exist in real ecosystems. They also are a compromise between age or size structured and individual-based models. Multispecies models generally do not represent individuals. More often they are expressed in terms of some aggregate measure of productivity, including age or size classes, guilds, or population biomass. They do have the benefit of being able to incorporate aspects of species-species interactions (e.g., competition, predation, predator search time, suitability of each prey item to a predator, probability of capture, mutualism, and commensalism), the effect of the environment on carrying capacity and reproductive rate, and removals by a fishery.

5.6. Important Conceptual Knowledge Gaps

The panel on the next page lists key gaps in our knowledge of ecosystem structure and its response to climate change and variability. The questions were gathered from a special workshop in September 2004, as well as from general knowledge of research topics from the Bering Sea and Gulf of Alaska.

6. Goals, Outcomes, Performance Objectives and Strategies

NPCREP has two goals, presented below, that address its mission (sec. 3). Associated with each goal is a series of outcomes, performance objectives, performance measures and strategies. *Outcomes* describe the intended purpose of the collected efforts related to attaining each goal. *Performance objectives* present values or characteristics used to evaluate achievement of an outcome; they are supported by *performance measures*. Some specific performance objectives are in response to needs communicated to us by the NPFMC.[1] *Strategies* describe the action taken to accomplish a performance objective, and these strategies are further described by the activities that they encompass.

NOAA subscribes to five specific activities: monitor and observe; understand and describe; assess and predict; engage, advise and inform; and manage. All of NPCREP's outcomes are directed toward providing better management tools and more fully participating in the management process. However, the act or strategy of management lies outside of the scope of NPCREP. In the narrative to follow, rationale for each goal is presented with appropriate scientific questions addressing performance objectives. Finally, at the end of this section, the relationships between NPCREP goals, NOAA goals and goals of the U.S. Climate Change Science Program are discussed.

[1] D. Stram (NPFMC), personal communication

Knowledge Gaps

Nutrient supply

- *How do climate variations impact mixed layer concentrations of available nutrients on the* Bering Sea *and Gulf of Alaska continental shelves?*
- *How important are summer storms in providing critical nutrients to support production?*
- *What percentage of nutrients must be replenished each year on the SE* Bering Sea *shelf? How could climate variability affect that?*
- *Is the Gulf of Alaska shelf ecosystem dependent on interactions of topography and shelf currents for replenishment of nutrients each year? How could climate variability affect that?*

Primary production

- *Is phytoplankton growth limited by iron on either the Gulf of Alaska or eastern* Bering Sea *shelf?*
- *Does climate variability contribute to outbreaks of single species (e.g., coccolithophorids), and what is the impact of these outbreaks on other species?*
- *What factors set the amount of annual primary production?*

Secondary production

- *What environmental cues end diapause for large copepods? How does climate variability affect these?*
- *How do variations in climate affect the spatial and temporal patterns of distribution, abundance, and species composition?*

Early life history stages of commercial species

- *How do variations in climate affect the spatial and temporal overlap of these stages and their prey?*
- *How do variations in climate affect the physical structure of the water column? What changes have the highest impact on the feeding and survival of early life history stages?*
- *How do changes in climate affect the transport of these stages to their nursery areas?*
- *How do changes in climate affect the ability of surviving age-0s to accumulate enough fat to survive their first winter?*

Commercial and protected species

- *How do climate variations affect the availability of optimal habitat?*
- *How do climate variations affect the availability of prey resources?*

Ecosystem-level questions

- *Does the structure of some systems make them inherently more resistant or vulnerable to the effects of climate variability?*

6.1. GOAL TO OBSERVE, UNDERSTAND AND PREDICT

The first goal is to observe, understand and predict relationships between climate and ecosystems. Very few stock assessment/forecast models presently use environmental data to increase the accuracy of their predictions. Yet, populations are extremely sensitive to the environment around them and "unfavorable" conditions lead to poor recruitment, below average growth, or large changes in distribution. Development of robust models that utilize climate data to predict the status of a stock must be preceded by development of understanding of how climate variability affects population recruitment, production, and distribution.

Questions concerning the influence of climate-related factors on recruitment, production and distribution of fisheries:

- *How does climate affect ocean transport? How does climate-induced change in transport affect the delivery of nutrients, plankton, and larvae to critical production areas?*
- *How do changes in ocean temperature affect ecosystem structure?*
- *How does changing the timing of the spring and fall transitions affect the growth and survival of larvae?*
- *Will climate-dependent change in the mean extent and duration of sea ice cause expansions and contractions in the home ranges of species and constitute a selective pressure on the genome of species?*
- *How does the presence of sea ice affect the timing of phytoplankton blooms? How does the timing affect the rest of the ecosystem?*

Stock assessment scientists are developing spatially-explicit stock assessment models. Important elements in these models are the rules governing the movement of fish. Climate forcing determines environmental factors that govern the behavior of fish prey (invertebrates, forage, and juvenile fish) and thus affect the distribution of predators.

Questions about physical and lower-trophic-level processes that determine prey location and abundance:

- *Will changes in the timing and extent of ice create temporal or spatial mismatches of predators and prey during key life history stages (e.g., between larval fish and their zooplankton prey)?*
- *How would climate-mediated changes in temperature or the cold pool interact with landscape ecology to influence major predator-prey relations?*
- *How would the food webs of the southeastern Bering Sea and northern Gulf of Alaska change if subarctic species expanded their distributions northward and arctic species retreated?*

GOAL TO OBSERVE, UNDERSTAND AND PREDICT RELATIONSHIPS BETWEEN CLIMATE AND ECOSYSTEMS

OUTCOMES	PERFORMANCE OBJECTIVES
A foundation of observations and experiment results yielding an understanding of processes that relate climate variability to ecosystem change. This understanding, in turn, brings development of predictive skills.	• Determine climate-related factors influencing recruitment, production and distribution of fisheries. (*Performance measure:* number of factors identified) • Determine and provide physical and lower-trophic-level forcing factors that are determinants of prey locations and abundance. (*Performance measure:* number of factors identified)

Strategies

- Design and implement a climate and ecosystem observation system (EOS). (*Activities:* monitor and observe)
- Conduct experiments to understand climate-ecosystem processes. (*Activities:* understand and describe)
- Analyze and synthesize the EOS and historical data. (*Activities:* understand and describe)
- Develop and utilize biophysical and other models to describe ecosystem function and response to climate. (*Activities:* assess and predict)

6.2. GOAL TO AID PROTECTION AND MANAGEMENT OF MARINE RESOURCES

The second goal is to aid protection and management of marine resources.

NPCREP asked representatives of the NPFMC to state specific needs relating to climate-induced change in ecosystems. The following responses reflect the Council's need for a process to assimilate and streamline use of climate and ecological indices in management decisions, for unbiased estimates of the abundance of fish and marine mammals, for accurate predictions of recruitment and growth, for predicting ecosystem reorganization in response to changing climate and for managing bycatch.

