LONG-TERM ECOLOGICAL CHANGE IN THE NORTHERN GULF OF ALASKA

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4.6. Groundfish

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4.6.1. Introduction

In this chapter, long-term changes are presented for several ecologically and economically important groundfish species in the Gulf of Alaska: walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), arrowtooth flounder (*Atheresthes stomias*), and Pacific ocean perch (*Sebastes alutus*). Walleye pollock and Pacific cod are in the family gadidae; arrowthooth flounder, pleuronectidae, and Pacific ocean perch, scorpaenidae. Various factors that might have impacted each of these populations and caused the observed changes are discussed. These species are generally representative of major fish species complexes of the GOA, and historical (20+ years) estimates of adult and larval abundances are used to examine population changes.

Total biomass of each groundfish species over the last 42 years (25 years for Pacific cod) has been estimated with species-specific age-based or length-based models (A'mar et al., 2003). Briefly, for walleye pollock, data integrated by the model include fishery catch and age composition, National Marine Fisheries Service (NMFS) bottom trawl and Echo-Integration Trawl survey estimates of age composition and biomass, and egg production estimates of spawning biomass (among other factors). The model for Pacific cod utilizes a length-structured model and includes commercial catch-data (biomass, size composition), NMFS survey data (size composition and abundance), and length–weight relationships to estimate total biomass (among other parameters). The model used for arrowtooth flounder includes survey estimates from the International Pacific Halibut Commission in addition to the NMFS groundfish trawl survey data, and size composition estimates for selected years. Fishery catch and size data are also incorporated. Finally, for Pacific ocean perch, the model used is a generic rockfish model that integrates information on age structure, size composition, fishery catch data, and survey biomass estimates (when available) to estimate total biomass. For all species, modeled results have been used instead of actual biomass estimates, because annual estimates are limited to survey data and some applied correction factors, whereas the models provide longer, more complete time series with retrospective analyses to estimate population biomass. The NMFS survey, conducted by the Resource Assessment and Conservation Engineering Division (RACE) of the Alaska Fisheries Science Center (AFSC), has been collecting data on a triennial basis since 1984 and biennially since 1999. The survey uses a high-opening Poly-Nor'eastern bottom trawl (127 mm mesh) with rubber bobbin roller gear. Surveys average 800 tows (range: 489–929 tows) and span the entire GOA (133–170°W). The GOA is divided into the Eastern (133–147°W), Central (147–159°W),

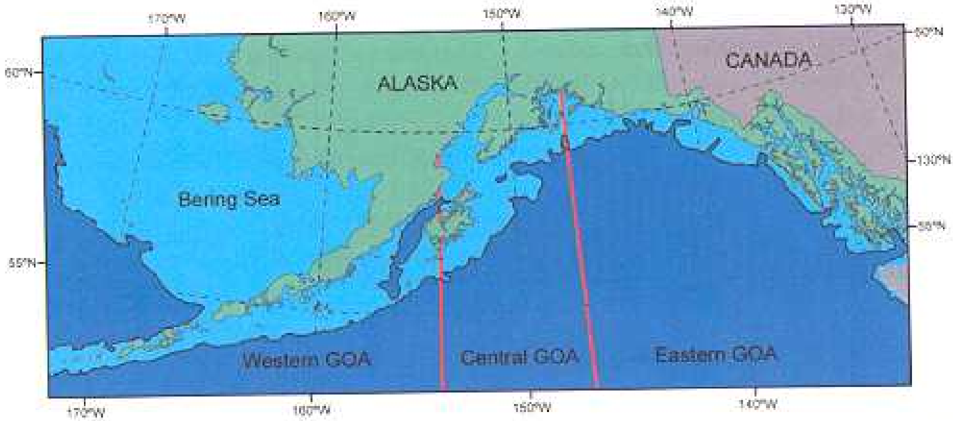

Figure 4.25: Three regions of the Gulf of Alaska sampled by the triennial NMFS survey. The survey takes place on the continental shelf (light blue).

and Western (159–170°W) regions (Martin 1997; Fig. 4.25). The modeled estimates of population biomass often exceed the results from the surveys due to catch efficiencies of the gear. Also, as new information on fish populations become available each year from fisheries or scientific surveys, estimates of previous years may change retrospectively. Therefore, estimates are sensitive and subject to change due to potential immigration and emigration, as well as the possibility of ageing errors.

