The Decline of Steller Sea Lions (*Eumetopias jubatus*) and the Development of Commercial Fisheries in the Gulf of Alaska and Aleutian Islands from 1950 to 1990[1]

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Abstract

Biomass removed from the Gulf of Alaska and Aleutian Islands rose from 100,000 tons in the early 1950s to a high of 700,000 tons in 1985. Average landings through the 1980s were 550,000 tons. Major growth in domestic fisheries in the Gulf of Alaska and Aleutian Islands occurred after the declaration of 200-mile zones in 1976. The traditional fisheries for salmon, herring, halibut and shellfish were augmented by major groundfish fisheries in the late 1960s. Total numbers of vessels involved in each of the major fisheries also rose with time, from an average of 6,500 vessels in the 1950s and 1960s, to about 12,000 through the late 1970s and 1980s.

Steller sea lions first began to decline in the eastern Aleutians in the late 1960s. Overall, however, the total population in the Gulf and Aleutians did not begin to decline until 1979 when it fell from a peak of 270,000 animals to 90,000 in 1990. A decline in the overall numbers of sea lions in Alaska has been coincidental with the growth in the numbers of vessels and the increase in catch.

Human activities, such as the shooting and entangling of sea lions, undoubtedly contributed to the population decline, but there does not appear to be any direct link between the timing of different declines in different regions of Alaska and the amount of human activity (numbers of vessels and amount of fish caught). Positive correlations between catches of crabs and shrimp with numbers of sea lions, and negative correlations between sea lions and landings of halibut and gadoids may reflect changes in the structure of the ecosystem that underline the population declines, and may be independent of human activities. Finer scale analysis of seasonal and localized removals of fish may yet reveal a possible link between commercial fisheries and sea lion abundance. Similarly, consideration should be given to whether commercial removal of some fish species may have indirectly affected the quality and quantity of food sources by restructuring the complex interrelationships among species in the marine ecosystem.

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Introduction

In 1997, the Steller sea lion was listed as an *endangered* species in parts of its Alaskan range (Loughlin, 1998). From an estimated 270,000 animals in 1980, the Alaskan population fell below 90,000 in 1990 (Trites and Larkin, 1996). It has continued to decline through the 1990s, but at a much slower rate. Why Steller sea lions have declined in Alaska remains unresolved. Factors suggested as possible causes include: nutritional stress caused by commercial fishery removals of sea lion prey; direct kills of sea lions by commercial and subsistence harvesting; intentional and incidental kills by fisheries; entanglement in marine debris; disease; and disturbance (Braham *et al*., 1980; Merrick *et al*., 1987; Hoover, 1988; Lowry and Loughlin, 1990; NMFS, 1992; Loughlin, 1998). To date, data to assess each of these possibilities has been limited.

The coincidental developments in the commercial fisheries in Alaskan waters are an obvious possible contributing factor to the decline of Steller sea lions. The goal of our study was therefore to compile and compare data describing fisheries and sea lion abundance for six regions of the Gulf of Alaska (Fig. 1), and to explore whether the population declines might be related to the amount of fish caught and to the number of vessels fishing from 1950 to 1990..

Changes in Sea Lion Abundance

Steller sea lion pups and adults have been counted sporadically at 38 major breeding sites in Alaska since 1956 (e.g. Mathisen and Lopp, 1963; Loughlin et al., 1992). Each of the rookeries appears to be genetically distinct from neighboring breeding sites, yet seems to share similar population trends. Compiling the counts of individual rookeries by regions sharing similar dynamics generally shows high numbers in the 1950s and 1960s followed by rapid population declines through the 1980s (Figs. 1 and 2).

Trites and Larkin (1996) estimated total population size by applying life table statistics to the compiled counts of pups and adults shown in Fig. 2. Smoothing the estimates suggests the total number of Steller sea lions inhabiting the Gulf of Alaska and Aleutian Islands rose from 225,000 animals in the mid 1950s to 260,000 in 1967 (Fig. 3; Trites and Larkin, 1996). The population did not increase again until the late 1970s. Since peaking at 270,000 in 1979, the population declined by over 60% (roughly 5% per year) and consisted of about 90,000 animals in 1990. Most of the decline took place in the Kodiak region (Area 3, Fig. 1), but there were also significant declines in areas westward of Kodiak along the Aleutian chain (Areas 4-6). Increases have occurred in the smaller populations of southeastern Alaska and Prince William Sound (Areas 1 and 2).

Steller sea lions are probably more closely associated with Gulf of Alaska and Aleutian resources than with those of the Bering Sea. During the summer season, females and pups are more or less confined to the immediate vicinity of their rookeries. However, home range sizes increase considerably in the winter

(Merrick and Loughlin, 1997), and there are indications from marked animals that males disperse further than females. Colder water temperatures and ice cover probably limits extensive dispersion of Steller sea lions into the Bering Sea.

Commercial Fisheries

The Alaska peninsula and the Aleutian Islands provide a natural boundary between the ecosystems of the Bering Sea and the Gulf of Alaska. In general, stocks of many species of fish and invertebrates are separate in the two areas, but there are many over-lappings. We chose to exclude the fisheries of the Bering Sea except for the western Aleutians area.

Historical Development of Commercial Fisheries

The traditional and early commercial fisheries (before 1950) of Alaska were mostly near shore and concentrated on species most readily captured on small-scale gear. Salmon, herring and halibut dominated the catch. But early in the 1950s a new era began to unfold. A major Japanese drift-net fishery for salmon spread across most of the North Pacific. At the same time, Japanese and Soviet crab fleets extended tangle net fisheries for king crabs into the eastern Bering Sea. Japanese also drift-netted for herring, and high seas trawling expanded into the Bering Sea, the Gulf of Alaska and the Pacific coast of Canada. These developments commanded the attention of the International North Pacific Fisheries Commission until the declaration of 200-mile exclusive zones, when many of the issues became more domestic than international.

The vigorous growth of Alaska based fisheries was underway before the declaration of 200 mile zones in 1976, and from those roots rapidly replaced unlimited foreign catches with licensed catches by foreign vessels, joint venture operations and expanded shore based domestic operations. Total catches remained high throughout this transition. By the late 1980s, the erstwhile Alaskan fisheries for salmon, herring and halibut had been almost overshadowed by a groundfish production well in excess of a million tons per year, much of which came from the Bering Sea.

Catch by Major Groups of Species

Catch statistics and numbers of vessels fishing the Gulf of Alaska and Aleutian Islands were summarized for six major species groupings: salmon, herring, halibut, groundfish, shrimp and crab. The fisheries data were grouped to coincide with the six sea lion areas of our study (Fig. 1), and were assembled from the records of a number of different management agencies that define different geographical regions for their statistical purposes. They were based on reported catches and do not include bycatches. Thus, they are minimal estimates of actual catch. Complete details of the sources and the methodology of assembling the statistics are given in Appendix 1.

Salmon. In the 1980s, sockeye and pink salmon, the most abundant species on the North American coast have reached record levels of abundance and were caught in record numbers (Figs. 4 and 5). Relatively stable catches of 75,000 tons were landed in Alaska from 1950 to the early 1970s. But catches rose quickly from 50,000 tons in 1974 to over 200,000 tons in 1985 and remained high. Major fisheries are located in Southeast Alaska (Area 1), Cook Inlet (Area 3), Prince William Sound and off the Copper River (Area 2).

Herring. The United States has conducted a herring fishery in the Gulf of Alaska since the early 1880s. Annual catches of approximately 100,000 tons were reported between 1925 and 1940, but dropped in the early 1960s to under 10,000 tons (Lyles, 1965). The annual amount of herring landed later rose to as high as 30,000 tons (Fig. 4). Major fishing areas (Fig. 5) are southeastern Alaska (Area 1), Prince William Sound (Area 2) and around Kodiak Island (Area 3). In the 1980s the fishery was aimed at the market for roe and was closely timed accordingly.

Halibut. Commercial fishing for Pacific halibut began in southeastern Alaska in 1895. Since 1910, halibut have been caught both inshore and offshore by American and Canadian vessels using setlines.

An average of 20,000 tons (about 45 million pounds) of halibut was caught each year in the Gulf of Alaska between 1950 and 1970 (Fig. 5). Catches dropped and remained low through the 1970s and did not return to earlier levels until the 1980s when large numbers of halibut were caught in Area 3 (Fig. 4).

Groundfish (excluding halibut). Total catch of groundfish in the Gulf of Alaska since 1962 is shown in Figs. 4 and 5. Until the late 1970s, large vessels from Japan and the Soviet Union conducted most groundfish exploitation in the Gulf of Alaska. Pacific ocean perch was the first species targeted by the Soviet Union in 1962, but catches were not officially reported by area until 1966 when a total of 83,000 tons was caught. Annual catches of ocean perch before 1966 may have been between 100,000 and 350,000 tons, but no records are available to confirm this. Japan began fishing flatfish, blackcod, pacific cod, pollock and ocean perch in 1963. As with the Soviet fleet, the principal fishing areas were the Aleutians (Area 6) and the Kodiak/Chirikof region (Area 3). Both Soviet and Japanese catches declined during the late 1970s and 1980s as the U.S. assumed greater control over fishing in its 200-mile zone.

Small quantities of cod were caught and reported by the domestic U.S. fleet in the southeastern Gulf (Area 1) beginning in the mid 1950s. It was not until 1973 that the U.S. fishery moved westward to other regions of the Gulf of Alaska. From then, through the 1980s, the total groundfish catch of the U.S. rose considerably, reaching 155,000 tons in 1988.

