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FISHERIES RESEARCH INSTITUTE
SCHOOL OF FISHERIES WH-10
UNIVERSITY OF WASHINGTON
SEATTLE, WA 98195

COMMERCIAL FISHERIES AND THE STELLER SEA LION (*EUMETOPIAS JUBATUS*): THE CONFLICT ARENA

DAYTON L. ALVERSON

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KEY WORDS

Abundance trends, competition for prey species, environmental factors, fatty fishes, fisheries/sea lion interactions, herring, nutrition, pollock, shootings.

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INTRODUCTION

On April 5, 1990, the U.S. National Marine Fisheries Service (NMFS) issued an emergency ruling listing the Steller sea lion (*Eumetopias jubatus*) as a threatened species. The action followed observations of serious declines in their population throughout significant sectors of their range, but in particular throughout much of Alaska, which had historically accounted for a majority of the animals. Sea lion counts in the region from the Kenai Peninsula to Kiska Island (Alaska) declined from 140,000 animals in the late 1950s to about 68,000 in 1985 to 25,000 in 1989; counts remained at this level in 1990 (Lowry in prep.). Declines in sea lion population sizes have also been noted in the Western Pacific region and off the California coast. Regardless of the infrequent and sporadic character of surveys in time and space upon which population index numbers[1] have been derived, it is difficult to avoid the conclusion that a dramatic collapse has occurred in the population of this species throughout much of its range.

The concern for marine mammals off Alaska is further heightened by the fact that the decline during this time period was not unique among other North Pacific pinnipeds. Reduction in the size of northern fur seal (*Callorhinus ursinus*) and harbor seal (*Phoca vitulina*) populations have also been noted. A long-term downward trend in the population of fur seals on the Pribilof Islands has been observed since the 1960s. Trites (1990) provides a detailed discussion of the fur seal decline. This decline, approximately 50% over 30 years, however, is not nearly as abrupt as that noted for Steller sea lions. Further, a sharp decline in the harbor seal population has also been noted at Tugidak Island in the Kodiak Island region between 1976 and 1984. Whether or not harbor seals have followed the longer-term trend as noted for sea lions and fur seals is not apparent from the data.

Although one might wish to bicker about the methodology, comparability of counts, and quality of the population estimates for these pinnipeds, it is generally well accepted in scientific circles that the populations of the Steller sea lions and northern fur seals have declined over the past three decades and that the observed decline in sea lion numbers justifies their classification as "threatened" under the U.S. Endangered Species Act.

Scientists concerned with the sea lion population trend are nevertheless much less certain as to what factors may have triggered and contributed to the observed decline. This, in part, may reflect the fact that historical records on environmental and biological events that may have influenced food supplies (prey species), level of disease, etc., are either lacking, fragmentary, of a qualitative character, or have not yet been examined in any detail. Only the record of fishing activities and fish and shellfish removals is intact and continuous over the 30-year span for which observations

[1]Counts include neither animals at sea nor those hauled out at survey sites.

are available on the Steller sea lion decline. Even these data sets are at times and in certain areas incomplete. These shortcomings are, however, more often the case than the exception when scientists attempt to sort out factors influencing the declines in the populations of living marine resources.

A number of papers discuss in generalities possible factors impacting population levels of Steller sea lions (Loughlin 1987, Merrick et al. 1987, Calkins and Goodwin 1988), and in late 1986, a working group organized by the National Marine Mammal Laboratory (NMFS) identified 12 factors (Exhibit 1) that potentially could have caused declines in the Alaska sea lion population. The 12 factors were further ranked as being "high," "moderate," or "low" in terms of their potential impacts. Factors ranked as "high" in terms of potential impact include disease and the combined impact of all fishing activities. Three other possible causes were considered by the working group to warrant the classification of having potential "moderate" impacts: (1) changes in prey abundance and composition, (2) incidental take, which one might easily have combined with "combined impact of all fishery efforts," and (3) intentional takes.

These classifications reflected the best judgments of participants, most of whom were experienced in fisheries and marine mammal sciences and were familiar with the relevant literature. On the basis of my own experience, I cannot quarrel with these conclusions, but perhaps would have, for various intuitive reasons, ranked environmental factors and authorized commercial harvests as having at least "moderate" potential impacts.

Since these rankings in late 1986, there does not appear to have been any comprehensive attempt by the marine science community to evaluate the range of fisheries and potential environmentally induced factors associated with the Steller sea lion demise. This is unfortunate in light of the decline, the implied impacts of fishing, and impending recommendations for recovery that may soon emerge from the Steller Sea Lion Recovery Team formed in April 1990. Lowry et al. (1989) and others have examined the importance of walleye pollock in the diet of marine mammals in the Gulf of Alaska and Bering Sea and discuss some aspects of fishery trends in relationship to sea lion populations. The various identified impacts have also been discussed by the Recovery Team, by Calkins and Goodwin (1988), and by others. It is a good start, but all of these efforts constitute a somewhat piecemeal discussion of the potential environmental/fisheries/marine mammal interactions. Perhaps the controversial nature of the subject among fisheries and marine mammal scientists or the perceived scarcity of useful information upon which to formulate scientific conclusions have made a more in-depth analysis of the fish/Steller sea lion issue appear premature or inadvisable. However, before actions for the species recovery or further studies are undertaken, at least a casual, if not comprehensive, review of some of the historical fisheries and environmental databases is recommended.

This paper examines the scope and magnitude of fisheries which operated in the Northeastern Pacific in the years following World War II, and their potential impacts on the Steller sea lion populations. In order to provide the reader an appreciation of the extent of the fisheries/sea lion interaction, the author first capsulizes post-World War Ii fisheries developments. after setting the fisheries scene, the recent trends in the abundance of potential Steller sea lion prey species which have been the target of the North Pacific commercial fishery is reviewed. Abundance patterns established are then examined in light of environmental facts which could have influenced observed trends. Finally, these datasets are considered in light of various fisheries-related impacts and hypotheses associated with the decline of the Steller sea lion.

FISHERIES DEVELOPMENTS—1950-1990: THE GROWING CONFLICT

When considering the potential impacts of fishing activities on the Steller sea lion population decline, attention has tended to focus on the growth and development of the trawl fisheries in the Bering Sea and Gulf of Alaska, with particular emphasis on the large-scale pollock fisheries because of the observed importance of this species in the Steller sea lion diet during the past fifteen years. Indeed, the growth of this fishery in the post-World War II period must be considered one of the most significant events in the development of the North Pacific fisheries, particularly when one considers its rate of growth and the magnitude of fish removals. Nevertheless, the dramatic growth of the groundfish industry in the Gulf of Alaska and Bering Sea constitutes only a fraction of the dynamic fishery developments that were pervasive throughout the range of the Steller sea lion during its observed period of decline. The complex of historical and new fisheries which evolved in the Northeast Pacific in the post-World War II era at times competed for the same resources, e.g., herring, salmon, and various groundfish and/or were involved in other fisheries/Steller sea lion interactions.

Although a number of small-scale fisheries developments also followed the explosive growth of fishery activities since World War II, e.g., fisheries for abalone, scallops, sea urchins, octopus, sea cucumbers, etc., those having the highest probability of impacting the sea lion population either directly or indirectly because of the gear characteristics and magnitude of their catches would seem to have included (1) Japanese and U.S. salmon fisheries, (2) Japanese, Soviet, and U.S. herring fisheries, (3) foreign and U.S. groundfish operations, (4) foreign and U.S. crab fisheries, (5) foreign and U.S. shrimp fisheries, and (6) foreign and U.S. line fisheries.

SALMON FISHERIES

The Japanese High Seas Fisheries

Japanese land-based line and gillnet fisheries for salmon (*Oncorhynchus* spp.) have been prosecuted in the waters off Japan since early in this century, but the explosive growth of high seas driftnet fisheries began in the early 1950s. During its early development, the fishery operated through much of the North Pacific between 160°E and 175°W longitude and from 46°N to 62°N latitude. In peak years, as many as 9 million tans[2] (about 450,000 km, or 270,000 miles) of driftnets were deployed in a season (Exhibit 2). An additional 6 million tans of driftnets were

[2]One tan of salmon net equals 50 meters (Fredin, 1985).

deployed by the Japanese landbased fleet in the Northeast Pacific, and catches soared from about 27,000 mt in 1952 to over 150,000 mt in 1955 (Exhibit 3).

Alaskan Salmon Fisheries

Large-scale U.S. salmon fisheries prosecuted predominantly by gillnetters, purse seiners, setnetters, and trollers off Alaska date well back into this century. The numbers and sizes of vessels operating in the U.S. fishery grew rapidly in the postwar period, and in the early 1980s 1,557 hand trollers, 886 power trollers, 7,784 gillnetters, and 1,274 purse seiners were harvesting salmon in the waters throughout Alaska. The total harvesting units are now in the vicinity of 10,600 vessels (NRC 1983).

Peak catches in the prewar period occurred in the mid-to-late 1930s when well over 100 million fish were taken annually (Exhibit 4). Following this period, landings of salmon in Alaska declined rather steadily and reached a post-World War II low in 1973 and 1974, but run sizes began to increase in the late 1970s and early 1980s, and catches rose to over 140 million fish in the mid-1980s (INPFC 1979).

Impacts

It is well known that the Japanese mothership and landbased fleets generated bycatches of porpoise and occasionally fur seals (International North Pacific Fisheries Commission [INPFC] Proceedings 1980-1988). However, U.S. observers aboard catcher vessels from 1981 to 1987 did not observe sea lions caught or drowned in the mothership driftnet fishery. Sea lions were, however, frequently observed in the vicinity of the nets feeding on salmon, and some shootings were known to have occurred. Secondary impacts could, of course, have occurred in terms of altered availability of prey.

The potential impacts of these coastal salmon fishing activities on Steller sea lions is similar to that noted for the high seas driftnet fishery, with the exception that losses due to bycatches, shooting to defend gear, etc., are considered to be significantly higher (Matkin and Fay, 1980). Nevertheless, the level of sea lion bycatch and shooting in the U.S. salmon fisheries and their impacts remain largely unknown. Similarly, the importance of the sizes of salmon runs and sea lions' feeding strategies is an unanswered question.

HERRING FISHERIES

Foreign

A Japanese herring gillnet fishery (*Clupea harengus pallasi*) in the Eastern Bering Sea was initiated in the early 1960s, and by 1965 close to 800,000 tans[3] (about 36,800 km, or 22,080 miles) of gillnets a year were being fished (Exhibit 5). Catches by this fleet increased to a high of 4,603 mt in the 1970-1971 fishing season and declined in subsequent years. Catches by Japanese trawls in the Eastern Bering Sea were reported at 1,362 mt in the 1964-1965 years and peaked at about 50,000 mt in 1968 (Exhibit 6).

Catches of herring taken by Soviet trawl vessels date back to the late 1950s, and relatively large catches were reported between 1966 and 1977.

United States

A U.S. herring fishery conducted by gillnetters and seiners operated throughout much of Alaska since the beginning of this century, but Bering Sea catches were small scale until the onset of the U.S. roe fishery in the late 1970s. By the 1980s, catches had reached levels exceeding 18,000 mt. Much larger U.S. herring fisheries existed throughout much of Central and Southeast Alaska since the first decade of the century, and catch levels approximating 100,000 mt annually were reported in the 1920s, 1930s, and 1940s, and remained at relatively high levels until the mid-1950s (Exhibit 7). Subsequently catches fell off sharply, apparently as a result of declining stock size, increasing economic problems, and changing fishery management strategies in Alaska (Skud 1970).

Impacts

All the herring fisheries could have induced bycatch mortalities and, of course, impacted sea lion prey species of considerable importance in the Gulf of Alaska and the Bering Sea. Shooting sea lions to defend gear probably also occurred in these fisheries.

CRAB FISHERIES

Foreign

The Japanese bottom tanglenet fishery for Alaska king crab (*Paralithodes camtschatica*) off Alaska dates back to the 1930s, ceased during World War II, and began again in the early 1950s. The level of fishing remained at about 100,000 tans[4] per year between 1953 and 1960, but then

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[3]One tan of herring driftnet is about 46 meters (Fredin, 1985).

[4]One crab tanglenet tan equals 40 meters.

increased sharply and exceeded 600,000 tans (>24,000 km, or 14,400 miles) in 1963. Following 1968, the number of tans fell off sharply and the fishery ceased in the early 1970s.

The Japanese also conducted king crab pot fisheries, and peak pot fishery effort occurred during the early 1970s, when over one million pots were set. Catches of red king crab by Japanese vessels operating in the Eastern Being Sea increased from just over one million crabs in the 1950s to just under six million crabs in the early 1960s (Exhibit 9).

Soviet fishing for king crabs in the Eastern Bering Sea started in 1959, after which the number of factory vessels and catcher vessels increased rapidly. During the 1960s, well over 609,000 tans of tanglenets were fished in several years. Soviet crab catches peaked at about 10,000 mt in 1961 and subsequently declined.

United States

The U.S. king crab trawl efforts in the Bering Sea, like those of the Japanese and Soviets, also began in the early 1950s. This trawl fishery was terminated in 1959, after which the U.S. pot fishery began to flourish. The number of vessels in the U.S. pot fleet in the Bristol Bay red king crab fishery rose steadily over the years, and in the 1979-1980 season, 236 vessels made landings (NRC 1983). Extensive high seas crab fisheries also occurred for Tanner crab (*Chionoecetes bairdi* and *C. opilio*) in both the Bering Sea and Gulf of Alaska. For catch and effort details, see Exhibits 11, 12, and 13.

Impacts

The impacts of crab fisheries on the sea lion population probably depend to a great extent on the areas of operation and the types of gear deployed. Few bycatch problems, for example, have been noted for the crab pot fisheries, but like other fishery groups, crab pot fishermen may at times have defended their gear from the threat of sea lions. It is much more likely, however, that the large-scale use of tanglenets over extensive shelf areas in the Bering Sea may have involved bycatch problems, and animals seen in and around the gear during hauling may have been purposely killed.

TRAWL GROUNDFISH FISHERIES

Foreign

Exploratory trawl fishing vessels from Japan entered the Bering Sea in 1929 and 1931, and commercial operations were begun in 1933. This fishery, conducted as a mothership operation, principally targeted on yellowfin sole (*Limanda aspera*). A second effort to develop commercial trawling occurred in 1940, but this effort was disrupted by the onset of World War II (Alverson et al. 1964).

Post-war Japanese groundfish fisheries in the Eastern Bering Sea began in the early 1950s and continued to increase between the early 1960s and the early 1970s, when over 400,000 hours (h) of trawl-effort-per-year were recorded (Exhibit 14). Japanese and other foreign trawl fishing began to decline in response to regulations imposed by the U.S. following the extension of national jurisdiction to 200 nautical miles in 1976.

Japanese trawl fishing in the Gulf of Alaska was first reported in 1963 and grew rather steadily until the mid-1970s, when 39,000 h of effort were recorded (Exhibit 15). Although the Japanese efforts in the Northeastern Pacific were largely centered in the Gulf, some trawl efforts extended south off British Columbia, Washington, and Oregon.

Soviet trawl efforts in the Bering Sea began in 1959 when a large fleet began harvesting Pacific ocean perch (*Sebastes alutus*) and various flounders. Although the Soviet fishing effort for groundfish did not match that of Japan, it nevertheless exceeded 100,000 h in 1974 and then declined rapidly following U.S. implementation of extended jurisdiction. Other participants in the Bering Sea groundfisheries included the Republic of Korea (R.O.K.), Taiwan, Poland, and West Germany.

Soviet trawling in the Gulf of Alaska began in 1962, and a peak in trawl effort (52,000 h) was reported for 1975. Soviet effort off British Columbia and the contiguous West Coast states of the U.S. exceeded that of any other nation (Exhibit 16).

United States

U.S. trawl operations were instituted in 1978, when an experimental joint venture operation was carried out. U.S. trawl effort, however, increased rapidly in subsequent years as joint venture efforts expanded and, by 1983, reached a level of 82,000 h. The first factory trawl operation conducted in the Bering Sea by the U.S. began in 1980 and the number of vessels in the fleet grew steadily over the remainder of the decade (Exhibit 17). U.S. Bering Sea trawl fishing effort and harvest now approximate those of the foreign fleets during the 1970s, but in the Gulf is probably significantly less than that of the foreign fleets displaced, since the catches and the effort have been limited by economics and management measures.

U.S. and Foreign Catches

The aggregate catches taken by U.S. and foreign fleets in the Eastern Bering Sea for the period 1960 through 1989 are provided in Exhibit 18. The largest total catches occurred in the early 1970s, when harvests exceeded 2.3 million mt. A great variety of species is taken in the trawl fisheries, but only a few species have dominated the catches. These include Pacific ocean perch, yellowfin sole, pollock (*Theragra chalcogramma*), and cod (*Gadus macrocephalus*). Catch trends for the major species taken in the Gulf of Alaska and Aleutian regions are shown in Exhibits 19 and 20. Dominant target species included Pacific ocean perch, cod, pollock, and Atka mackerel (*Pleurogrammus monopterygius*).

Impacts

The impacts of trawling on the sea lion populations include mortalities generated in bycatch, which may have exceeded 1,000 animals per year during the 1970s and early 1980s, potential effects on sea lion food species (herring, pollock, cod, sablefish, Atka mackerel, and flounder, interference with feeding behavior, and the killing of sea lions in defense of fishing gear.

SHRIMP FISHERIES

Japanese trawling for pink shrimp (*Pandalus borealis*) commenced in the Bering Sea in the late 1950s, peaked in the early 1960s, and was terminated in 1977 (Exhibit 21a). The effort associated with these fleets has generally been incorporated into the trawl fishing hours associated with the groundfish effort. Foreign and domestic catches of shrimp from the Gulf are provided in Exhibit 21b. Some indication of the significant growth of the U.S. shrimp fishery and its subsequent decline provided by the number of vessels operating in the Kodiak region between 1964 and 1986 (Exhibit 22).

Impacts

It would not appear that these shrimp fisheries competed to any large extent for important sea lion food items, although some bycatch mortalities are known to have occurred, and like other fisheries of the region, the fishery increased the likelihood of contacts with sea lions and probably involved shootings.

OTHER FISHERIES

In addition to the significant effort involved in the previously described fisheries, several other high seas fisheries warrant mention. These include the U.S. and Japanese line fisheries for halibut (*Hippoglossus stenolepis*), cod, and sablefish (*Anoplopoma fimbria*). Japanese line fisheries for halibut and later sablefish began in the Bering Sea in the 1960s, and toward the middle of the 1970s more than 320,000 hachi[5] a year were set (Exhibit 23). In the Gulf of Alaska, Japanese line effort increased to 1.4 million hachi in 1972 and remained over 1.0 million hachi a year until the

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[5]One hachi consisted of a groundline of about 75 m with about 45 hooks (See Bulletin #37, INPFC).

late 1970s. Further, Korean line vessels also participated in the Gulf fisheries through much of the early 1970s.

The estimated fishing effort for the U.S. halibut line fishery for the years 1952 to 1987 is provided in Exhibit 24. These efforts, however, constitute only a small part of the extensive U.S. line fishery that targets on sablefish, cod, and other groundfish—a fleet that now exceeds several thousand small and large vessels operating off Alaska. An indication of the increased U.S. line fishing effort is reflected by the reported growth of the line fleets, other than halibut, fishing the EEZ off Alaska (Exhibit 25).

Impacts

No significant bycatch problems have been noted with these fisheries, but they do compete for food items and involve gear interaction. The latter may also have involved some sea lion shooting.

SUMMARY COMMENTS

World War II, which concluded in the Pacific in August 1945, gave birth to an array of new technologies that rapidly galvanized fishery development and greatly altered the character of fisheries throughout the world, including those off Alaska. From the early 1950s to the present, Alaska fisheries have been subjected to an unparalleled series of foreign and domestic developments. In a matter of 4 decades the fleets of small coastal catcher boats targeting on salmon, halibut, and/or herring were transformed into diverse high-tech fleets of small and large vessels fishing a complex of demersal, pelagic, and anadromous fish and shellfish species inhabiting the continental shelf and slope to depths of 1000 meters (m), as well as extensive high seas areas well beyond the topographic influences of the continents. In fact, this development constituted a period of massive intrusion of human activity into a region previously, except for whaling, almost the exclusive domain of marine invertebrates, fishes, seabirds, and marine mammals.

It is evident that from the mid-1950s to 1990, a period which witnessed the explosive growth and changes in the fisheries of the Northeast Pacific, including the Bering Sea, there was a marked decline in Steller sea lion populations off Alaska. Major new fishing activity over this time period included the Japanese driftnet fishery for salmon and herring, Soviet and Japanese tanglenet fisheries for crab, the U.S. crab pot fisheries, the U.S. trawl shrimp fishery, foreign and U.S. trawl fisheries for bottomfishes, and U.S. and foreign line fisheries for sablefish, cod, and other bottomfish.

Each of these fisheries, along with the well established U.S. salmon, halibut, and herring fisheries (which were well entrenched long before World War II) at times and in certain areas introduced potential interactions with sea lions inhabiting the region. These interactions may have included competition for food sources, bycatch mortalities, interruption of normal feeding patterns, shooting in defense of gear, and shooting of an indiscriminate character. The aggregate addition of new fishery effort to the region, combined with that of historically established fisheries, constitute activities that must be considered in terms of their potential impacts on sea lion and other marine mammal populations.

The historical effort and catch data provide us some understanding of the potential fisheries/sea lion interactions involved, but they do not necessarily suggest the direction and magnitude of change in the population sizes of the major fish and shellfish resources being exploited. These trends, which may be influenced by fisheries harvest in conjunction with biological and environmental factors, are explored in the next section.

POPULATION TRENDS: CHANGING ABUNDANCE PATTERNS

It is apparent from the analysis of food items in the stomachs of marine mammals that fishermen and sea lions frequently compete for a variety of important fish resources. Chief among these are herring, salmon, pollock, flounders, and various rockfishes, all of which have been subject to large-scale fishing over the past 35 years. The abundance of some of the species has declined noticeably since the onset of large-scale fishing, while the stocks of other species appear to have been less influenced by fishing activities in the Northeast Pacific and Bering Sea regions.

Although catch data are frequently useful indicators of the condition of anadromous fish stocks, they frequently do not follow abundance trends for marine species. In the latter, independent estimates or indicators of biomass trends from catch-per-unit-effort (CPUE) data, research vessel surveys, and virtual population assessment (VPA) and cohort analyses provide more reliable indicators of the status of the resources. For species of interest in the Northeast Pacific, long-term population trends (>30 years) based on such indicators are available for only a few species. However, population trend data are available over shorter time periods for a number of the important fish and shellfish resources that are or have been targeted by Bering Sea and Gulf of Alaska fisheries.

On the basis of the historical catch records and Alaska Department of Fish & Game/Fisheries Research Institute forecasts, the abundance of salmon in the Northeast Pacific region having their origins in Alaska declined rather sharply in the early 1970s and reached an all-time low in the mid-1970s. The abundance and catches of Alaska salmon, however, rebounded from this low and catches soared to record highs in the mid-1980s.

A variety of abundance indices are available for the complex of groundfish in the Bering Sea and Gulf of Alaska. Stocks of pollock in the Bering Sea (Exhibit 26) were apparently at a relatively low level of abundance in the mid-1960s, increased through the latter half of the decade, dropped off in the early 1970s, and subsequently continued to grow until the mid-1980s. Since the mid-1980s, the population level has gradually declined. In the Gulf of Alaska, relatively good data sets from trawl surveys in the early 1960s strongly indicate that the biomass of pollock in the Gulf region was at a very low level—about 58,000 mt (Alverson et al. 1964). However, by the early 1970s a marked increase in the abundance of pollock was noted by Alton (in the Report of the Workshop on the Status of Northern Sea Lions (Lowry, in prep.)) who reported that in three selected index areas the CPUE for trawl surveys had increased from four- to twenty-fold. These observed increases were statistically significant at the 95% confidence level (Exhibit 27). Further, population estimates made by NMFS (Marasco and Aron, in press) showed a continued growth of the population between the late 1970s and the early 1980s (Exhibit 28). The remarkable growth in the relative abundance of pollock in the Gulf between 1962 and the early 1970s and shifts in the abundance of other species is noted by Ronholt et al. (1978). These analyses show that pollock, which constituted only a small fraction of the Gulf of Alaska groundfish and shellfish complex in 1962, became the dominant trawl-caught species in the 1972-1973 trawl surveys (Exhibit 29).

It is further evident that many species of flounders flourished during the latter half of the 1970s and early 1980s. The abundance of yellowfin sole in the Bering Sea, which had been the subject of intensive foreign fishing in the late 1950s and early 1960s, increased roughly fivefold between 1972 and 1982 despite continued fishing by the trawl fleets. Estimates of yellowfin sole biomass tended downward in the late 1980s but remained at levels well above those of the early 1970s. The abundance trend for a number of other flounder species, flathead sole (*Hippoglossoides elassodon*), rock sole (*Lepidopsetta bilineata*), and Alaska plaice (*Pleuronectes quadrituberculatus*), also followed the same general growth pattern (Exhibits 30a, b, c, and d), and biomass estimates for these species increased roughly fivefold. Finally, the downward trend in halibut stocks also turned in the early 1970s, and the stocks grew rapidly in the late 1970s and early 1980s (Exhibit 31).

Like the pollock and numerous flounder species, the abundance of Pacific cod in both the Gulf of Alaska and the Bering Sea grew rapidly during the late 1970s and well into the 1980s. For example, cod in the Eastern Bering Sea increased from roughly 300,000 mt in 1978 to about 1.65 million mt in 1984. A similar rapid rise in the abundance of cod apparently also occurred in the Gulf (Exhibits 32a and b).

CPUE or other indices of the state of North Pacific herring runs are available only for the Eastern Bering Sea and areas in Southeast and Central Alaska. These CPUE data from Japanese fisheries (Exhibit 33) indicate a marked reduction in the population levels during the early 1970s. Also, catch data for Alaska herring fisheries operating in the Gulf of Alaska imply that a long-term decline in the herring stocks of that region occurred between the late 1950s and the late 1970s, but this trend may in part reflect management and economic factors. Interestingly, longer-term catch records of herring from both the Northwest and Northeast Pacific suggest marked declines in the abundance of herring, depending on the regions, between the mid-1960s and the 1970s (Exhibit 34).

Species other than herring that declined during the 1955-1990 period include Pacific ocean perch throughout its range, Atka mackerel in the Gulf region, and Greenland turbot (*Reinhardtius hippoglossoides*)—for the most part species with relatively long life spans. It is also obvious that the abundance of many of the commercially important shellfish species, such as king crabs, Tanner crabs, and pink shrimp, declined sharply in the late 1970s and early 1980s.

Trends in the abundance of Pacific ocean perch for the Eastern Bering Sea and Aleutians are shown in Exhibit 35. There can be little doubt that the population level of Pacific ocean perch fell off rapidly during the 1960s, and that the stock abundance in these regions is but a small fraction of that which persisted prior to the onset of intense fishing in the late 1950s and early 1960s. Similar CPUE indices from the fisheries for Pacific ocean perch do not appear available for the Gulf. However, comparisons of trawl surveys undertaken in the 1960s and 1970s provide ample evidence of a sharp reduction of these stocks in this region. Ronholt et al. (1978), for example, note that the average catch rate for Pacific ocean perch in the Gulf of Alaska—all depth zones combined—fell from 36.8 kg/km to 3.9 kg/km between 1960 and 1970, and the catch rate in the 201- to 400-m depth range (the most abundant zone for this species) dropped from an average of 75.6 kg an hour to 3.9 kg an hour between the 1960s and 1970s. This dramatic decline in the abundance of Pacific ocean perch throughout the Northeast Pacific, and in particular the Gulf of Alaska in the late 1960s, is in stark contrast to the explosive growth of Pacific pollock during this period. Evidence showing the declining abundance of Atka mackerel in the Gulf of Alaska during the 1980s is provided in Exhibit 36, while biomass trends for red king crab and Tanner crab in the Bering Sea are provided in Exhibits 37a and b. The abundance of both species of Tanner crab, however, turned upwards during the latter half of the 1980s.

SUMMARY COMMENTS

Between 1960 and 1990, herring, Pacific ocean perch, Atka mackerel in the Gulf, and other rockfish species declined sharply. Conversely, pollock, several species of flounders, halibut, cod, and salmon generally increased in the late 1970s and 1980s despite rather intense fishing activities. It may also be true that other small forage species, such as capelin (*Mallotus catervarius*) and sandlances (*Ammodytes tobianus persanatus*), also declined between the late 1960s and the early 1980s. There are, however, no direct fisheries observations to support this conclusion, but this possibility is inferred by the changes in feeding patterns of fur seals and sea lions over this period. These changes in feeding patterns are discussed laterin the paper. Most commercial species of crabs and pink shrimp declined during the period of the increasing biomass of many groundfish species and salmon.

It is clear that large-scale shifts occurred in the abundance of major elements of the demersal and pelagic fish populations during the thirty-year decline of the Steller sea lion. The decline in the abundance of several species, rockfishes and herring in the Bering Sea, can be traced to intense commercial fishing activities. The increase in abundance of other species may also have been induced by the large-scale removals of the rockfish populations, but they may also have been triggered by changing environmental factors and cyclic biological adjustments within the ecosystem.

ENVIRONMENTAL CHANGES: POTENTIAL IMPACTS

The fact that there has been a massive intrusion of new fishing effort into the Northeast Pacific over the past 30 years is a matter of record. It is also possible that the ocean climate of the region has also undergone change, which may have affected the abundance of key forage species and thus altered feeding patterns, as well as the quantities and character of food available to the Steller sea lion population.