Each year, AFSC and PMEL scientists communicate to the NPFMC information on ecosystem status and trends. This information is contained in the Ecosystem Considerations chapter (e.g., Boldt, 2004) of the SAFE report for the Bering Sea/Aleutian Islands and Gulf of Alaska groundfish. Advice in the chapter helps managers track long- and short-term environmental change for stewardship of living marine resources. The Council has requested assistance in interpretation, consolidation, and assimilation of this information. NPCREP will provide the research to bridge this information into the stock assessment process. In the near term, efforts will focus on improving our understanding of climate impacts on shifts in predation mortality, annual reproductive success, growth and distribution of living marine resources. Once linkages are established on a single-species basis, the information will be incorporated into whole ecosystem models.

> ***How can NPCREP help the NPFMC understand the significance of climate and ecosystem trends?***
> - *What analytical or statistical techniques are available to distill the large amount of information available in the Ecosystem Considerations chapter?*
> - *What graphical/visual techniques are available to help summarize the data contained in the Ecosystem Considerations chapter?*
> - *Can an objective process be designed that will arrive at conclusions based on the synthesis of information in the Ecosystem Considerations chapter?*

Under the MSA, one of the overarching goals of fishery managers is to achieve optimum yields (OY) from each fishery. The definition of OY now includes the protection of marine ecosystems and considers maximum sustainable yields as reduced by any relevant economic, social or ecological factors.

> ***How does climate variability affect Optimum Yield?***
> - *What OY modifying factors does climate variability impact (e.g., predator/prey relationships, competitive interactions, habitat suitability)? Are some more important than others?*
> - *For each managed species, how does climate affect the OY quantitatively, or how should climate-related environmental conditions be considered as modifying factors for the OY?*

Current management plans for the Bering Sea/Aleutian Islands and Gulf of Alaska groundfish use OY range limits that were established with simple, single-species considerations. Both the NPFMC Scientific and Statistical Committee and Advisory Panel have recommended that these OY ranges be re-evaluated using an ecosystem/multi-species approach. The goal is to define targets and limits for aggregate or ecosystem-level indicators.

> ***How does climate variability affect ecosystem reference points?***
> - *How does climate affect the range limits of single species through bottom-up ecosystem interactions?*

The maximum amount of commercial fish that safely can be removed from a system depends on many variables related to the status and trends of individual species. For example, the biomass of pollock available for harvest may be related to their interactions with other (prey) species such as zooplankton and salmon smolts whose production is affected by climate. Thus, interactions among species are important factors in determining ecosystem thresholds.

How does climate modify ecosystem thresholds for species interactions?

- *How does climate affect the level of forage fish abundance at which predators shift from one forage species to another or become cannibalistic?*
- *How does climate affect the level of prey and predator abundance at which ecosystem control shifts from bottom up to top down?*
- *How does climate affect the level of zooplankton abundance at which fish shift from planktivory to piscivory?*

GOAL TO AID PROTECTION AND MANAGEMENT OF MARINE RESOURCES

OUTCOMES	PERFORMANCE OBJECTIVES
Improved management of marine resources from supplying the NPFMC with the immediate tools needed for pursuing an ecosystem approach to management	• Help NPFMC understand the significance of climate and ecosystem trends. (*Performance measure:* number of tools and techniques) • Determine how climate variability affects Optimum Yield. (*Performance measure:* number of factors for each managed species) • Determine how climate variability impacts ecosystem-level reference points. (*Performance measure:* number of OY range limits modified for ecosystem processes) • Determine how climate modifies ecosystem thresholds for species interactions. (*Performance measure:* number of ecosystem thresholds determined)

Strategies

- Disseminate real-time data from the observational network. (*Activities:* engage, advise and inform)
- Provide climate websites and other links to stakeholders. (*Activities:* engage, advise and inform)
- Develop forecasting tools with resource managers, enabling them to consider ecosystem response to climate change in their decisions (*Activities:* assess and predict).
- Publish annual assessments and advisories, as needed, of climate and ecosystem status. (*Activities:* engage, advise and inform)

6.3. RELATIONSHIP TO NOAA'S AND OTHER NATIONAL GOALS

NPCREP will address two of NOAA's Strategic goals for the period FY 2005-2010:

- Understand climate variability and change to enhance society's ability to plan and respond.
- Protect, restore, and manage coastal and ocean resources through an ecosystem approach to management.

These goals also are represented in the U.S. Climate Change Science Program's strategic goals and objectives:

- Enhance society's ability to plan and respond to climate–induced ecosystem change by understanding the sensitivity and adaptability of different ecosystems to climate.
- Increase the number and accuracy of forecasts of significant ecological events and trends.
- Support and facilitate NOAA's ecosystem approach to management.

7. IMPLEMENTATION ACTIVITIES

NPCREP is a matrix-managed program serving NOAA's Climate Goal Team and NOAA's Ecosystems Goal Team. The program's activities are a hybrid of the activities from the NOAA strategic plan: 1) monitor and observe the land, sea and atmosphere to create an observational and data collection network that tracks North Pacific climate variability and ecosystem response; 2) understand and describe how climate affects ecosystems through investigation and interpretation of information; 3) assess and predict the climate-induced changes of ecosystems and provide information about the future; 4) engage, advise and inform North Pacific ecosystem stakeholders to facilitate information flow, assure coordination and cooperation, and provide assistance in the use, evaluation and application of information about climate regimes and ecosystem productivity; and 5) contribute indirectly and directly to management of marine species by providing information to NOAA Fisheries and the NPFMC (NPCREP has no mandated management responsibilities of its own).

At present, NPCREP is a small program ($1.5M per year), and is highly dependent on leveraging from other regional research efforts to fulfill its initial goals.

- *Fisheries-Oceanography Coordinated Investigations (FOCI; NOAA)*
- *Fisheries and the Environment/Ecosystems Indicators (FATE; NOAA)*
- *Bering Sea Ecosystem Study (BEST; NSF)*
- *Global Ecosystem Dynamics (GLOBEC; NSF & NOAA)*
- *Study of Environmental Arctic Change (SEARCH; multi-agency)*
- *North Pacific Research Board (NPRB)*
- *Gulf Ecosystem Monitoring (GEM;* Exxon Valdez *Oil Spill Trustee Council)*
- *Alaska Ocean Observing System (AOOS)*

NPCREP's program of research is designed to be scalable to accommodate varied levels of funding and completeness of attaining its goals. Overall scalability is discussed later in this section. Initially the program will be predominantly in the Bering Sea where the climate signal is most pronounced and marine resources most plentiful. A small fraction of the program research will be in the northern Gulf of Alaska due to the strength of past research (e.g., Stabeno *et al*., 2004; Kendall *et al*., 1996), and to continue critical long-term time series that already exist there. These long physical and biological time series enable us to determine climate affects that are weaker than in the Bering Sea. Details of programmatic leverage and cooperation are presented at the end of the section.

