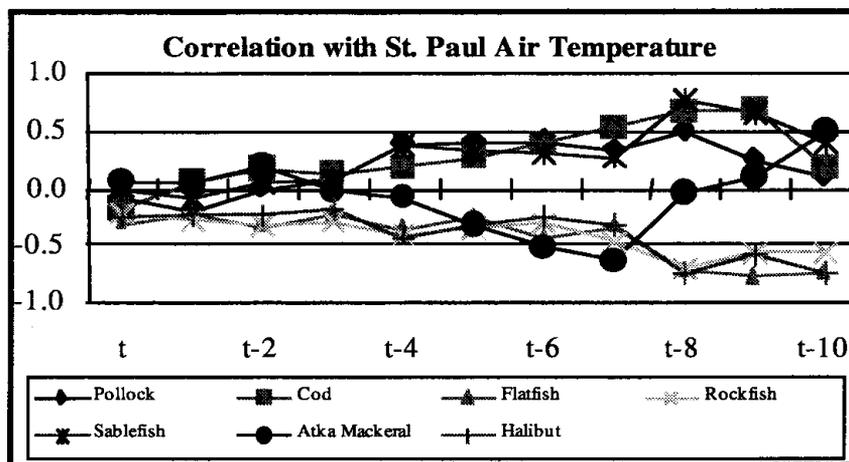


Because the mechanisms whereby oceanographic processes influence biological systems are latent and dynamic, apparent relationships will be found between population abundance and observable variables which result from or are correlated with the latent processes. For example, the dynamic correlations between the abundance of principal eastern Bering Sea fish stocks and the mean annual air temperature (°C) at St. Paul Island airport in the Pribilofs can be represented by:



Although it is possible (remotely) that air temperature directly influences survival, recruitment, and growth, it is far more likely that air temperature is correlated (positively or negatively) with associated oceanographic factors that truly affect the biological stocks. Fortunately, from the perspective of statistics, the confidence in our forecasts of changes in populations does not deteriorate if we use a closely correlated proxy for an unobservable process. Note however, that while forecasts may be unaffected by the useful inclusion of proxy variables, the estimated coefficients may lack causal significance. Thus, model performance may collapse under conditions that disrupt the correlative relationship. Because these correlations are the univariate manifestations of multivariate interactions, they are at best tenuous. Consequently, the performance of models that incorporate proxy environmental variables frequently degrades ex post. That is, changes in the state of a suite of environmental influences cause relationships that were found to be statistically significant when estimated ex post to be uninformative to ex ante forecasts.

Fish & Shellfish

The effects of climate variation on some Bering Sea fish populations are fairly well known in terms of empirical relationships but generally poorly known in terms of mechanisms. Descriptions of such empirical relationships are found in Pearcy (1984), Beamish and McFarlane (1989), and Beamish (1995). Data on commercially exploited species dates back to the mid-1960's for some groundfish species and to the early part of this century for some stocks of Pacific salmon, Pacific halibut, and Pacific herring. Data on forage fishes and lower trophic levels are generally poor to non-existent.

In addition, there was a strong increase in the abundance of copepods in 1974 through 1977 in the central North Pacific Ocean, with continued good levels into 1980. These data were reported from the Ocean Station P data series along with a new index of the Aleutian low pressure zone from 1965 to 1980 (Beamish and Bouillon 1993). The copepod index varied with the intensity of the winter low pressure. The major driving factors for observed changes in each of these variables are hypothesized to be variation in the mean position and intensity of the Aleutian Low; warm periods can be thought of as El Niño periods and cold periods as anti-El Niño periods. During cold periods the Aleutian low is minimal and to the west. During the warm periods the low is strong and to the east.

While the regime shift in the environment has probably resulted in better conditions overall for many stocks, there are still many other factors which influence fish population size. In particular the size of the population itself has a large role in determining the amount of egg production. For walleye pollock in the Bering Sea, the cannibalistic nature of the adults adds another dimension of complexity, as does predation by other species.