Joint-venture fisheries, in which domestic vessels may deliver catches to foreign vessels (primarily Soviet, Korean, Japanese and Polish), began in 1978 and expanded annually. In 1985, the total groundfish catch in the Gulf of Alaska peaked at just under 550,000 tons of which pollock accounted for over 95%. After

1986, groundfish catches by joint-venture vessels were less than 150,000 tons, and continued to fall as the domestic fleet took over. Joint-venture fisheries were not conducted in 1989 and 1990, except in the Aleutians (Area 6).

Shellfish. Commercial fisheries for shrimp, king crab, Tanner crab, Dungeness crab and other miscellaneous species are described by Larson (1990), Donaldson (1991), Kimker (1991), Koeneman *et al*. (1991), and Nippes (1991).

Commercial harvesting of shrimp began in 1915 in Southeastern Alaska. However, since 1959 the principal Alaskan shrimp fishery has been located around Kodiak Island in Area 3 (Fig. 4). Shrimp are caught in beam trawls, otter trawls and pot traps. Total landings in the Gulf of Alaska rose rapidly from 1964 to 1973 and then fell (Fig. 5).

The U.S. king crab fishery was centered in the central Gulf (Area 3: Kodiak Island, South Peninsula and Cook Inlet). It began as a trawl fishery in the 1940s and was replaced by a pot fishery beginning in 1959. The central Gulf has supported more king crab boats than all the other Gulf regions combined. The number of king crabs caught declined from 1965 to 1983 after which the fishery was closed. The Tanner crab fishery began in the late 1960s and grew rapidly as the king crab fishery declined. As with king crabs, the fishery was concentrated in the central Gulf (Area 3) and declined considerably through the 1980s. Dungeness crabs have been fished commercially since the turn of the century with the largest fisheries centered in Southeastern Alaska (Area 1) and around Kodiak Island (Area 3).

Overall, total catches of crabs were higher between the early 1960s and late 1970s, but dropped off considerably since 1980 (Fig. 5). The largest catch of crabs and shrimp came from Area 3 (Fig. 4).

Catch by Area

As indicated in the foregoing, the various fisheries are unequally distributed across the six regions of Alaska inhabited by Steller sea lions. In terms of quantities of fish landed, the Gulf of Alaska and Aleutian fisheries were dominated by catches of groundfish and salmon (Figs. 6 and 7). Areas 1 and 2 were heavily fished for salmon, herring and groundfish. Area 3 had a major groundfish fishery since the mid 1960s. Areas 4 and 5 supported mixed fisheries with greatest catches of salmon, groundfish and shellfish. Area 6 was dominated by groundfish fisheries since the mid 1960s.

The total biomass removed by the Gulf of Alaska and Aleutian fisheries rose abruptly from 100,000 tons in the early 1950s to about 400,000 tons in the late 1960s (Fig. 8). It remained at this level until the 1980s when increasing numbers of salmon and groundfish were caught. The highest total amount of fish landed was 704,000 tons in 1985.

Combining area catches from 1950 to 1990 shows that the historical dominance of fisheries in Area 1 was replaced by expansion of the fisheries in

Areas 3 and 6 (Fig. 9). Prior to 1964, about half of the fish landed in the Gulf came from Area 1, southeastern Alaska. This changed abruptly in 1964 when high numbers of groundfish were landed in Areas 3 and 6. Overall landings (all species combined) were relatively stable in all regions of the Gulf and Aleutians, except Area 3, which grew with time (Fig. 7).

Vessel Activity

Precise data on the numbers of vessels are difficult to obtain. In some cases, the numbers of vessels may be inferred from the numbers of licenses or permits for a fishery, or from the landings records. Many vessels fish in more than one area and fish seasonally for different species and therefore are counted more than once. For example, Tanner crab vessels may also fish for one or more of salmon, herring, halibut, groundfish and shellfish. For most vessels, there is no record of where and when they fished so that it is not possible to specify how many vessels fished in a particular area at a particular time. There are also substantial differences in vessel size both within and between the various fisheries, the largest vessels being those associated with the groundfish trawl fishery.

More vessels have fished in Area 1 (1950 to 1990) than anywhere else in Alaska (Fig. 9). Area 3 is fished by the second largest numbers of vessels. In the 1980s the numbers of vessels in Areas 2 and 5 increased substantially. From the 1950s to the late 1960s, the total number of vessels participating in various fisheries was between 6,000 and 7,000. It increased to between 12,000 and 14,000 in the early 1980s, then dropped to slightly more than 12,000 (Fig. 8). The number of vessels participating in several fisheries is not known, but the total fleet involved is considerably less than these sums would indicate.

Numbers of vessels involved in each of the six fisheries is not proportional to the amounts caught (Fig. 8), but may be related to the value of the catch. Most striking is the dramatic rise in the numbers of small vessels fishing halibut through the late 1970s and 1980s, compared to the small overall catch (Fig. 8). Similarly, the large groundfish catch is taken by relatively few vessels. Thus, vessel counts are an indicator of overall activity, but reveal little about overall size and fishing efficiency.

Averaging over the whole period, Areas 1 and 3 were fished by 76% of the vessels which took 58% of the total Gulf of Alaska and Aleutian Islands catch; Areas 4, 5, and 6 by 8% of the vessels for 29% of the catch; and Area 2 by 16% of the vessels for 13% of the catch (Fig. 9). It is important to keep in mind that over the entire period, the fishing capabilities of much of the fleet were greatly increased. Larger vessels with better gear and improved finding and navigation devices have greatly increased capacities for catching fish, even though the present fleet may be not much larger than that of 20 years ago.

Catch and number of vessels participating in a fishery, taken together, are useful as broad indicators of human activity that might have possible impact on sea lions, but their limitations as more precise indicators must be kept in mind.

Effects of the Fisheries on Sea Lions

Commercial fisheries might be tied to the decline of Steller sea lions in a number of different ways. For example, they may be competing with sea lions for prey species such as pollock and herring, and may have reduced the amount of fish available to them. Fishermen may also be responsible for the deaths of thousands of sea lions that were shot or unintentionally trapped in fishing gear. Commercial removal of certain fish species could even have unwittingly affected the sea lions' food sources by restructuring the complex interrelationships among other species in the North Pacific ecosystem.

None of the possible effects of commercial fisheries on Steller sea lions are easily tested. However, mathematical models suggest that intentional and incidental kills by fisheries impeded population growth of sea lions in the Gulf of Alaska and Aleutians from 1956 to 1980 (Trites and Larkin 1992). But fishery kills can only explain a small part of the sea lion decline since 1980. As for whether commercial fisheries have out-competed sea lions, the gross statistics of catch in the Gulf of Alaska (Fig. 8) would seem to present a circumstantial case for effects on food resources for sea lions: increases in the total catch have coincided with a decline in sea lion abundance. But as several authors have pointed out, life is never so simple. For example, sea lions are healthiest in southeastern Alaska (Area 1), an area that has the highest human activity in the Gulf of Alaska (Fig. 9). Out by the Aleutians (Area 5) the alarming sea lion declines occurred at a time of little fishing activity (Fig. 6).

Correlating counts of adults and pups (Fig. 2) with catch and vessels (Figs. 4 and 8) shows some intriguing patterns (Fig. 10). In southeastern Alaska where sea lions increased (Area 1), there is no apparent relationship between sea lion numbers and commercial catches. However, from the Alaska peninsula through the Aleutian Islands (Areas 2-6), catches of crabs and shrimp correlated positively with sea lion abundance (c.f. Hansen, 1997), while catches of halibut and gadoids (pollock and cod) were negatively correlated (Fig. 10). This means that sea lions tended to go up and down in parallel with catches of crabs and shrimp, while sea lions declined as catches of halibut and gadoids increased. This same pattern is generally reflected in numbers of vessels fishing (which tend to be proportional to the amount of fish caught).

There are two ways the catch statistics might be interpreted. One is that they reflect a depletion of prey available to Steller sea lions. The other is that they are an index of the relative abundance of prey available to Stellers. High catches of pollock, for example, might mean that pollock is extremely abundant or it could be interpreted to mean that Steller sea lions are being out-competed. The key to sorting out these interpretations is to understand what sea lions eat, and what proportion of the various stocks are caught each year.

Steller Sea Lion Diets and Prey Abundance

Stomach contents and fecal analysis indicate that Steller sea lions can eat a wide range of species such as walleye pollock, Pacific cod, octopus, squid, salmon, Pacific herring, Pacific sand lance, capelin, flatfish, rockfish and Atka mackerel (NMFS, 1992). The limited amount of information on diet indicates there are distinct regional differences in diversity of diet and types of prey consumed. The most intriguing pattern is the relationship between the rate of sea lion population declines and the diversity of their diets (Merrick et al., 1997). Diets of sea lions in areas of the Aleutians and Gulf of Alaska, with the highest rates of population decline, had little diversity and were typically dominated by pollock or Atka mackerel. This is in sharp contrast to the high diversity of prey consumed in areas such as southeastern Alaska where sea lions have been increasing (Merrick et al., 1997; Trites and Calkins, unpubl. data).