There are discrepancies in trends between the models and NMFS surveys (Fig. 4.26) and the small-mesh trawl surveys conducted by the Alaska Department of Fish and Game (ADF&G) (Anderson and Piatt, 1999), especially for pollock and cod. For example, from the 1980s – 1990s, gadid biomass fell according to the modeled estimates, while the ADF&G small-mesh survey shows an increasing trend. These incongruities are best explained by differences in sampling gear, region, and depths sampled. The smallmesh trawl surveys primarily sample some nearshore areas in the central and western GOA (150–163°W) and the smaller mesh size (32 mm) and high opening is designed to catch shrimp and juvenile fishes.

Since the 1970s, fish larvae (ichthyoplankton) dynamics have been monitored in the GOA (145–165°W, Shelikof vicinity) by the Recruitment Processes Program of the AFSC. Data are collected in oblique tows with a 60-cm bongo net (333 and 505-μm mesh) (Matarese et al., 2003). Most of this sampling was conducted in May. Results from these surveys document year-to-year changes in larval abundance.

The relationship between climate forcing factors and biological responses (see Table 4.1) were investigated with linear and nonlinear methods. The climate forcing factors were temperature and salinity data from the GAK 1 time series in Resurrection

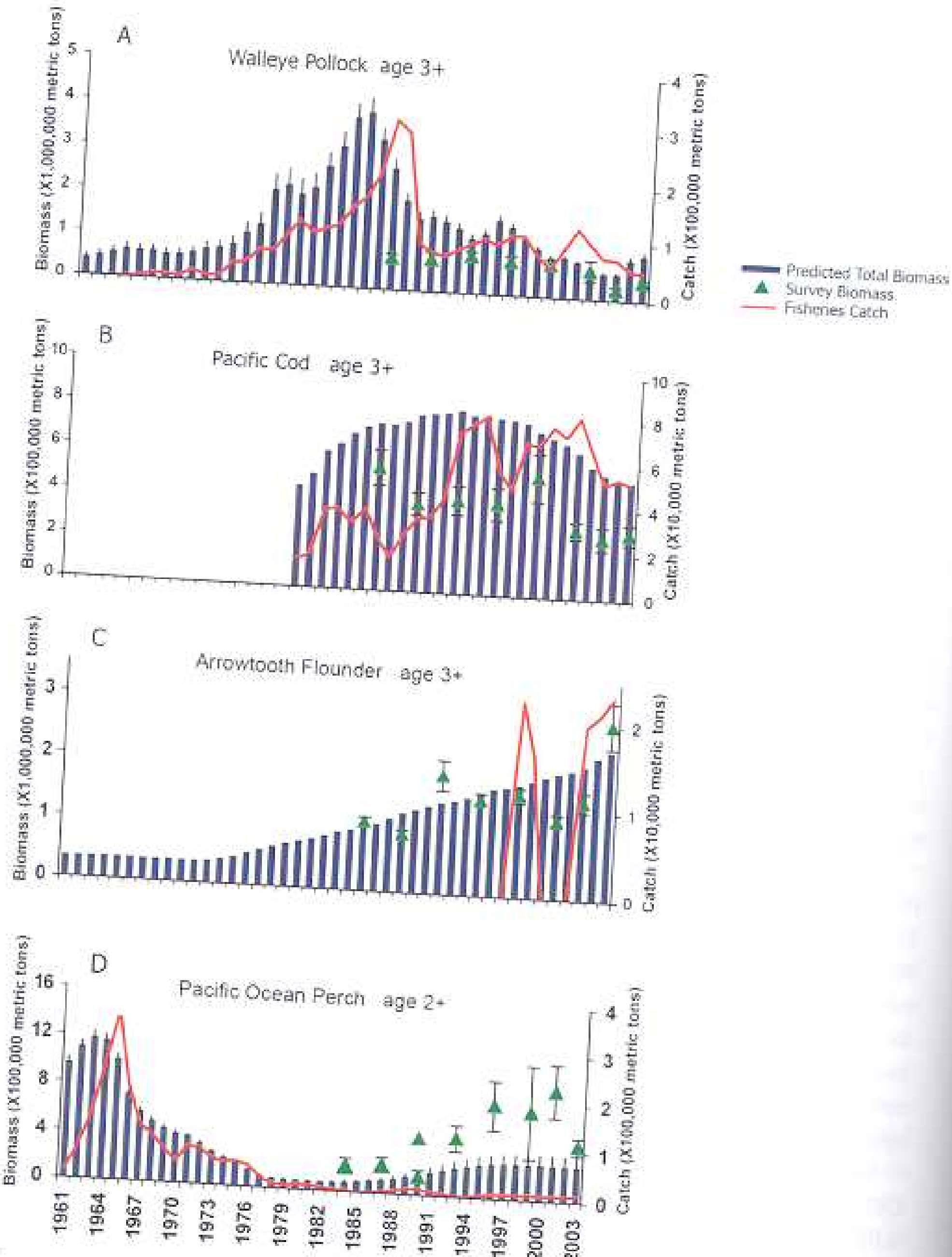

Figure 4.26: Biomass estimates of some groundfishes by model (columns) and survey (triangles) compared to fisheries catches (red lines; on left vertical axis).

Bay (http://www.ims.uaf.edu/gak1/), National Centers for Environmental Prediction reanalysis of surface temperature and the Pacific Decadal Oscillation (ftp://ftp.atmos.washington.edu/mantua/pnw_impacts/INDICES/PDO.latest). Wind-mixing data were provided by Nick Bond (pers. comm.; http://www.pfeg.noaa.gov: 16080/products/las/docs/), and the retention index was estimated by Mick Spillane (pers. comm.) from a semispectral primitive equation model (SPEM) of Shelikof Strait (http://www.pmel.noaa.gov/foci/spem-ibm.html).