Naumenko et al. (1990) note that in the Western Bering Sea there was a major shift in the abundance of important pelagic fishes in the region between the late 1960s and 1980s, with significant increases in pollock populations and declines in pelagic species, such as herring and capelin. Again, however, the causal factors are not easily documented. In his comprehensive review of the northern fur seal, Trites (1990) observes that "a periodicity in fur seal growth rates might be indicative of an underlying large-scale environmental factor" and concludes that "the data suggest the influence of environmental conditions on pinniped growth should be given greater attention when evaluating factors such as commercial fisheries that affect the abundance of prey species." He further notes that natural factors need to be taken into account when assessing the amounts of food available to northern fur seals.

For the Bering Sea and Gulf of Alaska, there are only a few indicators of environmental change or anomalies in the ocean environment for which reasonable amounts of direct and indirect data are available. These include information on temperature and currents in surface layers—the latter responding to surface wind patterns.

Considerable interseason changes in surface temperature regimes and currents occur throughout the Bering Sea and Gulf of Alaska. Furthermore, in many cases seasonal anomalies may mean only a change in the timing of a process. Nevertheless, the extent of anomalies in the Bering Sea and Gulf and their cyclic character are worth considering in terms of observed changes in key populations of the region's pelagic and demersal fish and shellfish.

Surface and near-bottom temperature anomalies in three areas in the Southeast Bering Sea (Bristol Bay, Central Shelf, and Outer Shelf and Slope) from 1953 to 1983 are shown in Exhibits 38 and 39. Considerable monthly spread of the anomalies is apparent in these exhibits (Swan and Ingraham 1984). Also, the anomalies are somewhat different from one area to another. Nevertheless, a general period of warming seems to have occurred during the mid-1970s and continued into the early 1980s, although only a few years and periods can be designated as distinctly colder (1972, 1973, and 1976) or warmer (1977 to 1980).

The observed temperature anomalies in the Bering Sea are relatively small (mostly less than 2°C), although these differences may reflect significant changes in wind and current patterns. Perhaps a more significant environmental anomaly with respect to fish ecosystems might be the sub-zero, cold-bottom water tongue on the Central Shelf that occurred in some years. The extent of this tongue and the time of its disappearance during the late summer is known to vary from year to year. However, the available data do not permit reliable time-dependent analysis of this tongue.

Time series spatial analyses of surface temperature in the Gulf of Alaska are much less meaningful owing to gaps in data. However, time series observations are available from fixed locations (weathership *Papa* and some coastal stations). The temperature anomalies are not, however, correlated in different locations. Furthermore, no significant trends or fluctuations in the long term can be detected with certainty in these data. The magnitude of the anomalies is also small (less than 2°C).

Temperature, of course, affects geographic and bathymetric distribution patterns of fish, as well as their physiology, which may in turn alter growth rates and food intake, and hence predation conditions. Changes in surface currents can modify the drift of fish eggs, larvae, and plankters (both plant and animal), and affect survival of larvae and availability of food to fishes by changing predator/prey overlap and encounter rates.

Various authors, Favorite et al. (1977), Swan and Ingraham (1984), and Laevestu et al. (1986), have speculated on the effects of temperature anomalies on the fluctuation of fish stocks in the Bering Sea and North Pacific regions. The fact that average sea surface temperatures began to rise in the Western and Eastern Bering Sea during the early 1970s and were generally above the mean observed historical temperatures during the late 1970s and early 1980s has been noted by both U.S. and Soviet scientists (Gunderson 1983, Khen and Glebova 1990, Rodinov and Krovin 1990). Major shifts in wind patterns were also recorded during the period. The consequence to the fish populations of the region, however, are more speculative and largely of a qualitative character. Nevertheless, some review of this body of literature is desirable.

Saetersdal and Loeng (1983), for example, note that between 1900 and the early 1980s, stronger year-classes of cod occurred during periods when temperature anomalies changed from cold to warm. In a simulation study that examined effects of temperature on growth, Laevestu et al. (1984) used observed temperature anomalies in the South Central Bering Sea to predict that many major commercial species would decline during periods of negative temperature anomalies and increase during periods of positive temperature anomalies. Significantly, the model also forecast that the abundance of smaller forage fish species, specifically capelin, showed the opposite relationship to temperature.

Summary Comments

In the end, there are just too many uncertainties to sort out to differentiate the effects of environmental impacts on the major fish and shellfish components of the ecosystem from those of fisheries or predator/prey adjustments (see, for example, Bax and Laevestu, in press.) *All we know with some certainly is that major shifts and adjustments within the ecosystem have occurred and that the biological structure is now significantly different than that which prevailed in the early 1960s.* These ecosystems adjustments, in association with other factors, may have influenced sea lion population sizes, but linkages to the environment are, at best, inferential.

THE STELLER SEA LION DECLINE: HYPOTHESES, OPINIONS, AND PERCEPTIONS

At the beginning of this paper, factors identified by the NMFS working group that potentially could have accounted for declines in the Steller sea lion population were noted (Exhibit 1). The list is quite comprehensive and would seem to cover, in one form or another, the gamut of natural and human events that may have increased mortality on the Steller sea lion population. Further, nothing in my study of this subject suggests that some unknown and unidentified factors could provide preferable or reasonable alternatives to the potential causes of decline presented by the working group. The remaining question is how do the marshalled facts bear on the listed possible causes?

Some pertinent factors can be deduced from the previous overview of fishery development and the status of major fish and shellfish resources in the Northeastern Pacific and Eastern Bering Sea environment over the three decades of Steller sea lion declines.

1. First, the past 35 years encompass a period of unparalleled growth and geographic expansion of the fisheries of the region. Waters that were visited by only the occasional halibut schooner or passing freighter saw a rapid intrusion of a plethora of small and large catcher vessels of all descriptions using salmon and herring driftnets, bottom tanglenets, trawls, pots, longlines, and salmon trolling gear. In addition to the catcher vessels, the fishery operations included a variety of support—cargo, fuel, and even patrol vessels. These activities augmented the historical salmon, herring, and halibut fisheries of the region. The consequence of this dramatic buildup was to greatly increase human encounters with the variety of marine life that inhabited these waters, including Steller sea lions. In essence, it constituted colonization and industrialization of Steller sea lion habitat by post-World War II high-tech fishing fleets. Over time, these fisheries stimulated growth of shore-based facilities and supporting infrastructure, which spurred population growth and activity throughout much of the Gulf of Alaska and Aleutian Islands and increased the likelihood of nearshore human/sea lion encounters.
2. The growth of the spectrum of ocean fisheries resulted in aggregate removals of fish and shellfish from the waters off Alaska which amounted to several billion pounds annually since the early 1970s. These fisheries targeted on a number of species which were common food items of the Steller sea lion, including herring, pollock, salmon, Atka mackerel, rockfish, and flounders. Some of the previously abundant species, such as Pacific ocean perch and probably herring and Atka mackerel in the Gulf of Alaska, have suffered from excessive fishing. Others, such as crabs and shrimp have been reduced to relatively low levels by factors such as from fishing, environmental causes, and biological adjustments

within the ecosystem (Larkin et al. 1990). However, other species important in the sea lions known diet, such as pollock, cod, salmon, and numerous species of flounders, seem to have fared well since the mid-1970s.

3. It is well known that short- and long-term changes in the ocean climate have the potential to influence the abundance and distribution of fish populations and that periods of anomalies, cooling, and warming have been observed in the Eastern Bering Sea and less obviously in the Gulf of Alaska.

   The effects of both changing ocean temperature and wind patterns may well have impacted abundance trends of many of the region's fish and shellfish species. However, differentiating between the population changes induced by climatic factors and those resulting from resource exploitation and internal adjustments between predator and prey is beyond the scope of this review and perhaps is not possible, considering existing data sources. We, however, can conclude that regardless of the underlying factors, significant changes in the abundance of key elements of the fish and shellfish complex of the Bering Sea and Gulf of Alaska have occurred over the past 30 years.

How, then, do these generalities bear on the decline in the Steller sea lion? Obviously the simultaneous growth of ocean fisheries in the Northeast Pacific and Bering Sea and collapse of the Steller sea lion population bears careful scrutiny. The number of vessels, amounts of gear, and diversity of fishing operations increased dramatically in the 1960s and 1970s and spread throughout the Steller sea lion habitat. The population of sea lions, on the other hand, spiraled downward.

The extent of incidental harvest and deaths of Steller sea lions due to all fishing activities remains speculative although relatively good observations are available for the various trawl fisheries that have operated off Alaska, particularly since the U.S. extension of national jurisdiction to 200 nautical miles in 1976. Loughlin and Nelson (1986), for example, estimated between 958 and 1,436 sea lions were caught in trawl fishing in the Shelikof region during 1982. Further, in a more comprehensive review of the Steller sea lion/trawler incidental take problem, Perez and Loughlin (1990) estimated that about 989 animals per year were taken by the foreign and joint venture fishery between 1966 and 1988. These bycatch numbers must be considered conservative, however, since they do not include sea lions taken by U.S. domestic trawlers, which became an important component of the fishery by 1988, nor mortalities involved in other fisheries.

Discussions of incidental bycatch generally end with the conclusion that these incidental takes contributed to the decline of Steller sea lions—a conclusion that is easily supported. The focus on the incidental catch of the trawl fleets, of course, stems from the fact that until very recently it constituted one of the few fisheries that had extensive observer coverage and for which bycatch levels were known to be relatively high. Bycatch rates, although probably not nearly as serious, are largely unknown for many of the other U.S. and foreign fisheries that have fished or continue to fish the waters off Alaska.

A perhaps more germane question concerns the losses associated with shooting sea lions in defense of fishing gear and/or harvest. We have previously noted that 305 Steller sea lions were calculated to have been killed while interfacing with salmon gilinets in the Copper River region in the spring of 1978. Although more recent observations in the area (Wynne 1990) suggest that the level of sea lion shooting has declined, a historical perspective suggests that wide-spread shootings are likely to have also occurred in other salmon fisheries throughout Alaska, as well as around line, trawl, and pot fisheries in offshore regions. In fact, such shootings were not uncommon to any domestic gear type and although the aggregate losses are unknown, they obviously played some role in the Steller sea lion decline.

The question of the magnitude of blatant and indiscriminate killings, a topic that is for the most part reduced to anecdotal information, is left unanswered. It has been reported that fishermen have been seen killing animals at rookeries and haulout sites and around their vessels (Lowry, in prep.). Unfortunately, it is a topic that is raised, casually discussed, and frequently dismissed because of the quality of supporting information. After all, no one at this juncture in history really wishes to be tagged as a marine mammal exterminator. Yet it is perhaps important to roll back time to another era in the growth and development of the Alaskan fisheries. Those of us with sufficient longevity to recall the late 1950s and 1960s remember well that fishermen, tender operators, cannery personnel, and even wildlife managers did not hold Steller sea lions or other marine mammals in great esteem. After all, the government was seeking ways to reduce their numbers, there was a bounty on harbor seals, commercial harvests of sea lions were authorized, cannery operators provided ammunition to fishermen and tender operators to shoot these "scoundrels," and even marine and wildlife biologists and "fish cops" were known to have joined in the shooting of "those fish-eating, gear-destroying rascals."

This perception was not the exclusive domain of fishermen, but was pervasive among the Alaskan coastal communities, and among many who ventured there to fish or work in the supporting industries. When the fishing fleets from Alaska and the Pacific Northwest moved north to develop the crab, shrimp, and bottomfish fisheries in the 1960s, 1970s, and 1980s, these attitudes went with them and the number of shootings most likely increased. After all, there was no shame or dishonor among one's peers in shooting sea lions or using them for crab bait, and few, if any, would have discouraged the act. Fortunately, a new conservation ethic has emerged, but it is not at all clear that old habits will be quickly abandoned. The overall impact of such shooting is unlikely[6] to be quantified, but its potential should not be underestimated when examining opportunities for stock recovery.

Commercial harvest of Steller sea lions was permitted in the Gulf of Alaska and eastern Aleutian Islands from 1959 to 1972 (Merrick et al. 1987). No precise figure on the total taken from commercial harvest is available, but a total of 45,788 pups were harvested in these two regions between 1963 and 1972. Lowry (in prep.) notes that such harvest could have depressed recruitment in the short term and may have explained declines noted at some sites. It does not, however, seem to explain declines in other regions. The commercial harvest of pups and experimental commercial harvest of adults certainly must have aggravated the broader decline noted off Alaska.

Additional known sources of mortality that can be associated with fishing and other human activities include subsistence harvest by native groups and potential losses of animals to entanglement in marine debris. Regarding subsistence takes, annual state-wide harvest levels have not been systematically documented (Lowry in prep.), but from various scattered reports (Haynes and Mishler, in prep.) it seems safe to say that such harvests were small, perhaps 150 or more animals a year. Losses from entanglement in marine debris are less certain, but it is not assumed to be a major factor, with perhaps fewer than 100 animals killed each year.

The consequences of fishery bycatch, shootings, authorized commercial harvest, subsistence takes, and losses to marine debris, each contributed to the declining number of Steller sea lions during the post-war period. Such losses have been noted by various authors who have discussed potential causes of the decline. The potential cumulative consequences of these added mortalities, however, appear not to have been addressed, probably because much of the quantitative documentation for losses are missing. Recognizing these limitations and potential criticism which may arise as a result of the speculative nature of some of the numbers that must be used, Exhibit 40, nevertheless, attempts to summarize Steller sea lion losses that may have occurred as a result of fishery bycatches and defensive shooting, indiscriminate shooting, commercial harvests, subsistence takes, and entanglement in marine debris.

The table of possible mortalities due to fishing activities and authorized commercial and subsistence hunts is based on little more than gut instinct regarding losses due to indiscriminate shootings, bycatch and defensive shootings in the salmon and other fisheries, and marine debris. Thus, the total magnitude of losses by gear is highly speculative. Nevertheless, the data provide some inclination of the minimal annual Steller sea lion losses due to direct human activity, e.g., those resulting from known authorized commercial harvest, subsistence takes, and trawl bycatch

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[6]An extensive interview of fishermen, cannery operators, and processors might yield a more quantitative answer to this question.

losses. The potential consequence of the overall losses on the population of sea lions off Alaska can be judged if indiscriminate shootings and bycatch and defensive shootings were as high as those projected.

Over the 1960-1990 period, documented losses amounted to 73,804 animals. If we use the 1978 Copper River estimate of 305 animals noted as being killed while interfering with salmon gillnets as an annual kill for all salmon fisheries off Alaska, the minimum observed kills rises to 83,259 for the period 1960-1990. The upper level of possible losses of 139,804 assumes an additional 34,000 deaths occurred due to indiscriminate shootings, 10,545 for bycatch and defensive shooting in all Alaska salmon fisheries, 9,000 deaths due to defensive shooting in all other Alaskan fisheries (crab, bottomfish, line, shrimp, herring, etc.), and 3,000 due to marine debris.

The distribution of losses over time is based on observed times of losses as noted in the literature for trawl bycatch and commercial takes. Losses for the subsistence fishery, incidental take, defensive shooting in "other fisheries," and marine debris were held steady over time. Deaths from subsistence fishing may have been higher during the earlier years when the Steller sea lion abundance was greater, and higher for the incidental take in other fisheries in more recent years. Finally, losses due to indiscriminate shooting, bycatch, and defensive shooting in salmon fisheries have been roughly scaled to the intensity (effort)[7] of the offshore fisheries in Alaska. If the estimates are in the ballpark, one could conclude that direct fishery-associated mortalities for all sources (including commercial and subsistence fisheries) ranged between 1.1% and 4.9% between 1960 and 1990 (Exhibit 41). The pressure on the population may have been relatively high during the period of authorized commercial harvest, after which it declined and then moved up over time as bycatch and defensive killings, indiscriminate shootings, and marine debris losses escalated (or did not substantially decline), while the Steller sea lion population fell off.

Increased levels of mortalities in the 1980s resulting from shootings and bycatch probably played some role in the accelerated rate of Steller sea lion decline, but the rate of population decline between 1985 and 1989 far exceeded the direct losses inferred from fishing-related activities. Indicators of the health of individuals (growth rates and fat levels) within the population indicate that factors other than direct fishery-related kills may have influenced the Steller sea lion population decline (Lowry et al. 1989).

Analysis of the stomachs of Steller sea lions (Calkins and Goodwin 1988) clearly shows that commercial fisheries compete with marine mammals for a variety of fishery resources (salmon, herring, rockfishes, Atka mackerel, sablefish, etc.), and the importance of walleye pollock in the

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[7]The decline noted in the years following 1987 reflects the results of education programs and growing fears over the Steller sea lion population decline.

diet of Steller sea lions has been noted by various authors. Lowry et al. (1989), for example, note the importance of pollock in the diets of marine mammals and provide examples of the fishery/Steller sea lion competition for pollock. The focus on the potential interactions between sea lions and the larger commercial pollock fisheries has been heightened by the observed high levels of pollock in the diets of sea lions taken in the Gulf of Alaska, particularly during the 1970s and 1980s.

The extensive removals of pollock by trawl fisheries are stated to have the potential of altering the abundance of the population or particular age-classes important to marine mammals. It is also apparent that the large-scale commercial fisheries for other marine fishes during 1955-1990 have resulted in a significant harvest of some of the primary Steller sea lion prey species—in particular, herring, pollock, sablefish, Atka mackerel, salmon, and flounders. Several investigators, however, who have examined the possible implications of fishery impacts note that ecosystem interactions and data limitations make it difficult to determine whether fishery removals of prey species actually negatively impacted the population levels of sea lions (Lowry et al. 1982, Loughlin and Merrick 1989, Harwood and Croxall 1988).

This may well be true, but there would appear to be adequate data at least to track the abundance trends of some of the more dominant Steller sea lion prey in the Bering Sea and Gulf of Alaska. In this respect, the Recovery Team notes that "the walleye pollock biomass in the Eastern Bering Sea rose from less than 5 million mt in the early 1960s to a peak of over 13 million mt in the early 1970s, and since has stabilized at about 8 million metric tons" (Lowry, in prep.). More recent cohort studies and adjusted CPUE data from Japanese fisheries, however, show a long-term increase in the pollock from a low of about 3 million mt in the mid-1960s to a high of about 11 million mt in the mid-1980s (Quinn and Collie 1990). We may wish to quibble over what constitutes the best trendline for pollock, but all the evidence points to increasing abundance of pollock in the Bering Sea during a period of significant decline in the Steller sea lion population.

What seems even more apparent is that the best scientific evidence available also strongly supports the conclusion that the pollock population in the Gulf of Alaska sharply increased between 1962 to the mid-1980s—again, a period which encompassed a long-term decline in the Steller sea lion population in the Kiska to Kenai region. Admittedly, however, the rate of decline in northern sea lion population size in this area increased after 1985, following the intense pollock fisheries in the early 1980s.

Lowry et al. (1988) observe that while the biomass of pollock has remained high, occasional low abundance of age-1 pollock between 1979 and 1984 could have resulted in fewer fish available in some years in the size range normally consumed by sea lions. Of course, this observation is "a priori," but the sheer weight of evidence is that average recruitment to the pollock population and population size were for over 2 decades on an upward trend in the Gulf of Alaska and Bering Sea, while sea lion stocks were declining in the Kiska to Kenai region (Exhibit 42). In this regard, Bakkala and Balsiger (1987) note that in the Aleutians and Eastern Bering Sea regions the fisheries harvests do not indicate an overall decrease in fish populations known to be the prey of Steller sea lions. In fact, the trend for pollock, a dominant food item, as well as cod, salmon, and flounder, was clearly toward greater abundance despite fishing activities. In addition, in a numerical study, Laevestu and Bax (1989) and Laevestu and Marasco (1991) concluded that removal of fish by a fishery does not necessarily affect the availability of total food resources of marine mammals because the fishery often removes the larger, more piscivorous components of the populations whose diet is similar to that eaten by competing marine mammals.

Lowry et al. (1989) have observed that the fisheries for pollock contributed to declines in their abundance. Other factors being equal, fishing obviously can only add to the overall population mortality. Nevertheless, as previously noted, the population of pollock in the Bering Sea and Gulf of Alaska trended upward during a significant period during which the Steller sea lion population was declining. In addition, throughout much of the period evaluated in the Lowry et al. (1989) study, the population of pollock in the Gulf was increasing significantly (e.g., between 1974 and 1981, the population more than tripled). Even in 1984, a period of heavy U.S. fishing, the pollock abundance was still much larger than in the mid-1970s (1976). The evidence available also indicates that between 1962 and 1982 the overall stock size of pollock in the Gulf was on the increase, but the relative demands of the fishery and sea lions for pollock were decreasing during the late 1970s and early 1980s, largely because of increasing pollock stock sizes and the decreasing size of the Steller sea lion population, a fact noted by the author.

One observation raised in the Lowry et al. (1989) study is of particular interest and bears further consideration; that is, "the existing pollock stock is far from adequate to support the number of sea lions in the Gulf of Alaska in the mid-1960s"—about 118,000 animals. The authors note that "food requirements based on 50% pollock in the diet would be about 308,000 mt" which is about equal to the current total exploitable biomass. However, Marasco and Aron's (in press) estimate of pollock stock biomass in the Gulf of Alaska, based on a stock assessment model to the aggregate Gulf of Alaska catch, show a stock size from 1986 to 1989 well in excess of 1.0 million mt (Exhibit 28), about three times the stated food demand. The difference here is due to updated stock estimating procedures or areas involved, and the author does not take specific issue with this conclusion.

More important, the observation of Lowry and others raises a most interesting issue. If the observations of Alverson et al. (1964) and Ronholt et al. (1978) concerning the abundance of pollock in the Gulf are reasonably on target, one must conclude that the pollock population in the early 1960s was at a very low level in the Gulf of Alaska compared to the 1970s and 1980s, that is, well under 60,000 mt. If true, one must conclude that pollock probably did not constitute an important component of the diet of sea lions in the Gulf of Alaska during this period of their peak abundance.

The enigma presented by the assumption that pollock played any significant role in the energetics of Steller sea lions in the 1960-1975 period is shown in Exhibit 43. The figure depicts the total food demand of the Steller sea lion population (assumes population is equivalent to 1.5 x index count for Kiska-Kenai region, an intake of 14.3 kilos/day of food (Calkins 1986)). Theoretical demand for pollock is calculated assuming 50% of diet being pollock (Lowry et al. 1989), while the estimated biomass of pollock 2 years and older is based on the work of Marasco and Aron (in press).

It is apparent from the graph that the Gulf pollock stocks could not have supplied any significant portion of the food needs of the Steller sea lions inhabiting the Gulf region from 1960 to the early 1970s. If this observation is correct, the major energetics question which must be addressed is what fish and/or shellfish resources formed the major food items in Steller sea lions during that period?

Regrettably, little other than circumstantial evidence exists in the fishery and environmental data reviewed to help answer this question. The fishery data do indicate that herring and rockfish stocks in the Gulf of Alaska and in the Bering Sea may have been more abundant at the onset of the 1960s, but little else. A review of the historical data on the feeding habits of Steller sea lions and fur seals, however, provides a possible answer to the question.

Lowry et al. (1989) note that pollock ranked fourth in the prey of a small sample of Steller sea lion stomachs collected in the Bering Sea between 1951 and 1962. Although this observation is consistent with the papers referenced (Wilke and Kenyon 1952, Fiscus and Baines 1966), the detailed data show that of 12 stomachs examined (1 in 1949, 1 in 1951, and 10 in 1960 and 1962), no pollock were found in the 1949 sample; the 1951 sample contained 3 pollock, or 10% by weight of stomach contents; and the 10 stomachs examined in 1960 and 1962 contained only 1.7% pollock by volume. Instead, capelin and sandlances—forage fishes—were dominant food items. Also, Tikhomirov (1964), reporting on a 1962 Soviet investigation in the Bering Sea, notes "stomach dissections of sea lions have shown that herring is the staple food of these animals during this period"—presumably winter and spring.

Of course, the samples of stomachs are small, but they certainly do not support a conclusion that pollock was an important element in the diet of these animals in the areas and at the times the samples were taken. Further, of seven animals examined by Fiscus and Baines (1966) taken from various areas in the Gulf of Alaska in 1960 and 1962, not a single pollock was observed. Rather, capelin and sandlance were the most important food items. A much larger sample of males, females and juveniles (114 animals) taken from near the Shumagin Islands in 1958, found various small fishes (smelt, rockfishes, and greenling) and shellfish (crabs, clams, and squid), but no pollock (Mathisen et al. 1962). Studies of 382 sea lion stomachs, mostly males, taken in 1959 in various areas of the Gulf found that rockfishes, sandlances, squids, and clams were important in the sea lions' diet. No pollock were reported (Thorsteinson and Lensint 1962). The only notable reference to the importance of pollock in sea lion diets between 1940 to 1970 is that of Imler and Sarber (1947), who identify pollock as one of the ten most important food items.

These studies also provide no supporting evidence that pollock were important Steller sea lion prey in either the Bering Sea or Gulf during 1949-1962. However, Steller sea lion stomachs taken from the Bering Sea during the 1980s showed that of 86 sea lions containing food, pollock was dominant in 67. In reasonably large samples taken from the Gulf of Alaska, pollock, as previously noted, constituted 58.3% and 44.2% of the volume of stomachs in the 1970s and 1980s, respectively (Lowry et al. 1989).

Admittedly, possible changes in feeding patterns observed are based on skimpy observations or very qualitative reporting for the early period, but they surely raise the possibility that a significant change in the type of the food intake may have occurred between the 1960s and mid-1970s. In hopes that more conclusive data might shed light on the question of the prey potential available to Steller sea lions in the Bering Sea and Gulf during the early 1960s, the extensive information on feeding patterns of the northern fur seals over the 1960-1990 time period was reviewed. These animals are admittedly smaller and have a much different life history. Nevertheless there are many similarities in their food sources and these data are somewhat more informative and reliable regarding changing availability of prey because they are based on larger sample sizes taken over a number of years.

In examining data presented on fur seal feeding patterns in the various unpublished annual reports of the U.S. Bureau of Commercial Fisheries (BCF) and NMFS[8] and the works of Perez and McAlister (1988) and Sinclair (1988), it becomes clear that pollock was on average of importance in the diet of fur seals in the Central Bering Sea and Unimak Pass areas as early as 1960 (Exhibits 44 and 45), but less important than small forage fishes. It is equally apparent that pollock's importance in the stomach samples in both of these areas increased sharply from 1968 onward, a trend noted by Swartzman and Haar (1983). Further, the data show that pollock and other whitefish[9] were not generally important[10] in fur seal stomachs examined from the Central and Western Gulf regions at any time during the 1960s (Exhibit 46).

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[8]A large number of unpublished annual and special reports on fur seal behavior, feeding, etc. are available at the NMFS Marine Mammal Laboratory in Seattle. See work of Bains, Biggs, Fiscus, Kajimura, Lander, Lanoev, Niggol, O'Brien, Perez, Wilke and York (1958-1980).

[9]Cod and flounder.

[10]Importance as used here refers to presence of a food item in the sample taken during a particular year and does not rule out the possibility of the prey being dominant in some samples, areas, and time periods during a year.

In all regions from which data are available, species of small schooling fishes, squids, and at times rockfishes were important in the fur seal diet in the early 1960s and pollock was far less important compared to the 1970s and 1980s.

The apparent upward trend in the importance of pollock in the diets of fur seals and sea lions between the 1960s and 1980s in these areas is of particular interest. The fur seal and Steller sea lion feeding data together reinforce the possibilities that herring, capelin, sandlances, squids, and other prey played a much larger role in the diet of these animals during the early 1960s, and that pollock and other whitefish have become increasingly more important only in the last 2 decades, a period of major sea lion decline.

There are several possible explanations of these observations on feeding habits. First, they could be an artifact of sampling patterns. Second, the increasing pollock population in the Bering Sea and Gulf during the 1970s and 1980s may have shifted sea lion predation away from other food sources to pollock. Third, the declining size of small forage fish populations, coupled with the rapid growth of pollock and other whitefish populations, may have forced or made it more advantageous for sea lions to feed on pollock.

Sinclair (1988), for example, notes that the combined effect of interannual variability in prey species resources other than pollock and the decreased availability of their potential alternative prey may have forced fur seals to switch to the "newly abundant." She suggests that it is possible that seals suffer food limitations in years of low pollock abundance. This, however, seems at odds with the available data on abundance trends of pollock and sea lions. Steller sea lions were at very high levels in the waters off Alaska during periods when there was little evidence that pollock was an important food item in their diet. Perhaps the reverse is true, that is, Steller sea lions do not fare well during periods of sharply reduced levels of herring, capelin, sandlances, Atka mackerel, etc.—fishes having much higher oil content than pollock, cod, and flounders (Exhibit 46). Of course, this debate is tantamount to "Which came first, the chicken or the egg?"; that is, "What are the sea lions' more traditional prey species?" For an opportunistic feeder such as the sea lion, probably whatever is abundant and easy to catch at a particular location and time becomes the "traditional" prey species, even though some preferential selection may occur.

A more pertinent question, however, is what species are most likely to provide the nutrition needed to support and maintain a healthy Steller sea lion population. In this respect, it may well be that the small forage fishes, which display the classic schooling behavior and are easier to capture, are nutritionally superior. This may explain why Steller sea lions flourished during periods of higher abundance of small fatty fishes and became increasingly distressed as they turned to pollock and other whitefish as their major food sources.