The occurrence of gadoids (mostly walleye pollock) in scats and stomachs from the declining sea lion population in the Kodiak Island area has increased from 32% in 1976-78, to 60% in 1985-86, and 85% in 1990-93 (Merrick et al., 1997). Flatfish consumption also increased in the same area from 0% to 13% from 1976-78 to 1990-93. Small schooling fish occurrence in scat and stomach samples decreased from 61% in 1976-78, to 18% in 1990-93 (Merrick et al., 1997).

The changes in consumption of different prey species appear to reflect changes in their relative abundance in the North Pacific between the 1950s and 1980s. Shrimp, crab and small pelagic fishes are generally believed to have been in relatively high abundance during the 1950s (Anderson et al., 1997; Trites et al., 1998). As their numbers declined through the 1970s, gadoids (mostly pollock) and large flatfish (mostly halibut and arrowtooth flounder) began dominating the ecosystem (NRC 1996). Pollock landings (which make up most of the gadoid catch) have averaged 11.8% of the exploitable biomass per year in the Gulf of Alaska and 14.1% in the eastern Bering Sea and Aleutian Islands (calculated for the period 1977-1997 from statistics compiled by Alverson, 1998). Total landings of pollock appear to have paralleled the rise in pollock dominance in the North Pacific. Removal rates of pollock are low and conservative compared to other fisheries in the world targeting species of similar sizes and life histories (c.f., Alverson 1992, 1998; Alverson and Larkins, 1994; Pauly, 1996; Garcia and Newton, 1997).

Discussion

If there is indeed a relationship between commercial catches and sea lion abundance, it may be more subtle than the grossly aggregated statistics reveal. Attempts by others to demonstrate a connection have also come up empty handed. For example, Loughlin and Merrick (1989) compared sea lion counts and pollock catches for eight major rookeries, and tested for time-lagged effects. Their results were equivocal; few significant correlations were detected and they were both positive and negative. Ferrero and Fritz (1994) also tested the hypothesis that commercial catches of pollock were correlated with sea lion abundance using additional rookeries and data collected since 1987 between Kodiak Island (Area 3) to the western Aleutian Islands. They too failed to find a relationship between sea lion abundance and pollock harvest using the available data. A third attempt by Sampson (1996) found that large winter catches of pollock occurred near sea lion rookeries that suffered large declines in the early 1980s. However, Sampson also reported sharp sea lion declines in other areas in the late 1980s, where no winter catches of pollock occurred. Nor could he relate the decline to the amount of fishing effort, total catches of groundfish, or catches of Pacific cod and Atka mackerel.

Over the past two decades there is good evidence for some major changes in the relative and total abundance of the various species of fish in the Gulf of Alaska and the Bering Sea (Alverson, 1992; Fritz et al. 1995), changes which may reflect long term periodic oceanographic changes and perhaps long term climatic change (Hare and Francis, 1995; Hollowed and Wooster, 1995; Francis et al., 1998; Springer, 1998). For example, Brodeur and Ware (1992) report that zooplankton biomass in the Gulf of Alaska increased by a factor of 1.7 during the period 1957 to 1980. Species in relatively high abundance during the 1950s included shrimp, crab and small pelagic fishes. Those in highest abundance in the 1980s included gadoids (mostly pollock) and large flatfish (mostly halibut and arrowtooth flounders). Both gadoids and flatfish share considerable dietary overlap with marine mammals and may be significant competitors (Trites et al., 1999).

In discussing the interaction between fisheries and Steller sea lions, there is a tendency to only emphasize the quantities of individual fish species available to sea lions or the quantity removed from their ecosystem. Little or no consideration is given to the diversity or quality of prey available to them. Pollock, the dominant prey being consumed in the areas of sharpest population decline, are generally poor in energy or nutritional content. They have about half the energy content as herring (Perez, 1994), and have less usable energy due to various costs of digestion (Rosen and Trites, 1997). There are also nutritional deficiencies associated with eating certain types of prey that can have negative population consequences (Geraci, 1981; Thompson et al., 1997). Raw quantities may not be the most appropriate unit for distinguishing impacts of fisheries on Steller sea lion or other marine mammals.

With the possible exception of salmon, stock and recruitment relationships are weak, non-existent or unknown for most species. Interactions among species are complex and the ecosystem dynamics are fast paced. Present state of understanding of the role of pollock in the ecosystems of the Bering Sea is poor (Springer, 1992), but ecosystem models are beginning to offer some insights (Trites et al., 1999, in press). The models suggest that a fishery that shifts the biomass of pollock from older to younger age classes should result in more prey for Stellers, not less. Steller sea lions tend to feed on small pollock, while the fishery targets older and larger fish. Similarly, an increase in adult catch might increase juvenile pollock abundance (the preferred prey size of sea lions) by reducing cannibalism; or, more ideally for Steller sea lions, reducing pollock might increase the abundance of other prey types, particularly small schooling fish.

The present lack of understanding has not come about from lack of effort. The long term studies of the National Marine Fisheries Service have abundantly demonstrated the very large amount of knowledge that is necessary to build a descriptive model of the Gulf of Alaska and Bering Sea ecosystem, not to mention a predictive model. Similar enterprises related to European and North Atlantic waters have explored a variety of approaches, none of which has proven particularly relevant to management needs. Current proposals for exploration of the meaning of the catch phrase "ecosystem management" are indicative of the state of the art (Larkin, 1996). With these sorts of considerations, it is not yet profitable to speculate with a multispecies, multiple gear simulation of the region by time and by subregion or of a multispecies model incorporating ecosystem dynamics.

Some modelling exercises might be appropriate given certain kinds of data that are currently not available. For example, seasonal patterns of abundance of fish that arise from migratory movements and the seasonal pattern of fishing activities are far more likely to be related to sea lion biology than the gross statistics of catch. If the actual numbers of vessels in each area at each season is not known, some guesses might be made about which fisheries on which species in which areas would be most or least likely to have an impact on sea lion food resources. Fisheries on pollock in Area 3 would seem a likely place to further investigate the resource depletion hypothesis. Fisheries on salmon seem unlikely to have had an impact on availability of salmon as food: total salmon production was at record high levels through the 1980s. Herring stocks were at relatively low levels although it is doubtful whether the fishery was responsible.

To gain substantive appreciation of the impact of fishing on food resources for sea lions it will be necessary to obtain information at a much more local level on much shorter time scales than is available from current information. The sort of information needed for particular rookeries includes, seasonal patterns in diet and foraging behaviour of sea lions, seasonal depletion of food resources of various types within the foraging range of male, female and juvenile sea lions, and implications of depletions for meeting energetic requirements for maintenance and growth. The lack of information of this kind, which is required to build other than a broad circumstantial case, has been recognized in the Steller Sea Lion Recovery Plan (NMFS, 1992).

All of the foregoing having been said, it seems likely that the removals of large quantities of fish, in combination with natural changes in the ecosystem, can impact local availability of food for sea lions. The effect of these removals would presumably be more severe on juveniles than adults, and on females rather than males as has been intimated by others. However, effects of this kind on sea lion abundance have yet to be demonstrated and there are no reports of sea lions competing with active fishing activities.

In summary, the direct effect of incidental capture in fishing gear, and the shooting of sea lions explains only a small portion of the recent population decline through the 1980s. Whether these losses are caused by the removal of food resources is a circumstantial possibility, but other causes, such as diseases and parasites must also be kept in mind as possible contributing factors. Similarly, serious consideration needs to be given to the possibility that nutritional deficiencies in the prey available to Steller sea lions in the 1970s and 1980s (primarily pollock, as opposed to a mixed diet containing fattier fishes) has caused reproductive failure and increased mortality of sea lions.

Steller sea lion populations generally declined as commercial fisheries for shrimp and crab declined, and catches of groundfish and halibut increased. These significant correlations can be interpreted as a cause-and-effect, or as a dependent response to large-scale environmental perturbations. Catches of the major stocks in the Gulf of Alaska and Aleutian Islands appear to have paralleled, rather than to have driven the abundance of targeted fish. Significant correlations resulting from aggregating sea lion abundance and fishing activity over large geographic ranges may be indicative of large-scale ecosystem changes.

A better understanding of direct interactions between Steller sea lions and commercial fisheries is only likely to come by gathering data on a much finer time scale (days to months) and reduced geographic range (tens to hundreds of kilometers). Estimates of local prey abundance available to particular segments of the population at particular times of the year are needed to build a convincing case. Efforts are needed now to begin collecting such data that gets to the root of the issue looming over Alaska's fisheries: Are Steller sea lions negatively affected by commercial fisheries?

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Appendix 1: Sources and methodology of assembling the fishing statistics

Data for shellfish, halibut, groundfish, herring and salmon fisheries were grouped to coincide with the six sea lion areas of our study. Total catches and numbers of vessels fishing in each of the six areas were assembled from the records of a number of different management agencies that define different geographical regions for their statistical purposes. The following details the sources and methodology of assembling the fishery statistics.

Salmon. The amount of salmon caught and the number of vessels (including set nets) engaged in the U.S. salmon fishery was determined from catch statistics kept by the Alaska Department of Fish and Game for the years 1969 to 1990 (Carol Smith, pers. comm., Commercial Fish Division, ADFG, Juneau) and from Eggers' (1989) summary of commercial salmon catches for the years 1950 to 1968.

Since 1969, the total catch and number of commercial vessels landing salmon have been recorded in 21 management areas in the Gulf of Alaska and Bering Sea. We pooled the data to reflect the six sea lion areas of our study as follows: Area 1 (Statistical Regions A, B, C and D), Area 2 (E), Area 3 (H and K), Area 4 (L), Area 5 (M) and Area 6 (O and R).