4.6.2. *Walleye Pollock*

Walleye pollock (*Theragra chalcogramma*) are widely distributed in the Pacific Ocean north of California. Adult pollock form schools in the open ocean and are close to the bottom over the continental ocean shelf. They reach maturity at around 4 years and live up to 15 years. For the last two decades, it has been one of the most abundant groundfish in the GOA and supported a large commercial fishery since the early 1970s (Megrey, 1989). The GOA biomass of adults (3+ years) was estimated to be 500,000 metric tons (t) during the 1960s and early 1970s, and the model shows a steady, strong increase until the population peaked in 1982 at just below 4 million t (Fig. 4.26(A)). The rapid decrease following 1982 was interrupted in the early 1990s before it continued downward to a minimum value of 570,000 t in 2000–2001. This is comparable to the values recorded in the 1960s. Since 2001, the biomass has increased again due to a strong recruitment in the 1999 year-class (Livingston, 2003), and the current estimate is just below 1 million t. Although triennial survey data indicate that walleye pollock were fairly steady from 1984 to 1999 at around 750,000 t, they exhibited a significant decrease over time ($r^2 = 0.54$) due to the low estimates of the last two surveys. Traditionally pollock were most abundant around Kodiak Island, but survey catches in recent years have increased west of the Shumagin Islands along the Alaska Peninsula (Fig. 4.25).

In the GOA, pollock spawn in Shelikof Strait mainly in late March and early April, with females producing up to 1.2 million eggs (Matarese et al., 2003), and their larvae are more abundant than any other species in the spring (Matarese et al., 2003). Larval abundance is highly variable from year to year, although average catches in May stayed typically below 1000 larvae per 10 m^2, except for the extremely high abundances observed in 1981 (coinciding with maximum adult pollock biomass) and 1996 (Fig. 4.27).