The fact that sampling time (time of year and time of day), areas, sex, etc., can greatly influence the amounts and types of food found in Steller sea lion stomachs and other marine mammals is well documented (Kajimura 1984). Nevertheless, the persistence of the trend of reduced fatty fishes in Steller sea lion and fur seal stomach contents between years and between areas is difficult to ignore. Also, the sharp decline in the frequency of certain fatty fishes in the stomachs of fur seals in areas where earlier sampling found their occurrence common further supports the hypothesis that a major shift in the abundance of prey species occurred (BCF/NMFS seal reports for 1958-1975). The continual decrease in fatty fish in the diets of Steller sea lions in the Gulf of Alaska between the 1970s and 1980s, with reasonably large samples in both areas, lends additional weight to the view that a major shift in available food supply could have occurred between the 1960s and 1990s, forcing sea lions to become increasingly more dependent on pollock and other whitefish, particularly in the Gulf of Alaska during the late 1970s and 1980s.

From the above observations, the author hypothesizes the following:

1. During the 1960s and perhaps earlier, sea lions and fur seals fed largely on small forage fish species, squids, Atka mackerel, and rockfishes, and that with the exception of portions of the Bering Sea, pollock were relatively unimportant in the diets of these animals.
2. The abundance of herring, smelts, and other small forage fishes, as well as shrimp, crabs, rockfishes, and Atka mackerel in the Bering Sea and/or Gulf of Alaska was much reduced during the 1970s and 1980s as a result of a large-scale shift in the ecosystem brought about by biological and environmental changes or fishing activities or both.
3. The ecosystem adjustments, in association with fisheries management, resulted in a major increase in cods, pollock, flounders, and salmon during the last 2 decades.
4. Steller sea lions' shift to pollock and other whitefish species as a major food source followed the dramatic change in the dominant components of the pelagic and demersal fish and shellfish complex. This shift in feeding patterns led to a diet much lower in caloric intake and available fats per weight of food intake, which has contributed to a dietary deficiency.

Facts supporting these conclusions are as follows:

1. Pollock was not abundant in the Gulf of Alaska during the early 1960s when Steller sea lions were at high abundance level.
2. CPUE surveys and cohort studies suggest that a significant increase in pollock and other whitefish species occurred in the Gulf of Alaska and Bering Sea during the 1970s and 1980s.
3. Catch and CPUE data suggest a marked decline in herring population in the North Pacific and Bering Sea between the late 1950s and early 1970s.
4. Stomach analyses of Steller sea lions provide little to support the view that pollock was an important food item in the Bering Sea in the early to mid-1960s, and no evidence supports

the view that pollock was an important food source for Steller sea lions or fur seals in the Gulf of Alaska during the 1960s. The increasing dependence of sea lions on pollock and other groundfish species during the past two decades corresponds to the period of rapid growth of pollock stocks in the Gulf of Alaska and Bering Sea.

5. For both fur seals and sea lions, fatty fishes constituted the dominant component of the diet of these animals in almost all regions and years for which data are available during the early 1960s.
6. Condition indexes for Steller sea lions indicate that members of the population may be suffering from nutritional deficiency.
7. The observed diets of sea lions were much richer in caloric intake-per-unit-volume of consumed food in the 1960s than they are now in the Gulf of Alaska and Bering Sea.

The author recognizes that nutritional support and energy requirements for marine mammals is a much more complicated issue than availability of fats, protein, and carbohydrates in prey species and there seems to be little specific information that addresses this issue for Steller sea lions. Rastelein et al. (1990) note that "different species of fish have a different energy content per unit weight." It is also apparent from Stansby (1976) (Exhibit 47) that the oil content of potential prey may vary by area, season, etc. Exhibit 48 indicates that the food "energy value (k cal/gm)" of pollock, cod, and sole is very low in comparison to herring, capelin, and salmon. Pollock, along with cod and flounders, have on average a relatively low fat content. It is the author's supposition that the fatty species provide significantly greater gross energy and other nutritional requirements per-unit-weight of prey consumed than the gadoids and flounders. This would seem to be supported by data provided by Lavigne et al. (1982).

Authors who have examined the potential of a nutritional problem for Steller sea lions have focused more on the issue of localized overfishing and disturbance of aggregates of prey species (for example, the breaking up of pollock schools). There is reasonably good evidence that the extensive trawl fishery for pollock that began in the late 1960s expanded and became a major source of direct mortality to pollock stocks in the Bering Sea during the time the Steller sea lion population numbers were dwindling. Whether or not these activities significantly altered Steller sea lion access to this food source is uncertain. Even if we accept this possibility for the Bering Sea, a much different trawl fishing scenario occurred in the Gulf of Alaska and along the Aleutian Islands. In these areas trawling throughout the 1960s focused almost exclusively on Pacific ocean perch and other rockfishes, and it was not until the mid- and late 1970s that any significant pollock fisheries were developed. In fact, in the Aleutian Islands no significant pollock fisheries existed until 1980, and in the Western Gulf of Alaska pollock fisheries were at a very low level throughout the 1970s. Also, in the Eastern Gulf around Kodiak Island, pollock was not a major target of trawl fisheries until the late 1970s. Additionally, throughout much of the late 1970s, foreign fisheries were excluded from operating in much of the waters adjacent to Kodiak Island during the periods from August 10 to May 15, and the waters south of Unimak Pass were closed throughout the year (Fredin 1987).

Thus, it is difficult to conclude that the pollock fisheries played any important role in interfering with normal feeding activity that would have accounted for the declines noted between 1960 and the mid-1980s. Perhaps a somewhat stronger argument, however, can be made for the period from the mid-1980s to the present, even though pollock populations remained at relatively high levels. There is certainly a need to better identify current Steller sea lion feeding areas and prey species throughout their lives, and to track their abundance trends, as well as those of target commercial fishes.

SUMMARY AND CONCLUSION

During the postwar era, high seas fisheries developed rapidly throughout much of the Western and Eastern North Pacific regions. Fisheries for salmon, herring, crab, bottomfish, shrimp, etc., which occurred over much of the Continental Shelf and Slope area and extended over much of the open ocean region beyond the influence of the continents, greatly increased encounters between humans and marine mammals of the region. The extensive removals by these fisheries sharply reduced the abundance of Pacific ocean perch and other rockfishes along the Continental Slope and perhaps herring throughout much of the North Pacific. Following the decline of these species in the late 1960s and early 1970s, many finfish species, such as salmon, and a variety of bottomfish increased sharply in abundance, while crab and shrimp populations collapsed.

The author concludes that no single factor can be identified as the sole or even major factor responsible for the Steller sea lion population collapse over the past 3 decades. Also, the factors influencing the Steller sea lion decline may have changed and the importance of any one factor in the combination of causes responsible for the decline may have varied markedly over time. Nevertheless, four major causes seem to have been the primary sources of increased mortality on sea lions. These are, not necessarily in order of importance, as follows:

1. A nutritional deficiency resulting from heavy reliance on pollock and other whitefish, which followed a decline in availability of fatty fishes or other prey in the 1960s, and significant growth in the abundance of pollock over the 1960-1990 period. The absence of fatty fishes in the Steller sea lion diet, which provide greater amounts of caloric energy and perhaps other needed nutritional components, is presumed to be a factor influencing the current health and possibly mortality of the animals in the Steller sea lion population; and
2. Indiscriminate shooting by fishermen and other sectors of society
3. Bycatch in commercial fisheries and authorized shooting in defense of fishing gear/catch or both
4. Authorized commercial harvests

All of these factors have in one form or another been previously identified. However, I would perhaps place greater emphasis on indiscriminate killing than seems to be the case in other discussions of the Steller sea lion decline. In addition, I find scant support for the view that the large-scale trawl fisheries for bottomfish have reduced the populations of pollock, currently an important food source for Steller sea lions over the period of the sea lions' decline between the late 1950s and early 1980s. There is also little evidence that the fisheries disturbed either the schooling or aggregation feature of key prey species or their availability to sea lions. In fact, the opposite may be true, that is, the emergence of the trawl and other high seas fisheries may have enhanced access to certain species through easy capture or prey trapped in nets and/or discards of undersized and unwanted species. On the other hand, the possibility that trawling may break up and alter distributional features (availability) of Steller sea lion prey species cannot be ruled out. It simply needs further study.

On a smaller scale, the author suggests there indeed may be a nutritional deficiency, but it is more likely associated with the decline in the abundance or availability (or both) of fatty fish resources which have much higher caloric value and perhaps other nutritional attributes not available in pollock and other low-fat species. In this regard, a better knowledge of the bioenergetics of Steller sea lions and their prey may be a prerequisite to enlightened ecosystem management (Lavigne et al. 1982).

Lower abundance of small fish species, particularly herring, capelin, and other forage species, may well have resulted not only from a synergistic effect of fishing and environmental changes, but also by greatly increased predation on forage fish resulting from the growing abundance of salmon, pollock, cod, and a variety of flounders (Skud 1982).

I do not suggest that the evidence set forth in this review is sufficient to conclude that the primary causes identified should preclude other alternatives or that adequate evidence exists to substantiate that the nutritional hypothesis put forth is indeed fact. Rather, I suggest that there is more than adequate evidence to warrant its acceptance as a legitimate addition to the list of current alternative causes, all of which require further documentation and study.

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EXHIBITS

Exhibit 1. Potential causes of recent northern sea lion population declines in Alaska. Source: Loughlin (1987).

Cause	Potential impacts	Comment
Disease	High	Diseases cause reproductive failures, sterility, and adult or juvenile mortality
Combined impact of all fishery effects	High	Combined effect of following three causes
Changes in prey abundance or composition	Moderate	Prey (pollock) biomass decreased somewhat; abundance of target size prey low in some years
Incidental take	Moderate	Annual take probably <1000 animals
Intentional take	Moderate	Unknown amount of mortality
Commercial pup harvest	Low	May have depressed and redistributed population in 1970s; should have little effect now
Entanglement in marine debris	Low - Adult ? - Juvenile	Low incidence of observed adult mortality; juvenile mortality unknown
Increased predation	Low	No apparent increase in predator (killer whale) populations
Climate and ocean changes	Low	Little direct impact, but may affect prey
Subsistence harvest	Low	Small annual take (<200) should affect local groups only
Pollution	Low	No apparent effect on other Bering Sea pinniped populations
Harassment	Low	May have redistributed populations, but no major effect on numbers overall

Exhibit 2. Japanese mothership fishing fleet, 1952-1983. Source: INPFC (1979).

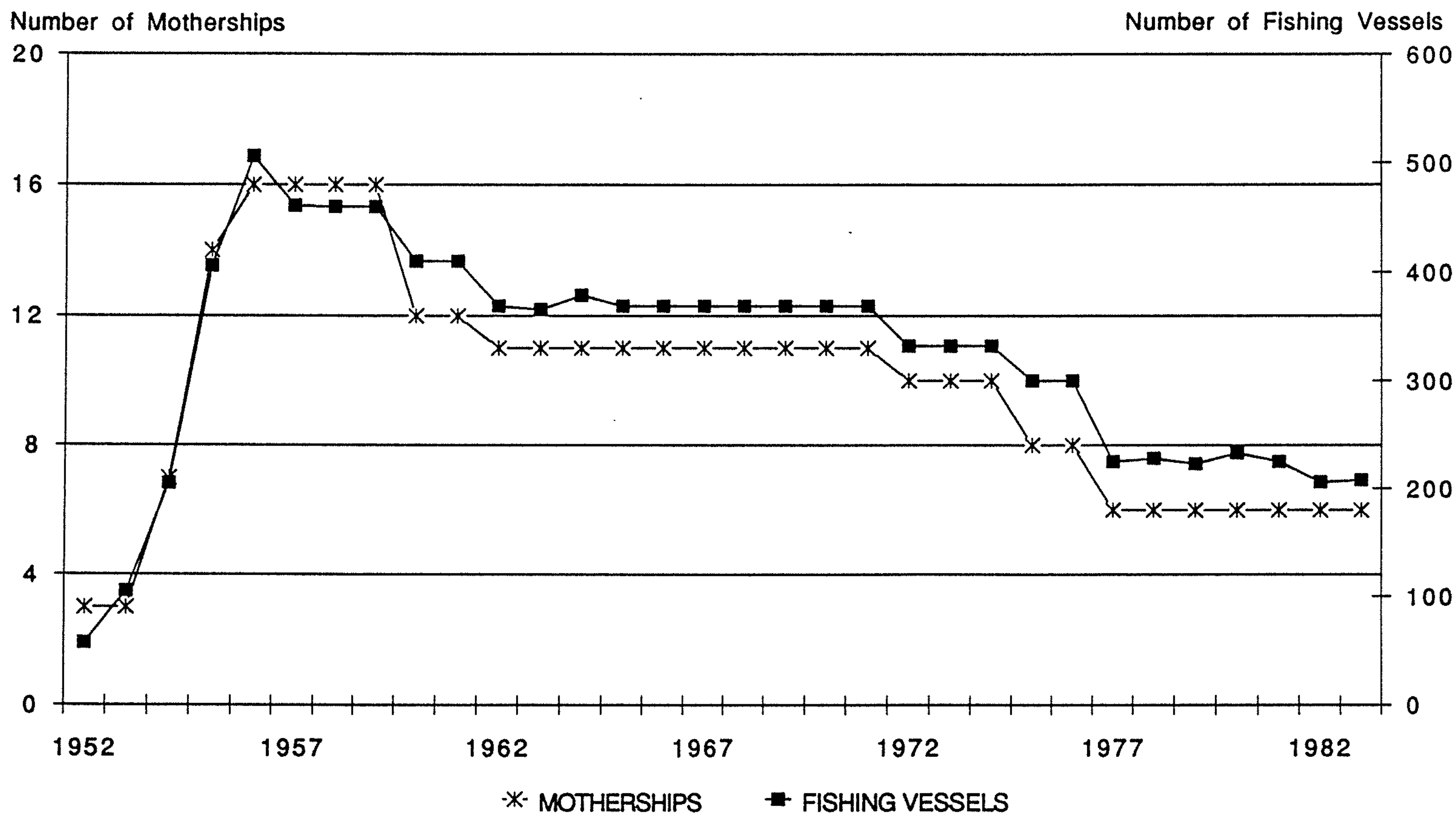


Exhibit 3. Harvest of Salmon by Japanese mothership and land-based fleets, 1952-1976. Source: INPFC (1979).

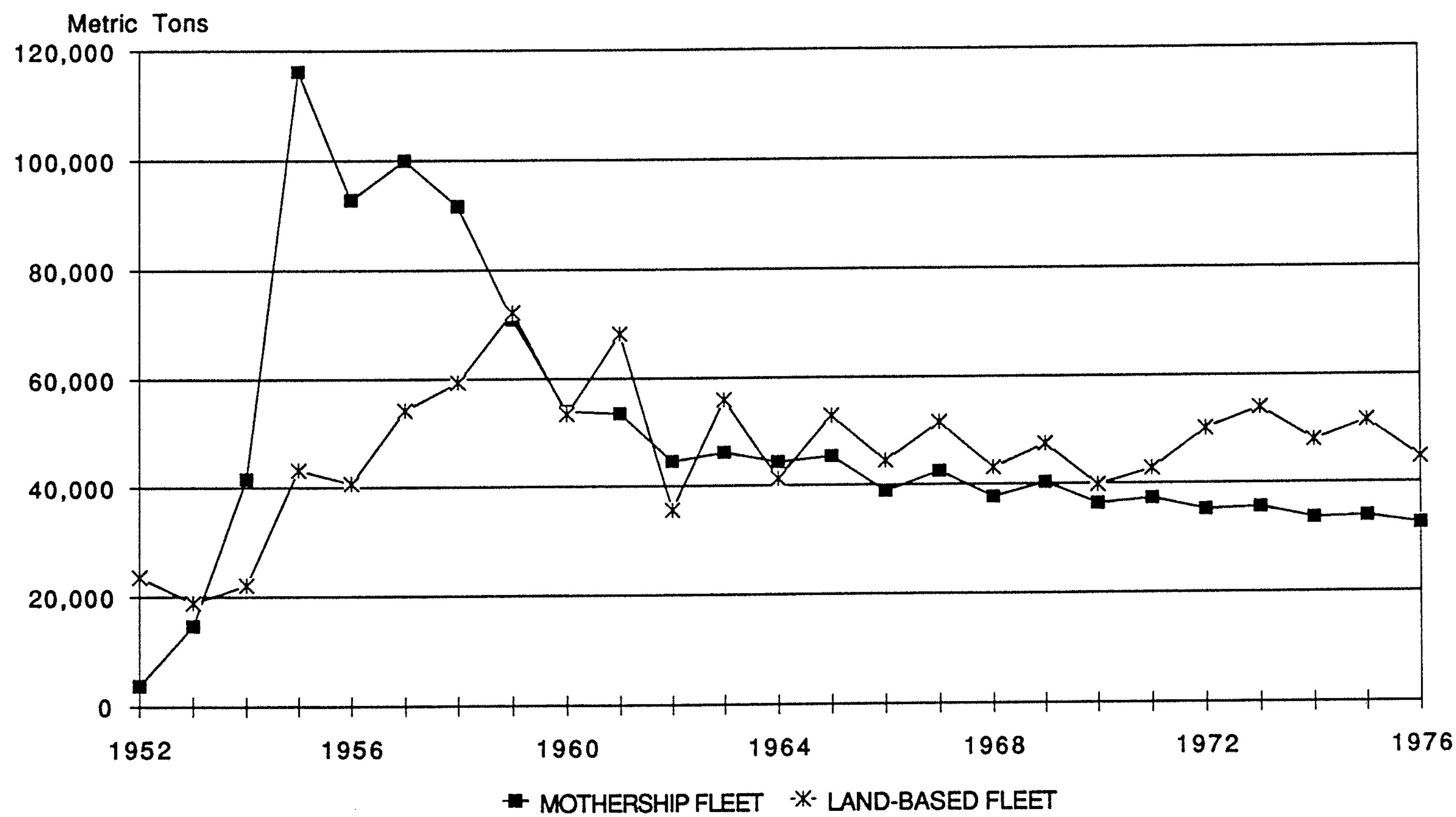


Exhibit 4. Alaska salmon catch, 1932-1986, in millions of fish. Source: ADF&G (1985, 1990a).

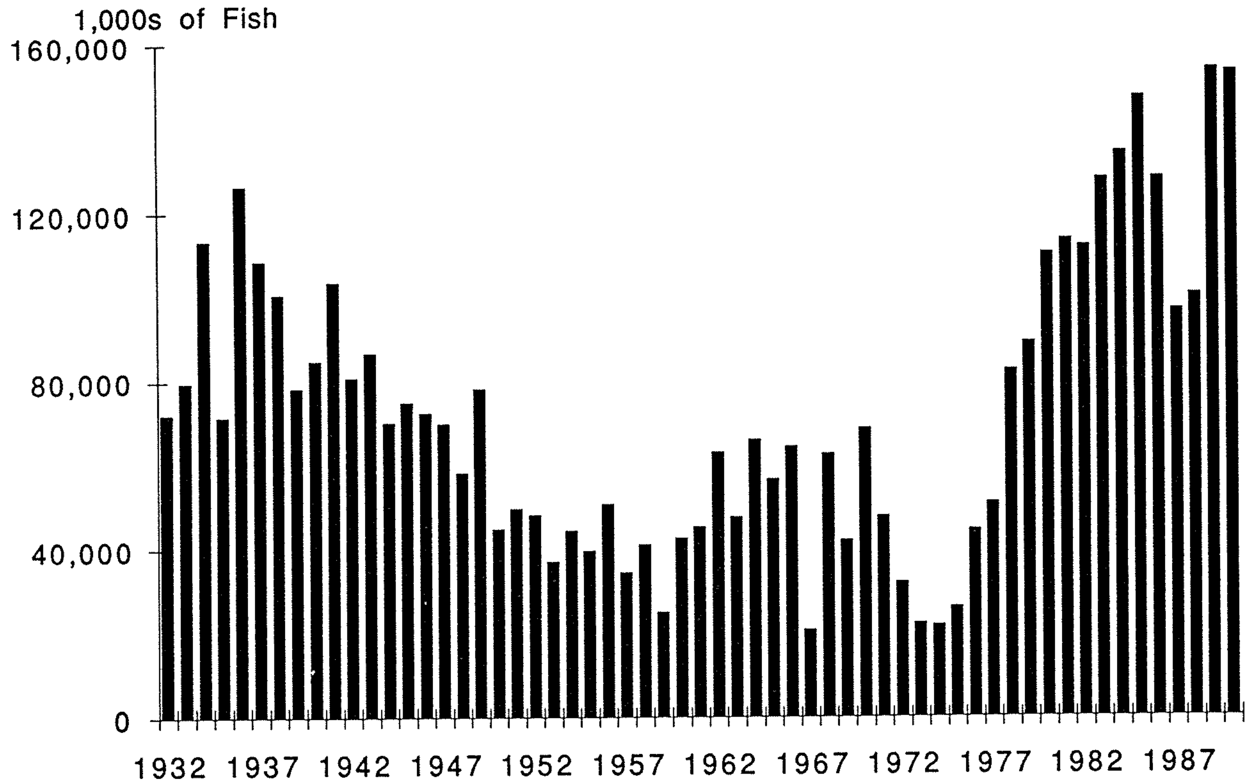


Exhibit 5. Gillnet fishing effort for herring by Japan in the Bering Sea, 1963-1983. Source: Fredin (1985).

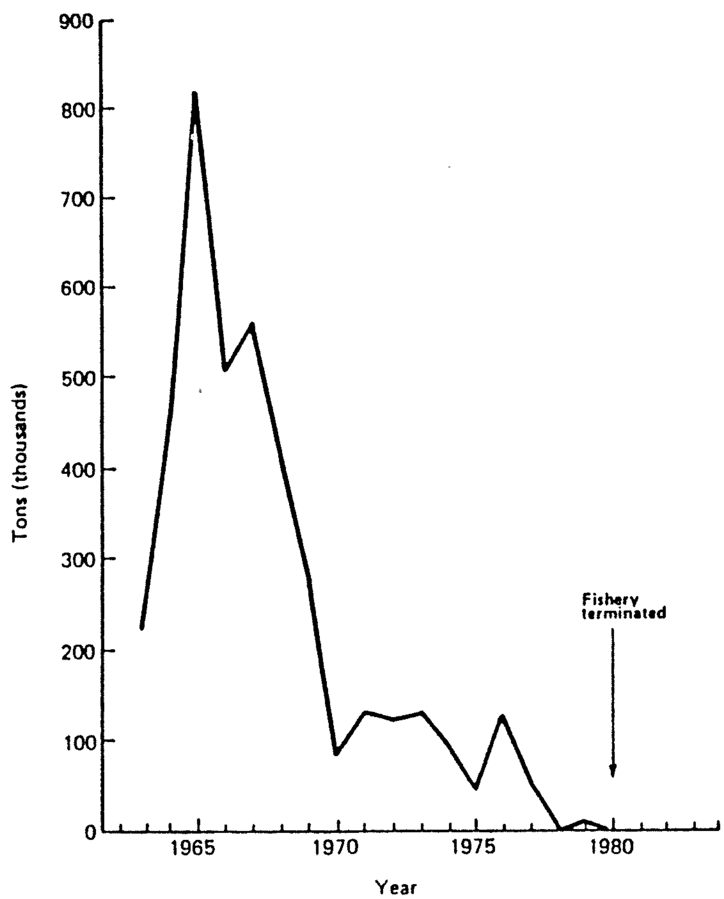


Exhibit 6. Catch of Pacific herring in the Eastern Bering Sea by nation, 1960-1982. Source: Wespestad and Fried (1983).

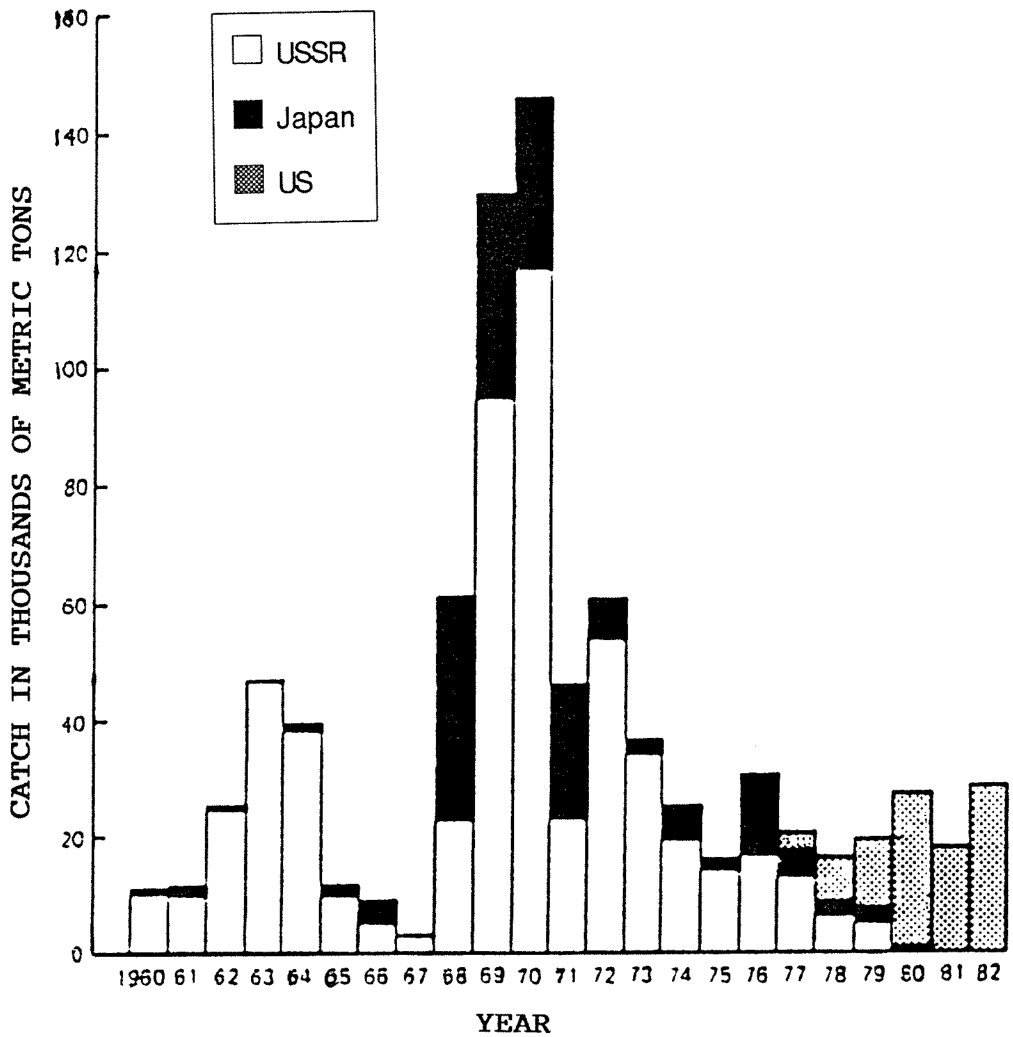


Exhibit 7. Landings of herring by U.S. nationals in the Southeastern, Central, and Western Districts of Alaska, 1908-1979. Small landings prior to 1908 not shown. Source: Alverson and Pruter (1980).

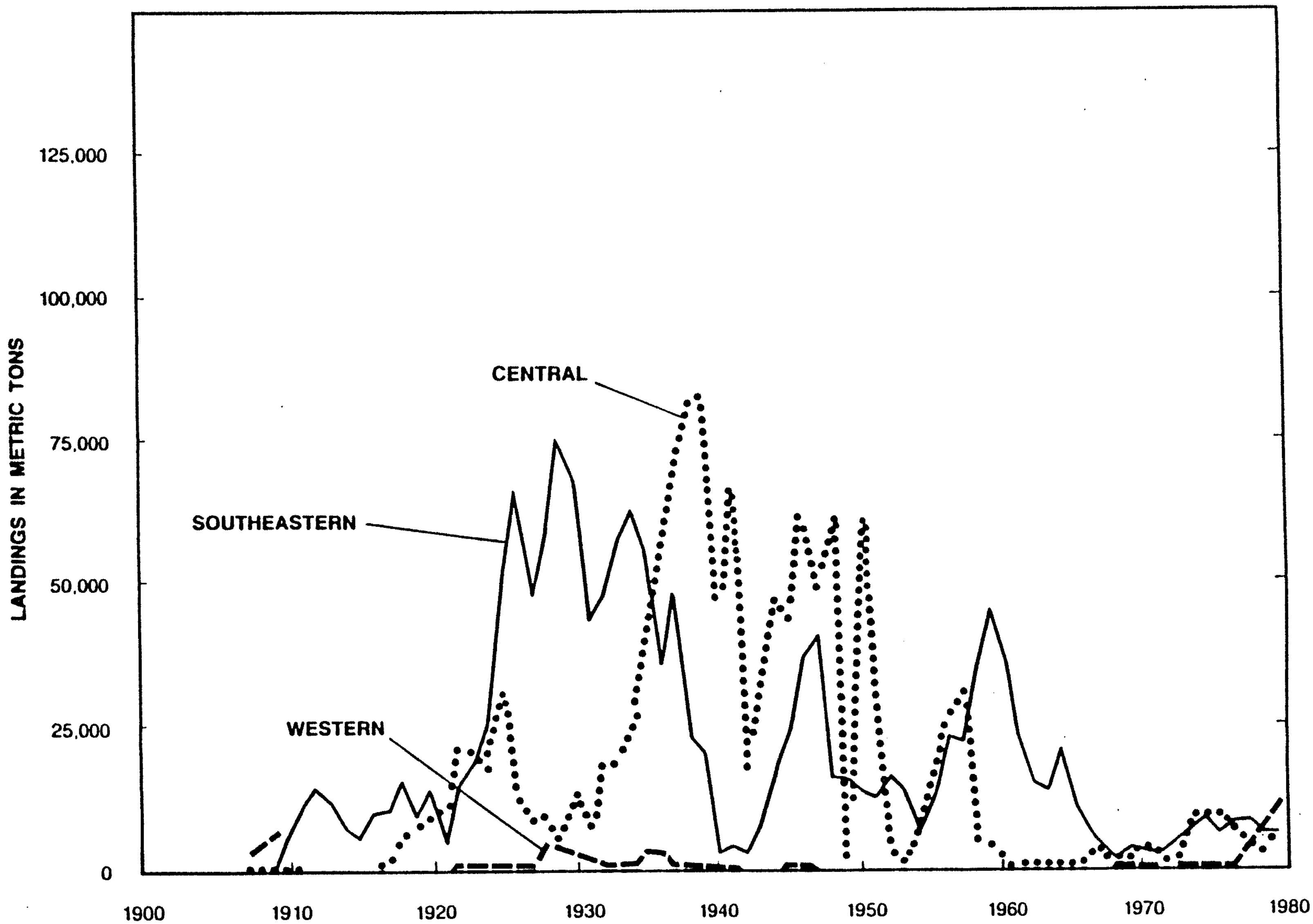


Exhibit 8. Number of tans of crab tanglenet set by Japanese and USSR fisheries in the Bering Sea. Source: Fredin (1985).