The numbers of salmon caught between 1950 and 1968 are summarized by Management Regions contained in Eggers (1989) and were assumed to correspond to the following sea lion areas: Area 1 (Southeastern Alaska), Area 2 (Cordova Area), Area 3 (Kodiak), Area 4 (Chignik), Area 5 (South Peninsula) and Area 6 (Aleutian Islands). The mass of salmon caught in each area from 1950 to 1968 equaled the numbers of each species landed multiplied by their respective average weights. Average weights were calculated by species and area from catches landed between 1969 and 1990.

The annual numbers of vessels fishing salmon in Areas 1 to 6 were not available for the period 1950-68 and were assumed to be equal to the average number for the period 1969-73 for Area 1, 1969-75 for Areas 3 and 5, and 1969-78 for Areas 2 and 4, in each case, years in which the catch was relatively stable. It was assumed that ten vessels fished Area 6 between 1950 and 1967.

Herring. The amount of herring caught and the number of vessels engaged in the U.S. herring fishery were determined from catch statistics recorded by the Alaska Department of Fish and Game (1969 to 1990) and from annual reports published by the International North Pacific Fisheries Commission (1952 to 1968) (e.g. INPFC, 1960). Since 1969, the total catch and number of vessels landing herring have been recorded in 21 management areas in the Gulf of Alaska and Bering Sea. The data, obtained from the Commercial Fish Division (ADFG, Juneau), were pooled to reflect the six sea lion areas of our study: Area 1 (Herring Statistical Regions A, B, C and D), Area 2 (E), Area 3 (H and K) Area 4 (L), Area 5 (M) and Area 6 (O and R). From 1952 to 1968 herring catches detailed in the INPFC reports are grouped by region, either Southeastern Alaska or Central Alaska, and were assumed to correspond to sea lion Areas 1 and 3 respectively. Note however that Central Alaska data also includes Prince William Sound (Area 2), but a breakdown of herring catches between Kodiak and Prince William Sound could not be obtained.

Halibut. The International Pacific Halibut Commission maintains fishing records (catch and effort) from 30 regulatory areas in the Gulf of Alaska (see Myhre et al., 1977, and annual reports e.g. IPHC, 1989). Catch and effort data from the regulatory regions were pooled for the six sea lion areas as follows: Area 1 (14-18s), Area 2 (18n-25), Area 3 (26-30), Area 4 (31-33), Area 5 (34-38), Area 6 (39-43).

G.J. Peltonen (pers. comm., International Pacific Halibut Commission, University of Washington, Seattle, WA) estimated the annual number of vessels fishing for halibut in the Gulf of Alaska between 1956 and 1990. Unfortunately the vessel data were compiled for broad statistical regions and can only be apportioned to the 6 sea lion areas by making simplifying assumptions. Vessel counts between 1956 and 1974 did not include boats that landed less than 10,000 pounds per year. We therefore assumed that the number of small vessels fishing halibut increased linearly by multiplying the 1956 large vessel count by 1.0 and increasing the correction factor for subsequent years in a stepwise fashion such that by 1974 the total number of vessels equaled the number of large vessels times 4.0. From 1950 to 1955, we assumed there were 120 vessels in Southeastern Alaska (Area 1) and a total of 250 in the other 5 areas, based on the average numbers of large vessels fishing between 1956 and 1960.

From 1950 to 1980, we apportioned the total vessel count among Areas 2 - 6 according to the amount of fishing effort expended in each of the areas. CPUE was consistent between areas from 1950 to 1980, but varied greatly from 1981 to 1990. We therefore allotted vessel counts from 7 halibut management regions (1981 to 1990) according to region and/or fishing effort, weighted by catch. Prior to 1981, vessels fishing in southeastern Alaska (Area 1) were grouped in a statistical area that extended as far south as Oregon. We therefore assumed that 1) 30% of the southern fleet was in southeastern Alaska from 1950 to 1974, and 2) this proportion increased from 30 to 50% between 1975 and 1980.

Groundfish (excluding halibut). The amount of pollock and groundfish (including pollock) landed in the Gulf of Alaska by the foreign fleet (Japan and Russia), the U.S. Domestic Fleet, and the Joint Venture Fisheries were obtained from Forrester *et al*. (1978, 1983) as well as from the annual statistical yearbook publications (1977-88) of the International North Pacific Fisheries Commission (INPFC). Total catches in 1989 and 1990 were obtained from Galen Tromble (pers. comm. NMFS, Juneau Alaska) and Heather Weikart (pers. comm. NMFS, Seattle WA). No information could be obtained on the amount of groundfish caught by foreign fleets registered in Korea, Poland, China, Taiwan and West Germany.

The INPFC groundfish statistical regions corresponding to the sea lion areas were: Southeastern (Area 1), Yakutat (Area 2), Kodiak and Chirikof (Area 3), Shumagin (Areas 4 and 5) and Aleutian (Area 6).

Records detailing the number of vessels (longliners, processors and catcher boats) landing groundfish by region and year are incomplete. INPFC annual reports contain the number of Japanese and American vessels by type that fished for groundfish in the Northeast Pacific Region from 1963 to 1979 (an area extending from California to the Gulf of Alaska). These reports do not detail the number of vessels by groundfish statistical region, nor the number of vessels operated by other nations. Since 1980, the number of vessels and days spent fishing by foreign and joint venture fisheries have been tabulated for the Gulf of Alaska and Bering Sea. Records have also been maintained since 1980 on observer effort in each of the INPFC statistical regions (Ren Narita, pers. comm., NMFS, Seattle, WA).

We apportioned the numbers of foreign vessels participating in the fishery (1980-90) by the number of observer days in each INPFC region, and assumed vessels fished more than one region in any given year. For years prior to 1980, we assumed that foreign vessels in the Gulf of Alaska were distributed equally among the INPFC regions and crudely indexed the total vessel count in each year to the known number of Japanese vessels. Vessel counts for the joint venture fisheries (1980-90) were made by Heather Weikart (pers. comm.), while numbers of domestic US boats were determined from the numbers of licenses issued (G. Tromble, pers. comm.).

Our counts of foreign vessels should be considered reasonable guesses, not firm estimates. Comparing numbers of boats operating in each of the groundfish fisheries can be misleading because of the great difference in trawler size. In particular it should be noted that the largest U.S. vessels were smaller than the smallest Soviet and Japanese vessels.

Shellfish. Commercial fisheries for shrimp, king crab, Tanner crab, Dungeness crab and other miscellaneous species are described by Larson (1990), Donaldson (1991), Kimker (1991), Koeneman et al. (1991), and Nippes (1991). Their reports contain catch statistics for eight shellfish management regions corresponding to our six sea lion areas as follows: Area 1 (Southeastern Alaska), Area 2 (Prince William Sound), Area 3 (Cook Inlet, Kodiak, and Chignik), Area 4 (South Peninsula), Area 5 (Eastern Aleutians: Dutch Harbour / Adak) and Area 6 (Western Aleutians). In general the number of vessels fishing shellfish was recorded throughout the 1970s and 1980s. In earlier years (notably the 1960s), only the weight or numbers caught were noted, while little or no information could be obtained for the 1950s fisheries. In such cases we estimated the numbers of vessels based on the amount of shellfish landed, and made conservative guesses when all that was obtainable was an historical confirmation that a fishery took place.

Figure 1. Six regions of the Gulf of Alaska and Aleutian Islands grouped according to the proximity of Steller sea lion rookeries to one another and by the similarity of population trends at individual sites (adapted from Merrick et al., 1987).

Figure 2. Total numbers of Steller sea lion pups and adults (non-pups) counted in six regions of Alaska shown in Fig. 1. Sources of data are contained in Trites and Larkin (1996). Note that scales on the y-axes are not all the same.

Figure 3. Estimated total population of Steller sea lions (including pups) within the six regions of Alaska shown in Fig 1 (from Trites and Larkin 1996). The bottom panel shows the regional population trends, while the top panel shows the cumulative population trend for all of Alaska and the relative contribution of each region.

Figure 4. Regional commercial landings by species (shrimp, crabs, halibut, herring, groundfish and salmon) in thousands of tons. Note that axis scaling differs between each of the panels.

Figure 5. Total cumulative commercial landings by species (shrimp, crabs, halibut, herring, groundfish and salmon) in thousands of tons. Note that axis scaling differs between species caught, and that regional catches are stacked from Area 1 (bottom) to Area 6 (on top).

Figure 6. Commercial fish landings by Area (1-6) scaled in increments of 25,000 tons.

Figure 7. Total cumulative fish landings by Area (1-6) in thousands of tons. Scales on all panels are equal.

Figure 8. Total amount of seafood landing and numbers of vessels fishing in the Gulf of Alaska and Aleutian waters.

Figure 9. Distribution of catch and numbers of vessels across six regions of the Gulf of Alaska and Aleutian waters.

Figure 10. Significant correlation coefficients ($p < 0.05$) between numbers of sea lions counted (pups and adults) and fishing activity (amounts landed and numbers of vessels fishing) for 6 species of fish in 6 regions of Alaska (Areas 1-6, Fig. 1).