4.6.3. *Pacific Cod*

Pacific cod (*Gadus macrocephalus*) is a benthic gadid living along the continental shelf. This species matures at 2–3 yrs and lives as long as 13 years. Cod show significant

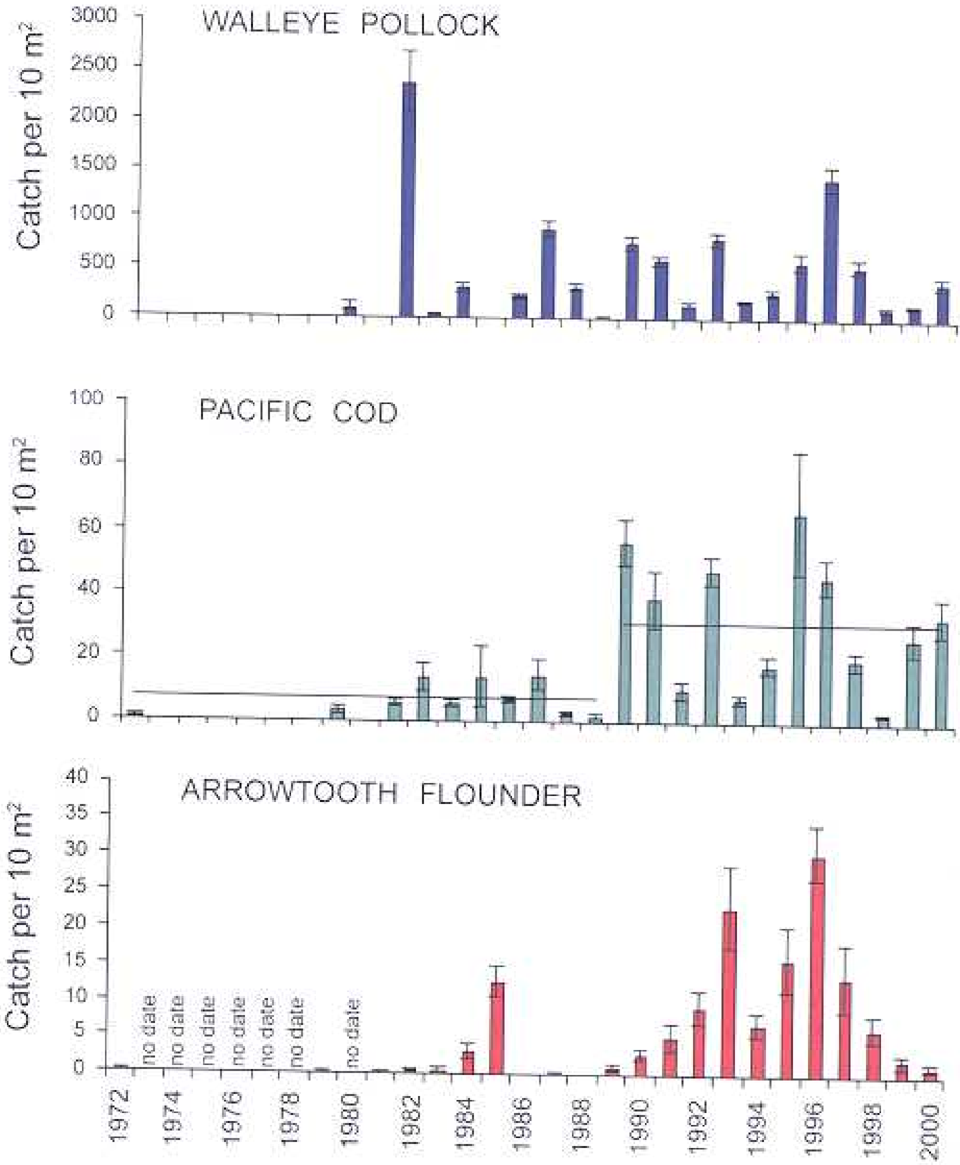

Figure 4.27: Larval abundance of selected groundfish species in the Gulf of Alaska.

migration between the GOA and Bering Sea (Shimada and Kimura, 1994), and genetic studies have been unable to separate them into distinct stocks (Grant et al., 1987). According to model estimates, biomass of Pacific cod showed a slight increase through the early 1990s (from 500,000 t in 1978 to 860,000 t), followed by a gradual decline (540,000 t in 2003) (Fig. 4.26(B)). Similar to walleye pollock, the survey biomass estimates have been consistently below the modeled estimates, but they also show a decreasing trend since 1984 ($r^2 = 0.52$). Between 1984 and 1996, biomass values were above 400,000 t and below 300,000 t since 1999.