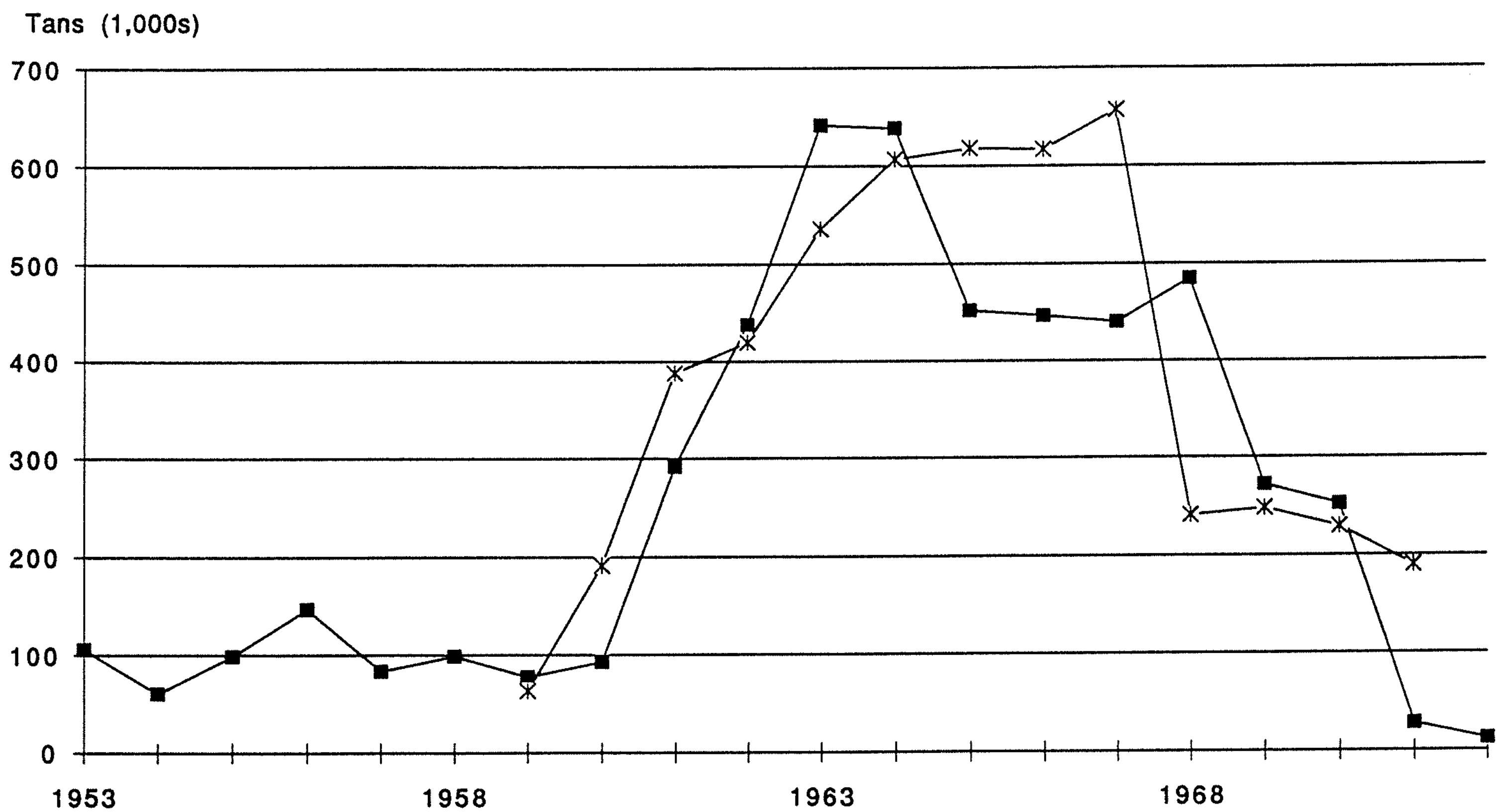


Exhibit 9. Annual all-nation red king crab catch in Eastern Bering Sea, 1958-1982. Source: Fukuhara (1985).

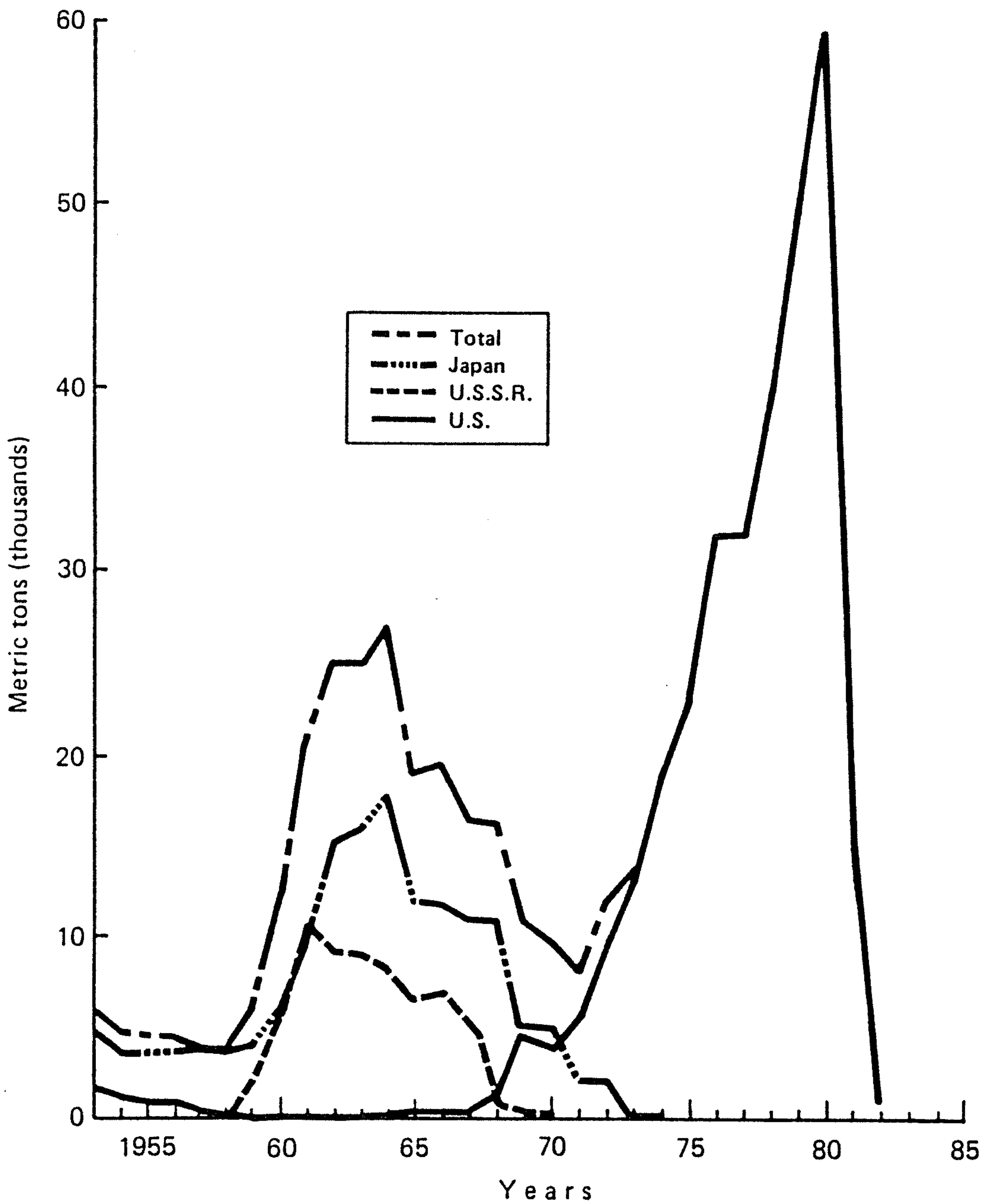


Exhibit 10. Pot lifts in Western Region king and Tanner crab fisheries, 1964-1989. Source: ADF&G (1990b).

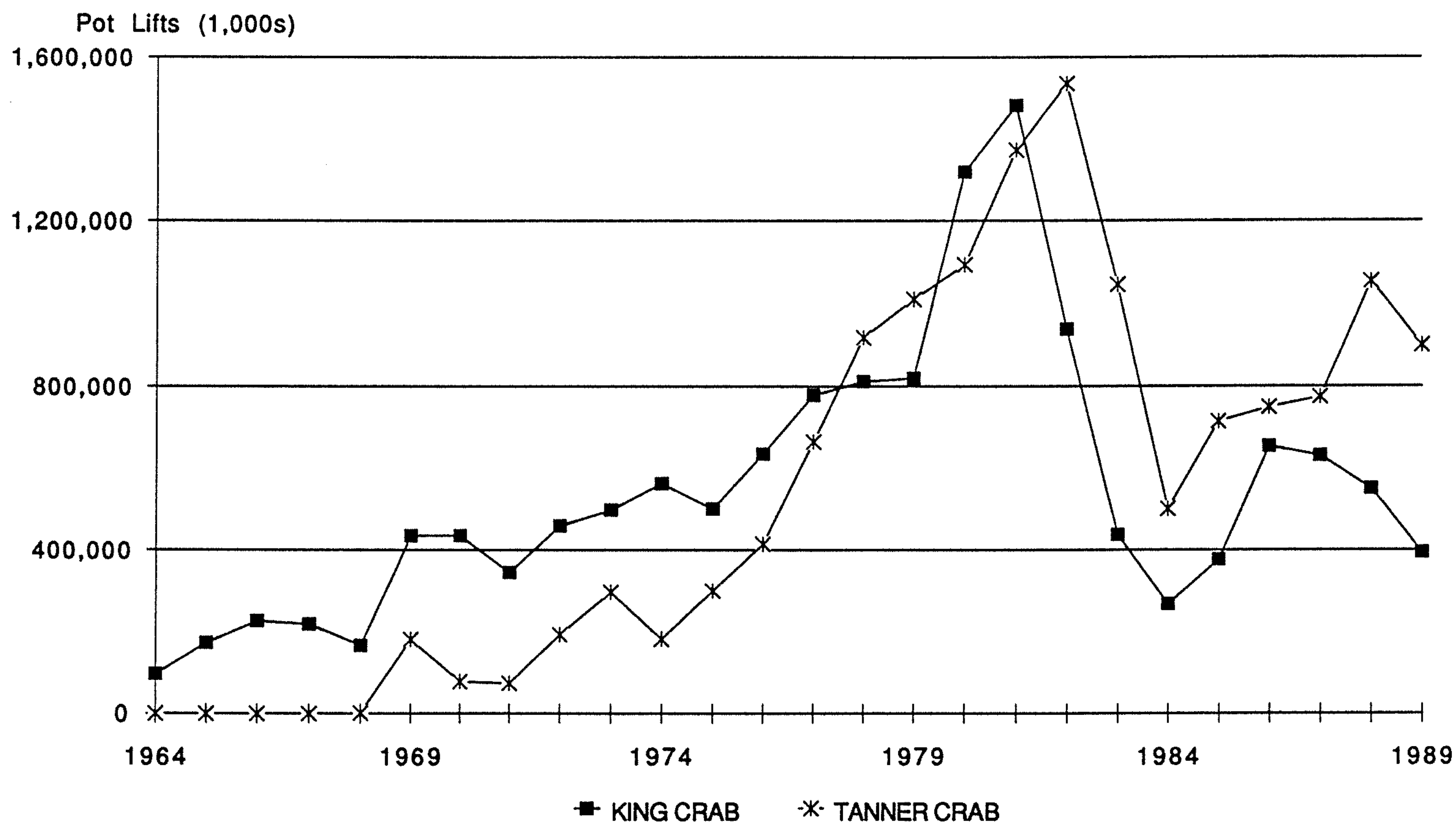


Exhibit 11. Western Region king crab harvest, 1950-1989. Source: ADF&G (1990b).

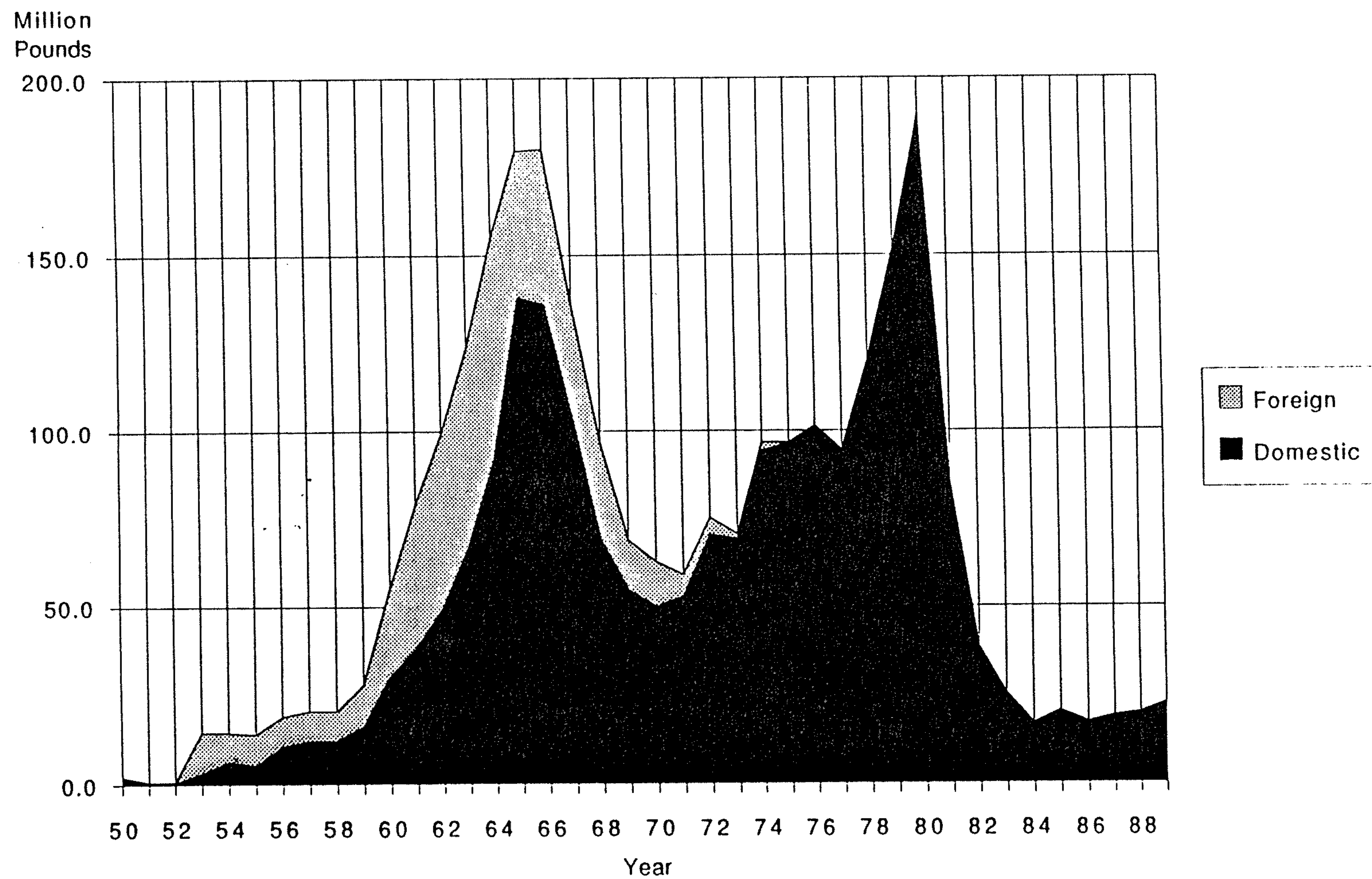


Exhibit 12. Western Region Tanner crab *(Chionoecetes opilio)* harvest, 1978-1989. Source: ADF&G (1990b).

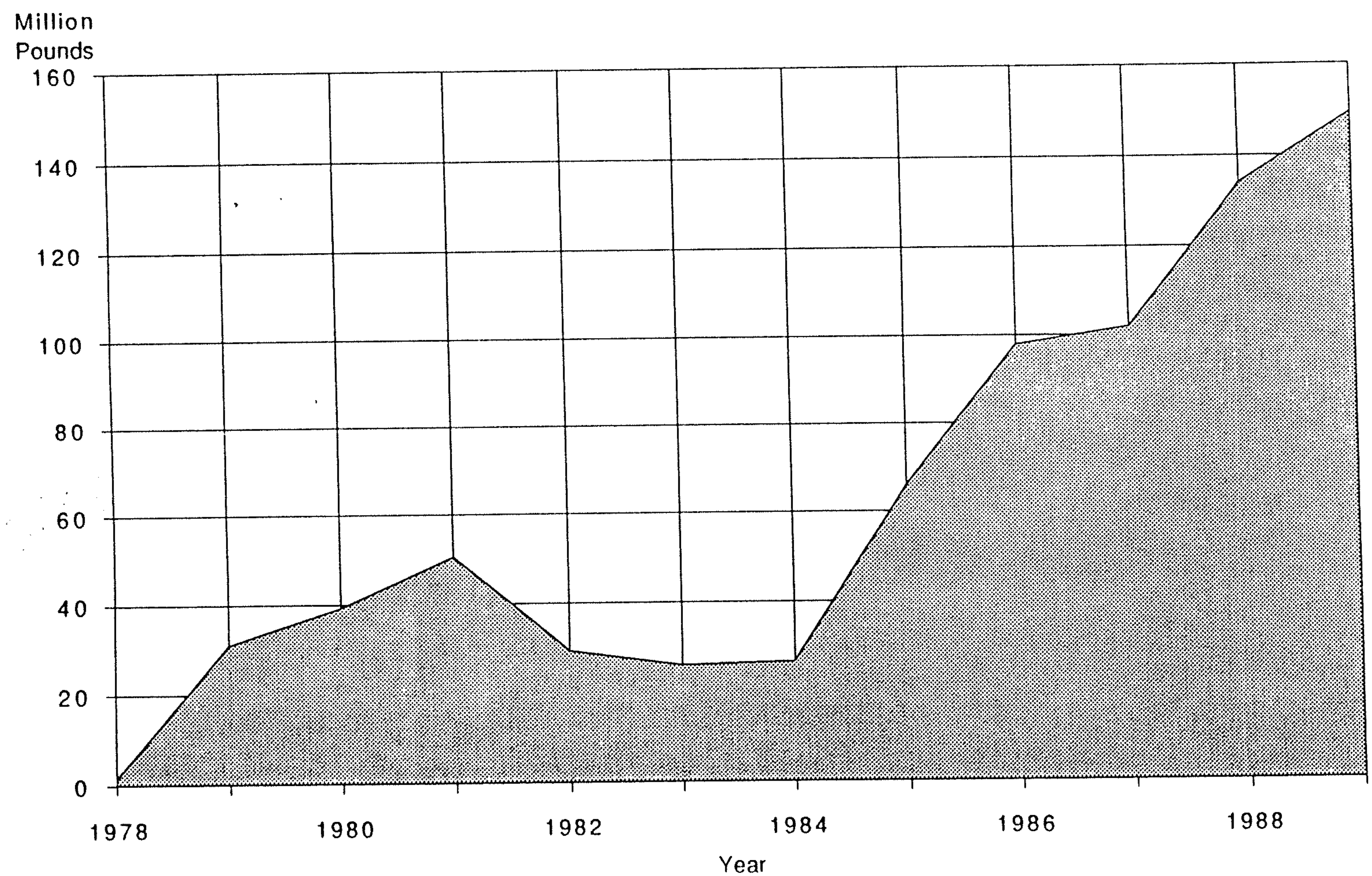


Exhibit 13. Western Region Tanner crab (*Chionoecetes bairdi*) harvest, 1965-1989. Source: ADF&G (1990b).

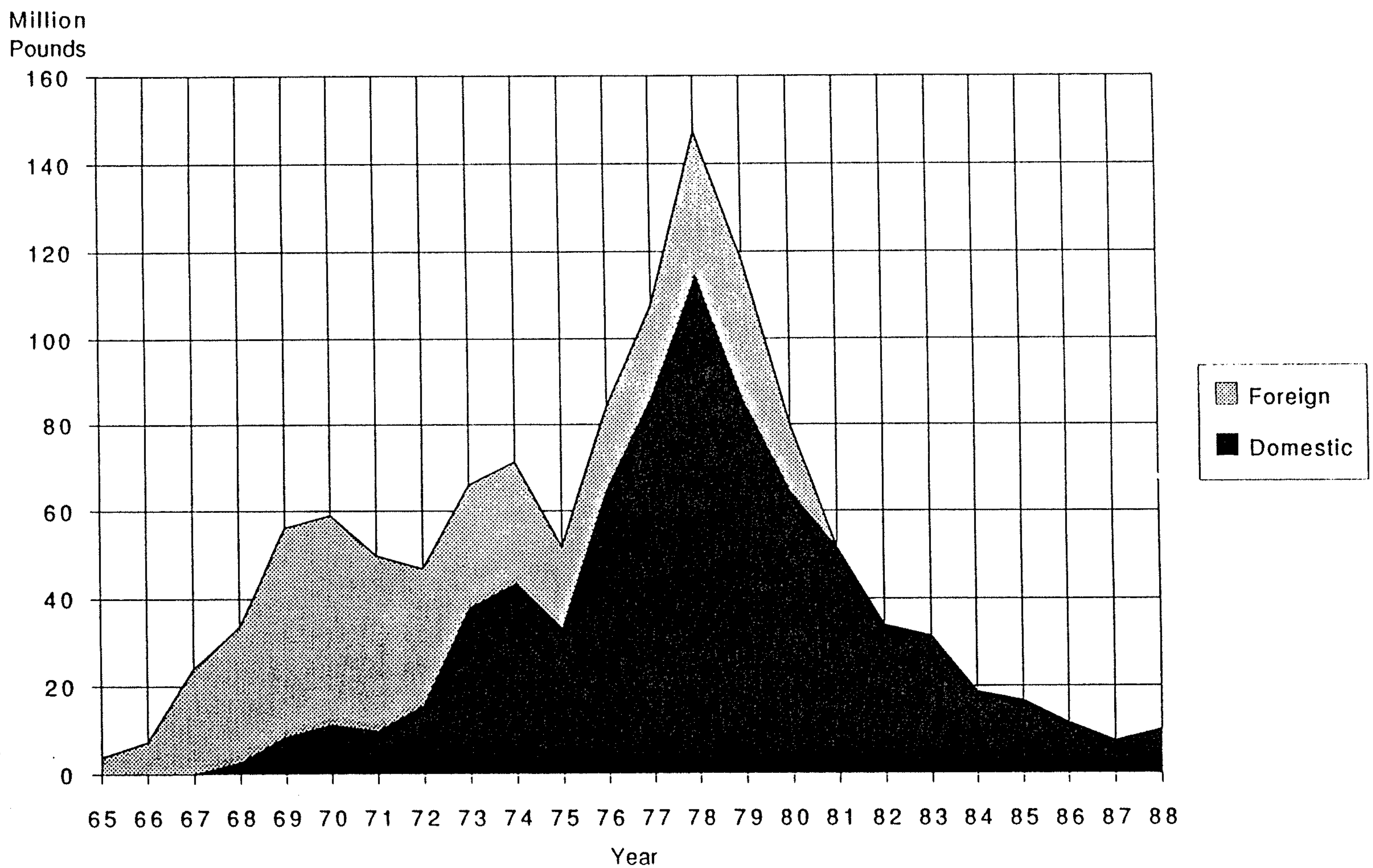


Exhibit 14. Trawl fishing effort for groundfish, shrimp, and herring by foreign and U.S. fisheries in the Bering Sea/Aleutian Islands Region, 1963-1983. Source: Fredin (1985).

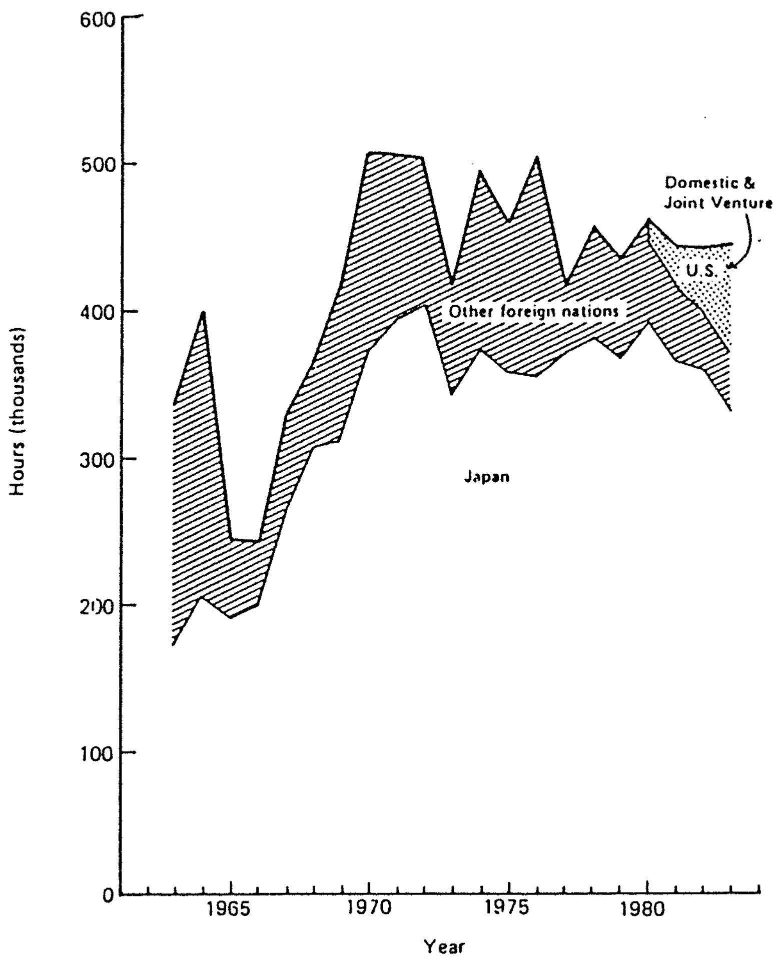
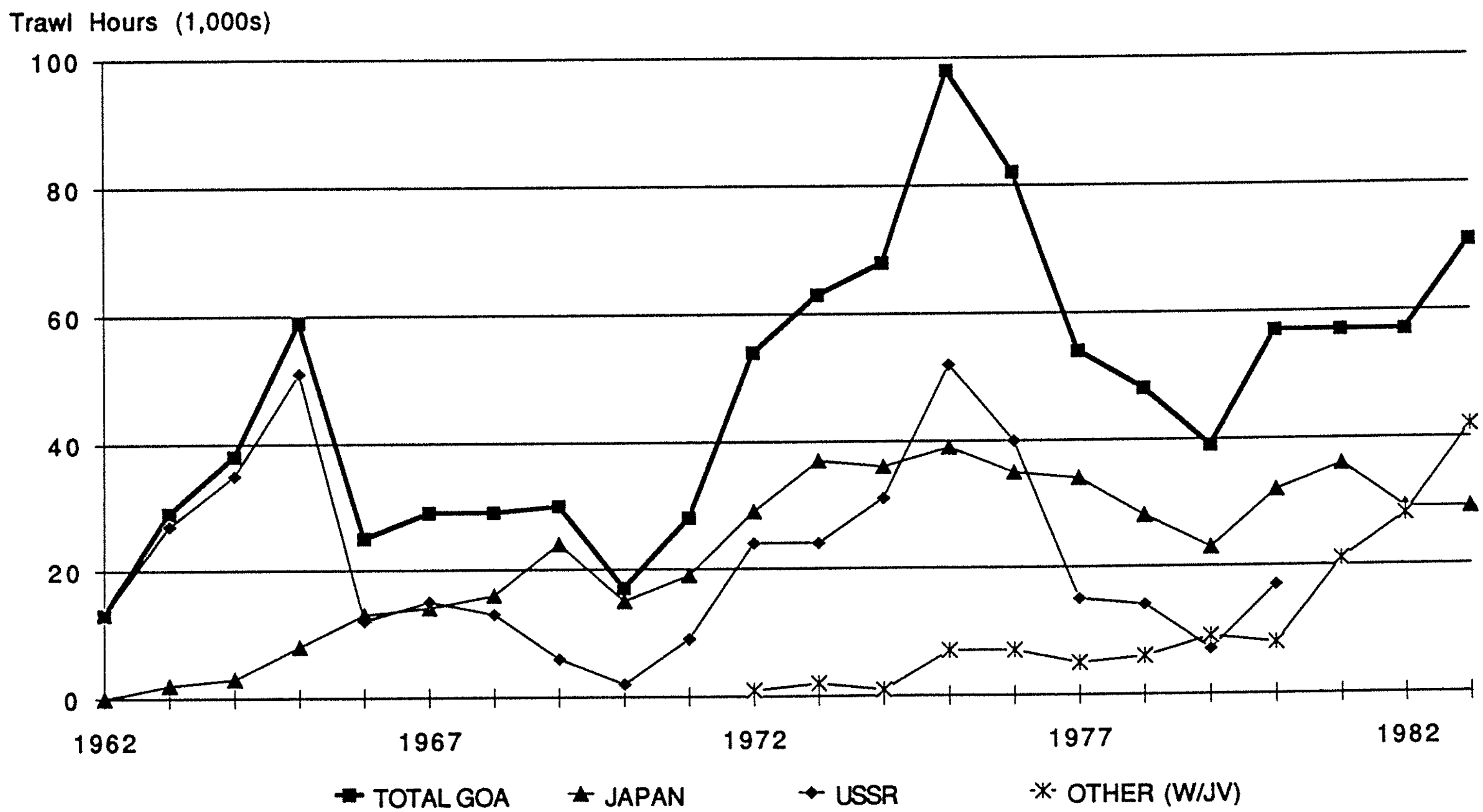


Exhibit 15. Number of trawl hours in Gulf of Alaska foreign and joint venture groundfish fisheries, 1962-1983. Source: Fredin (1985).