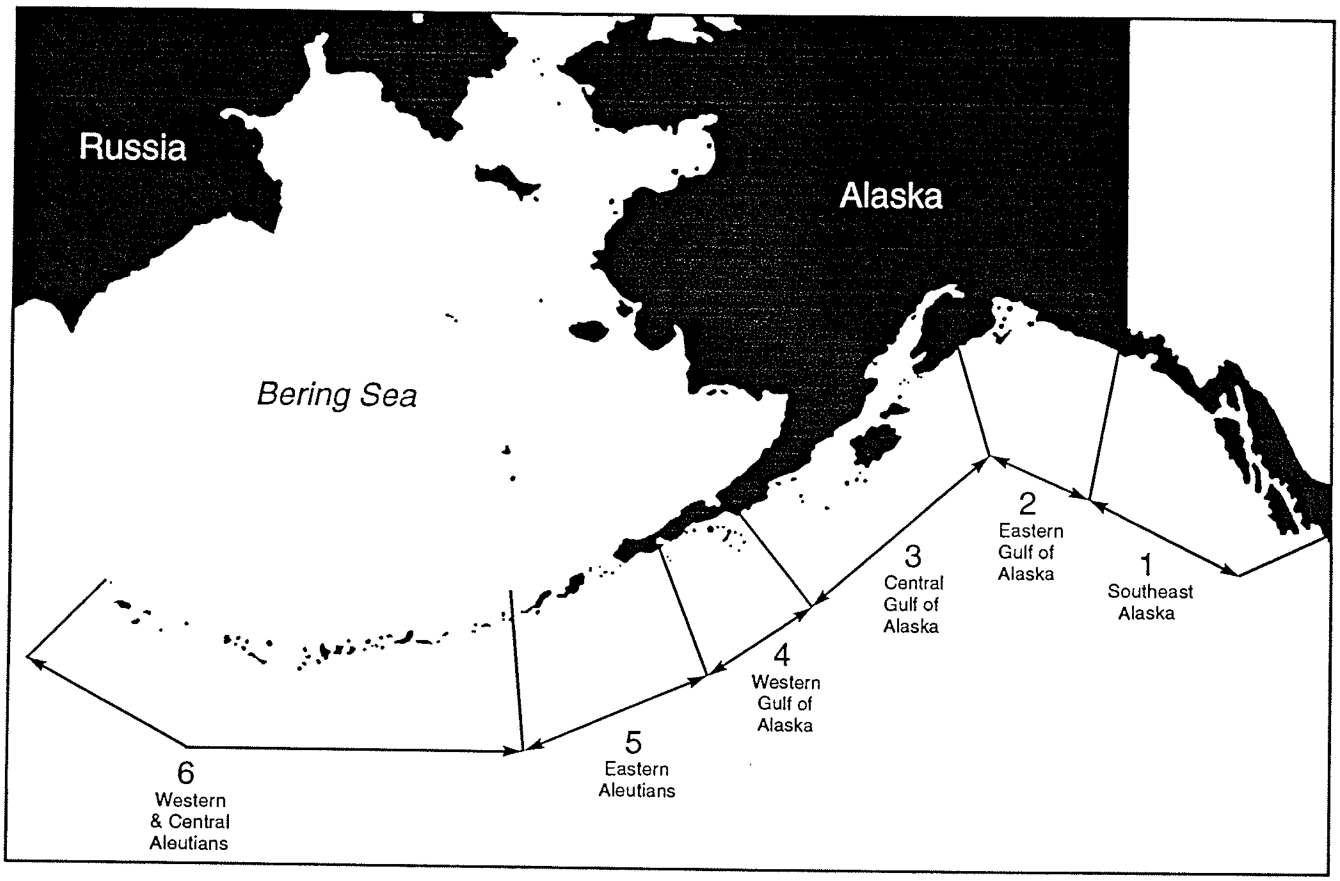
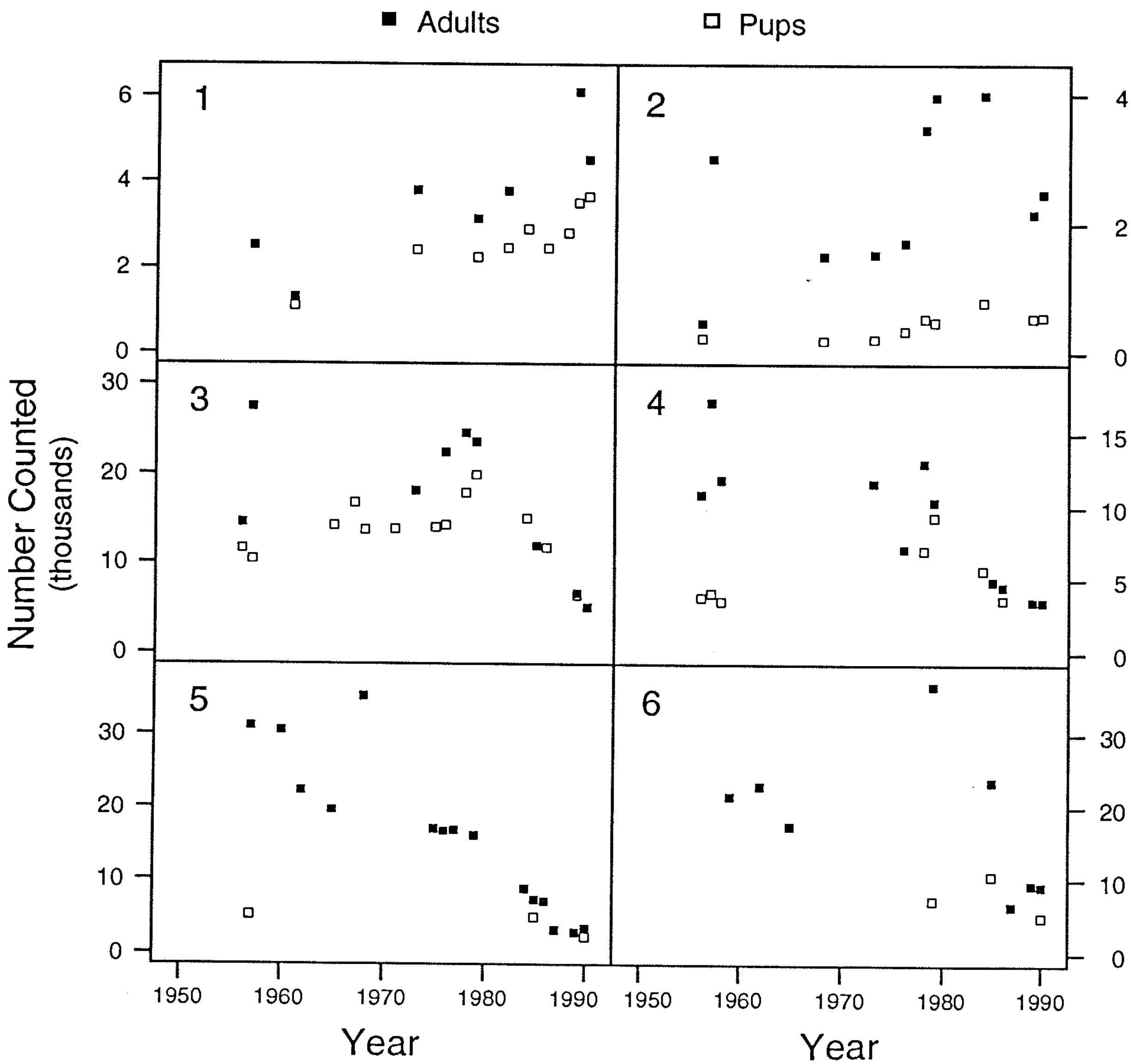

Russia
Alaska
Bering Sea
1
Southeast
Alaska
2
Eastern
Gulf of
Alaska
3
Central
Gulf of
Alaska
4
Western
Gulf of
Alaska
5
Eastern
Aleutians
6
Western
& Central
Aleutians

Figure 1



Adults
Pups
1
2
3
4
5
6
Number Counted
(thousands)
Year
Year
0
2
4
6
0
10
20
30
0
10
20
30
1950
1960
1970
1980
1990