Pacific cod are winter–spring spawners, and their larvae are most abundant in April and May. Females produce up to 3 million demersal eggs. Highest larval abundance is found west of Kodiak Island along the Alaska Peninsula in spring (Matarese et al., 2003). There was a stepwise increase of larval abundance from the 1980s (7 larvae per 10 m^2) to the values after 1989 (31 larvae per 10 m^2) (Runs test, $p = 0.001$; Fig. 4.27) despite the decreasing trend of adult biomass.

4.6.4. Arrowtooth Flounder

Arrowtooth flounder (*Atheresthes stomias*) range from the Bering Sea to central California. They are commonly found along the continental shelf and slope and prefer soft muddy bottoms. They mature at approximately 3–5 years of age (Zimmermann and Goddard, 1996; Zimmermann, 1997) and may live as long as 23 years (Eschmeyer et al., 1983). Adult biomass was estimated to be around 335,000 t between 1961 and 1971. Subsequently, the population in the GOA steadily increased to 2,400,000 t in 2003 (Fig. 4.26(c)). It is currently the most abundant groundfish in the GOA. Survey estimates of arrowtooth flounder biomass show an increasing trend over time, which is significant for the eastern ($r^2 = 0.70$) and western ($r^2 = 0.51$) but not the central GOA.

Spawning takes place after September in the GOA, and larvae are found from January until June with highest abundance along the shelf edge (Matarese et al., 2003). Larval abundance is also clearly higher in the 1990s as compared to the 1980s (Fig. 4.27), although recent years have shown a decrease.

4.6.5. Pacific Ocean Perch

Pacific ocean perch (*Sebastes alutus*) is the most abundant rockfish along the continental slope from California to the Bering Sea. They are very slow-growing, mature at approximately 7 or 8 yrs of age, and may live more than 90 years (Leaman, 1991). Biomass estimates were high in the early 1960s with a peak of 1,150,000 t in 1963. Afterwards, biomass dramatically declined to about 70,000 t in the late 1970s and early 1980s. Since the mid-1980s, the population biomass has slowly recovered and is currently estimated at around 290,000 t (Fig. 4.26(D)). Estimates from the triennial survey reflect the recovery since the mid-1980s ($r^2 = 0.52$), and are above the modeled estimates. Unusually large survey catches, especially of the 1996–2001 surveys, have made these estimates highly uncertain and may indicate that the annual biomass estimates from the model are imprecise (Hanselman et al., 2003).

Spawning occurs in early winter, and species of the genus *Sebastes* are live-bearers. Larvae are released in April–May, but can rarely be identified to species except by molecular analysis (Gharrett et al., 2001), so species-specific larval abundance estimates are not available.

4.6.6. Explaining Population Change

There have been three major shifts in population biomasses among key species in the GOA: Pacific ocean perch reached their peak biomass in the mid-1960s and declined rapidly thereafter; gadids (walleye pollock and Pacific cod) were the dominant biomass in the GOA throughout most of the 1980s; and the biomass of arrowtooth flounder, and to a lesser extent of other flatfishes has continually increased since the mid-1970s, recently (early 1990s) surpassing walleye pollock as the dominant fish biomass in the region. Changes in population biomass in the GOA may be due to physical factors, such as climate forcing, biological factors (such as density-dependent competition and predation), fishing mortality, or, more likely, to some combination of these effects, influencing each species at particular life history stages.