7.1. MONITOR AND OBSERVE

Monitoring of climate, upper ocean physics and biology is an essential element of any program that seeks to develop quantitative predictions. It is necessary for both the development of conceptual models and the actual predictions themselves (Fig. 6). A well-designed system of measurements, which are consistent from year-to-year, will form the backbone of the NPCREP observing network. The system needs to be both stable to produce a consistent product over the years, yet flexible to respond quickly to shifts in climate (e. g., PDO, ENSO, AO). Major tasks to initialize the observation system are:

- Identify and prioritize the information needed to meet the goals of the program.
- Create a relational database that permits retrospective investigations and assists in designing observing networks
- Identify the models needed to assist in the design of observing networks.
- Prioritize areas of focus and data to be collected.
- Using the first four items, design and implement the observing systems.
- Disseminate data using database and web pages.
- Evaluate changing conditions and adjust observing systems appropriately.

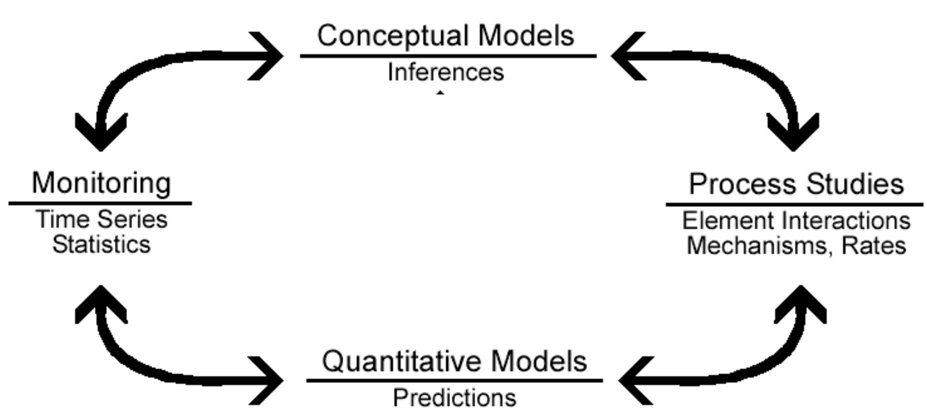

Fig. 6. Flow of information for understanding and predicting climate-forced ecosystem processes.

To successfully monitor and observe an ecosystem, data collection systems must be carefully designed. Because NPCREP will study both stationary and moving targets, four different observational components are necessary:

- Moored biophysical platforms using existing and new *in situ* sensors.
- Autonomous drifting buoys and gliders.
- Surveys of ocean, atmosphere, plankton, fish, birds, and mammals from ships and aircraft.
- Satellite remote sensing tools (existing and new).

7.2. UNDERSTAND AND DESCRIBE

Precise, robust predictions require comprehension of the processes that produce the outcomes we wish to predict. Understanding is an integral part of the process that leads to quantitative models (Fig. 6).

A current misconception in the area of prediction is that understanding is not necessary. Nature has not provided a small number of deterministic processes of limited stable states, nor have all possible states been observed in the past. Ecological processes are complex, and recruitment of individual populations comprises combinations of deterministic and stochastic processes, each with a different intrinsic period (e.g., Bailey, 2003; Ciannelli *et al.*, 2004; Duffy-Anderson *et al.*, in press). Thus, predictions achieved by correlation between the result and primary functions usually fail once some piece of the mechanism changes in response to climate or in response to a re-organization of the ecosystem structure. Efforts to increase our mechanistic understanding of ecosystem processes are essential to programs that will establish the linkages between climate regimes and ecosystem productivity.

NPCREP will conduct research to understand: 1) the functioning of coastal and ocean ecosystems, including the ecological and biological population aspects of living marine resources (commercial and protected species) and 2) the dynamics and impacts of climate on coupled ocean/atmosphere ecosystems.

7.3. ASSESS AND PREDICT

NPCREP, through the delivery of new decision-support tools, will support the NPFMC as it develops an ecosystem approach to management. There is presently need for a prediction of ecosystem "shape" or status to support broad-based resource decisions, and there is also need for improved single-species predictions that incorporate environmental variables. The decision support tools that NPCREP is able to develop and apply will be a direct result of investment in monitoring and understanding.

NPCREP will implement projects to generate two types of predictive tools: 1) qualitative tools that yield a prediction of the trend or state and are used as stand-alone metrics or in combination with other metrics, and 2) quantitative tools that yield a numerical, categorical, or ordinal prediction of the abundance of a species. Examples of qualitative tools are the metrics and indices used in the Ecosystem Considerations chapter of the SAFE reports. These are used by themselves or in combination to give a general picture of what is happening (or may happen) in the ecosystem. Examples of quantitative tools are models that provide quantitative prediction of populations or vital rates and events of populations. Examples of these are single-species, multispecies and ecosystem analyses that predict the number or biomass of fish available for harvest and the Fisheries-Oceanography Coordinated Investigations (FOCI) recruitment forecast that uses environmental indicators and the strength of the current year class of Gulf of Alaska pollock to predict the abundance of two-year-old recruits.

The NPFMC and its Plan Teams currently consider ecosystem processes as they develop an ecosystem-based approach to management. However, there are a very large number of indices reported in both the Ecosystems Considerations chapter and the PICES Report on Marine Ecosystems of the North Pacific (North Pacific Marine Science Organization, 2004). The fundamental challenge is to arrive at a small set of simple indices that are meaningful. What resource managers have requested is an objective way to decrease the number of indices considered, and to summarize their predicted effect. One summary method that will be tested and implemented by NPCREP is the stoplight technique shown below (Fig. 7). The technique provides a strong visual representation to the viewer and incorporates an "answer," the combined indices. Color-coded approaches to communicate ecosystem status to managers are being used in Canada. It is challenging, however, to assign colors to different outcomes of each index. For example, what color or attribute is assigned to a positive PDO or negative AO? These are just some of the challenges.