Many fish populations appear to exhibit responses to the environment over different time scales than just the regime shift period. For Pacific halibut, there appears to be a long 30-year cycle in recruitment that may be influenced by the solar-lunar node cycle of Royer (1993). Walleye pollock in the Bering Sea appear to be affected by inter-annual changes in the environment, so that year-to-year differences contribute to year-to-year fluctuations in recruitment (Quinn and Niebauer 1995). On the other hand, walleye pollock in the Gulf of Alaska had good recruitment over a number of years in the late 1970's and then a long period of poor recruitment. The effects of climate change on the spatial distributions of fish populations are even less well understood. While declines and increases in fish populations are often accompanied by contractions and expansions in range, this need not be the case. For Pacific salmon, it is well known from high seas studies that threshold temperature ranges affect distribution. Temperature increases of a few degrees can shift distributions dramatically.

Groundfish

Several groundfish stocks in the eastern Bering Sea showed a strong change during the decade starting in 1977 or 1979 (Bakkala 1993, NPFMC 1996 a,b,c, NRC 1996). The total groundfish complex and its Acceptable Biological Catch (ABC) have increased compared to the mid-1970's. In particular, Pacific cod showed a 600% increase to about 1.1 million tons, while rock sole showed about a 350% increase. Pacific halibut, yellowfin sole, flathead sole, Alaska plaice, arrowtooth flounder, and Atka mackerel showed large, persistent increases in abundance during this period. Other species showing a pronounced increase include walleye pollock and mixed skate species. Pacific herring showed strong and regular recruitment increases following 1976 in the eastern Bering Sea and in various localities in the Gulf of Alaska, including Prince William Sound (Fritz et al. 1993). Hollowed et al. (1987) showed that many groundfish stocks exhibit synchrony in recruitment, most likely due to changes in environmental conditions. For example, the 1977 and/or 1978 year-classes were quite large for Bering Sea walleye pollock, Pacific cod, Pacific Ocean perch, arrowtooth flounder, Atka mackerel, and sablefish. This increase coincided with a large positive anomaly in air temperature in 1979 (Quinn and Niebauer 1995). Conversely, some stocks have had a negative response during this period. Greenland turbot, a species more adapted to colder climates, decreased from approximately 120,000 t to 10,000 t. King crab stocks in the eastern

Bering Sea and Kodiak declined during the 1980's, and this decline is thought to be due to a combination of factors including environmental effects, overfishing, natural mortality, and changes in reproductive parameters (Tyler and Kruse 1996). Some very limited information suggests that there has been a decline in some forage fishes (NRC 1996).

Pacific Salmon

The survival and growth of salmon depend on the influence of environmental factors in freshwater and oceanic life-stages. It has been long known that salmonid populations show responses to changes in climatic conditions (Percy 1984). This has been reinforced by recent retrospective studies using regression and time series analyses (Quinn et al. 1989, several papers in McFarlane and Beamish 1989, and Beamish 1995, NRC 1996, Adkison et al. 1996). Elevated stream temperature, stream flow rates, and air temperatures have been identified as beneficial freshwater factors (Rogers, 1984). The effect of the warming has been positive for most stocks; some of the highest salmon catches on record in Alaska have occurred in the last decade. While there has still been inter-annual variability, catches and populations in this later period have been above average at the least. Positive correlations between salmon returns and positive air and sea surface temperature anomalies, reduced Bering Sea ice cover, negative Southern Oscillation Index anomalies have been reported by Quinn and Marshall (1989), among others. Unless accompanied by significant changes in the strength of ocean upwelling zones, changes in precipitation and temperature anticipated by Weller et al. (Chapter 2) can be expected to enhance salmon productivity.

Red King Crab¹

The once large stock of red king crabs of the Bristol Bay region of the eastern Bering Sea crashed in the early 1980s and has not recovered. It is one of the few stock demises in that area. One suspicion is that the fishery was to blame for the crash because of the large landings that occurred during the late 1970s and early 1980s, and another possibility is that the demise was caused by oceanographic factors.

Tyler and Kruse (1997) looked at the January pressure anomalies for the North Pacific since 1966 for the area of the Pacific Ocean between 20° and 60° north latitude. Except for three years, the pressure was above average from 1966-1975 inclusive, and from 1976-1988 the pressure was lower than normal. It was during this intense low pressure that brood strength was progressively reduced. Because numbers of young decreased while catch of adults (males only; females are returned to the ocean) rapidly increased, there was scant replacement of spawning biomass. Of course, atmospheric pressure changes do not kill king crab, and so we have not found the specific cause of mortality. It is likely that a combination of events have acted simultaneously through the complex life history of the species to produce the lowered brood strength. Unfortunately, many measures will correlate with this nearly monotonic decline in brood strength and barometric pressure. Therefore, we suggest that further exploration of correlation statistics will only produce many significant correlations but no new understanding. Instead, we suggest the development of process studies.