Climate Forcing

The North Pacific Ocean appears to oscillate between warm and cold regimes on a multidecadal timescale (Hare and Mantua, 2000). The shift in 1976–1977 from a cold to a warm regime is believed to be the cause for the extensive restructuring of the marine community in the GOA, and in particular, to the rise of groundfish and flatfish stocks over forage fishes and shrimps (Anderson and Piatt, 1999). Temperature could directly affect adult or larval mortality. It is also possible that the dramatic changes in the marine community of the northern GOA in the mid-1970s are caused by interaction of increased precipitation, stronger wind, and higher temperatures that are manifested through changes in the distribution and abundance of planktonic production and mediated through the food web. The data presented here suggest little relation between immediate shifts in adult groundfish biomass and climate indices. Such a result was not entirely unexpected, and it seems unlikely that mortality of adult fishes would be directly impacted by shifts in the abiotic environment, given that adult fish are able to compensate for suboptimal climate conditions by altering their metabolism and/or behavior (Bryan et al., 1990; Thurston and Gehrke, 1993). Populations of long-lived organisms are buffered from or can lag dramatic climatic changes to the extent their populations integrate over longer periods of time than short-lived animals. Shifts in biomass of adult fishes may be more closely tied to shifts in distributional abundance since adult fish are highly mobile and able to follow optimal clines in temperature, salinity, or food availability. Juvenile mortality is also less likely to be directly impacted by abiotic stresses for many of the same reasons that adult mortality is largely unaffected. Larval stages, however, are far more responsive to shifts in the physical environment and, in fact, increases in recruitment in several groundfishes were observed after the regime shift (Hollowed et al., 2001). Larvae are underdeveloped at hatching; they are weak swimmers that depend on favorable water currents to transport and retain them in suitable nursery areas. Furthermore, larvae have very high energy needs for their size and no energy reserves (Brett and Groves, 1979), so they are at increased risk of starvation compared to adult and juvenile stages, making their survival particularly vulnerable to even subtle physical changes i.e., water temperature; Houde and Zastrow, 1993), salinity (Ottesen and Bolla, 1998), turbulence (Bailey and Macklin, 1994), or advection to unsuitable nursery areas (Bailey and Picquelle, 2002). Therefore, larvae are probably the most vulnerable life stage to direct impacts of climate variations, while mortality among juvenile and adult stages are probablly modulated more by indirect biotic effects (see the following text). However, there are many climate factors (Table 4.1) that may confound discovering simple relationships (see the section titled "Biological controls"). Of the examined species, walleye pollock larval abundance was positively correlated with higher retention (years of high eddy occurrence on the continental shelf). Temperature and wind mixing negatively affected abundance of Pacific cod larvae; however, recruitment had a positive relationship to temperature. Similarly, arrowtooth flounder had increased larvae abundances in years of high retention, although recruitment was negatively affected by that relationship (Table 4.1). These examples demonstrate that total larval abundance is not

Table 4.1: Impact of environmental variables on larval abundance and recruitment. Values represent significant correlation coefficients.

	Walleye pollock		Pacific cod		Arrowtooth flounder	
	Larvae	Recruitment	Larvae	Recruitment	Larvae	Recruitment
Temperature	n.s.	n.s.	−0.77	0.68	−0.44	n.s.
Salinity	n.s.	0.62	0.76	n.s.	n.s.	−0.46
Wind mixing	n.s.	n.s.	−0.67	n.s.	n.s.	n.s.
Retention index	0.64	n.s.	n.s.	−0.70	0.82	−0.55

connected to survival but that both, abundance and survival can be directly or indirectly affected by climate variables.

Biological Controls

There are can be three major categories of biological controls: parasites/disease, competition, and predation.

Parasites and diseases negatively affect fitness. Even closely related species, for example northern and southern rock sole in the GOA (*Lepidopsetta polyxystra* and *L. bilineata*, respectively), can have very different parasite infection rates, and parasites may significantly reduce fish weight (Zimmermann et al., 2001). Often, parasite abundance and richness correlates positively with temperature (Poulin and Rohde, 1997) and, thus, should have a larger impact on some fish species within the community during warmer regimes.

Density-dependent mortality, potentially induced by changes in physical factors, probably contributes to most of the fluctuation in population size among juveniles and adults (Bailey, 2000). For example, food limitation produced by climate shifts may lead to heightened inter- and intra-specific competition among juveniles and adults. Such a mechanism is suggested by the lower-than-average weight of pollock during strong year-classes, indicating competition for food and/or space at advanced stages (Fig. 4.28). In exceptional cases, it has been shown that larval mortality can also be locally enhanced due to food competition (Duffy-Anderson et al., 2002).