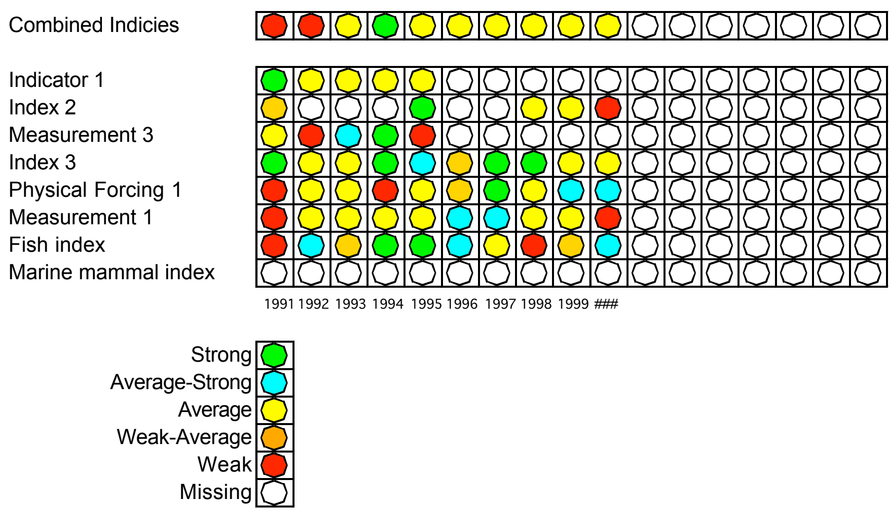

Fig. 7. The "stoplight" model of ecosystem status permits simple understanding and grasp of indicial information.

This technique provides an early indicator of change but does not provide managers with advice on what actions, if any, they should consider to change the ecosystem condition. Managers need two types of information, long-term (~10-yr) forecasts to warn stakeholders of expected change and short-term forecasts of expected changes that could be altered by management decisions. Thus, forecast methods must be established to provide managers with the tools necessary to form precautionary advice.

Another useful way to depict indices to managers is to construct a matrix (Table 2) of environmental factors (rows) and their effects on different species (columns). Rows would include present stock assessment of each species. Columns could include ecosystem-level properties like the ones shown in the table or "biomass of pelagics", "primary production", and "biomass of piscivorous fishes". This decision-based tool would provide managers with a way to look at the big picture. Note that this can also be used as an information-needs matrix to indicate what is least reliably known for the ecosystem.

Table 2. Hypothetical management matrix of environmental factors (rows) and their effects on different species (columns) for the Bering Sea.

		Species Biomass Response		
Environmental Factor	Tendency	Zooplankton	Snow crab	Fur seals
Ocean Temperature	Warm	+	-	-
	Cool	-	+	+
Wind Mixing	Less	-	-	?
	More	+	+	?
Timing of Spring Bloom	Early	-	+	?
	Late	+	-	?

Existing and emerging numerical models will be the basis for NPCREP's quantitative prediction. Although empirical models are attractive for their simplicity and expediency, these statistical models typically fail with time when new data are available or the climate and ecosystem enter a new regime or phase. For this reason, we prefer to concentrate on dynamic models that incorporate processes.

The greatest challenge today is how to incorporate ecosystem information into quantitative models that predict species abundance. This is a necessary first step for ecosystem-based management. Note that NPCREP will not develop climate models. The approach is to:

- Develop and implement models that incorporate climate/environmental forcing to nowcast population abundance of commercial and protected species.
- Incorporate estimates of reliability (including precision) in model predictions.
- Develop and implement models as tools to investigate the impacts of plausible climate scenarios on ecosystems.

Developing decision support tools that incorporate probabilistic statements of the likelihood of outcome are a goal of NPCREP. Recently, there has been a movement towards using Bayesian approaches in fisheries. There is merit to predicting on a qualitative (as opposed to quantitative) scale; these are still based on probability theory, hence quite valid.

7.4. ENGAGE, ADVISE AND INFORM

These activities will be the litmus test of NPCREP's commitment to end-to-end products for its stakeholders. Primary stakeholders are the NPFMC, the U.S. Integrated Ocean Observing System and the general public. NPCREP must remain responsive to operational needs of stakeholders. Staying engaged will allow incorporation of fresh ideas, as well as dissemination of results to the correct audience at the right time. NPCREP has a unique opportunity to support North Pacific and Bering Sea fisheries management by focusing advice primarily on the status and projection of the climate/ecosystem state for the multi-year time scale. Addressing this large-scale question will produce preliminary information that influences many of the NPFMC's detailed management decisions. Last, NPCREP is uniquely positioned to inform our stakeholders. NOAA possesses a wealth of climate and ecosystem data, as well as the tools to make data products easily accessible to the public using the Internet.

- Develop real-time reporting for some components of the observing system.
- Develop effective means of two-way communication with the NPFMC and its Plan Teams.
- Develop effective means of web-based communication with general stakeholders.
- Take an active role in the annual preparation of data and syntheses for the Ecosystem Considerations chapter of the SAFE report and the PICES report.
- Develop techniques for rapid updates and analyses of the state of the North Pacific and Bering Sea ecosystems.
- Streamline the process of assimilating ecological information into the management process.
- Publish periodic assessments and forecasts of climate and ecosystem status.

A stated goal of NPCREP is to inform stakeholders to enhance their ability to respond to climate variability. Strategies to attain this goal are primarily accomplished using passive and active information delivery techniques on the Internet.

- Disseminate real-time data from the observational network.
- Provide regular input to marine resource managers, native communities, shipping industry, and other stakeholders.

7.5. SCALABILITY

Table 3 indicates the current level of effort for NPCREP. This program is scalable by ecosystem, i.e. research can be focused on multiple LMEs or restricted to a single LME or a sub-part of an LME. We have learned that it is not sufficient to manage fisheries by single-species assessments and predictions in an ecosystem approach to management (Sainsbury *et al.*, 2000; Witherell *et al.*, 2000). We know intuitively that an ecosystem cannot be fully understood by observing and analyzing only part of it. It may hold, as well, that ecosystems themselves are interrelated, and that studying a single ecosystem within a region provides insufficient information to characterize and predict the effects of climate change on the whole region.

For these reasons, we suggest a level of effort (Table 4) that may be scaled to observation, analysis and prediction within regions of North Pacific Ocean ecosystems: eastern Bering Sea, northwestern Gulf of Alaska and eastern Aleutian Islands, listed in order of their fisheries economic value (Hiatt *et al.*, 2004). The most conservative effort would focus almost exclusively on the eastern Bering Sea shelf. With additional funds, the other ecosystems would be added, so that at the highest effort, all three ecosystems, and their interrelationships, would be targeted. For this planning document, we developed timelines and metrics assuming the highest level of effort, i.e., research all three ecosystems. It is important to conduct work in all three systems, as prior research has shown that the three are biologically and hydrographically interconnected (Schumacher *et al.*, 1982; Loughlin and Ohtani, 1999). Simultaneous work in all three systems will further elucidate the interrelationships and interdependencies that each system has on the other, and will ensure that the propagation of climate effects between ecosystems is examined.

Table 3. Current level of effort in terms of strategies and activities.