Figure 2

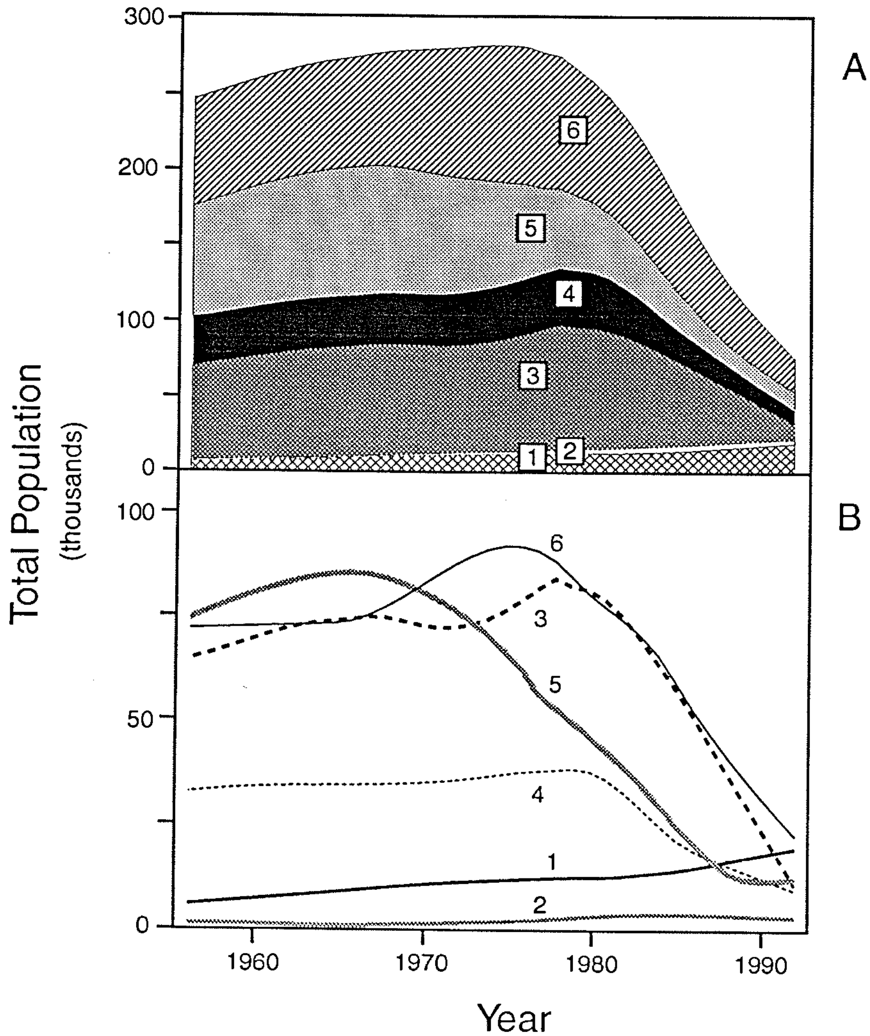
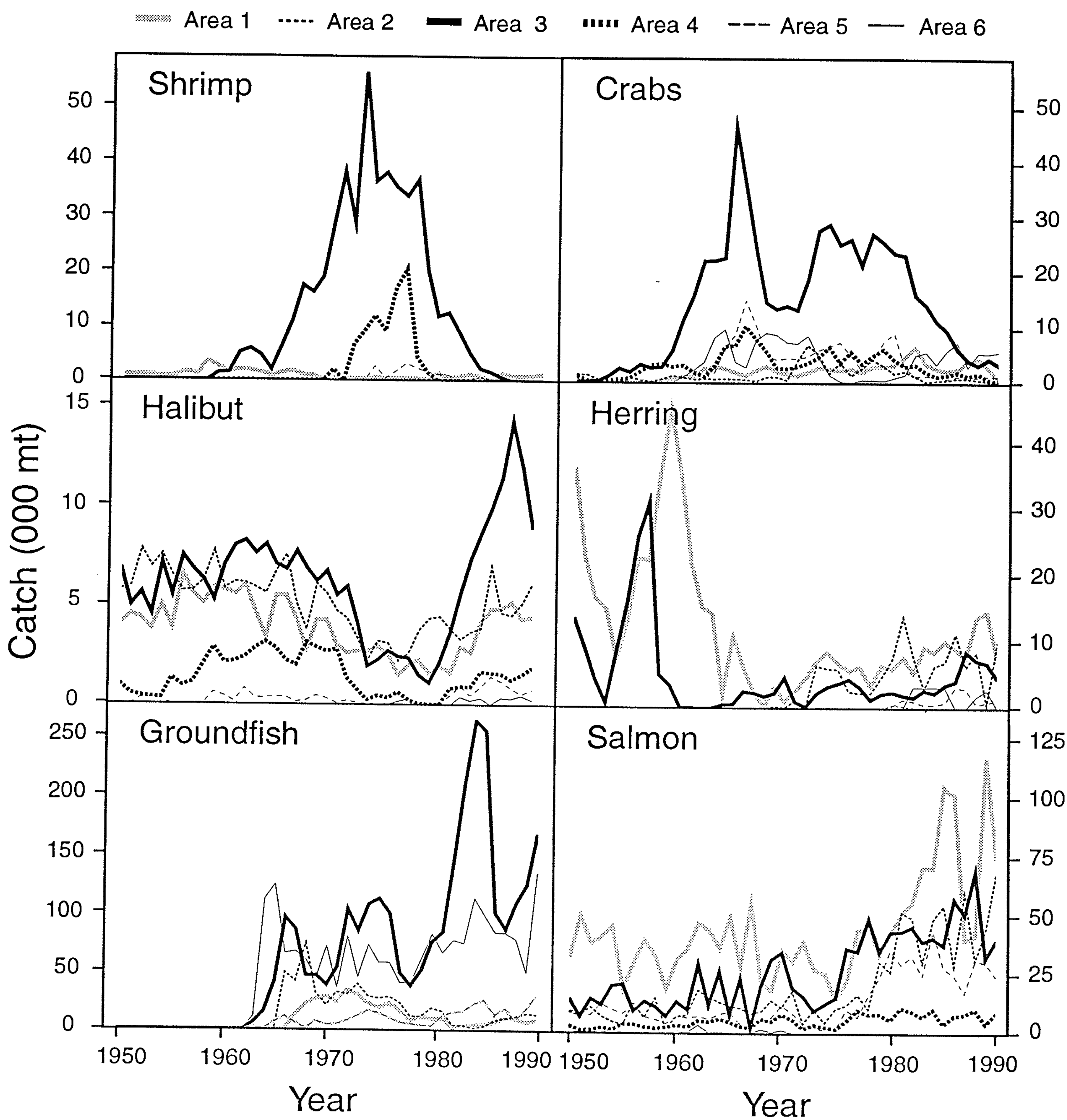

300
200
100
0
100
50
0
A
B
6
5
4
3
1
2
6
3
5
4
1
2
Total Population
(thousands)
1960
1970
1980
1990
Year

Figure 3



Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Shrimp
Crabs
Halibut
Herring
Groundfish
Salmon
Catch (000 mt)
Year
Year