Domestic trawl hours not included.

Exhibit 16. Trawl fishing effort for groundfish in the Northeast Pacific Region by Japanese, Soviet, Republic of Korea, Polish, Canadian Joint Venture, and U.S. Joint-Venture fisheries, 1962-1983. Source: Fredin (1985).

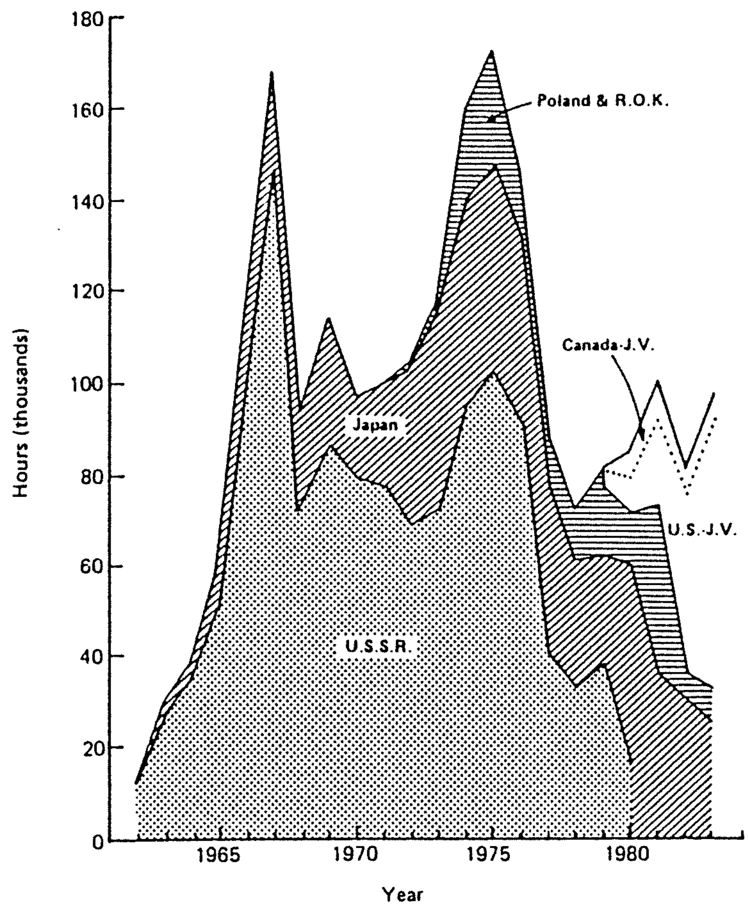


Exhibit 17. Number of factory trawlers by year, 1985-1990. Source: NRC data files.

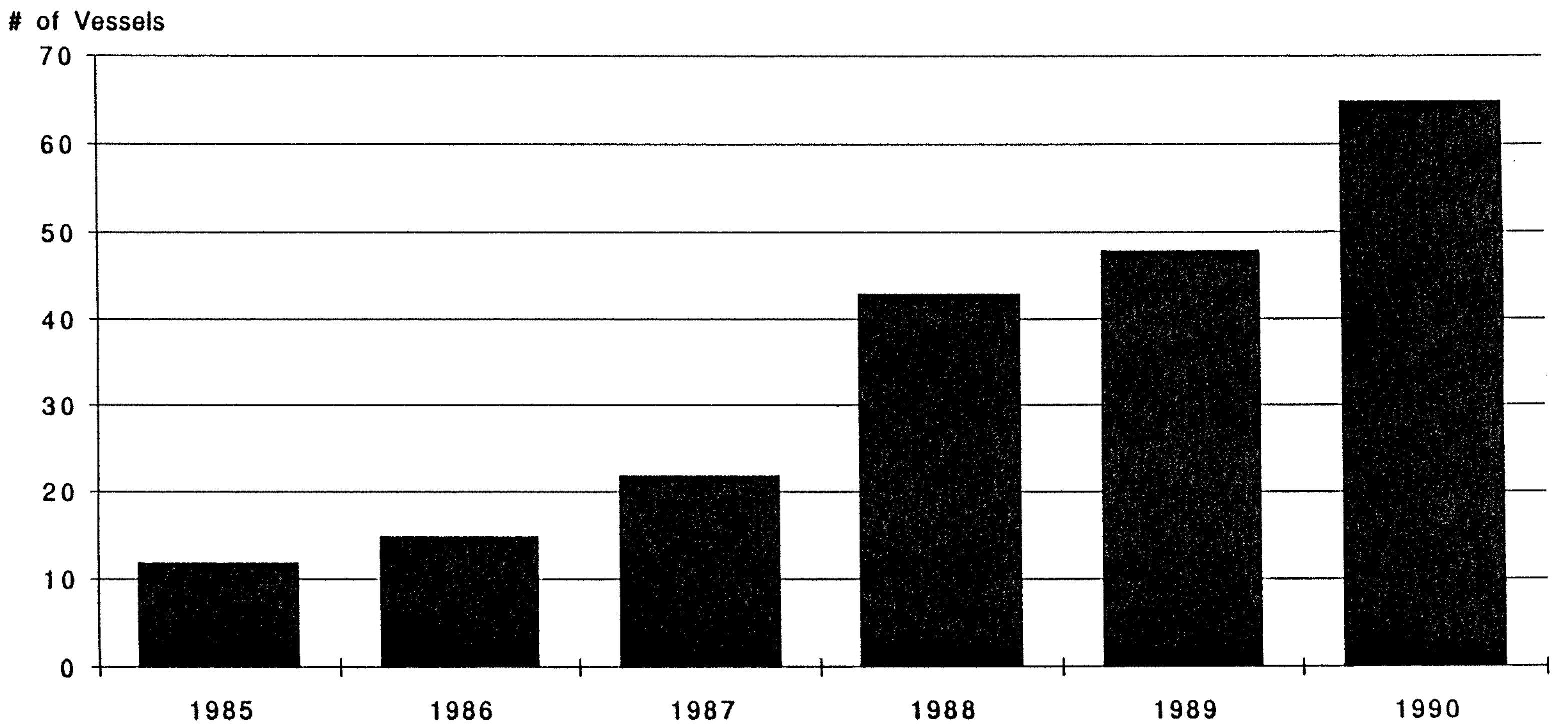


Exhibit 18. Groundfish harvest in the Eastern Bering Sea, 1954-1990. Source: NRC data files.

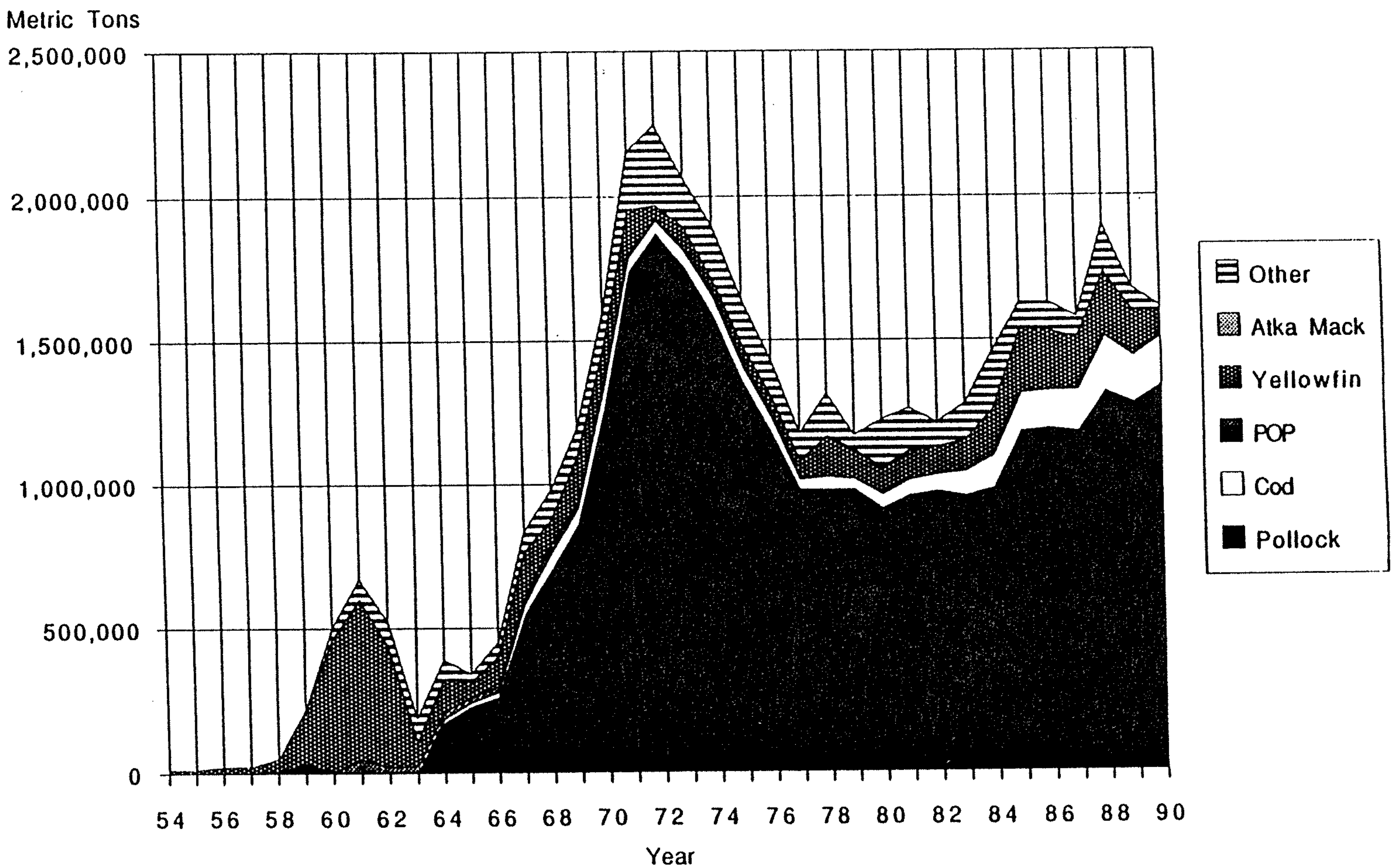


Exhibit 19. Groundfish harvest in the Gulf of Alaska, 1964-1990. Source: NRC data files.

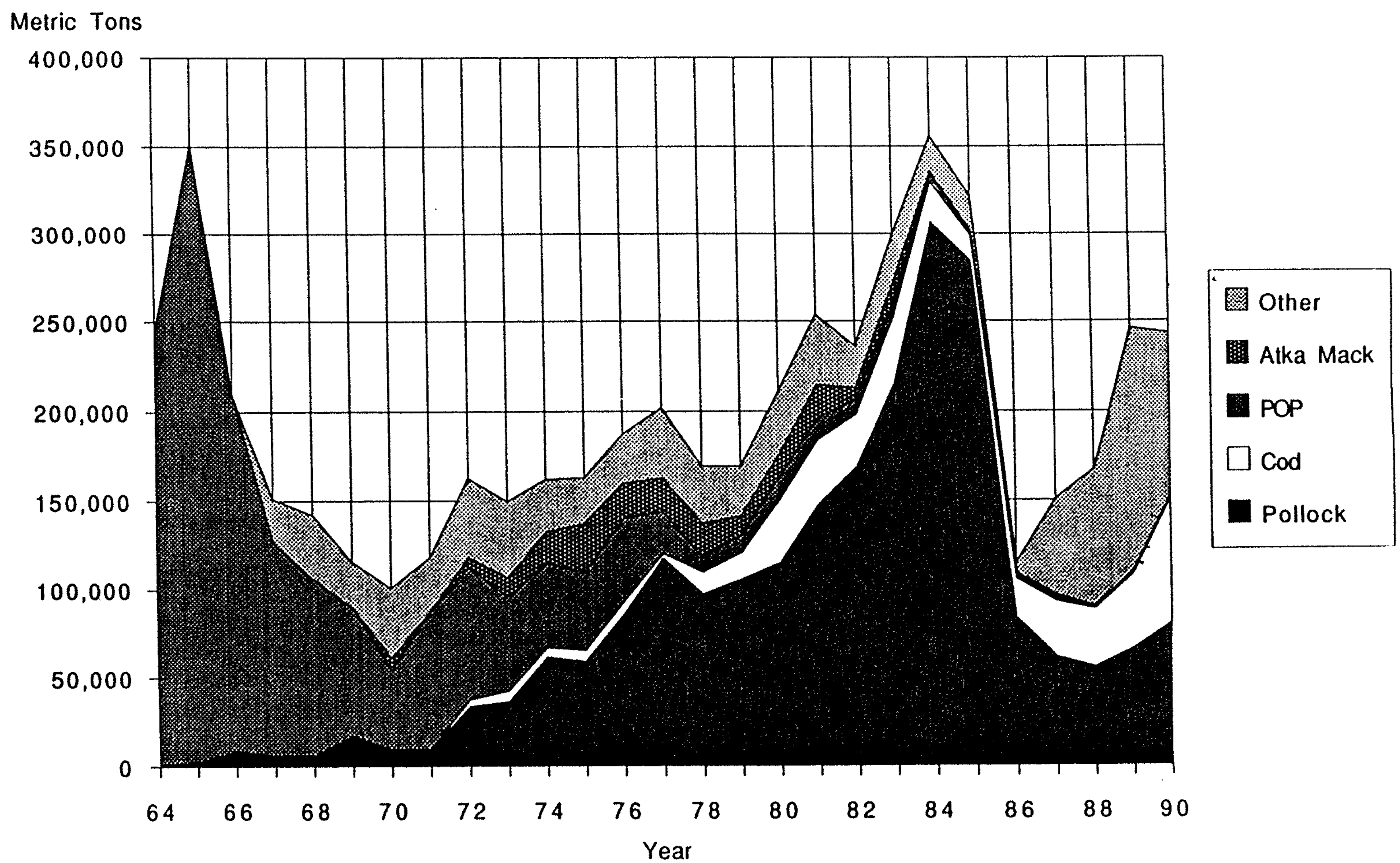


Exhibit 20. Groundfish harvest in the Aleutian Islands, 1962-1990. Source: NRC data files.

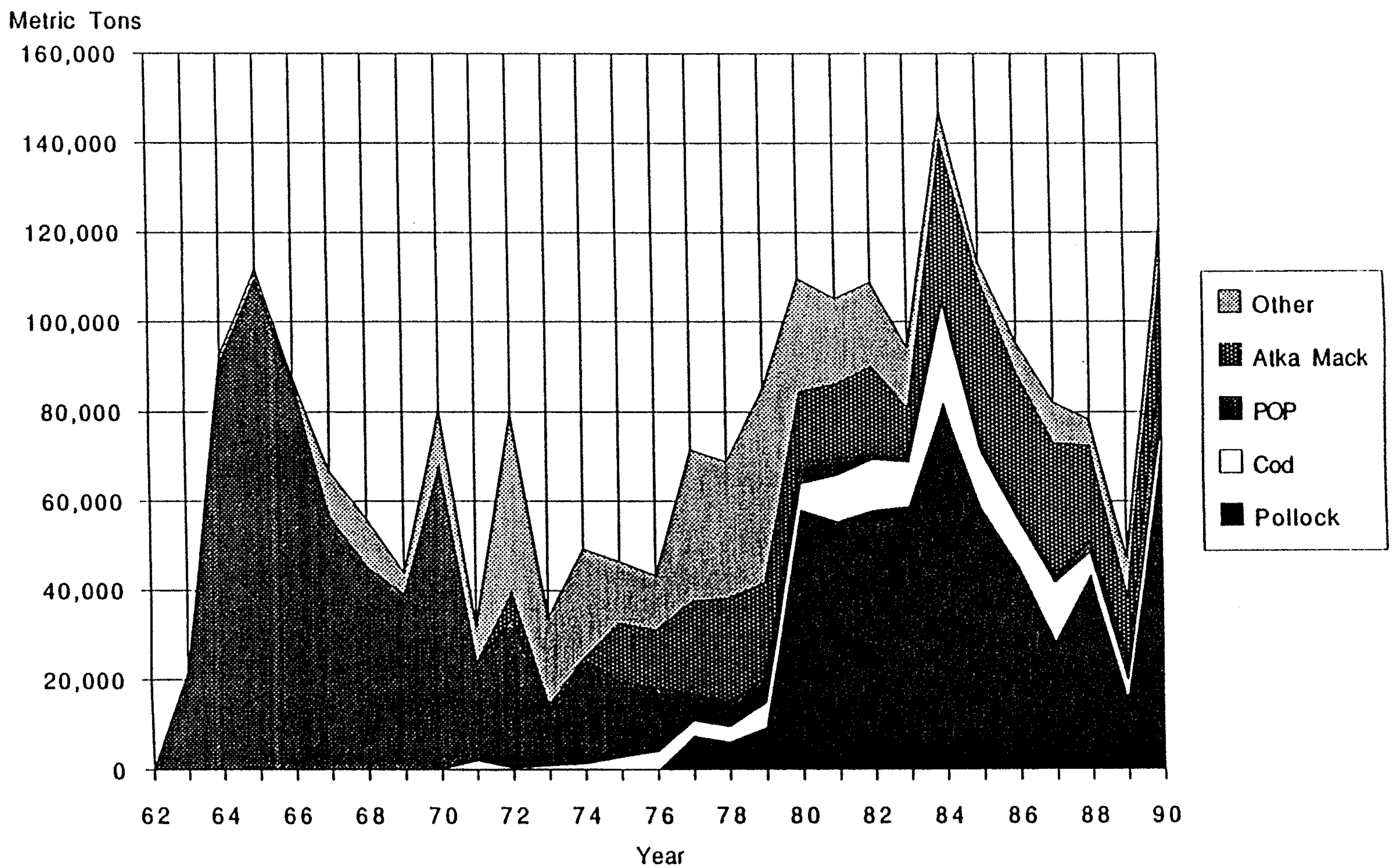
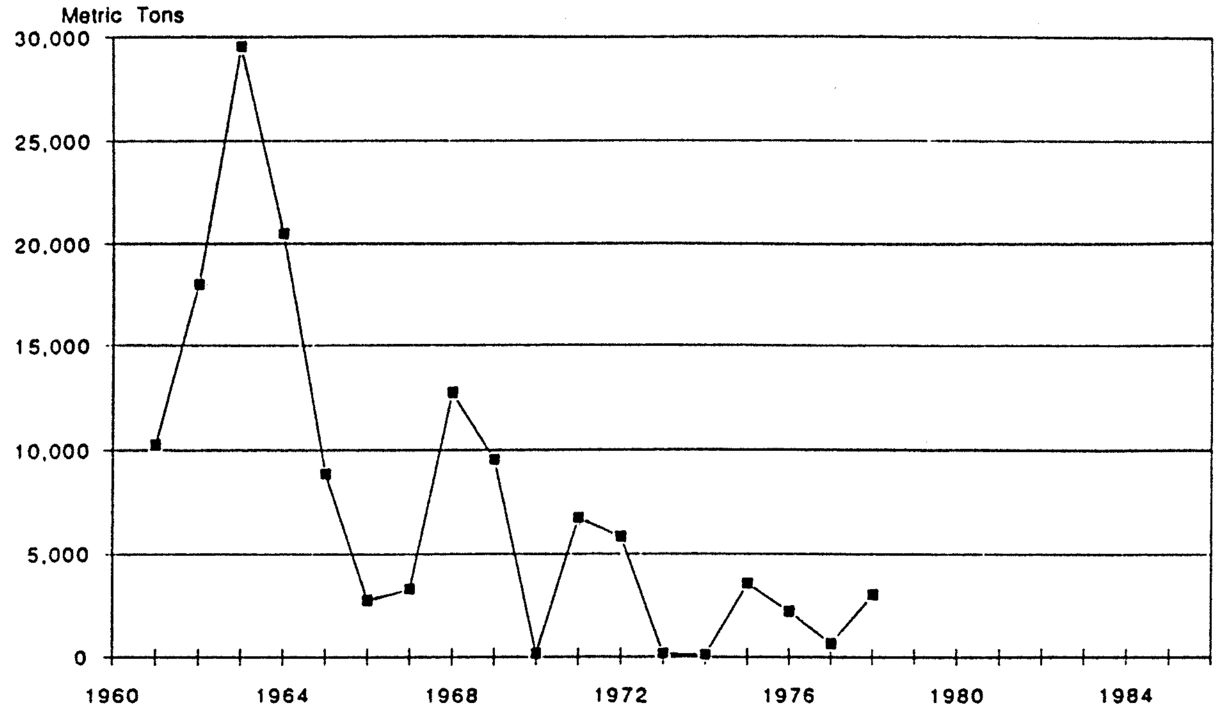


Exhibit 21. (a) Harvest of shrimp in the Bering Sea, 1962-1978. Source: INPFC (1979). (b) Harvest of shrimp by foreign and domestic vessels in the Gulf of Alaska, 1964-1986. Source: ADF&G (1990b) and INPFC (1979).

(a)



(b)

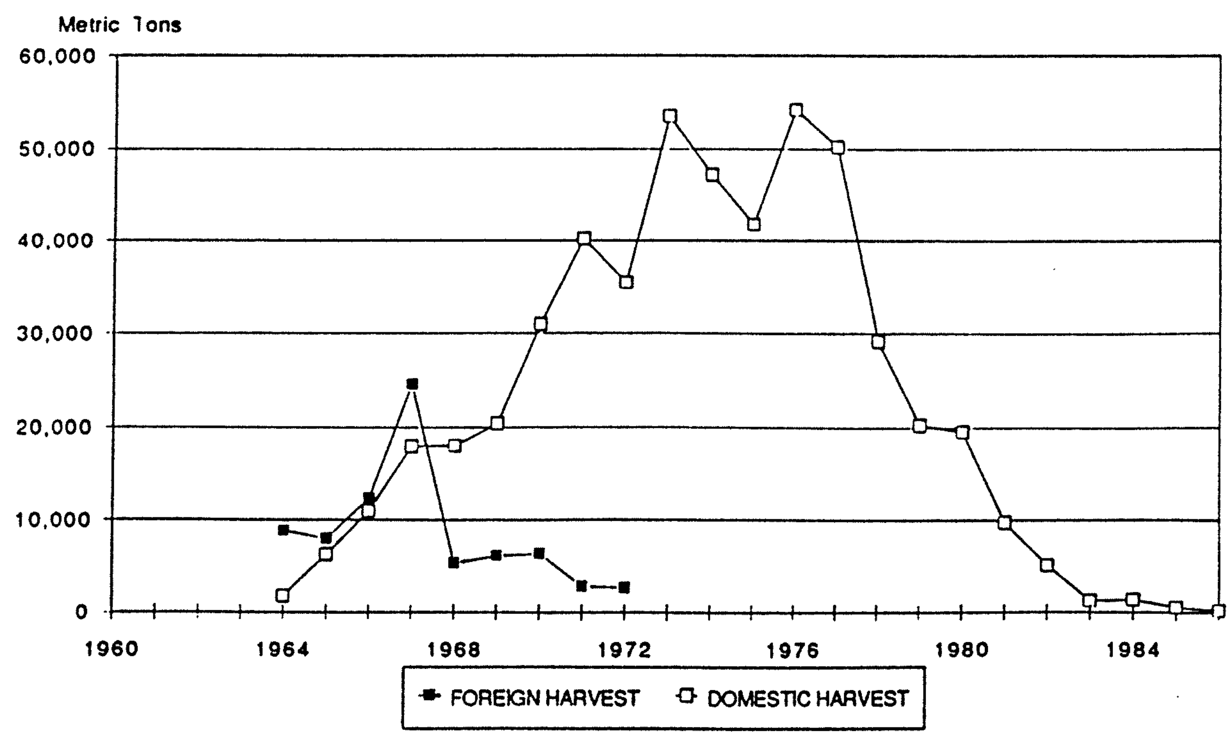


Exhibit 22. Number of vessels participating in Kodiak commercial shrimp fisheries, 1960-1985. Source: ADF&G (1990b).

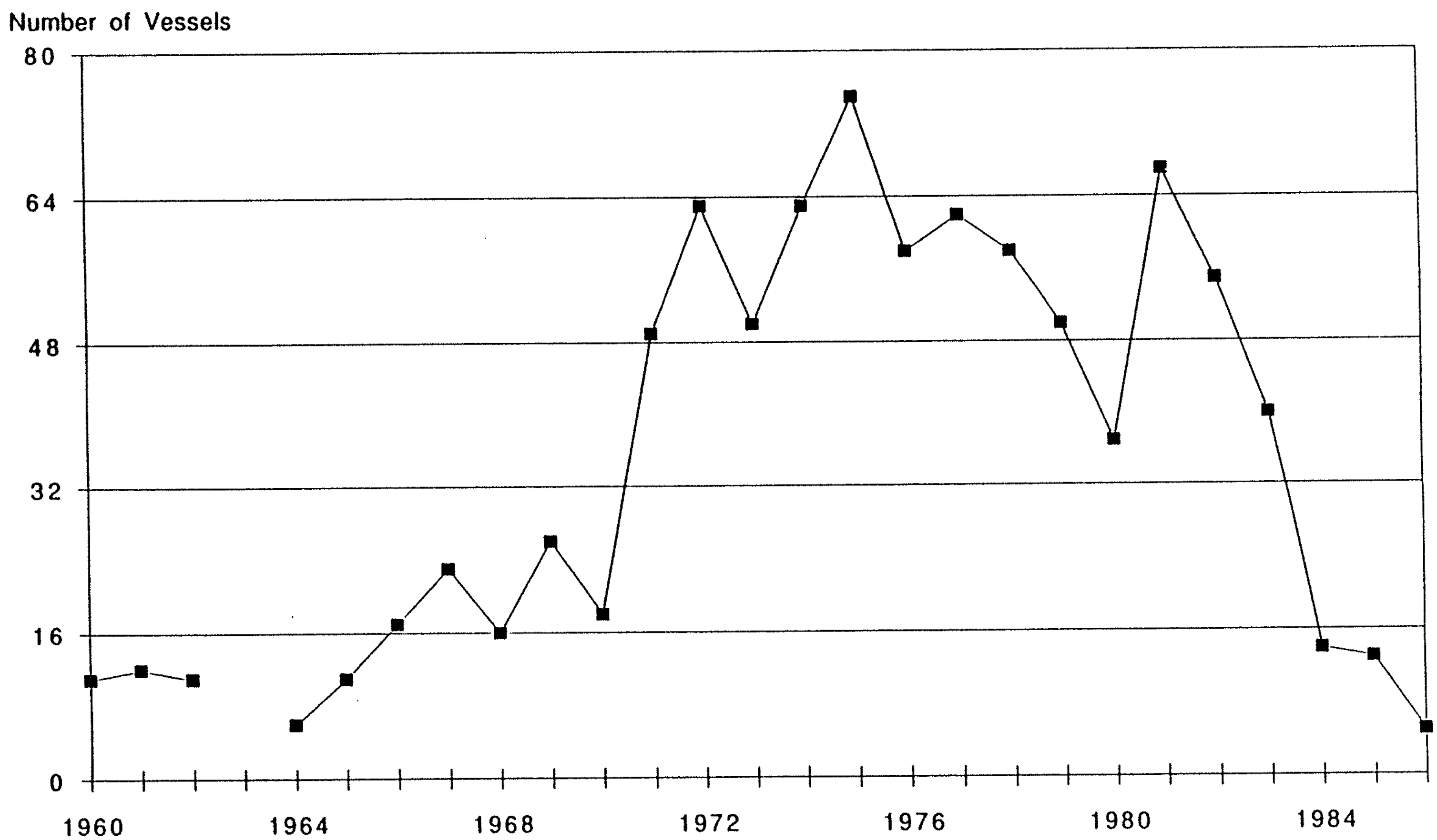


Exhibit 23. Number of hachis set by Japanese longliners in the Bering Sea, 1952-1987. Source: INPFC Annual Proceedings, 1988-1989.