Strategy	Activity	Current (FY 2005) Level of Effort $1.2 M and 30[2] ship days Bering Sea
Monitor and observe	Ecosystem monitoring network	• Biophysical platforms: 2 • Drifters: 25 satellite-tracked drifters • Ship surveys: two biophysical cruises • Remote sensing: selected images of ocean color and temperature • Support predator/prey collections and analyses
Understand and describe	Retrospective and process studies	• Two retrospective studies, two process studies
	Biophysical models	• Develop conceptual models • Develop ocean circulation model
Assess and predict	Ecological forecasting	• Develop objective techniques to streamline ecological index reporting and use • Incorporate climate data into single-species and ecosystem assessment models
Engage, advise and inform	Web sites and publishing	• Establish liaison and dialogue with NPFMC • Disseminate regional data and ecosystem assessments • Enhance Bering Climate web page • Establish NPCREP web page

8. DELIVERABLES

NPCREP will supply the following products for NOAA and public use:

- Ecosystem monitoring network
- Real-time dissemination of data through the Internet
- Analyses and results from network observations, retrospective and process studies
- Ecosystem dynamics models
- Assessments and forecasts of ecosystem status

8.1. TIMELINE

This section will be developed following initial review of this plan.

9. PROGRAM STRUCTURE

The NPCREP program will borrow from proven administrative structures that have fostered successful outcomes for other NOAA and joint NOAA-academia research programs (Macklin, 1999; Macklin *et al.*, 2002). The objective is to provide scientific leadership with focus and

[2] 30 sea-day contribution from OAR augments sea days shared with NOAA/FOCI. NOAA presently allocates no sea days to NPCREP.

flexibility, responsiveness to stakeholders' needs, rapid dissemination of information, and a legacy network and data archive.

Table 4. Scales of effort to implement NPCREP.

Strategy	Activity	Level of Effort		
		$3 M and 90 ship days	$6 M and 150 ship days	$10 M and 200 ship days
		Geographic Region		
		BS	BS and GoA	BS, AI and GoA
Monitor and observe	Ecosystem monitoring network	• Biophysical platforms: 5, real-time data dissemination • Drifters: 3 ARGO floats, 1 glider and 25 satellite-tracked drifters • Ship surveys: two biophysical cruises; one zoo/ichthyoplankton survey; one age-0 juvenile fish, marine mammal, and seabird survey • Observations of plankton and benthic prey, and predator/prey interactions during the main feeding season • Remote sensing: selected images of ocean color and temperature for selected regions	• Biophysical platforms: 8 incorporating new sensor technology, real-time data dissemination • Drifters: 5 ARGO floats, 2 gliders and 40 satellite-tracked drifters • Ship surveys: three biophysical cruises; two zoo/ichthyoplankton surveys; two age-0 juvenile fish, marine mammal, and seabird surveys • Observations of plankton and benthic prey, and predator/prey interactions during the main feeding and other seasons • Remote sensing: selected images and monthly summaries of ocean color and temperature	• Biophysical platforms: 15 incorporating new sensor technology, real-time data dissemination • Drifters: 10 ARGO floats, 3 gliders and 50 satellite-tracked drifters • Ship surveys: four biophysical cruises; three zoo/ichthyoplankton surveys; three age-0 juvenile fish, marine mammal, and seabird surveys; three forage fish surveys • Observations of plankton and benthic prey, and predator/prey interactions during all seasons • Remote sensing: selected images of ocean color and temperature for selected regions
Understand and describe	Retrospective and process studies	• Highest ranked retrospective study, two highest ranked process studies, and one dedicated cruise	• Two highest ranked retrospective studies, three highest ranked process studies, and two dedicated cruises	• Three highest ranked retrospective studies, four highest ranked process studies, and three dedicated cruises
	Biophysical models	• Develop conceptual models • Develop and couple models (ocean circulation, NPZ, upper trophic level)	• Develop conceptual models • Develop and couple models (ocean circulation, NPZ, upper trophic level)	• Develop conceptual models • Develop and couple models (ocean circulation, NPZ, upper trophic level)
Assess and predict	Ecological forecasting	• Single, integrated, forecast model for SE Bering with reliable predictive capability in 9 years	• Two alternative forecast models with enhanced predictive capability for the SE Bering and W GoA (7 years)	• Multiple forecast approaches; enhanced predictive capabilities for the SE Bering, W GoA, and Aleutians (5 years)
Engage, advise and inform	Web sites and publishing	• Conduct regional needs assessment • Disseminate regional data and ecosystem assessments	• Conduct regional needs assessment • Disseminate regional data and ecosystem assessments	• Conduct regional needs assessment • Disseminate regional data and ecosystem assessments

9.1. MANAGEMENT

The program will be managed by a team consisting of a senior scientist from each of the primary research institutions involved in NPCREP. This will include, at least, a scientist from the NOAA Fisheries' Alaska Fisheries Science Center and a scientist from NOAA Research's Pacific Marine Environmental Laboratory. Academic leaders, e.g., from the University of Alaska, will be involved, as well. A program coordinator will assist program managers with communications, planning, and execution.

9.2. ADVISORY BOARD

An advisory board of extra-program stakeholders, NOAA Climate Team and Line Office representatives, and scientists will provide guidance to program managers. Principal guidance will be in developing and modifying scientific teams, objectives and deliverables. The advisory board would perform periodic critiques of the program.

9.3. SCIENCE COUNCIL

A science council will be formed from senior program scientists and managers. The science council will provide a forum for scientific discipline representation, operational planning, and information synthesis.

9.4. DATA MANAGEMENT

Data from NPCREP's monitoring network, retrospective and process studies, and modeling endeavors are recognized as one of the program's most important assets. Accordingly, all program participants will enter into a data agreement to insure data quality, delivery, and accessibility. A data manager will enforce the program's data policy, provide program and public access to real-time information, archive program data, and cooperate with regional, national, and international ocean observing systems.

9.5. INFORMATION TRANSFER

The program will maintain intranet and Internet web sites for documentation and transfer of information to program personnel and to stakeholders. All data will include necessary thematic, semantic and syntactic descriptors for cataloging in the North Pacific Ecosystem Metadatabase and dissemination to the Global Ocean Observing System.

10. RELATIONSHIP TO OTHER PROGRAMS

NPCREP builds on the award-winning, internationally recognized FOCI program, an early example of successful, cross-Line-Organization, cooperative, applied research. NPCREP's goals complement the NOAA program "Fisheries and the Environment" that funds research linking ecosystem indicators to stock assessment advice. Additional bases for NPCREP are other nationally and internationally recognized programs within the AFSC. NPCREP will leverage information from a number of regional, national, and international programs. These include NOAA Fisheries stock assessment surveys, Hokkaido University Faculty of Fisheries research programs in the Gulf of Alaska and Bering Sea, ongoing research by the North Pacific Research Board and the *Exxon Valdez* Oil Spill Trust Council's Gulf Ecosystem Monitoring and Research program, Alaska Department of Fish and Game's salmon program, University of Alaska Institute of Marine Science, and NASA remote sensing products division. Through its development and installation of regional ecosystem monitoring networks, NPCREP will contribute to Alaska, US, and global ocean observing systems. NPCREP will work closely with the North Pacific Marine Science Organization (PICES) in assessing the status of North Pacific regional ecosystems. This program will have strong ties to the National Science Foundation's developing Bering Sea Ecosystem Study (BEST).