Predation on older fish is another important cause of population change. Juvenile and adult fishes are eaten by other adult groundfish, marine birds, and mammals

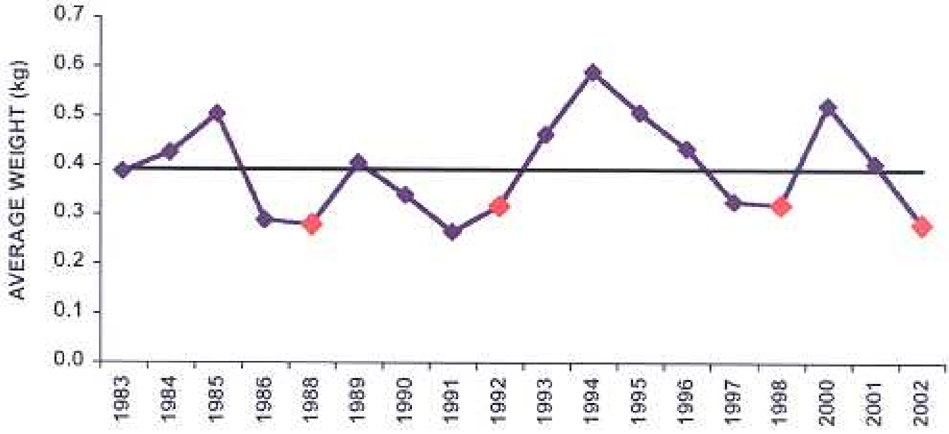

Figure 4.28: Mean weight of age-4 pollock in the Shelikof Strait echo integration–trawl survey. Strong year-classes are indicated by the large red symbols. Adapted from Dorn et al. (2003).

(Brodeur and Wilson, 1996). The control of pollock recruitment to the adult population changed from the larval to the juvenile stage after the 1976–1977 regime change (Bailey, 2000), an excellent example of the effects of predation. This shift in control of recruitment from the larval to the juvenile stage is presumably due to increased predation by large numbers of predatory fishes on juvenile pollock (see Chapter 6 for a discussion of top-down controls of fish recruitment). Predators also eat large numbers of eggs (Brodeur et al., 1996) and larvae (Fancett and Jenkins, 1988; Bailey and Houde, 1989), though it is generally believed that survival among larvae is primarily controlled by density-independent factors (Bailey et al., 1996).

According to the oscillating control hypothesis (OCH) (Hunt et al., 2002), a close connection between climate and biological controls exists in the North Pacific. A warm regime is believed to favor high zooplankton production, providing a plentiful food source for larvae and juvenile fishes. Such a scenario would support strong recruitment to the adult population of predatory fishes (e.g., walleye pollock and arrowtooth flounder), which in turn exerts a strong top-down regulation (predation) on smaller fish (e.g., forage species and their own juveniles). Further, the OCH predicts that a cold regime will lead to bottom-up regulation. Low temperatures will limit zooplankton production, enhancing competition and reducing larval and juvenile fish survival. The hypothesis predicts that the adult piscivorous fish community would decline, releasing small fish species from predation pressure. Adult piscivorous fish are also hypothesized to more susceptible to fishing pressure during cold climate regimes. (Also see the discussion on OCH in Chapter 6).

Fisheries Effects

Climate shifts and their indirect repercussions in the food web certainly have contributed to observed changes in fish biomass in the GOA due to shifts in recruitment (Hollowed et al., 2001), but the effects of fishing should not be overlooked. In contrast to climate forcing, fisheries have little or no direct effect on larvae or juvenile mortality. Also species of low commercial value such as arrowtooth flounder (Greene and Babbitt, 1990; Porter et al., 1993) are only minimally impacted by fishing efforts (i.e., bycatch). However, fisheries can significantly contribute to mortality of adult fish populations, especially species with low growth rates and an advanced age at maturity (sexual reproduction). The fishery for Pacific ocean perch provides a prime example. In the 1960s, up to 35% of the Pacific ocean perch biomass was caught on an annual basis, and it is largely believed that this overfishing was responsible for the precipitous crash of the Pacific ocean perch population in the GOA in the late 1960s and early 1970s (Kramer and O'Connell, 1995; Hanselman et al., 2003). Quotas regulating fisheries activity started in 1986, and management efforts seem to be successful in aiding species recovery (Fig. 4.26(D)). It is interesting to speculate that the rise in gadid populations in the 1980s may have been precipitated not by climate shifts alone, but also by a release from competition for food due to the diminished numbers of Pacific ocean perch. We caution, however, that the effects of fisheries on population biomass in general are somewhat obscure due to the confounding effects of directed fishing effort, and to the superimposed effects of climate variation.