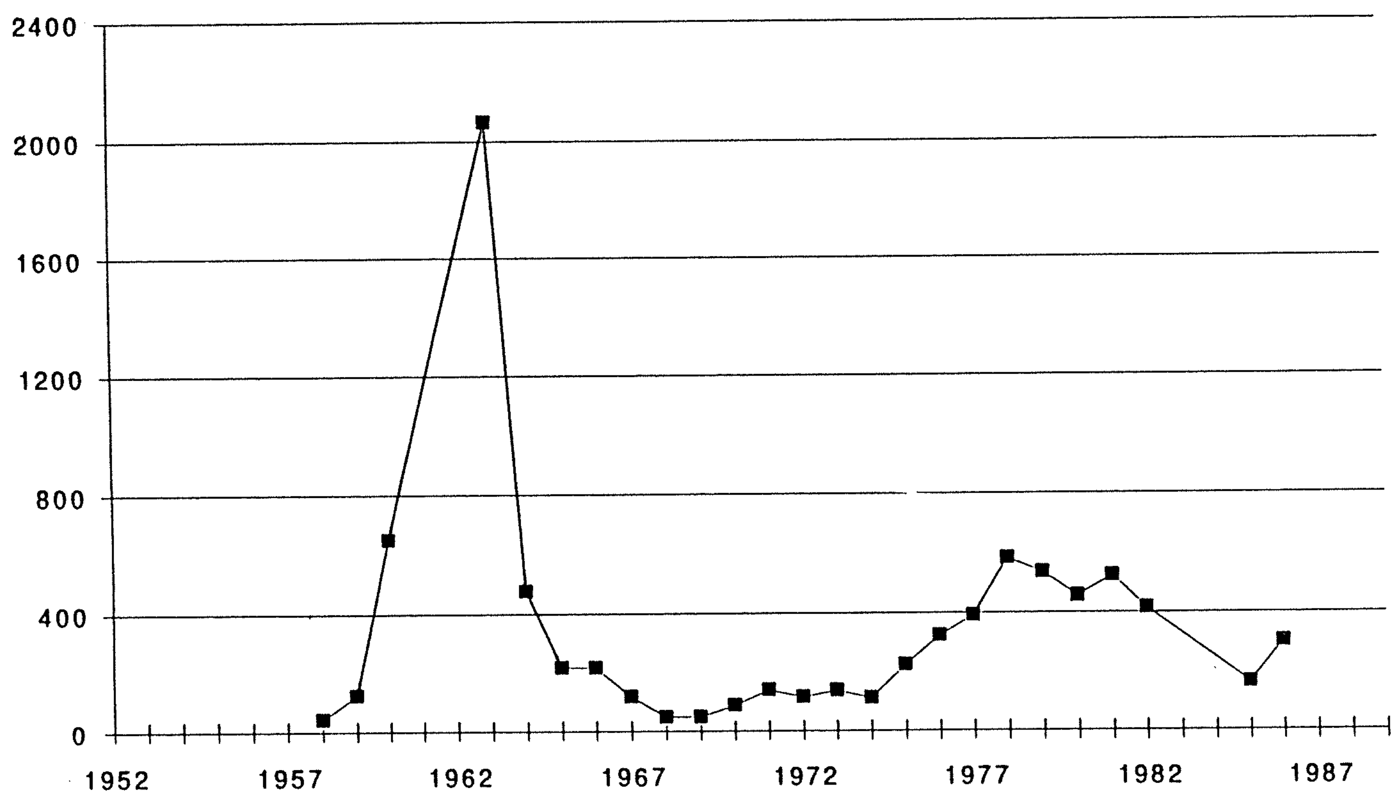


Exhibit 24. Number of skates set in the Bering Sea and Gulf of Alaska halibut longline fisheries. Source: IPHC Annual Reports.

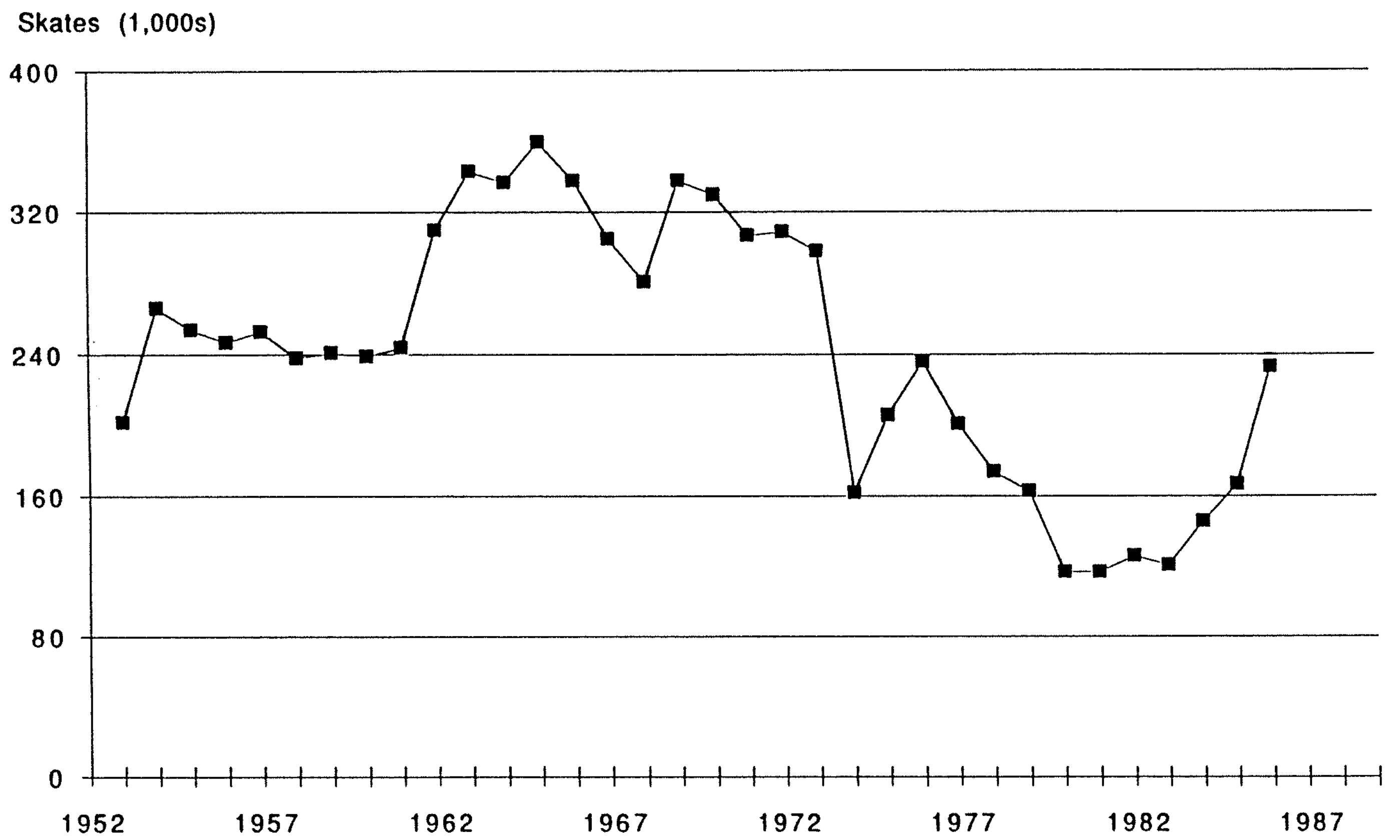


Exhibit 25. Number of line vessels by size category fishing in Alaskan fisheries. Source: Marasco and Aron (1991).

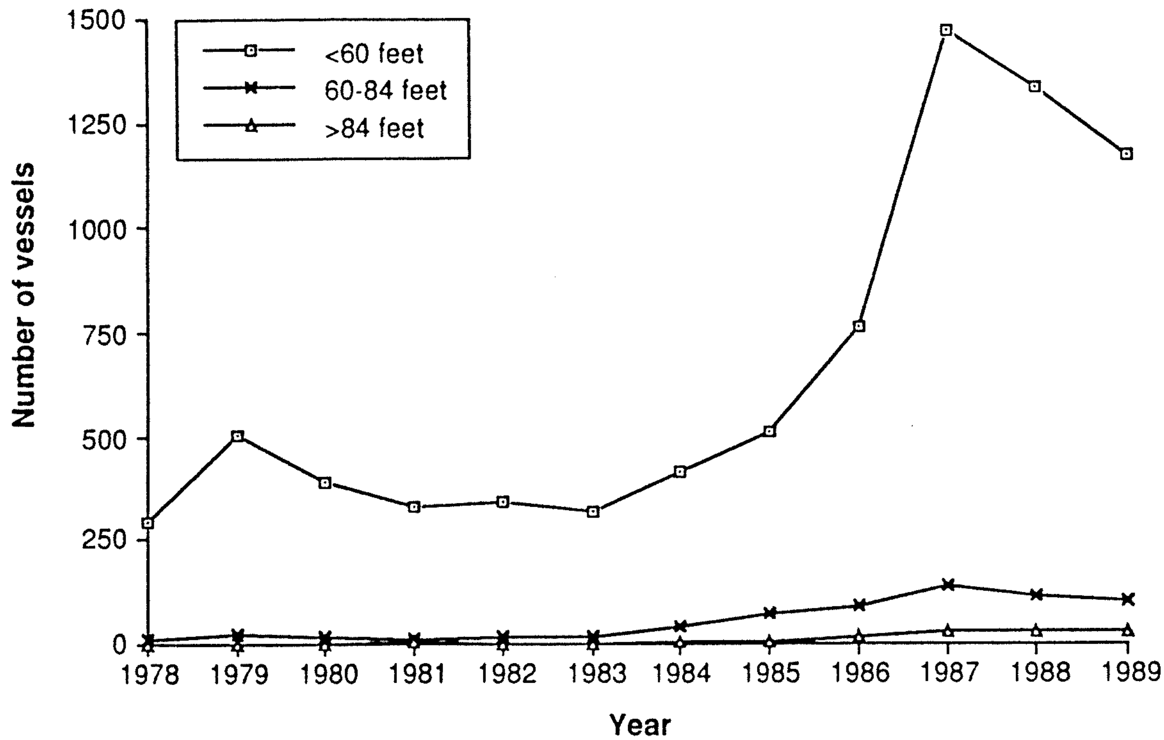


Exhibit 26. Eastern Bering Sea pollock abundance, 1964-1989. Source: Quinn and Collie (1990).

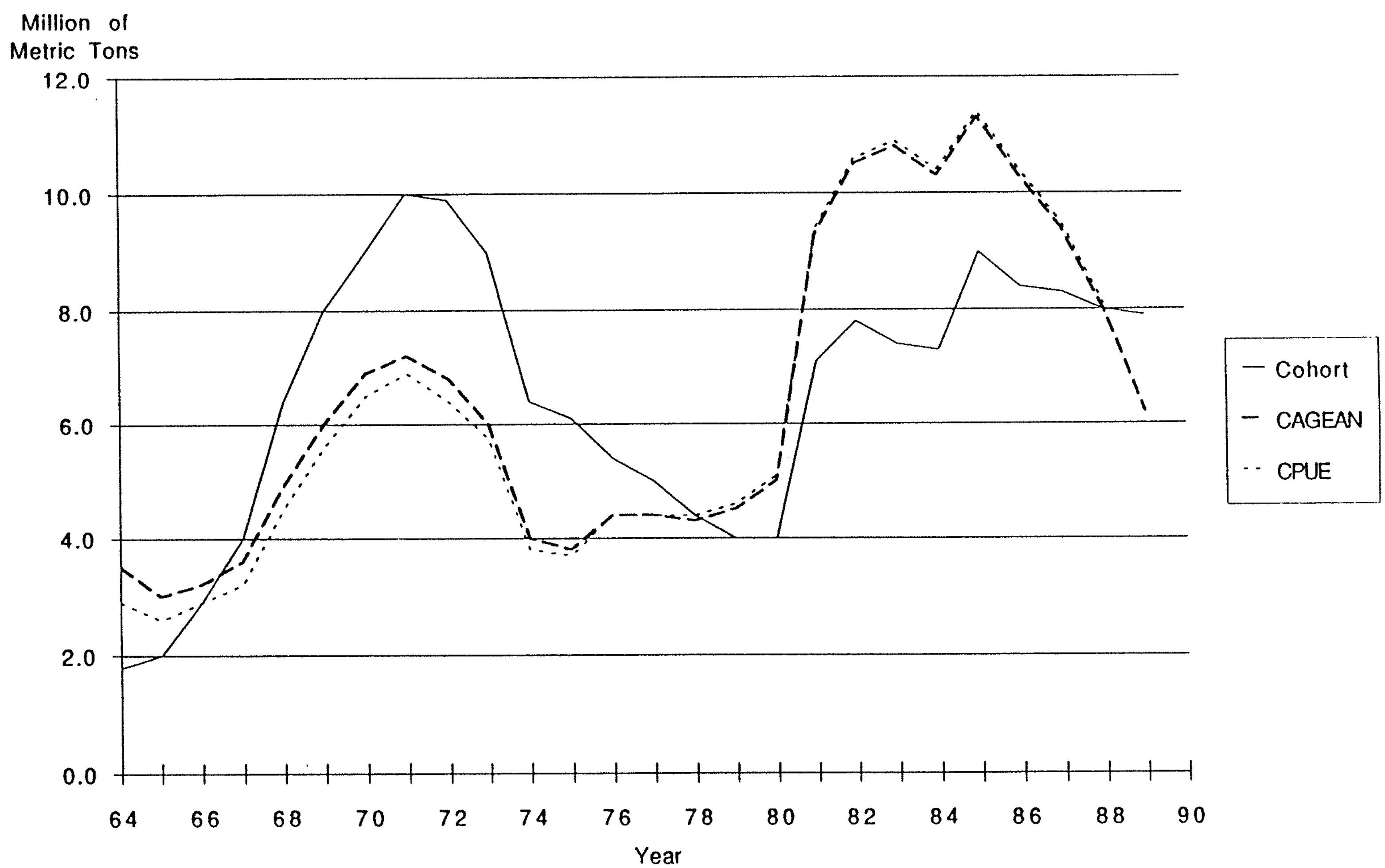


Exhibit 27. Comparison of catch rates between 1961 International Pacific Halibut Commission and 1973-1975 NMFS research trawl surveys. Catch rates are from only those stations that were located at bottom depths between 100 and 300 m. Source: M. Alton, NMFS.

Region	Period	Number of stations	Catch per standard haul (kg)[1]	F (df)
Kodiak (151°-154°W. Long.)	July-Sep. 1961	16	123	4.7* (1,35)
	July-Sep. 1973	21	494	
Chirikoff (154°-159° W. Long.)	June-July 1961	46	37	4.3* (1,71)
	June-July 1975	27	417	
Shumagin (158°-167° W. Long.)	July-Aug. 1961	44	19	10.7* (1,78)
	July-Aug. 1974	36	454	

[1]For the 1961 surveys, a standard tow was 1.0 hour in duration and for surveys in 1973-75, duration was 0.5 hour.

*Significant at 95% level.

Exhibit 28. Trend in Gulf of Alaska exploitable biomass. Source: Marasco and Aron (1991).

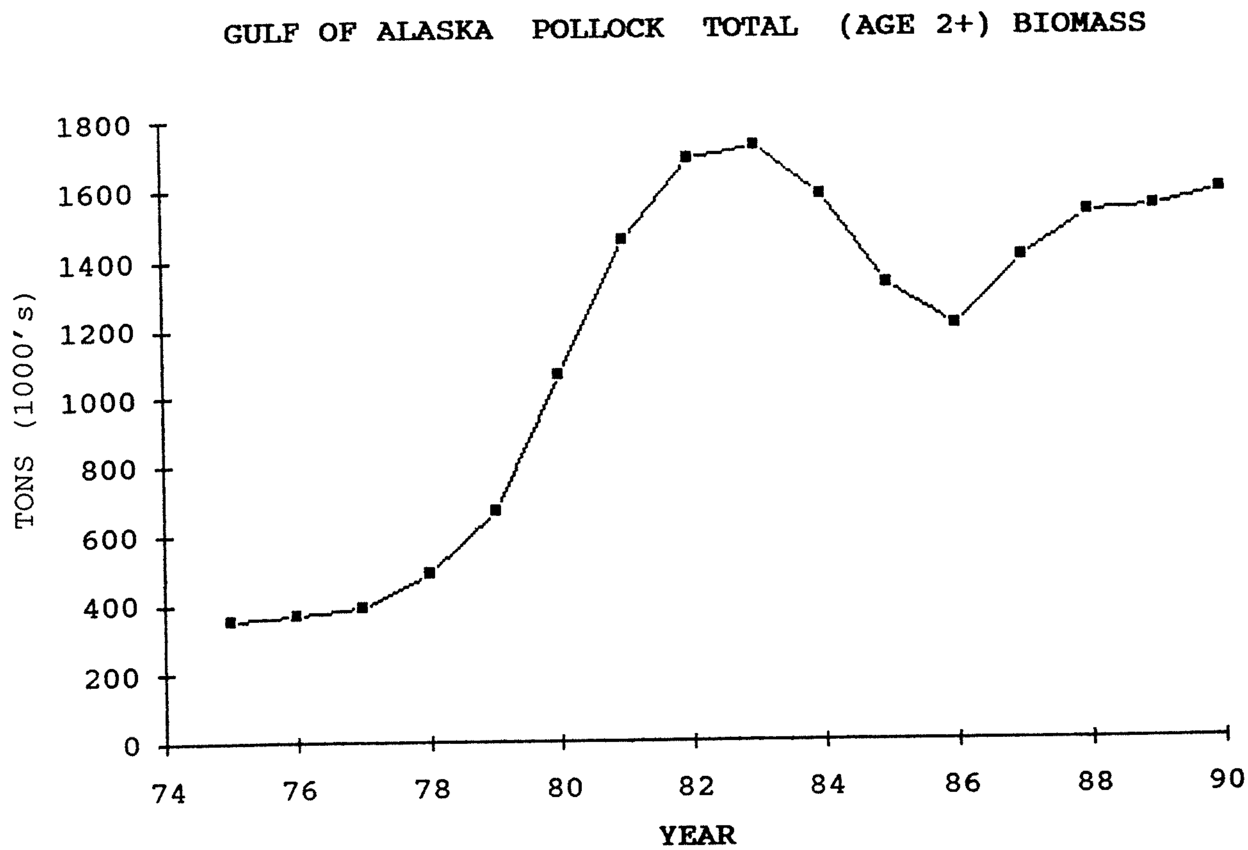
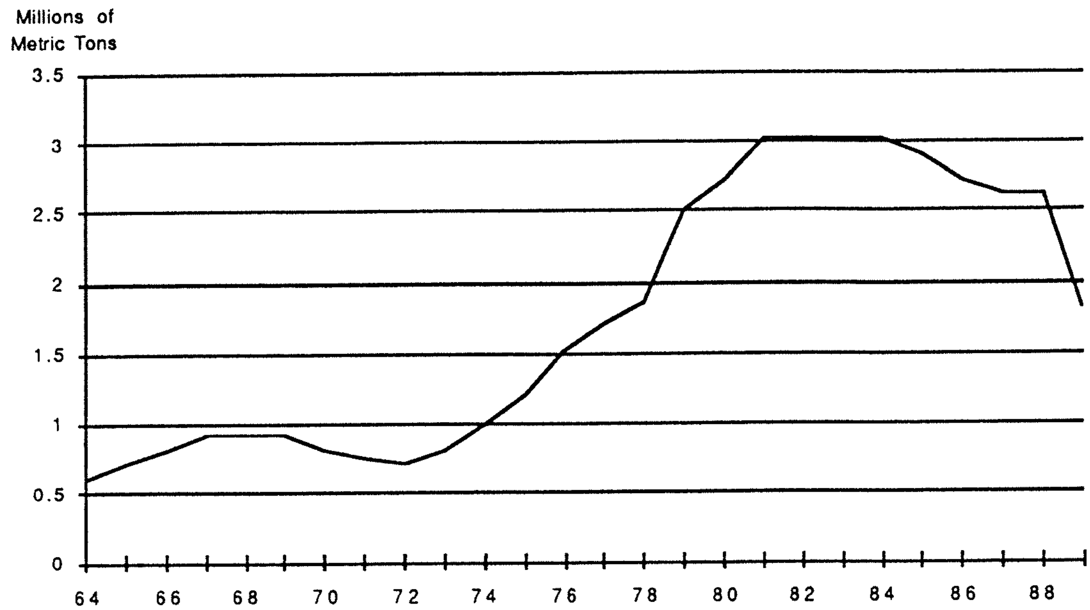


Exhibit 29. Fifteen most prominent species in the 1960 and 1970 resource assessment surveys in the Gulf of Alaska (all depth zones and regions combined). Source: Ronholt et al. (1978).

1960 (kg/hr)	1970 (kg/hr)
Turbot (91.0)	Walleye pollock (320.5)
King crab (72.3)	Turbot (82.8)
Tanner crab (47.9)	Pacific cod (47.6)
Pacific cod (43.6)	Rock sole (46.9)
Cottids (40.3)	Flathead sole (43.7)
Pacific ocean perch (36.8)	Tanner crab (36.9)
Flathead sole (31.0)	Cottids (21.6)
Rock sole (29.2)	Rex sole (19.7)
Halibut (20.7)	Dover sole (19.3)
Walleye pollock (15.9)	King crab (18.9)
Skates (9.5)	Halibut (18.0)
Sablefish (7.9)	Skates (11.2)
Rex sole (4.1)	Shortspine thornyhead (4.9)
Shortspine thornyhead (3.2)	Sablefish (4.2)
Dover sole (2.9)	Pacific ocean perch (3.9)

Exhibit 30. (a) Relative abundance of yellowfin sole in the Eastern Bering Sea, 1964-1989. Source: Based on biomass from NMFS cohort analysis. (b) Relative abundance of rock sole in the Eastern Bering Sea, 1975-1990. Source: Based on NMFS CPUE (kg/ha) data from annual resource assessment surveys.

(a)



(b)

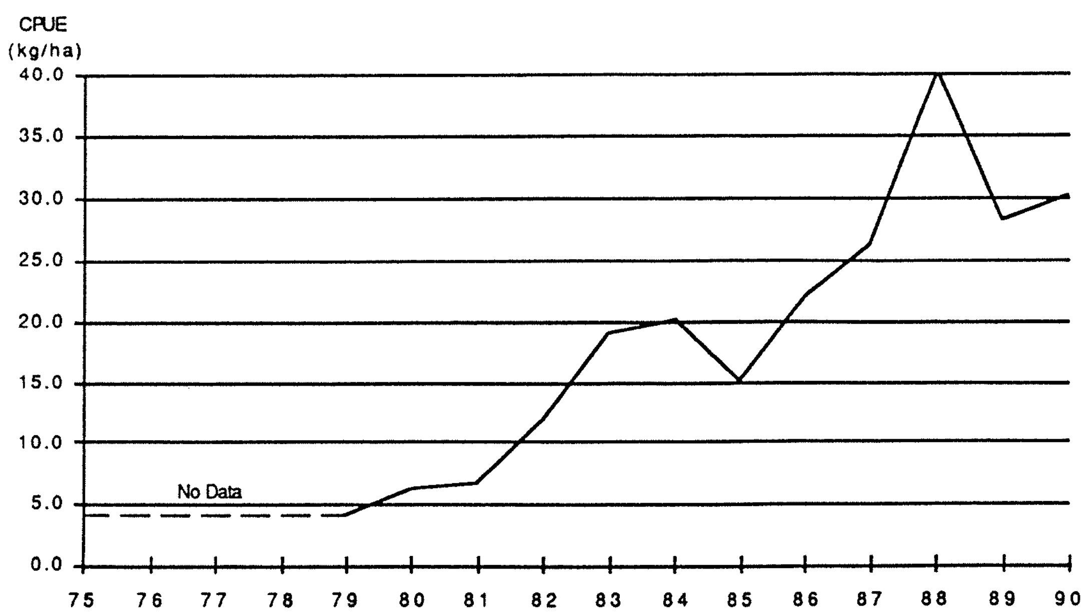
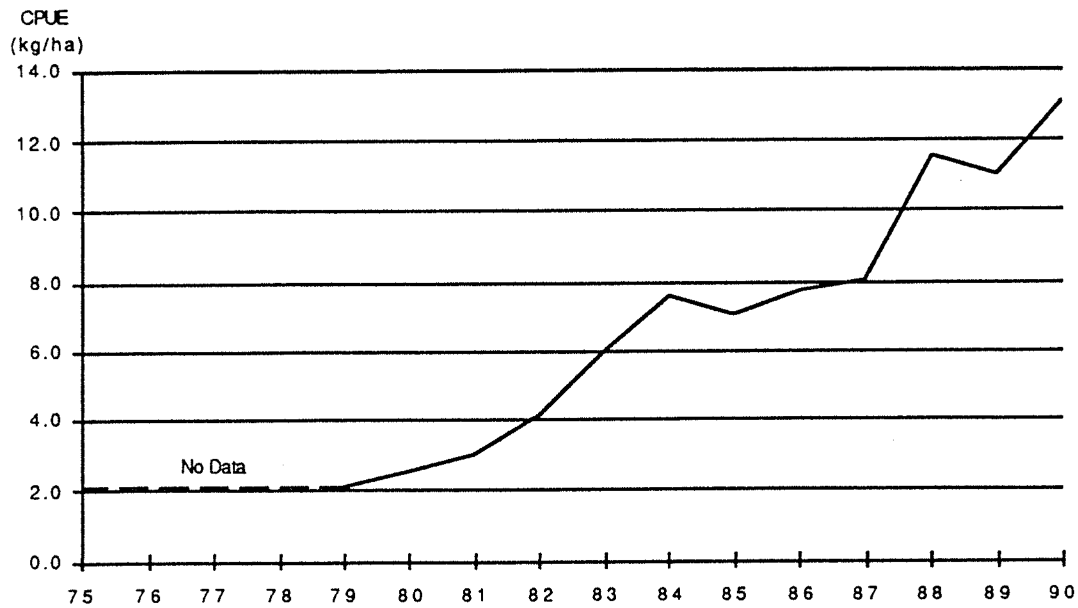


Exhibit 30. (c) Relative abundance of flathead sole in the Eastern Bering Sea, 1975-1990. Source: Based on NMFS CPUE (kg/ha) data from annual resource assessment surveys. (d) Relative abundance of Alaska plaice in the Eastern Bering Sea, 1975-1990. Source: Based on NMFS CPUE (kg/ha) data from annual resource assessment surveys.

(c)



(d)

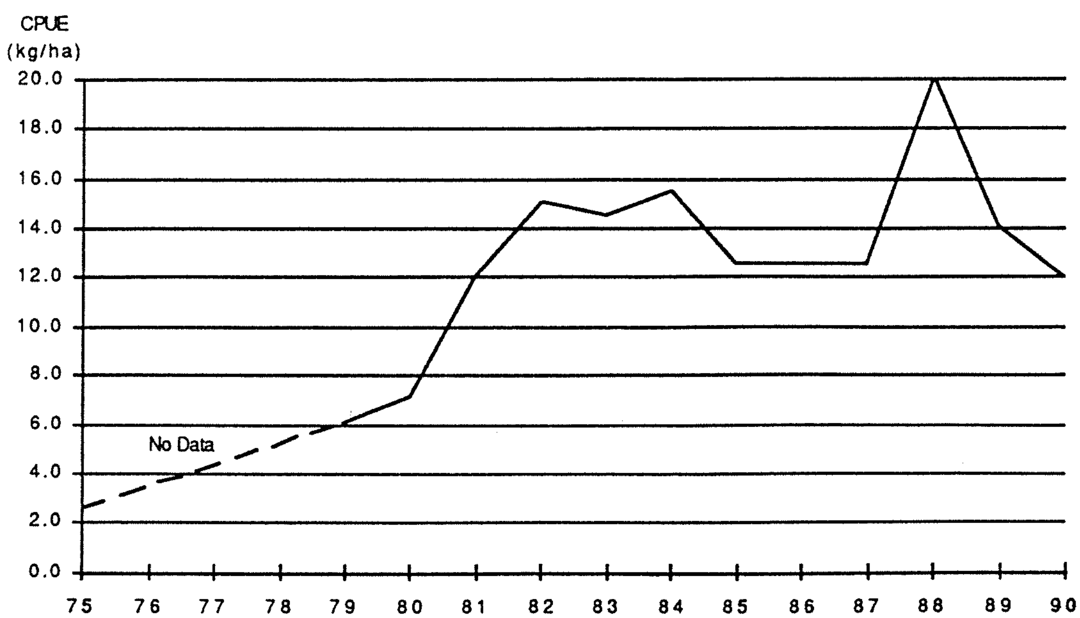


Exhibit 31. Exploitable biomass of halibut in the North Pacific Ocean, 1935-1988. Source: IPHC Annual Reports.