11. NATIONAL IMPLEMENTATION

NPCREP has been designed as the first of six regional NOAA Climate and Ecosystem programs for the nation. The regions are: 1) Gulf of Alaska and Bering Sea/Aleutian Islands, 2) Northwest Atlantic (New England), 3) Eastern North Pacific (California Current), 4) Northwest Atlantic (Southeast U.S.), 5) Pacific Islands, and 6) Gulf of Mexico. Each regional program will address NOAA's strategic goals and the needs of the nation in its geographic domain. Regional programs are to be brought online every two years with full implementation of each program within four years of initiation. A science plan will be submitted the year before implementation begins. A national Executive Council consisting of representatives from each region, plus a representative from the Climate Board and each contributing Line Organization will guide the national implementation. Also at the national level, serving the Executive Council, will be a Scientific Steering Committee, a Data/Information Management Working Group and a Policy Implementation Working Group. Each working group will consist of equal representation from each of the regions.

12. REFERENCES

Anderson, P.J., and J.F. Piatt, 1999: Community reorganization in the Gulf of Alaska following ocean climate regime shift. *Mar. Ecol. Prog. Ser. 189*, 117-123.

Anon, 2004: Impacts of a Warming Arctic: Arctic Climate Impact Assessment. ACIA Overview report, Cambridge University Press, http://www.acia.uaf.edu/.

Aydin, K., 2002: The Eastern Bering Sea, pp. 33-38. In: The use of ecosystem models to investigate multispecies management strategies for capture fisheries, Pitcher, T. and Cochrane, K (eds.) *Fish. Cent. Res. Rep. 10*.

Baier, C.T., and J.M. Napp, 2003. Climate-induced variability in *Calanus marshallae* populations. *Journal of Plankton Research 25*, 771-782.

Bailey, K.M., and S.A. Macklin, 1994: Analysis of patterns in larval walleye pollock *Theragra chalcogramma* survival and wind mixing events in Shelikof Strait, Gulf of Alaska. *Marine Ecology Progress Series, 113*, 1-12.

Bailey, K.M., A.B. Hollowed, and W.S. Wooster, 2004: Complexity of marine fisheries dynamics and climate interactions in the northeast Pacific Ocean. In: Marine Ecosystems and Climate Variation. The North Atlantic. A Comparative Perspective (N.C. Stenseth, G. Ottersen, J. Hurrell, and A. Belgrano, eds.), Oxford Press, pp. 147-151.

Bailey, K.M., L. Ciannelli, and V. Agostini, 2003: Complexity and constraints combined in simple models of recruitment. In: The Big Fish Bang. Proceedings of the 26th Annual Larval Fish Conference, Browman, H. and A. Skiftesvik (eds.), Institute of Marine Research, Bergen, Norway, 293-301.

Boldt, J. (Ed.), 2004: Ecosystems Considerations for 2005: In: 2004 North Pacific Fishery Stock Assessments and Fishery Evaluation reports, NMFS/AFSC, Seattle, WA, 98115-6349, http://www.afsc.noaa.gov/refm/stocks/assessments.htm.

Brodeur, R.D., and D.M Ware, 1992: Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. *Fisheries Oceanography 1*, 32-38.

Brodeur, R.D., C.E. Mills, J.E. Overland, G.E. Walters, and J.D. Schumacher, 2000: Evidence for a substantial increase in gelatinous zooplankton in the Bering Sea with possible links to climate change. *Fisheries Oceanography 8*, 296-306.

Ciannelli, L., and K.M. Bailey, 2005: Landscape dynamics and resulting species interactions: the cod-capelin system in the southeastern Bering Sea. *Mar. Ecol.-Prog. Ser., 291*, 227–236.

Ciannelli, L., K.-S. Chan, K.M. Bailey, and N.C. Stenseth, 2004: Non-additive effects of environmental variables on the density-dependent recruitment of a large marine fish population. *Ecology 85* (12), 3418-3427.

Coyle, K.O, and A.I. Pinchuk, 2002: Climate-related differences in zooplankton density and growth on the inner shelf of the southeast Bering Sea. *Progress in Oceanography 55*, 177-194.

Duffy-Anderson, J.T., K.M. Bailey, L. Ciannelli, P. Cury, A. Belgrano and N.C. Stenseth, 2005: Phase transitions in marine fish recruitment processes. *Ecological Complexity, 2*, 205–218.

Global Learning Resource Network, 2004: Global Change. Iowa State University, http://www.iitap.iastate.edu/gccourse/model/basic/images/text2.html.

Hare, S.R., and N.J. Mantua, 2000: Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Progress in Oceanography 47*, 103-146.

Hermann, A.J., S. Hinckley, B.A Megrey and J.M. Napp, 2001: Applied and theoretical considerations for constructing spatially explicit Individual-Based Models of marine larval fish that include multiple trophic levels. *ICES J. Mar. Sci. 58*: 1030-1041.

Hiatt, T., R. Felthoven, C. Seung and J. Terry, 2004: Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Island area: Economic status of the groundfish fisheries off Alaska, 2003. NMFS/AFSC, http://www.afsc.noaa.gov/refm/docs/2004/Economic.pdf, December 2004.

Hinckley, S., A.J. Hermann, K.L. Mier, and B.A. Megrey, 2001: Importance of spawning location and timing to successful transport to nursery areas: a simulation study of Gulf of Alaska walleye pollock. *ICES J. Mar. Sci. 58*, 1042-1052.

Hollowed, A.B., and W.S. Wooster, 1995: Decadal-scale variations in the eastern subarctic Pacific. II. Response of Northeast Pacific fish stocks. *Can. Spec. Publ. Fish. Aquat. Sci. 121*, 373-385.

Hollowed, A.B., S.R. Hare, and W.S. Wooster, 2001: Pacific basin climate variability and patterns of northeast Pacific marine fish production. *Progress in Oceanography 49*, 257-282.

Hunt, G.L., Jr., P.J. Stabeno, G.E. Walters, E.H. Sinclair, R.D. Brodeur, J.M. Napp, and N.A. Bond, 2002: Climate change and control of the southeastern Bering Sea pelagic ecosystem. *Deep-Sea Research II 49*, 5821-5853.

Incze, L.S., and J.D. Schumacher, 1986: Variability in the environment and selected fisheries resources of the Eastern Bering Sea ecosystem, pp. 109-143. In: Sherman, K. and L.M. Alexander (Eds.) Variability and Management of Large Marine Ecosystems. AAAS Selected Symposium 99

Jurado-Molina, J., and P.A. Livingston, 2002: Climate-forcing effects on trophically linked groundfish populations: implications for fisheries management. *Can. J. Fish. Aquat. Sci. 59*, 1941-1951.