The change in weather pattern that occurred in the mid-1970s coincided with a decrease in brood strength of red king crabs. An accompanying increase in water temperature was correlated to decrease in the red king crab stocks of Kodiak and Bristol Bay (Müter et al.

¹Excerpted from Tyler and Kruse (1997).

1995), although their Kodiak relationship appears more related to availability of crabs to the fishery and changes in fishing effort. There are several hypotheses presented here that relate temperature change to change in productivity of red king crabs. The optimum temperature for embryo development of red king crabs is 3-8°C (Nakanishi 1985). For ocean fishes, hatch success is often highest at an intermediate temperature, with decreases at higher temperatures (Alderdice and Forrester 1971). Cumulative exposure to optimal temperature is sometimes necessary for both egg and embryonic development of some fish (Kruse and Tyler 1983), and so it may be for king crabs. In unusually warm years spawning may be skipped because a cool temperature cue is needed or degree of maturation is insufficient. The mechanisms of response to warming that might bring about a decrease in brood strength are manifold. Specifics for the red king crab are wanting, and so it is not possible to rule out hypotheses presented here.

Hypotheses relating survival and productivity to physical factors:

- ◆ A critical number of degree-days is necessary to bring on ovary maturation
- ◆ High temperatures will increase egg mortality
- ◆ After fertilization, cool temperatures will delay hatching
- ◆ High percentage of successful hatch is linked to an optimum temperature

Other physical factors that could be of major influence are advection and mixing. Advection is critical to the development of brood strength in processes related to hatching, to survival of zoea, and to the settling of the glaucothoe stage. The prevailing currents flow to the northeast along the Alaskan Peninsula toward Bristol Bay then turn northward (Stabeno and Reed 1994). Since high-profile, rocky bottom with attached fauna is critical for survival of the glaucothoe larval stage during settling, an increase in the strength of currents moving larvae away from this bottom type would increase mortality

Changes in concentrations of diatoms are generated by the mixing of nutrients into the euphotic zone. The mixing could be tidal or possibly be from Ekman upwelling along the north coast of the Alaskan Peninsula caused by winds from the northeast, though this is not documented. It is possible that the fertilized embryos of red king crab hatch only if there are concentrations of diatoms present, as though a chemical cue were necessary (T. Shirley, University of Alaska Fairbanks, Juneau Center, unpublished).

A period of high recruitment of the 1960s and early 1970s in the eastern Bering Sea stock of red king crab led to the high biomass of that species, making possible the major fishery of the late 1970s and early 1980s. This high recruitment level did not pass unchanged into the new oceanographic regime following the climate shift of the mid 1970s. That the decrease in productivity of king crabs was due to oceanic climate change seems likely, but is not proven. This hypothesis by no means discounts the density-dependent relationship proposed by Reeves (1990) and Zheng et al. (1995) with a critical stock-size below which the small size of the spawning stock interferes with recruitment productivity.

Marine Mammals

In addition to affecting the productivity and availability of intensively harvested fish stocks, climate change can be expected to affect non-target fish stocks, seabirds, and marine mammals. Trillmich and Ono (1991) document the effects of El Niño on the abundance and distribution of pinnipeds throughout the Pacific. Strong evidence exists for impacts from

British Columbia to Chile. While the authors speculate on the possibility of impacts on Gulf of Alaska and Bering Sea pinnipeds, the baseline data are not extensive, and the results that they report are not statistically significant.

7.4 Institutional Structure

The Bering Sea region's marine and freshwater fisheries are managed by various regional and national governments, and international treaties. Fisheries in the US Exclusive Economic Zone (EEZ) are managed by the North Pacific Fisheries Management Council under the guidelines of the Magnuson Fisheries Conservation and Management Act. The State of Alaska claims jurisdiction over freshwater fisheries and marine fisheries inside the three-mile state waters under the Constitution's equal footing clause and common law. However, because states lack authority to enter treaties, the federal government retains certain responsibilities for the management of transboundary stocks. In addition, the federal government has asserted authority to intervene in state fisheries management in order to guarantee provisions of the Alaska National Interest Lands Conservation Act (ANILCA) with respect to subsistence priority. The Canadian Department of Fisheries and Oceans (DFO) is responsible for the establishment and enforcement of catch limits in the Canada. Management of Pacific halibut is governed by a treaty between the U.S. and Canada. The Canadian and U.S. governments are currently engaged in renegotiating a treaty that governs management of salmon stocks near British Columbia and in the Yukon River. The U.S. and Russia are also engaged in negotiating their common seaward boundary in the Bering Sea.