Figure 4

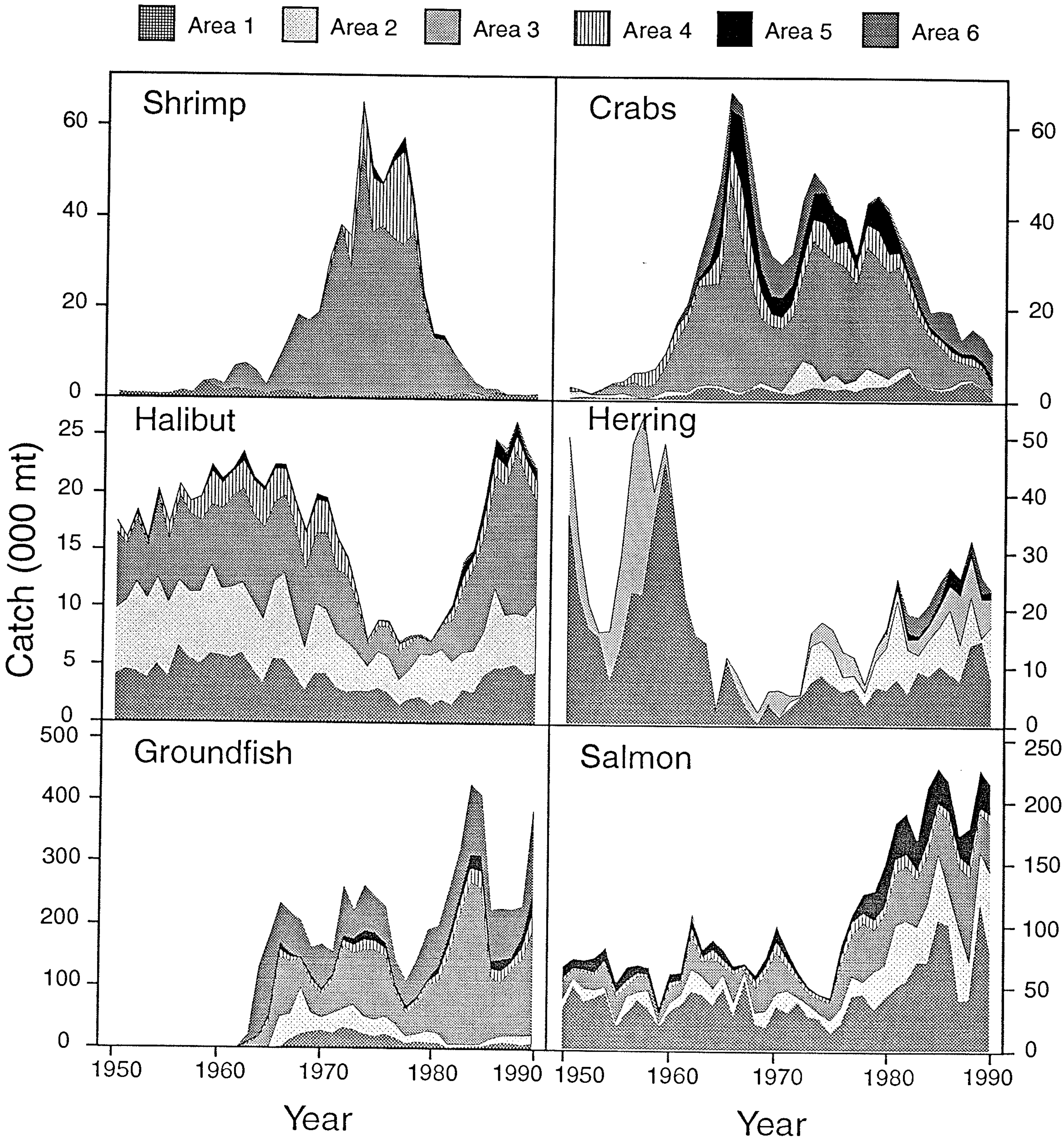
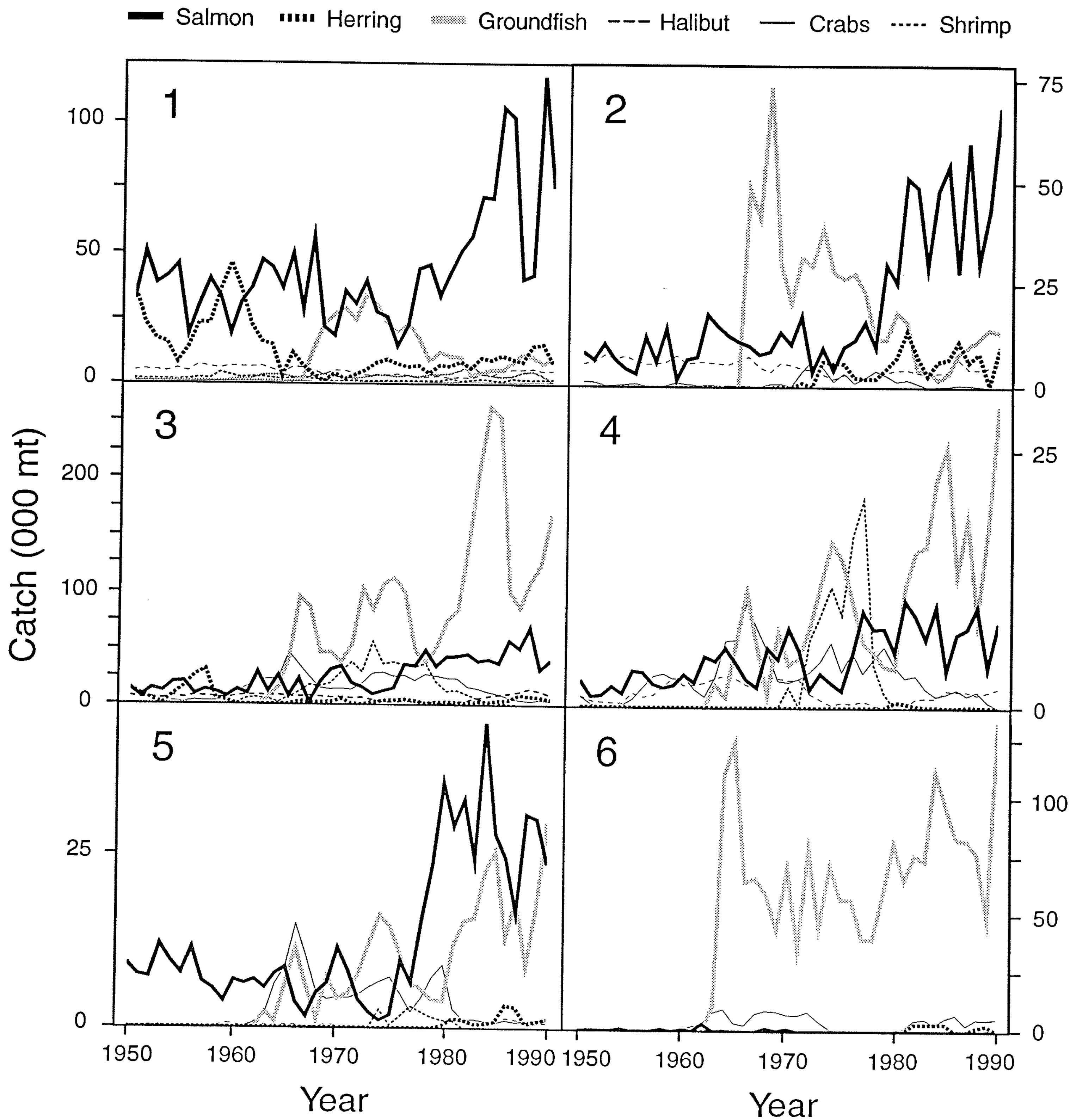

Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Shrimp
Crabs
Halibut
Herring
Groundfish
Salmon
Catch (000 mt)
Year
Year
0
20
40
60
0
5
10
15
20
25
0
100
200
300
400
500
0
20
40
60
0
10
20
30
40
50
0
50
100
150
200
250
1950
1960
1970
1980
1990

Figure 5



Salmon
Herring
Groundfish
Halibut
Crabs
Shrimp
1
2
3
4
5
6
100
50
0
75
50
25
0
200
100
0
25
0
25
0
100
50
0
1950
1960
1970
1980
1990
Catch (000 mt)
Year
Year

Figure 6

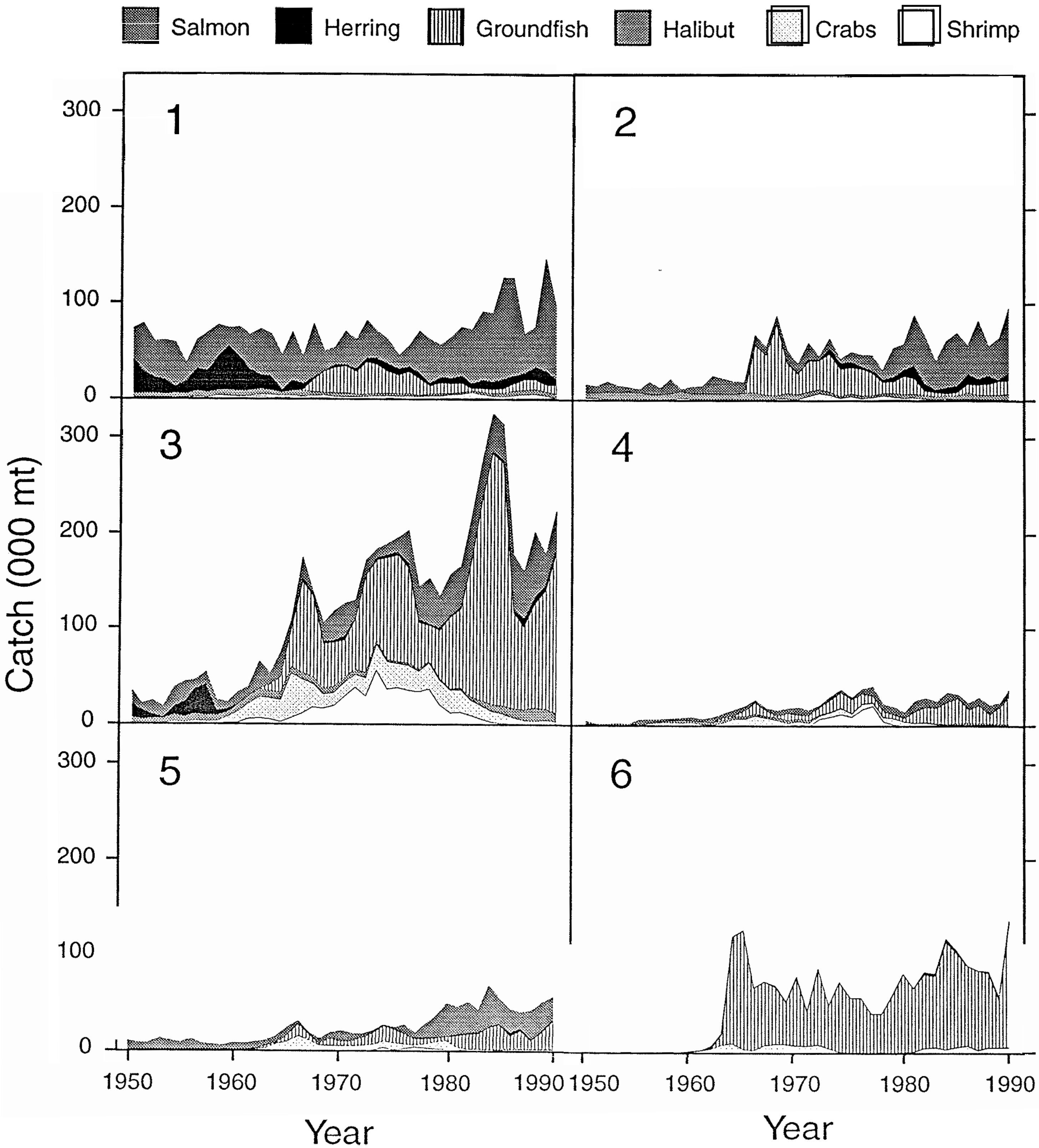

Salmon
Herring
Groundfish
Halibut
Crabs
Shrimp
1
2
3
4
5
6
300
200
100
0
Catch (000 mt)
1950
1960
1970
1980
1990
Year