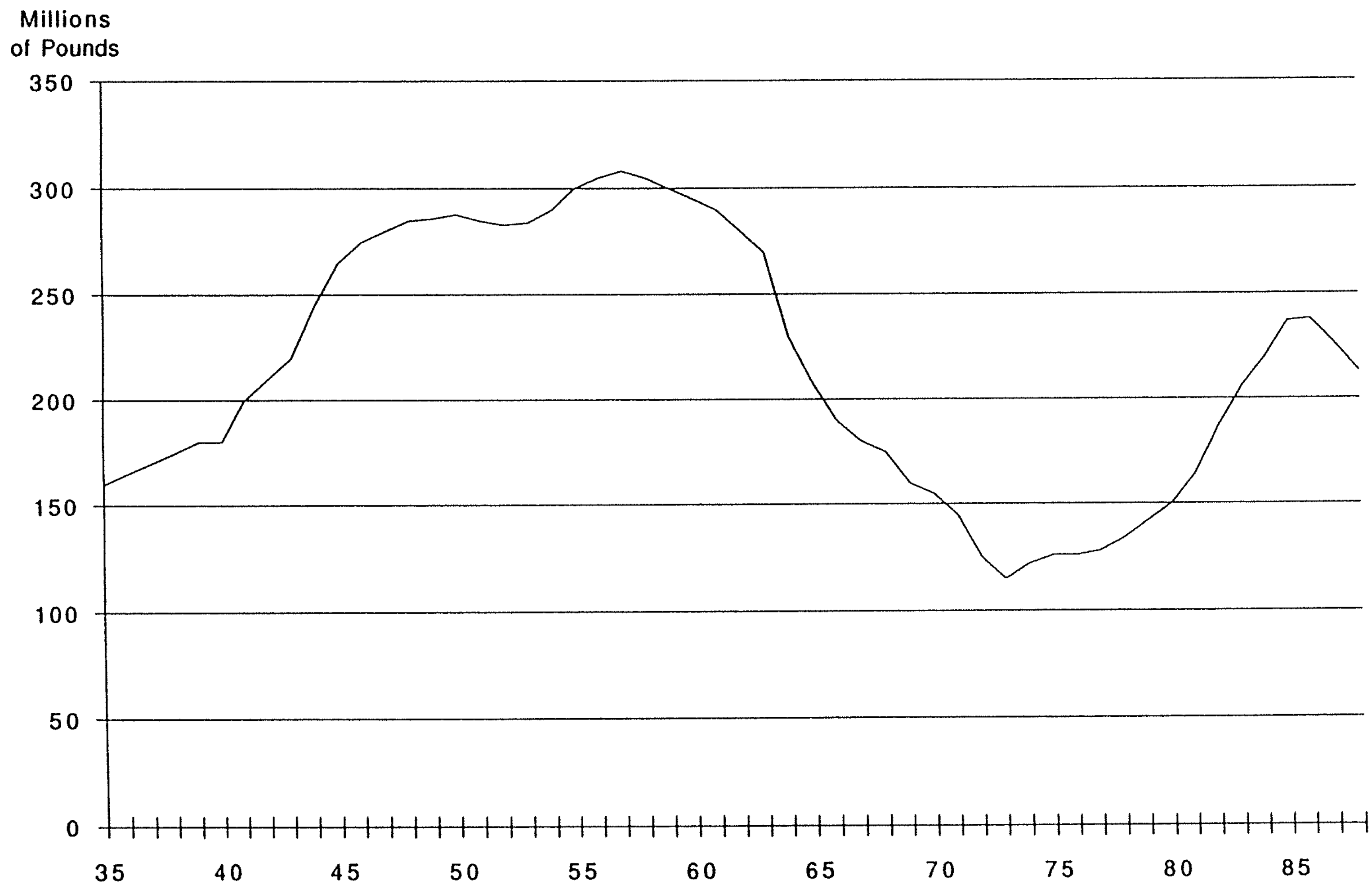
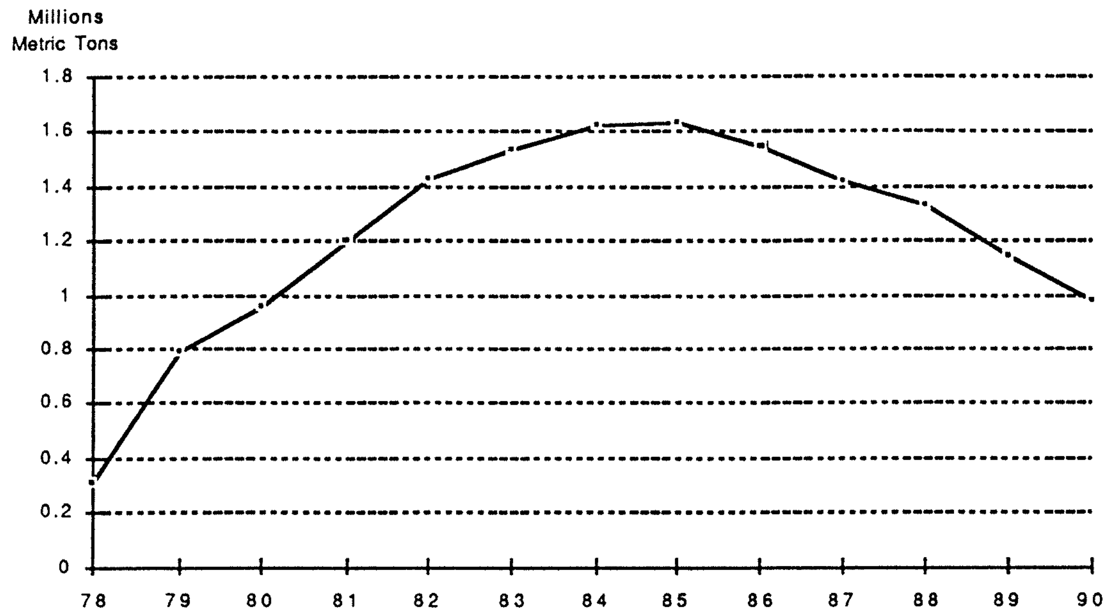


Exhibit 32. (a) Relative abundance of Pacific cod in the Eastern Bering Sea. Source: Based on U.S. Biomass Estimates, 1978-1990. (b) Relative abundance of Pacific cod in the Gulf of Alaska, 1978-1990. Source: Based on Japanese CPUE (mt/1,000 hooks) and biomass (mt) from annual NMFS resource assessment surveys.

(a)



(b)

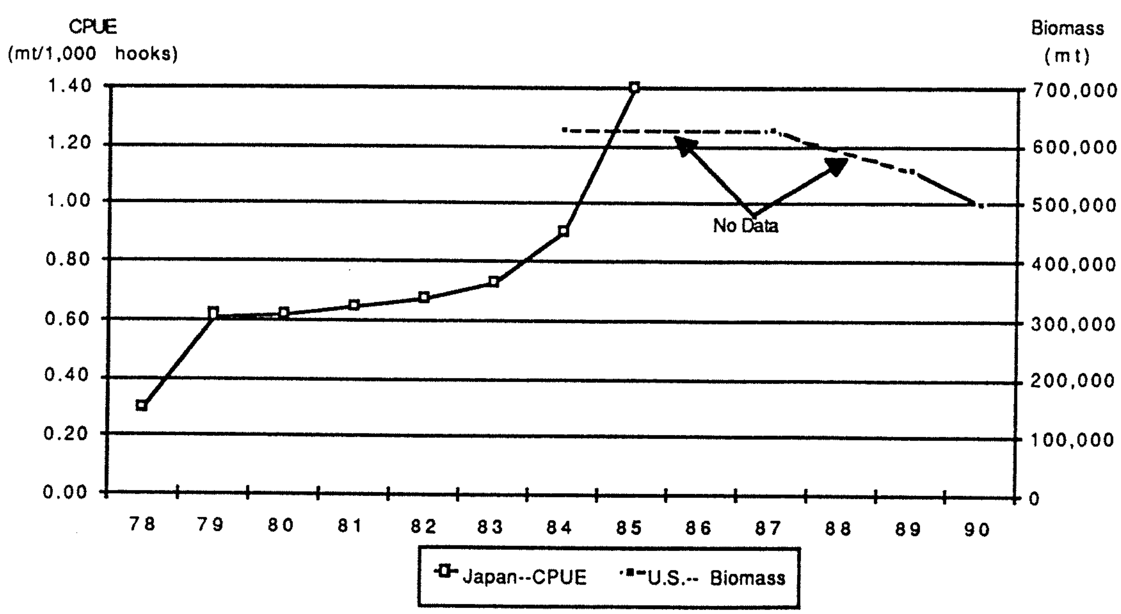


Exhibit 33. Pacific herring CPUE, 1967-1974. Source: INPFC Annual Reports, 1975-1986.

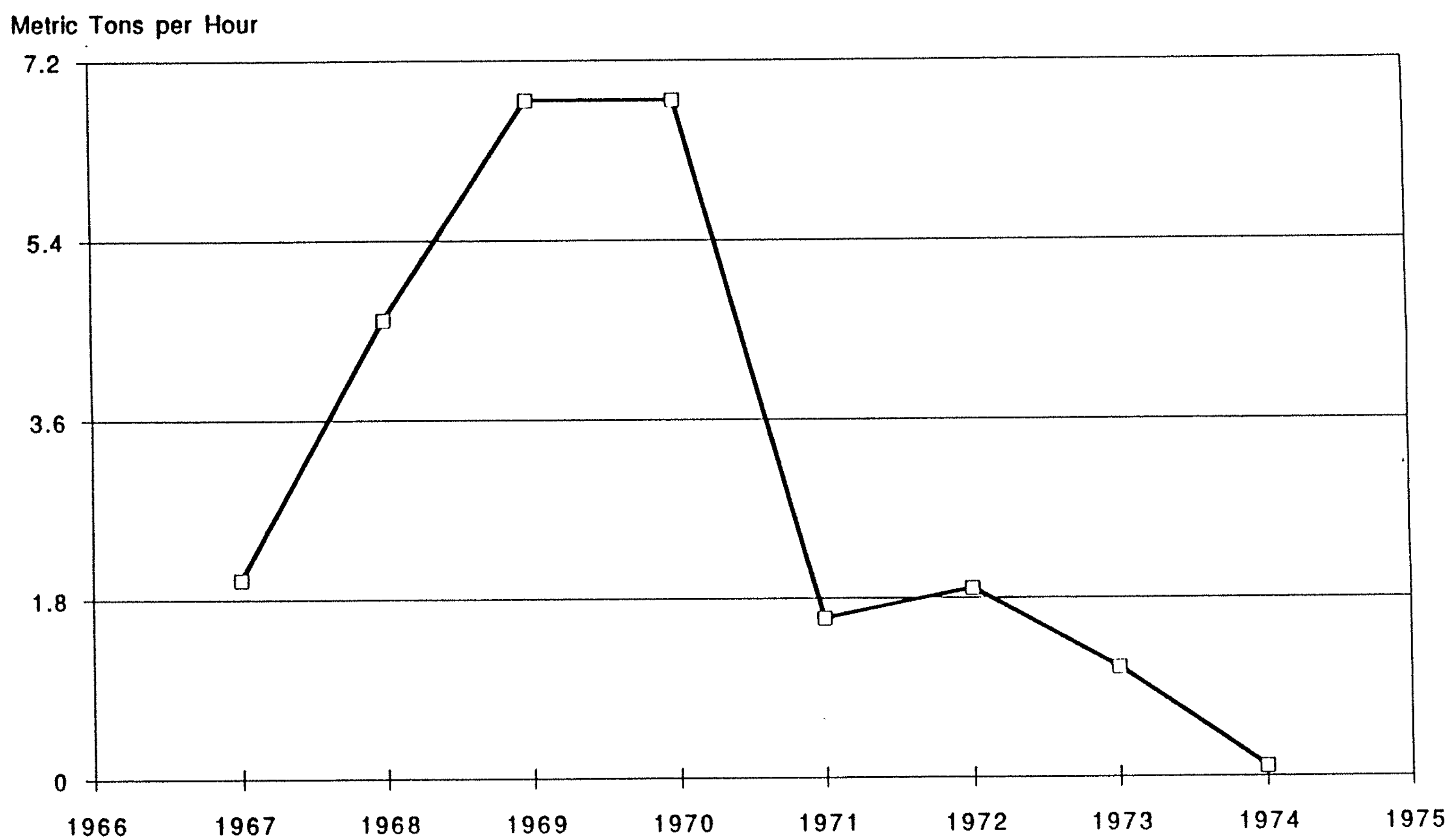


Exhibit 34. Landings of herrings from the Northeast and Northwest Pacific Ocean, including the Bering Sea, 1955-1978. Northwest Pacific is for Japan and USSR and does not include catches by North Korea, South Korea, or Mainland China. Source: Alverson and Pruter (1980).

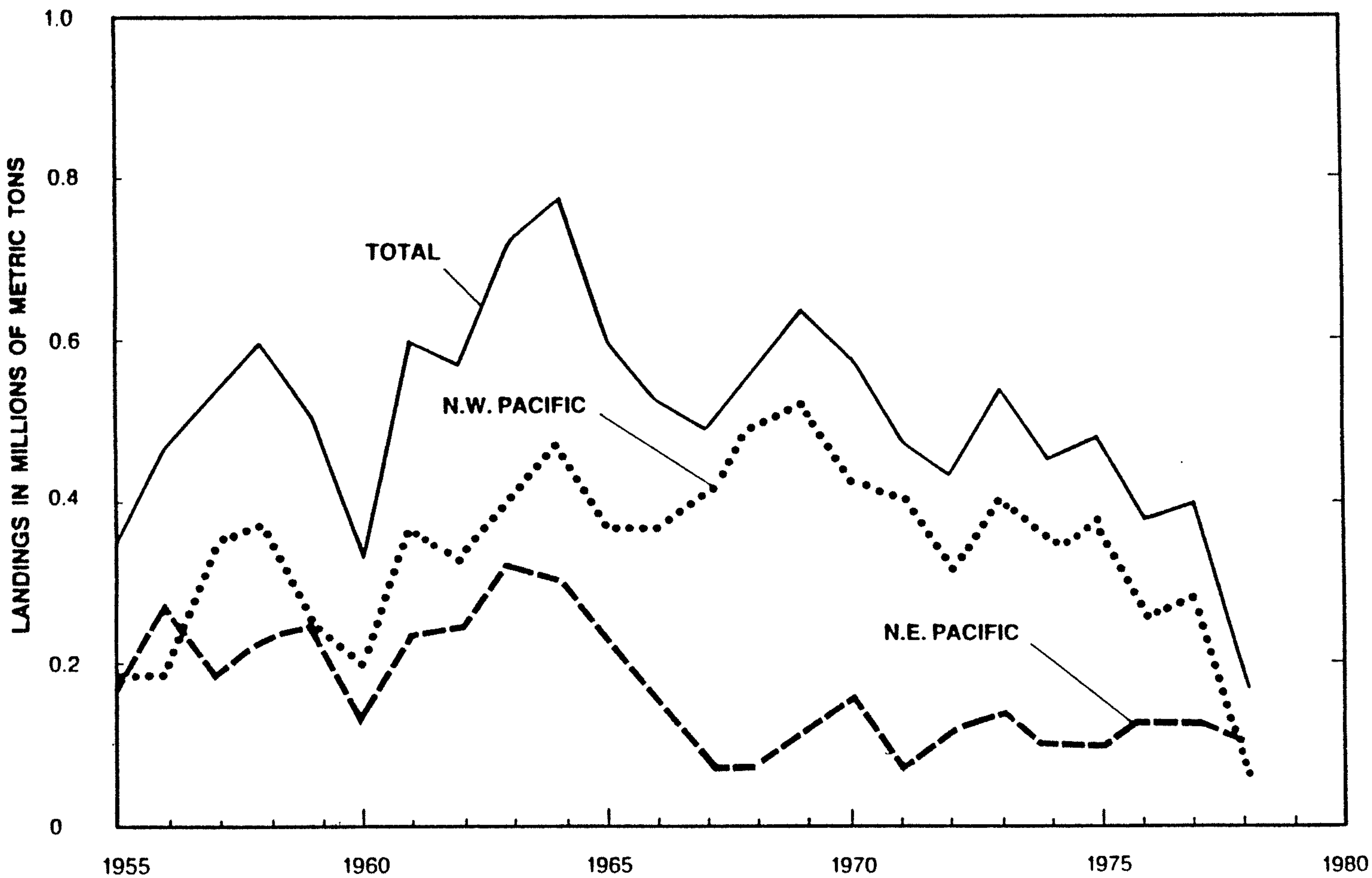


Exhibit 35. Relative abundance of Pacific Ocean perch in the Eastern Bering Sea/Aleutian Islands, 1960-1990.
Source: Based on NMFS SRA Biomass Analyses.

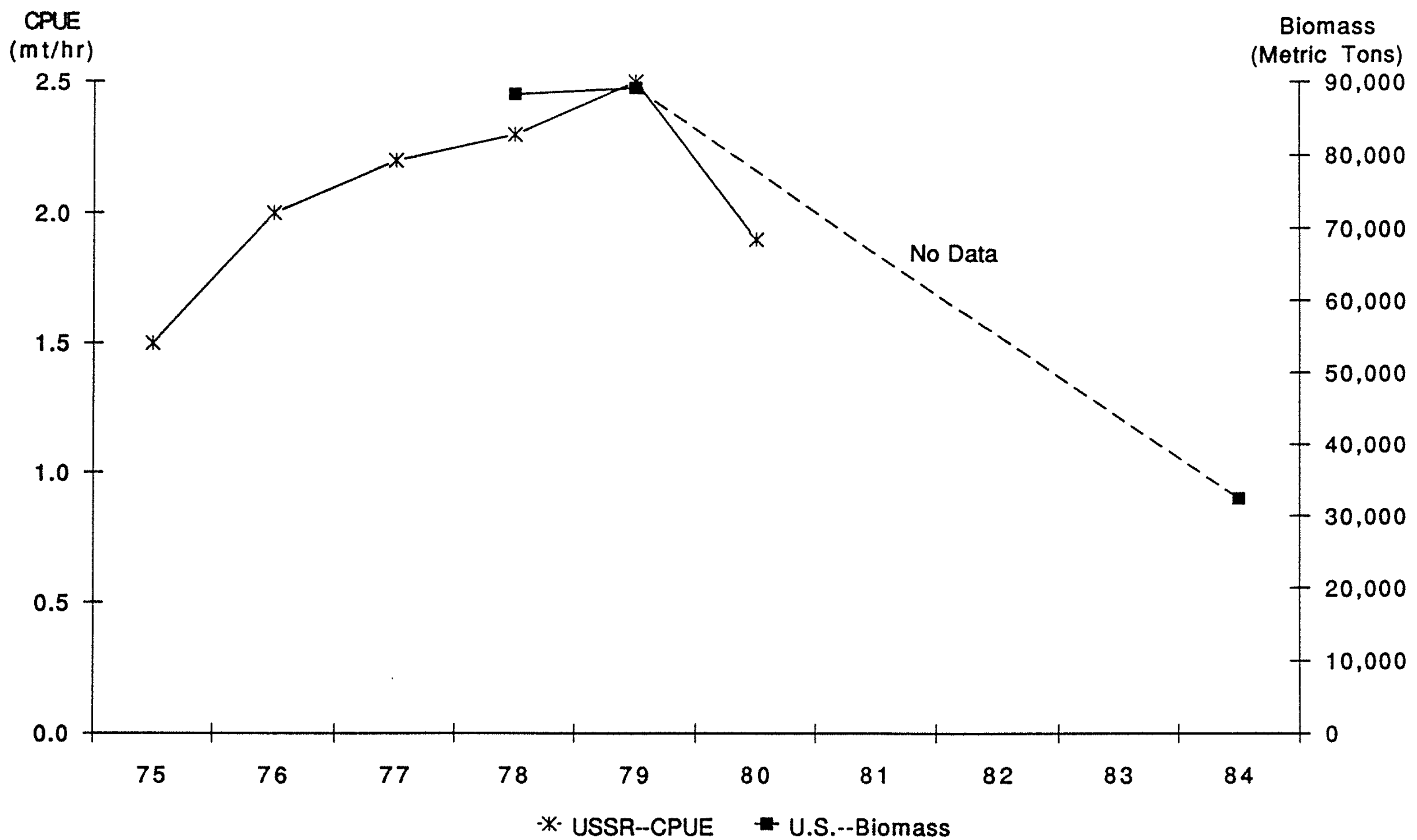


Exhibit 36. Relative abundance of Atka mackerel in the Gulf of Alaska, 1975-1984. Source: Based on USSR CPUE (mt/hr) data and from annual NMFS resource assessment surveys.

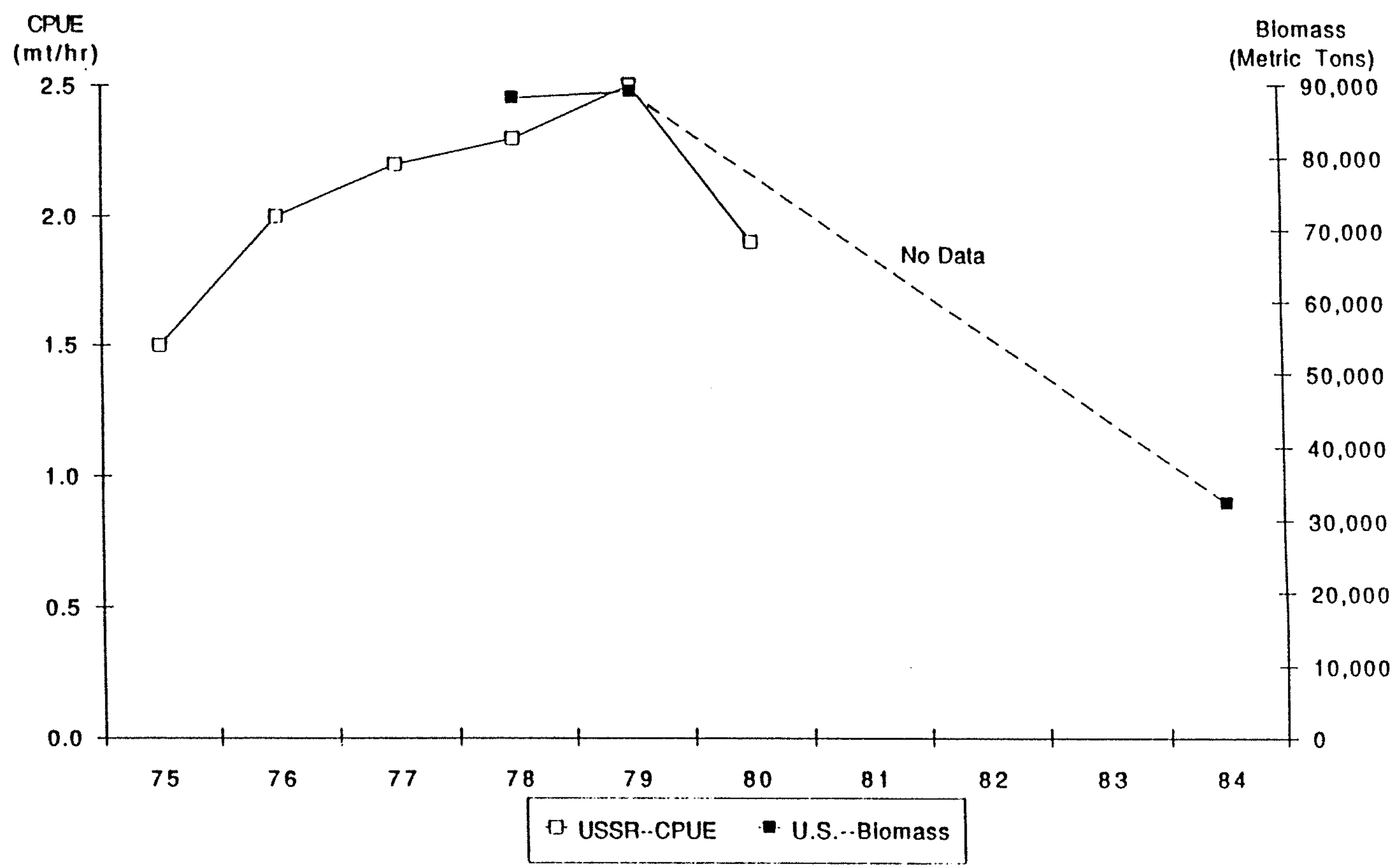
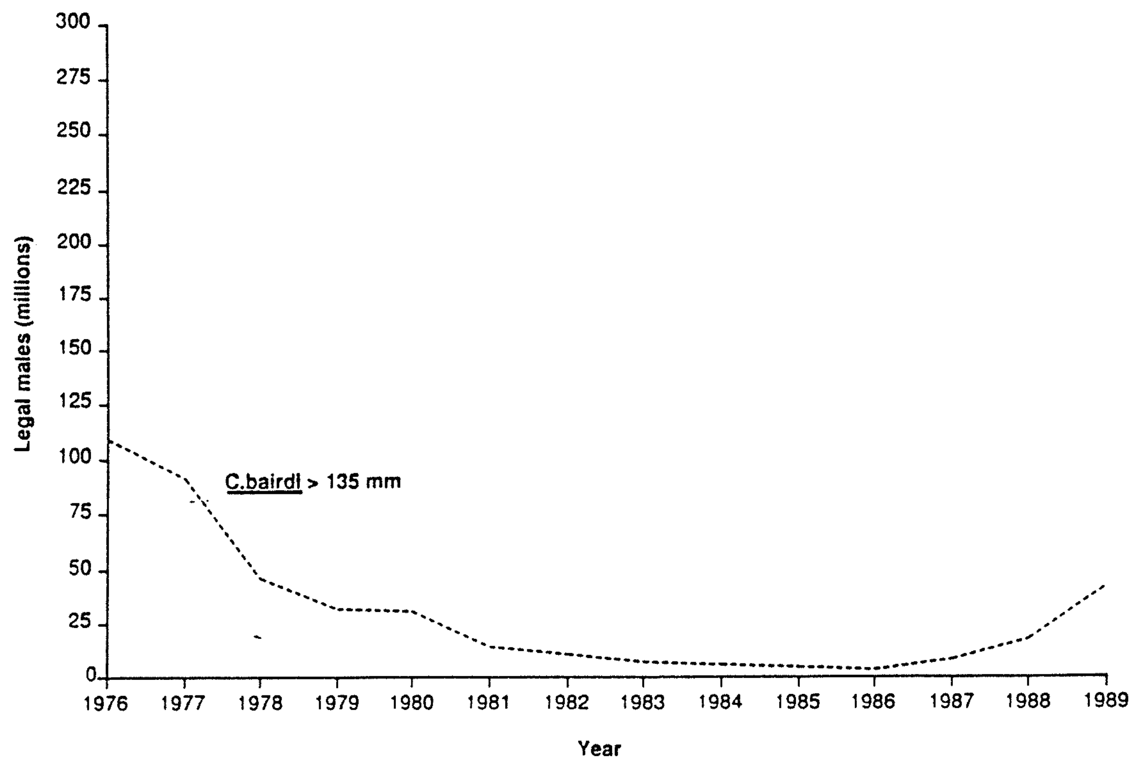


Exhibit 37. (a) Trend in Tanner crab *Chionoecetes bairdi*, legal males, Eastern Bering Sea. (b) Abundance trends for red king crab. Source: Marasco and Aron (1991).

(a)



(b)

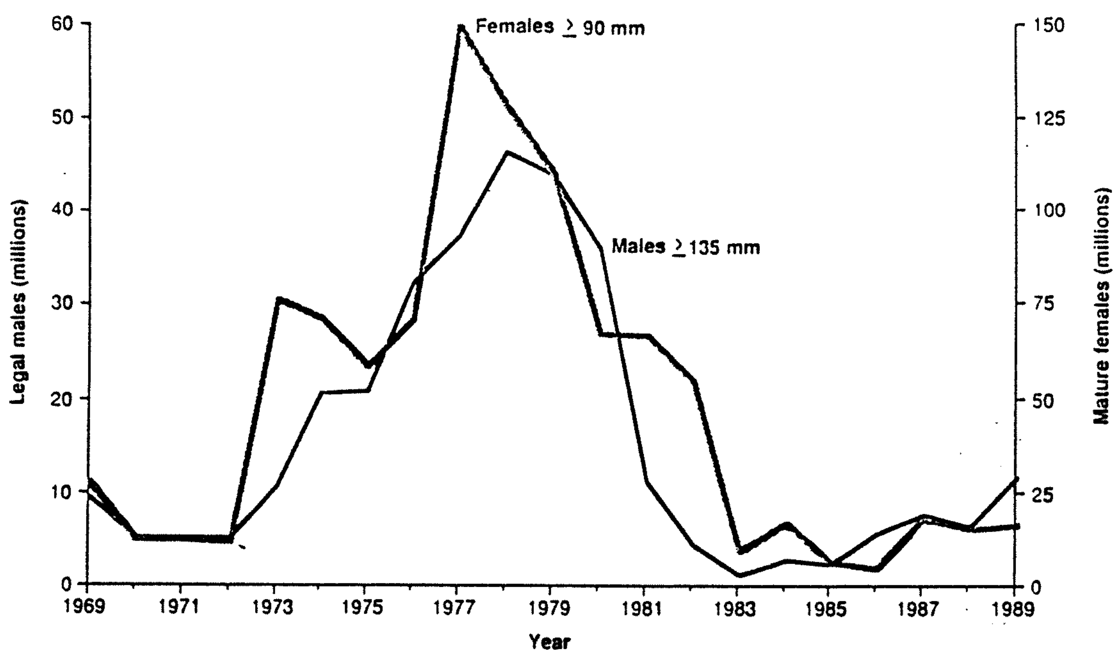


Exhibit 38. Time series from 1950 to 1982 of ranges and average sea-surface temperature anomalies for Regions 1, 2, and 3 of the DYNUMES grid. Source: Swan and Ingraham (1984).