7.5 Direct and Indirect Users

The Bering Sea region's biological resources provide many sources of human value. In addition to the direct values that arise from recreation, tourism, and subsistence, sport, and commercial harvests, and to consumers, these resources provide existence and option values. Each of these sources of value should be investigated.

Commercial Harvests

Eastern Bering Sea groundfish harvests in the 1950-1980 period were largely conducted by distant water fleets from Japan and the Soviet-bloc nations. During the 1950's, these fleets focused on yellowfin sole. When catches of yellowfin sole began to taper off in the 1960's, the distant water fleets switched to sablefish, Pacific Ocean perch, and various rockfish. Development of the technology for shipboard processing of surimi, a fish paste, led to the rapid growth of the walleye pollock fishery in the late 1960's and early 1970's. A rapid evolution of the commercial fishery was induced by the passage of the Magnuson Fisheries Conservation and Management Act of 1976 (MFCMA) and the concomitant expansion of various fishing vessel construction subsidy programs. The initial phase of this evolution was the development of a joint-venture fleet. Joint ventures consisted of US-flagged harvester vessels (generally 90-130' trawlers) that delivered to non-US-flagged motherships. The expansion of joint venture activities virtually eliminated foreign directed fishing by 1985. By 1990, the joint venture fleet was completely supplanted by fully domestic operations (shoreside, mothership, and catcher-processor).

The region fishery for walleye pollock exceeded 4.8 million metric tons of landings and accounted for approximately 5% of the combined world landings of fish, shellfish, and crustaceans in 1991. Pacific salmon, Pacific cod, Pacific halibut, sablefish, yellowfin sole, Greenland turbot, arrowtooth flounder, rock sole, flathead sole, other flatfish, Atka mackerel, Pacific herring, various rockfish and thornyheads, crabs, and weathervane scallops form the primary focus of current commercial fisheries in the Gulf of Alaska and Eastern Bering Sea. These same species, with the addition of Arctic cod and saffron cod, are harvested in the Western Bering Sea, Sea of Okhotsk, and Chukchi Sea.

The economic effects on commercial fisheries of changes in fish populations depend on the elasticity of demand for fish. When ex-vessel prices are inversely related to demand, the total revenue functions are dome shaped. Portions of the demand curve associated with upward sloping portions of the revenue function are called elastic. Portions of the demand curve associated with the downward sloping section of the revenue function are called inelastic. Increases in catch result in increased revenue where demand is elastic, but result in decreased revenues where demand is inelastic. Fisheries for Pacific halibut and Pacific salmon have been shown (Criddle 1993, and Herrmann 1993, respectively), to operate in the inelastic region of their demand curves thus increased landings will fail to increase revenues unless total demand expands. Although the current ex-vessel demand for walleye pollock is elastic, modest increases would cause demand to become inelastic (Herrmann et al. 1996, Criddle et al. in press). Whenever costs are an upward sloping function of catches, profit maximizing harvest levels will be even smaller than revenue maximizing harvest levels. Although formal demand systems have not been estimated for other region fisheries, it is likely that the demand for most of the remaining groundfish stocks is inelastic (or nearly so). The likely exceptions to this generalization are sablefish and commercial targeted crabs, high valued species with depressed harvests.