Kendall, A.W., Jr., J.D. Schumacher, and S. Kim, 1996: Walleye pollock recruitment in Shelikof Strait: applied fisheries oceanography. *Fisheries Oceanography 5* (Supplement 1), pp. 4-18.

Kendall, A.W., Jr., R.I. Perry, and S. Kim, 1996: Fisheries oceanography of walleye pollock in Shelikof Strait, Alaska. *Fisheries Oceanography 5*, Supplement 1, 203 pp.

King, J.R. (Ed.), 2005. Report of the Study Group on Fisheries and Ecosystem Responses to Recent Regime Shifts. PICES Scientific Report No. 28, 162 pp., http://www.pices.int/publications/scientific_reports/default.aspx.

Kruse, G.H., F. C. Funk, and J. Zheng, 1996: Were Alaskan Red King Crabs overfished, pp295-299. In: High Latitude Crabs: Biology, Management, and Economics, Alaska Sea Grant College Program AK-SG-96-02.

Livingston, P.A., L.L. Low and R.J. Marasco, 1999: Eastern Bering Sea ecosystem trends, pp. 140 - 162. In: Q. Tang and K. Sherman (Eds.). Large Marine Ecosystems of the Pacific Rim: Assessment, Sustainability, and Management, Blackwell Science, Boston.

Livingston, P.A., and J. Jurado-Molina, 2000: A multispecies virtual population analysis of the eastern Bering Sea. *ICES J. Mar. Sci. 57*, 294-299.

Loughlin, T.R., and K. Ohtani, (Eds.), 1999: *Dynamics of the Bering Sea*. University of Alaska Sea Grant, AK-SG-99-03, Fairbanks, 838 pp.

Mackas, D.L., W.T. Peterson, and J.E. Jamon, 2004: Comparisons of interannual biomass anomalies of zooplankton communities along the continental margins of British Columbia and Oregon. *Deep-Sea Res. II 51*, 875-896.

Mackas, D.L., R.E. Thompson, and M. Galbraith, 2001: Changes in the zooplankton community of the British Columbia continental margin, 1985-1999, and their covariation with oceanographic conditions. *Can. J. Fish. Aquat. Sci. 58*, 685-702.

Macklin, S.A., G.L. Hunt, Jr., and J.E. Overland, 2002: Collaborative research on the pelagic ecosystem of the southeastern Bering Sea shelf. *Deep-Sea Research II 49*, 5813-5819.

Macklin, S.A., 1999: Bering Sea FOCI. In: Dynamics of the Bering Sea (T.R. Loughlin and K. Ohtani, eds.), University of Alaska Sea Grant, Fairbanks, Alaska, AK-SG-99-03, 733-751.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis, 1997: A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society 78*, 1069-1079.

McBeath, J., 2004: Greenpeace v. National Marine Fisheries Service: Steller sea lions and commercial fisheries in the North Pacific. *Alaska Law Review 21,* 1-42.

McGowan, J.A., D.R. Cayan, and L.M. Dorman, 1998: Climate variability and ecosystem response in the northeast Pacific. *Science 281*, 210-217.

McGowan, J.A., S.J. Bograd, R.J. Lynn, and A.J. Miller, 2003: The biological response to the 1977 regime shift in the California Current. *Deep-Sea Res. II 50*, 2567-2582.

Moore, S.M., J.M. Grebmeier, and J.R. Davies, Jr., 2003: Gray whale distribution relative to forage habitat in the northern Bering Sea: current conditions and retrospective summary. *Can. J. Zool. 81*, 734-742.

Mordy, C.W., P.J. Stabeno, C.A. Ladd, S.I. Zeeman, D.P. Wisegarver, S.A. Salo and G.L. Hunt, Jr., 2005: Nutrients and primary production along the eastern Aleutian Island Archipelago. *Fisheries Oceanography 14 (Supplement 1)*, 55-76.

Mueter, F.J., C.A. Ladd, M.C. Palmer, and B.L. Norcross, 2006: Bottom-up and top-down controls of walleye pollock (*Theragra chalcogramma*) on the Eastern Bering Sea shelf. *Progress in Oceanography 68*, 152-183.

Napp, J.M. and G.L. Hunt, Jr., 2001: Anomalous conditions in the southeastern Bering Sea 1997: linkages among climate, weather, ocean, and biology. *Fisheries Oceanography 10*, 61-68.

Napp, J.M., A.W. Kendall, Jr., and J.D. Schumacher, 2000: A synthesis of biological and physical processes affecting the feeding environment of larval walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea. *Fisheries Oceanography 9*, 147-162.

National Research Council, 1996: The Bering Sea ecosystem. Washington DC, National Academy Press, 307 pp.

National Research Council, 2002: A century of ecosystem science: planning long-term research in the Gulf of Alaska. Washington DC, National Academy Press.

NOAA, 2004: New prioties for the 21st century – NOAA's Strategic Plan (Updated for FY 2005-FY 2010). http://www.spo.noaa.gov/pdfs/NOAA%20Strategic%20Plan.pdf, October 2004.

NPFMC (North Pacific Fishery Management Council), 2004: Stock Assessment and Fishery Evaluation Report. http://www.afsc.noaa.gov/refm/stocks/assessments.htm, March 2005.

Overland, J.E., and P.J. Stabeno, 2004: Is the climate of the Bering Sea warming and affecting the ecosystem? *Eos, Transactions, American Geophysical Union 85*, 309-316.

Package, C., and J. Sepez, 2004: Fishing communities of the north Pacific: Social science research at the Alaska Fisheries Science Center, pp. 1 - 11. In: Alaska Fisheries Science Center Quarterly Report. April-May-June. U.S. Department of Commerce.

Pew Oceans Commission, 2003: America's Living Oceans: Charting a Course for Sea Change, http://www.pewoceans.org/, September 2004.

PICES, 2004: PICES Report on Marine Ecosystems of the North Pacific. http://www.pices.int/publications/ecos_status/2004/npesr_2004.aspx, October 2004.

Porter, S.M., L. Ciannelli, N. Hillgruber, K.M. Bailey, K.-S. Chan, M.F. Canino and L.J. Haldorson, 2005: Environmental factors influencing larval walleye pollock *Theragra chalcogramma* feeding in Alaskan waters. *Marine Ecology Progress Series*, *302*, 207-217.

Reed, R.K., 2003: A surface heat flux climatology over a region of the eastern Bering Sea. *Journal of Climate 23*, 1255-1263.

Rosenkranz, G.E., A.V. Tyler, and G.H. Kruse, 2001: Effects of water temperature and wind on year-class success of Tanner crabs in Bristol Bay, Alaska. *Fish. Oceanogr. 10*, 1-12.