Figure 7

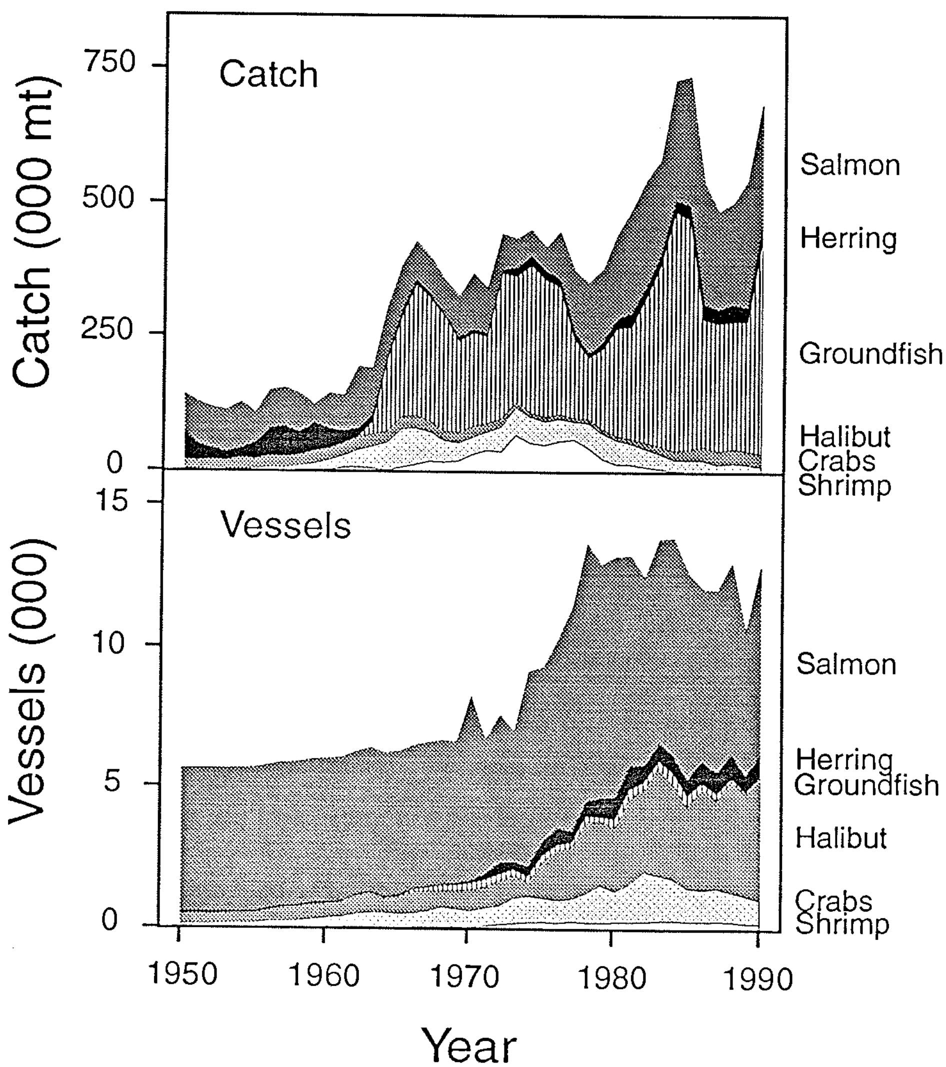
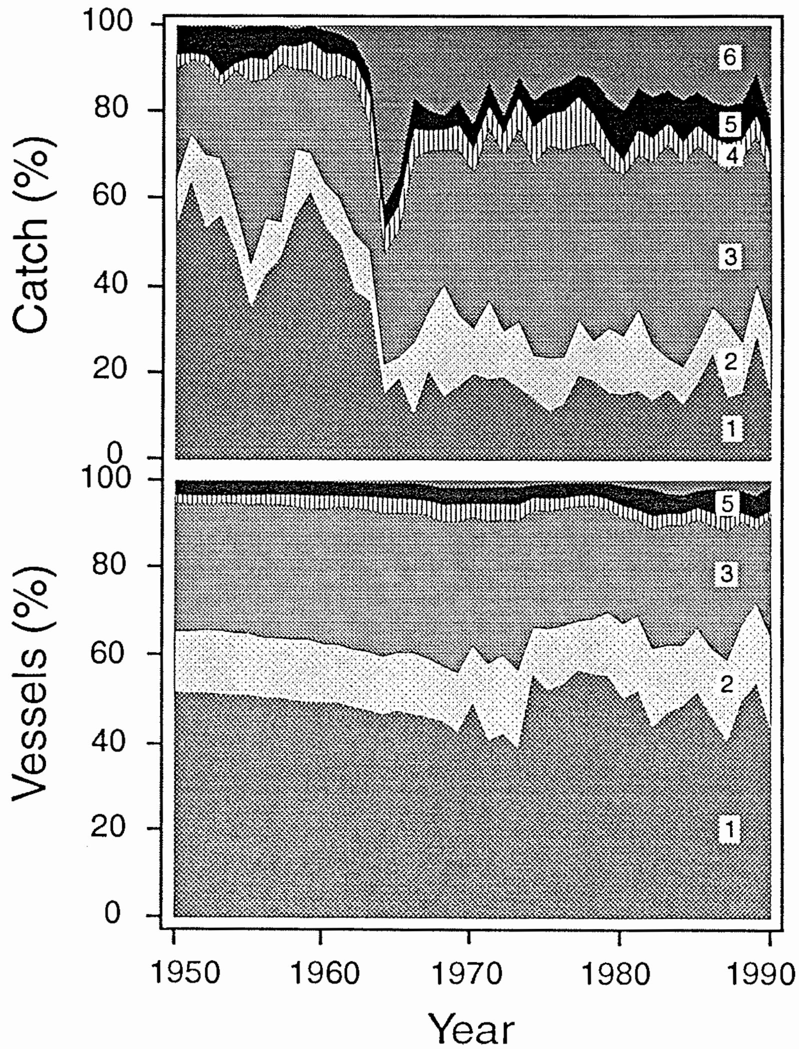
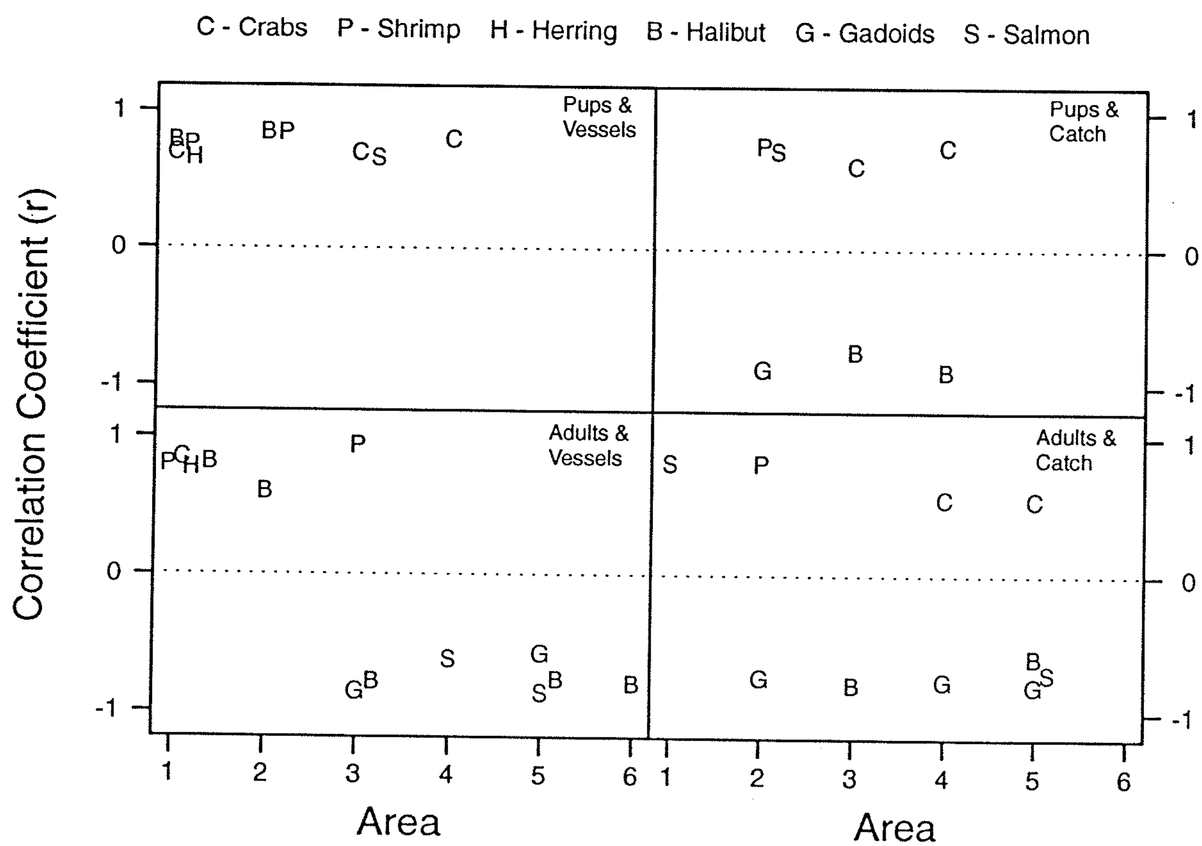

Catch
Catch (000 mt)
750
500
250
0
Salmon
Herring
Groundfish
Halibut
Crabs
Shrimp
Vessels
Vessels (000)
15
10
5
0
Salmon
Herring
Groundfish
Halibut
Crabs
Shrimp
1950
1960
1970
1980
1990
Year

Figure 8



100
80
60
40
20
0
Catch (%)
6
5
4
3
2
1
100
80
60
40
20
0
Vessels (%)
5
3
2
1
1950
1960
1970
1980
1990
Year

Figure 9



C - Crabs
P - Shrimp
H - Herring
B - Halibut
G - Gadoids
S - Salmon
Pups & Vessels
Pups & Catch
Adults & Vessels
Adults & Catch
Correlation Coefficient (r)
Area
Area

Figure 10