In addition to indirect effect of warming on harvest revenues, climate change can be expected to affect the effectiveness and cost of fishing. For example, if warmer air temperatures reduce the extent of sea ice cover in the Bering Sea, fishers may have improved access to seasonally aggregated stocks. That is, catch-per-unit-effort (CPUE) could be increased even without an increase in stock abundance

7.6 Additional Research Needed

Additional information that would contribute to improved decision making includes:

- ◆ expansion and maintenance of oceanic, atmospheric and hydrologic monitoring systems/programs to ensure access to critical information on the current state of the ocean-atmosphere system and the development of reliable data sets to support analysis of long-term trends;
- ◆ historical analyses and paleoclimate investigations of seasonal-to-interannual climate conditions in the region to determine whether the current “regime shift” reflects a cycle of natural variability (e.g., associated with decadal and longer patterns in ENSO) or could represent a permanent long-term trend;

- ◆ exploration of the predictability of seasonal-to-interannual climate variability in the region, particularly related to ENSO and the Aleutian Low system, and the potential benefits of such forecasts for fisheries development and management as well as marine mammal and sea bird conservation in the region;
- ◆ improved understanding of the impact of climate variability and change on precipitation in the region with particular attention to the influence of changes in rainfall-runoff patterns for the region's fisheries (especially freshwater species like whiting and anadromous species like salmon);
- ◆ improved understanding of the nature and consequences of changes in sea ice conditions, particularly in terms of: (1) fisheries, marine mammals and sea birds which rely on ice-edge productivity; (2) the impact of changing ice conditions on fishing access and safety (particularly important vis-a-vis subsistence users);
- ◆ improved understanding of the impact of climate variability on ocean circulation and productivity, particularly in terms of the impact of anticipated changes on the levels and health of critical stocks of fish, marine mammals, and sea birds for commercial, recreational, and subsistence use;
- ◆ improved understanding of current trends and anticipated changes in the state of ice-rich permafrost in the region and the role of melting permafrost on stream flow quantity and quality as well as impacts on supporting infrastructure;
- ◆ improved understanding of the potential consequences of climate change on severe storms and weather extremes;
- ◆ improved understanding of the influence of climate variability and change (in the context of other existing or anticipated environmental stresses) on inter-species competition;
- ◆ a more thorough understanding of the key processes and mechanisms responsible for determining productivity, species composition, distribution and abundance;
- ◆ changes in biodiversity and the influence of climate variability and change on those changes;
- ◆ exploration of the influence of the region on the global climate system with particular attention to the role of the region's ocean ecosystem as a sink for carbon (and, conversely, whether the region's terrestrial ecosystems might represent a potential source of carbon to the atmosphere associated with the release of clathrates in association with melting coastal zone permafrost);
- ◆ exploration of the region and/or some of its species as "indicators" of global change.

7.7 Integration with other Working Groups

The development of effective adaptation or mitigation options for the region requires the integration of information on current and anticipated changes in climate as a consideration in a variety of resource management and economic development decisions. In some cases, these are decisions that directly affect access to fisheries and marine mammals resources (e.g., determinations of allowable catch limits). In other cases, however, these decisions will be

associated with activities which indirectly affect the ocean ecosystem and the resources it supports (such as the influence of changes in land use on freshwater, anadromous, and marine species). Many of these indirect consequences are discussed in the other chapters of this report but the participants in the Ocean System Working Group thought it would be helpful to highlight some of them here as well. The following section provides a list of some of the more critical policy decisions with consequences for the fisheries sector:

- ◆ changes in land use policies particularly with respect to those activities which involve either large-scale changes in vegetation cover (e.g. forestry) or resource extraction activities, such as mining, which affect stream flow quantity and quality as well as nutrient and freshwater flow in the near-coastal and shelf ecosystems;
- ◆ infrastructure maintenance and improvement policies which affect access to fishing and hunting grounds as well as commercial markets;
- ◆ infrastructure and resource transfer decisions which might increase (or decrease) the vulnerability of fisheries-dependent communities to climate change;
- ◆ water resource management decisions which affect stream flow quantity and quality as well as direct access to water resources for subsistence communities;
- ◆ economic investment and subsidy decisions particularly as they affect resource demand and industrial capitalization;
- ◆ land use and economic development decisions related to the development of and support for aquaculture/fish farming projects, particularly as they relate to salmon;
- ◆ infrastructure development and protection decisions which either increase or decrease the vulnerability of coastal ports and communities to the influences of climate change;
- ◆ national and international decisions related to fossil fuel use and access which could decrease the contribution of oil and gas resources to the region's economy and result in an increase in the region's reliance on fisheries resources and other development sectors;
- ◆ changes in tourism policies which affect access to critical habitats and resources;
- ◆ international negotiations which involve the exchange of fisheries resource access/availability for other goods and services;
- ◆ and endangered species protection and enforcement activities on fisheries stocks analysis of the consequences of changes in marine mammal and activities.

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