Rugolo, L.J., R.A. MacIntosh, C.E. Armistead, J.A. Haaga, and R.S. Otto, 2003: Report to Industry on the 2003 Eastern Bering Sea Crab Survey. AFSC Processed Report 2003-11. U.S. Dept. Commerce, NOAA, National Marine Fisheries Service, 60 pp.

Sainsbury, K.J., A.E. Punt, and A.D.M. Smith, 2000: Design of operational management strategies for achieving fishery ecosystem objectives. *ICES J. Mar. Sci 57:* 731-741.

Sambrotto, R.N., H.J. Niebauer, J.J. Goering, and R.L. Iverson, 1986: Relationships among vertical mixing, nitrate uptake and phytoplankton growth during the spring bloom in the southeast Bering Sea middle shelf. *Cont. Shelf Res. 5*, 161-198.

Schumacher, J.D., N.A. Bond, R.D. Brodeur, P.A. Livingston, J.M. Napp, and P.J. Stabeno, 2003: Climate change in the southeastern Bering Sea and some consequences for its biota, pp. 17 - 40. In: Large Marine Ecosystems of the World: Trends in Exploitation, Protection, and Research, Hempel, G. and K. Sherman (Eds.) Elsevier, Amsterdam.

Schumacher, J.D., C.A. Pearson, and J.E. Overland, 1982: On exchange of water between the Gulf of Alaska and Bering Sea through Unimak Pass. *J. Geophys. Res. 87,* 5785-5795.

Sherman, K., 1991: The Large Marine Ecosystem concept: Research and management strategy for living marine resources. *Ecol. Applications 1*, 349-360.

Stabeno, P.J., J.D. Schumacher, K.M. Bailey, R.D. Brodeur, and E.D. Cokelet, 1996: Observed patches of walleye pollock eggs and larvae in Shelikof Strait, Alaska: their characteristics, formation and persistence. *Fisheries Oceanography 5*, Supplement 1, 81-91.

Stabeno, P.J., N.B. Kachel, M.E. Sullivan, and T.E. Whitledge, 2002: Variability of physical and chemical characteristics along the 70-m isobath of the southeastern Bering Sea. *Deep-Sea Research II 49*, 5,931-5,943.

Stabeno, P.J., N.A. Bond, A.J. Hermann, N.B. Kachel, C.W. Mordy, and J.E. Overland, 2004: Meteorology and oceanography of the northern Gulf of Alaska. Continental Shelf Research, Vol. 24, Issue 7-8, pp. 859-897, (May 2004).

Stabeno, P.J., and G.L. Hunt, Jr., 2002: Overview of the Inner Front and Southeast Bering Sea Carrying Capacity Programs. *Deep-Sea Research II 49*, 6,157-6,168.

Sugimoto,T., and K. Tadokoro, 1997: Interannual-interdecadal variations in zooplankton biomass, chlorophyll concentration and physical environment in the subarctic Pacific and Bering Sea. *Fisheries Oceanography 6*, 74-93.

Thompson, D.W. J., and J.M. Wallace, 1998: The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. Geophys. Res. Lett., 25, 1297-1300.

Tynan, C.T., and D.P. DeMaster, 1997: Observations and predictions of arctic climate changed: potential effects on marine mammals. *Arctic 50:* 308-322.

Venrick, EL, J.A. McGowan, D.R. Cayan, and T.L. Hayward, 1987: Climate and chlorophyll *a*: long-term trends in the central North Pacific Ocean. *Science 238*, 70-72.

Walsh J.J., and C.P. McRoy, 1986: Ecosystem analysis in the southeastern Bering Sea. *Cont. Shelf Res. 5*, 259-288.

Wespestad, V.G., L.W. Fritz, W. Ingraham, and B.A. Megrey, 2000: On relationships between cannibalism, climate variability, physical transport, and recruitment success of Bering Sea walleye pollock (*Theragra chalcogramma*). *ICES Journal of Marine Science 57*, 272-278.

Whipple, S.J., J.S. Link, L.P. Garrison, and M.J. Fogarty, 2000: Models of predation and fishing mortality in aquatic ecosystems. *Fish and Fisheries 1,* 22-40.

Wilderbuer, T.K, A.B. Hollowed, W.J. Ingraham, Jr., P.D. Spencer, M.E. Conners, N.A. Bond, and G.E. Walters, 2002: Flatfish recruitment response to decadal climatic variability and ocean conditions in the eastern Bering Sea. *Prog. In Oceanogr. 55*, 235-247.

Witherell, D., C. Pautzke, and D. Fluharty, 2000: An ecosystem-based approach for Alaska groundfish fisheries. *ICES J. Mar. Res. 57:*771-777.

Wyllie-Echeverria, T., and W.S. Wooster, 1998: Year-to-year variations in Bering Sea ice cover and some consequences for fish distributions. *Fisheries Oceanography 7*, 159-170.

13. BUDGET ($ MILLIONS)

As originally proposed:

NOAA LO	FY04	FY05	FY06	FY07	FY08	FY09	FY10
Fisheries	1.5	1.2	1.2	3.5	4.0	4.0	4.0
Research	0	0.	0	1.0	1.5	2.0	3.0
TOTAL	1.5	1.2	1.2	4.5	5.5	6.0	7.0

As adopted by Climate Goal Team for PPBES:

NOAA LO	FY04	FY05	FY06	FY07	FY08	FY09	FY10
Fisheries	1.5	1.2	1.2	2.0	2.0	2.0	2.0
Research	0	0	0	0	0	0	0
TOTAL	1.5	1.2	1.2	2.0	2.0	2.0	2.0

14. APPENDIX – LIST OF ACRONYMS

AFSC	Alaska Fisheries Science Center
AI	Aleutian Islands
AO	Arctic Oscillation
BEST	Bering Sea Ecosystem Study
BS	Bering Sea
EEZ	Exclusive Economic Zone
ENSO	El Niño/Southern Oscillation
EOS	Ecosystem Observing System
FOCI	Fisheries-Oceanography Coordinated Investigations
GoA	Gulf of Alaska
IBM	Individual-Based Model
LME	Large Marine Ecosystem
MSA	Magnuson-Stevens Fishery Conservation and Management Act
NOAA	National Oceanic and Atmospheric Administration
NPCREP	North Pacific Climate Regimes and Ecosystem Productivity
NPFMC	North Pacific Fishery Management Council
NPZ	Nutrient-Phytoplankton-Zooplankton
OY	Optimum Yield
PDO	Pacific Decadal Oscillation
PICES	North Pacific Marine Science Organization
PMEL	Pacific Marine Environmental Laboratory
SAFE	Stock Assessment and Fishery Evaluation
SAM	Statistical Age-structured Model
SLP	Sea Level Pressure
SR	Stock Recruitment
SST	Sea Surface Temperature