Summary

Modeled long-term dynamics and sampling data of several groundfish species in the Gulf of Alaska were analyzed. Pacific ocean perch (*Sebastes alutus*) dominated in the 1960s, the gadid walleye pollock (*Theragra chalcogramma*) in the 1980s, and arrowtooth flounder (*Atheresthes stomias*) is presently the most abundant species in the fish community.

Although inter-decadal changes in the groundfish community in the Gulf of Alaska are well documented, the exact causes remain elusive. Simultaneously varying forcing factors obscure the relationship between forces of change (climate, competition, predation, fishery, and parasites or disease) and groundfish population dynamics. Most likely, the major driving force for fish larvae and its food supply are climatic factors; for juvenile fishes, biological factors, and for the adult populations; biological factors and fishing pressure.

Climate change, indirect biological controls, and fishing mortality exert considerable influence. Disease and parasities can also contribute to population fluctuation. It seems most likely that these and other factors act in concert over all life history stages to affect population abundance of groundfishes in the GOA. We found evidence that fishing in the 1960s and 1970s caused the decline of Pacific ocean perch. Biological and climate forcings combined with a high population doubling time probably delayed the recovery of the population. The population dynamics of gadids are complex, and top-down and bottom-up factors seem to alternate as the driving force. Favorable climate possibly contributed to the increase in biomass of walleye pollock in the 1980s, and biological top-down factors may have led to the decline. Arrowtooth flounder is only minimally impacted by fisheries, and we expect that biological forcings – such as release from competition and predation by gadids- and climate forcings dominate population dynamics. The GOA is an enormously complex and dynamic ecosystem, and continued effort directed toward long-term monitoring is essential to credibly forecast future population trends.

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4.7. Seabirds in the Gulf of Alaska

Alan M. Springer

4.7.1. Introduction

Approximately 8 million seabirds of 26 species nest at some 800 colonies around the rim of the GOA, and an additional 10 million birds and 2 species nest in the Aleutian Islands (Table 4.2 and Fig. 4.29). Clearly, it is not possible to monitor population trends of all species or of any individual species at all locations where they are found. Many nest underground, are nocturnal, or both, and are especially difficult to study. Others nest away from the coast or in forests and are similarly inaccessible.

Species about which we know the most in the GOA are those that are abundant, widespread, and conspicuous. These are common murres (*Uria aalge*) and black-legged kittiwakes (*Rissa tridactyla*), and, to a lesser extent, tufted puffins (*Fratercula cirrhata*). (Fig. 4.30). On the order of 600,000 murres and 700,000 kittiwakes are found in the northern Gulf of Alaska, with nesting colonies located on exposed cliff faces and bluffs in numerous locations. As a result, more is known about these two species, and their closely related congeners, thick-billed murres (*Uria lomvia*) and red-legged kittiwakes (*Rissa brevirostris*), in the Aleutians and elsewhere than about any other species of seabirds in Alaska. Tufted puffins score highly on the first two criteria – about 1,000,000 birds are widely distributed among many colonies in the GOA, but they nest in burrows and crevices and thus are more difficult to study than murres and kittiwakes. Still, some things are known about them, and because their strategies for survival differ from murres and kittiwakes in several important ways, they are included here as focal species for what they may tell us about ecosystem change in the GOA.

Although less is known overall about most other species, we can learn from then about the nature of change in the GOA. Among these other species are Leach's and fork-tailed storm petrels (*Oceanodroma furcata* and *O. leucorhoa*), marbled and Kittlitz's murrelets (*Brachyramphus marmoratus* and *B. brevirostris*), and pelagic and red-faced cormorants (*Phalacrocorax pelagicus* and *P. urile*) (Fig. 4.31).

Murres and kittiwakes are conspicuous and comparatively easy to count, yet care must be taken to count in ways that allow comparisons between years and locations (Hatch and Hatch, 1988, 1989; Byrd, 1989). This is especially important for murres, which have attendance patterns at colonies that vary throughout the day, between days, and between stages of the nesting cycle, and which often nest in such huge aggregations that counting all of them is not feasible. Therefore, monitoring protocols