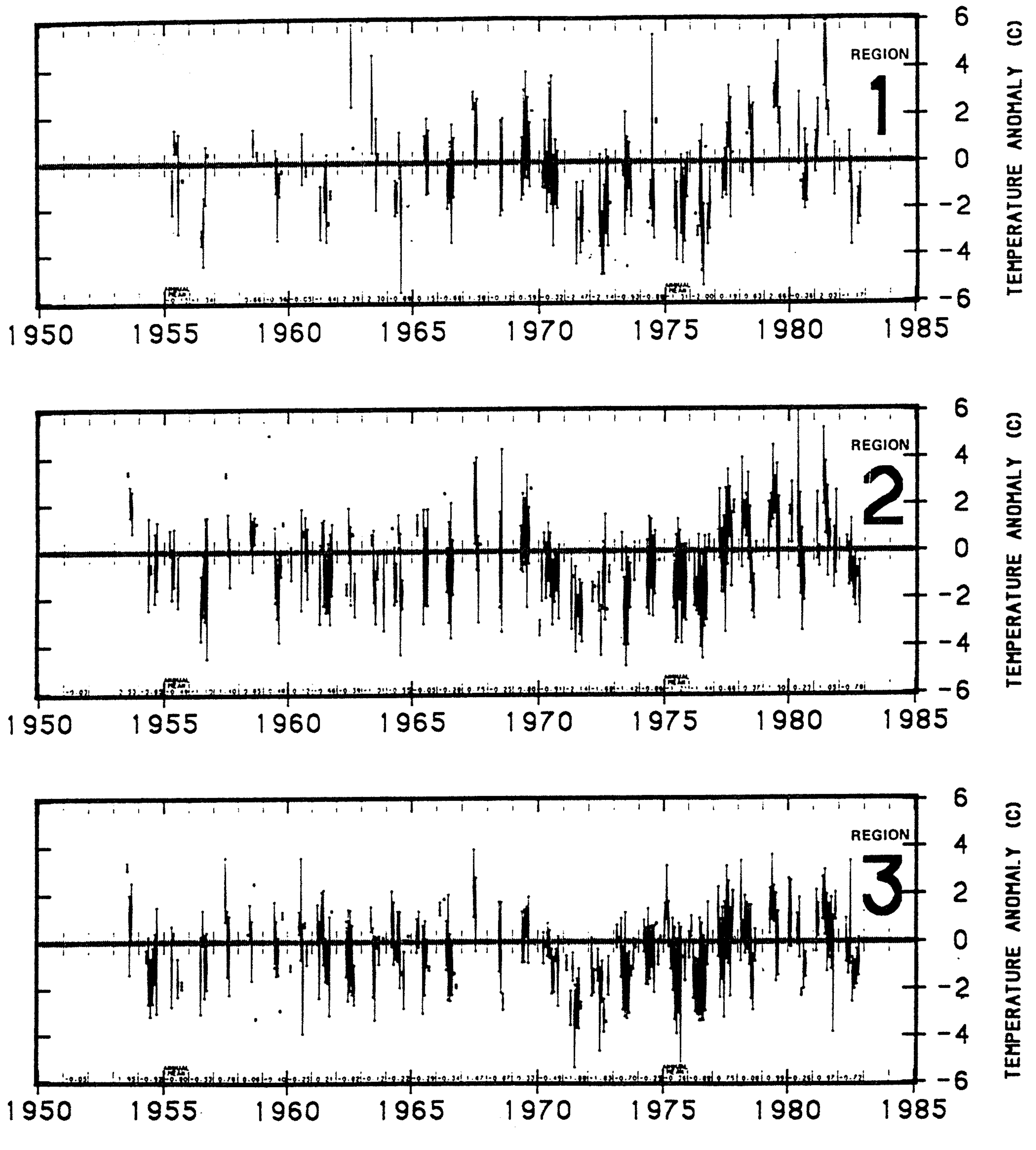


Exhibit 39. Time series from 1950 to 1982 of ranges and average near-bottom temperature anomalies for Regions 1, 2, and 3 of the DYNUMES grid. Source: Swan and Ingraham (1984).

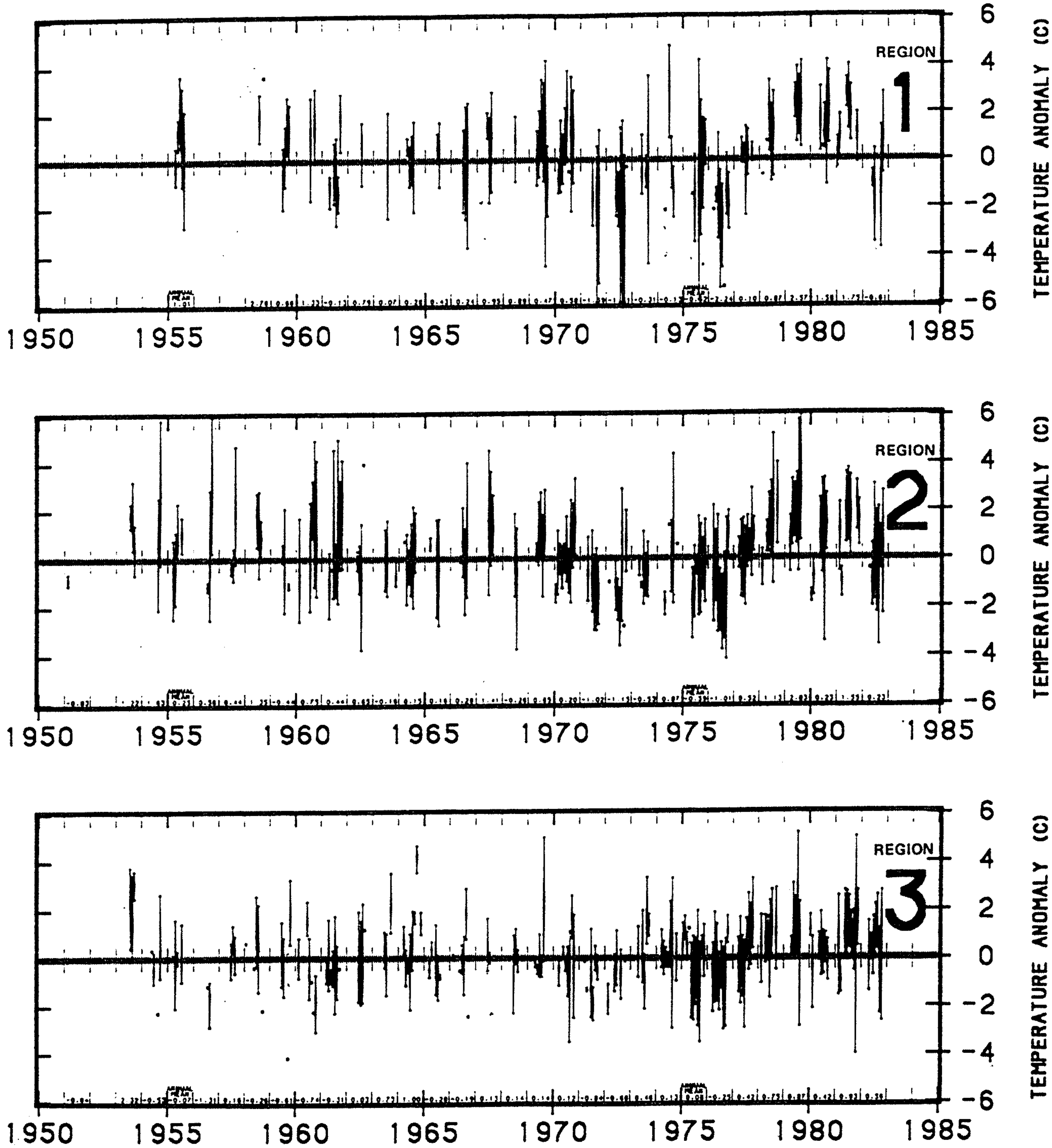


Exhibit 40. Estimated kills of Steller sea lions due to various fishery and subsistence activities. Source: NRC table.

	MORTALITIES DUE TO:							
Year	Commercial Harvest	Subsistence Harvest	Incidental Harvest & Defensive Shootings In Trawl Fisheries	Incidental Harvest & Defensive Shootings In Salmon Fisheries	Incidental Harvest & Defensive Shootings In Other Fisheries	Indiscriminate Shootings All Fisheries	Marine Debris	Total Estimated Annual Mortality
1960	0	150	989	418	290	400	97	2,344
1961	0	150	989	443	290	400	97	2,369
1962	0	150	989	618	290	500	97	2,644
1963	4,518	150	989	467	290	500	97	7,011
1964	4,518	150	989	647	290	700	97	7,390
1965	4,518	150	989	554	290	700	97	7,298
1966	4,518	150	989	630	290	800	97	7,474
1967	4,518	150	989	206	290	800	97	7,049
1968	4,518	150	989	613	290	800	97	7,457
1969	4,518	150	989	412	290	900	97	7,356
1970	4,518	150	989	674	290	900	97	7,617
1971	4,518	150	989	467	290	1,000	97	7,511
1972	4,518	150	989	314	290	1,000	97	7,358
1973	0	150	989	220	290	1,200	97	2,945
1974	0	150	989	215	290	1,200	97	2,941
1975	0	150	989	258	290	1,400	97	3,184
1976	0	150	989	437	290	1,400	97	3,363
1977	0	150	989	500	290	1,400	97	3,426
1978	0	150	978	810	290	1,600	97	3,925
1979	0	150	394	873	290	1,600	97	3,404
1980	0	150	428	1,082	290	1,600	97	3,648
1981	0	150	223	1,115	290	1,600	97	3,475
1982	0	150	1404	1,100	290	1,800	97	4,842
1983	0	150	875	1,256	290	1,800	97	4,468
1984	0	150	700	1,317	290	1,800	97	4,354
1985	0	150	582	1,445	290	1,800	97	4,364
1986	0	150	369	1,258	290	1,700	97	3,864
1987	0	150	199	949	290	1,700	97	3,385
1988	0	150		500	290	700	97	1,737
1989	0	150		100	290	200	97	837
1990	0	150	28	100	290	100	97	765
Total	45,178	4,650	23,976	20,000	9,000	34,000	3,000	139,804

Exhibit 41. Northern sea lion commercial harvest and fishery-related mortality as a percentage of sea lion population size, 1960-1989. Source: NRC table.

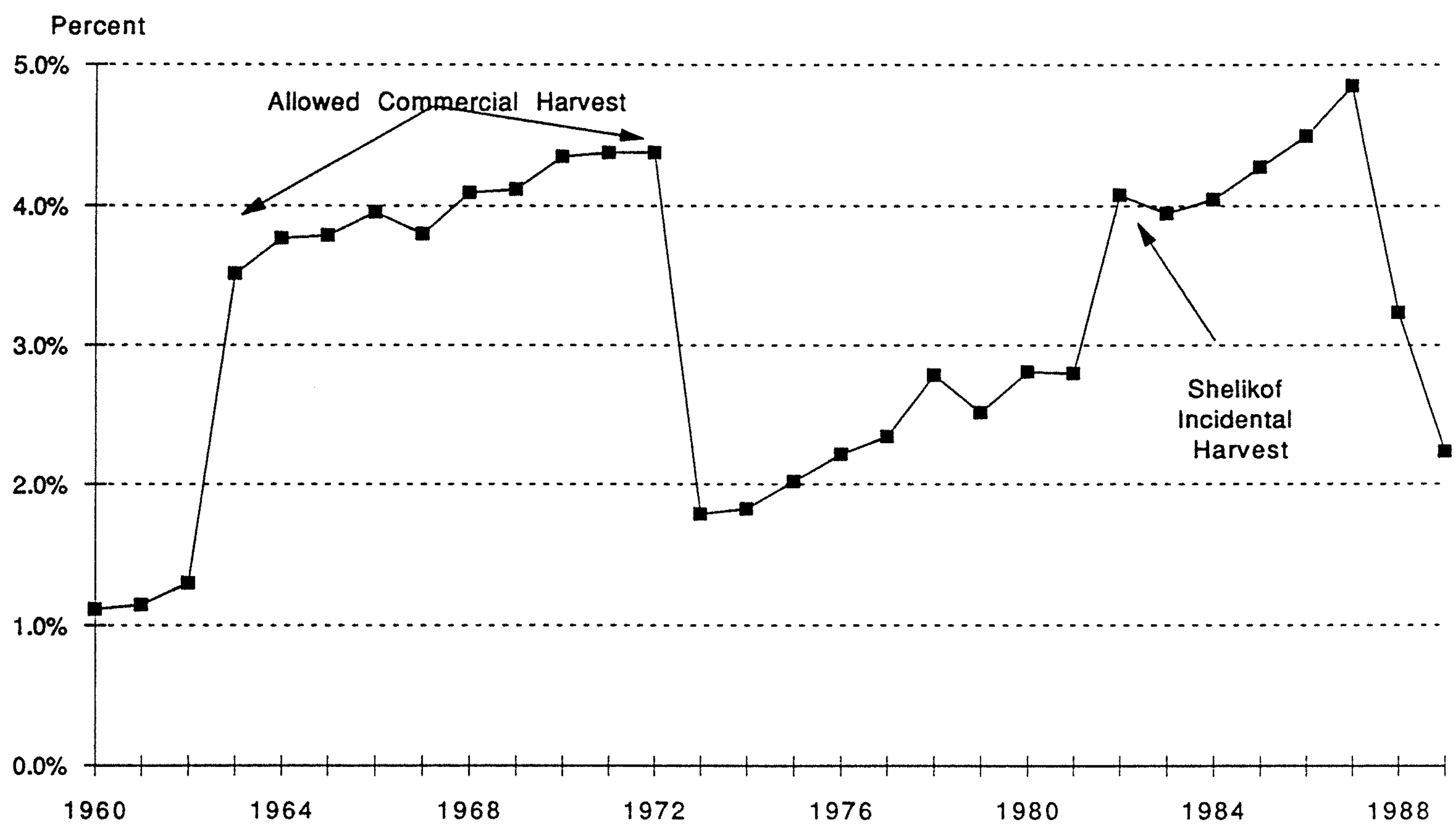


Exhibit 42. Relative abundance of pollock in the Eastern Bering Sea/Aleutian Islands and the Gulf of Alaska compared to northern sea lion counts, 1960-1990. Source: Quinn and Collie (1990), Marasco and Aron (1991).

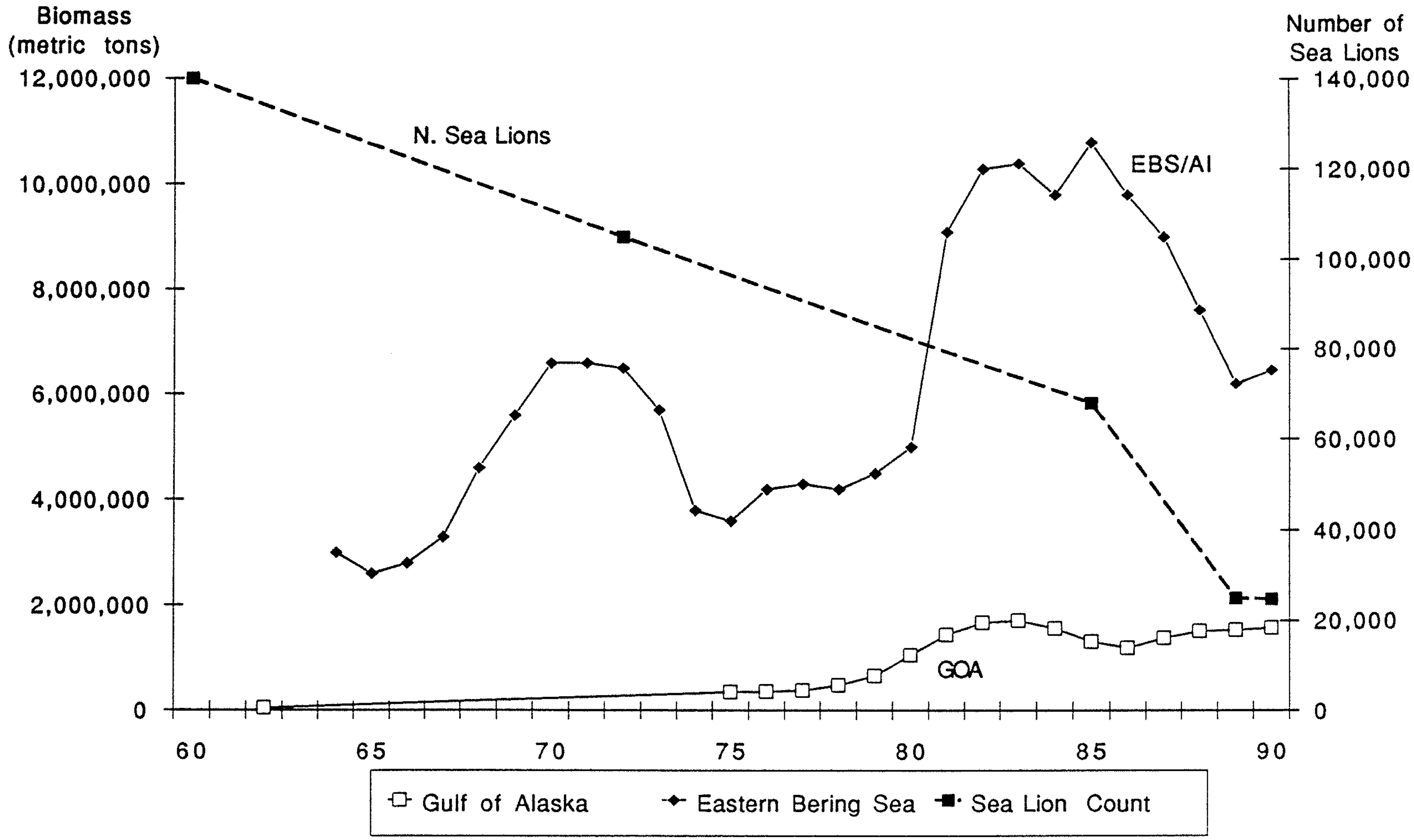


Exhibit 43. Change in total northern sea lion food requirements, sea lion demand for pollock, and pollock biomass in the Gulf of Alaska, 1960-1989. Source: NRC table.

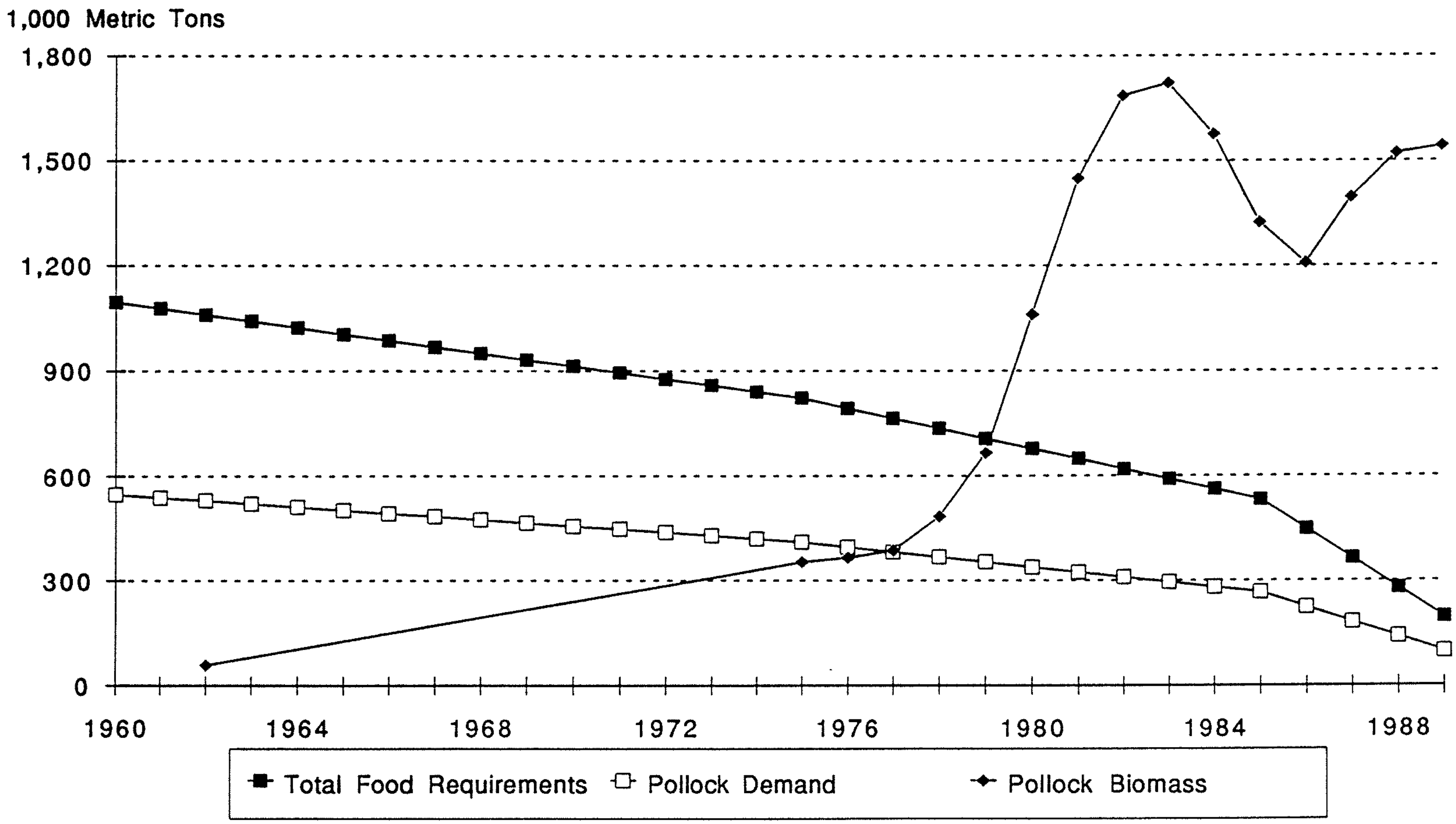


Exhibit 44. Percent of pollock and fatty fish in stomach contents of northern fur seals sampled in the Eastern Bering Sea, 1960-1985. Values in the 1980s are percent by number. all other values are percent by volume. Source: Perez and Bigg (1981), Sinclair (1988).

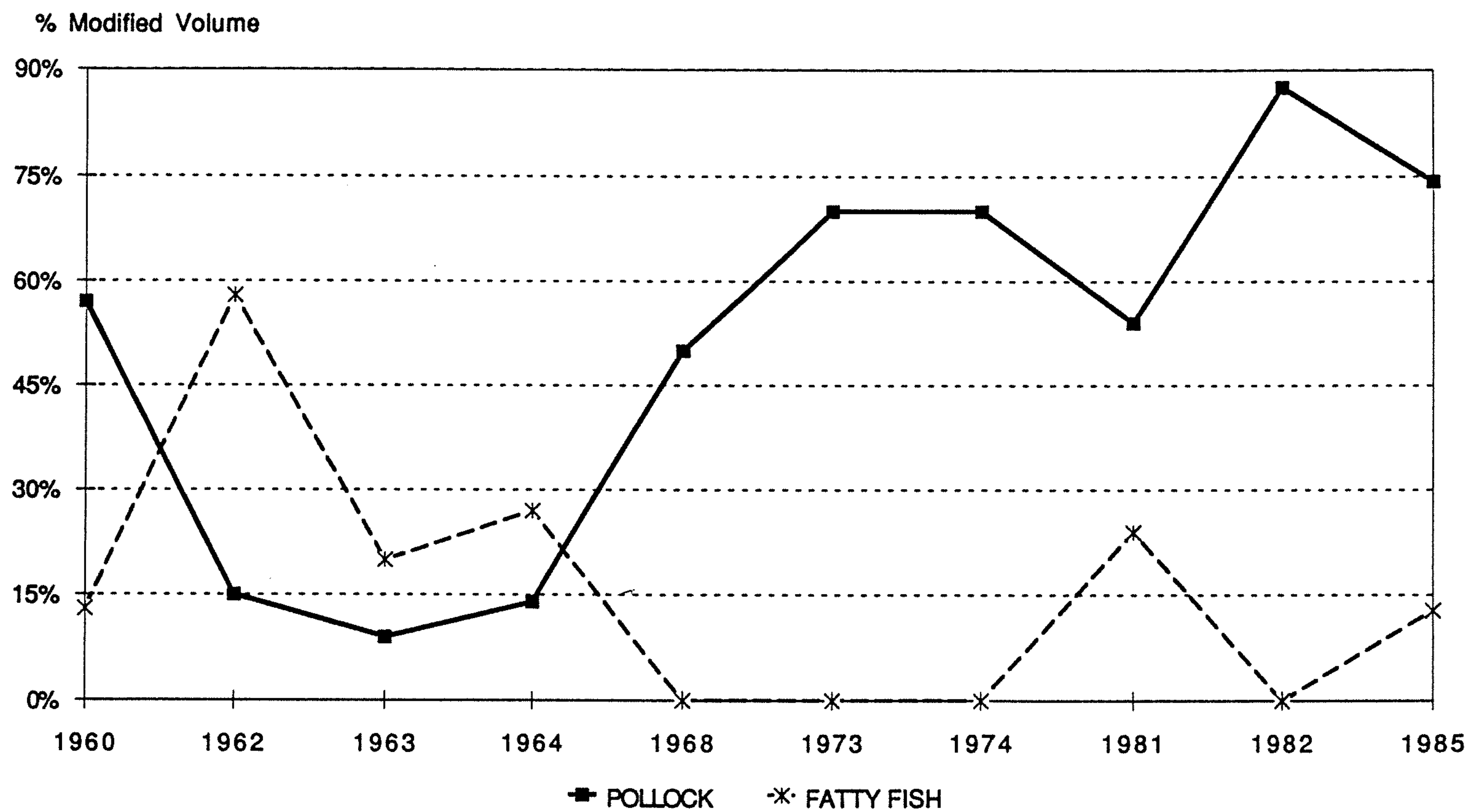


Exhibit 45. Percent of pollock and fatty fish in stomach contents of northern fur seals sampled in the vicinity of Unimak Pass, 1960-1982. 1982 value is percent by number. All other values are percent by volume. Source: Perez and Bigg (1981), Sinclair (1988).

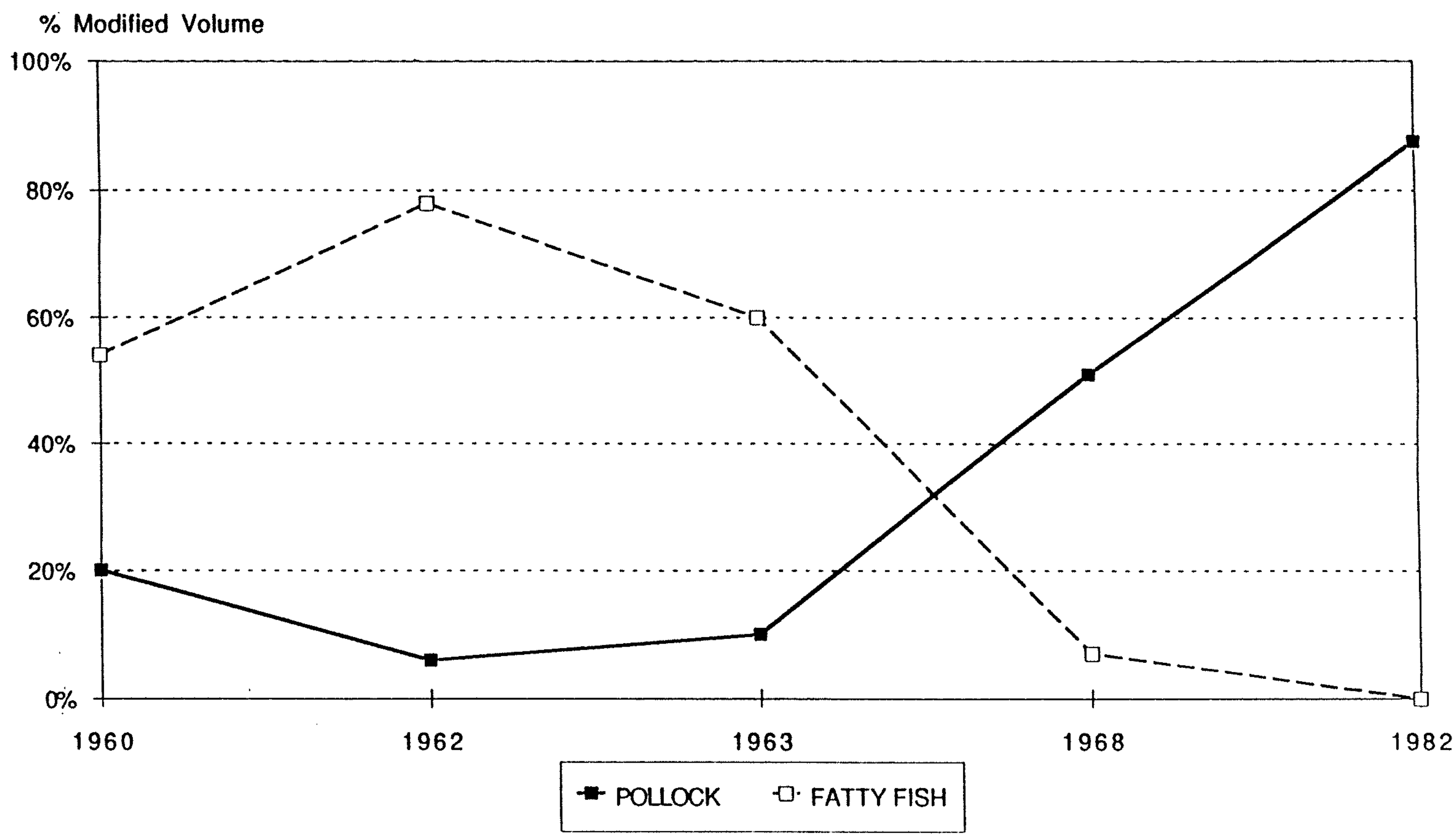


Exhibit 46. Percent of pollock and fatty fish in stomach contents of northern fur seals sampled in Western Alaska, 1958-1974. Source: Perez and Bigg (1981).

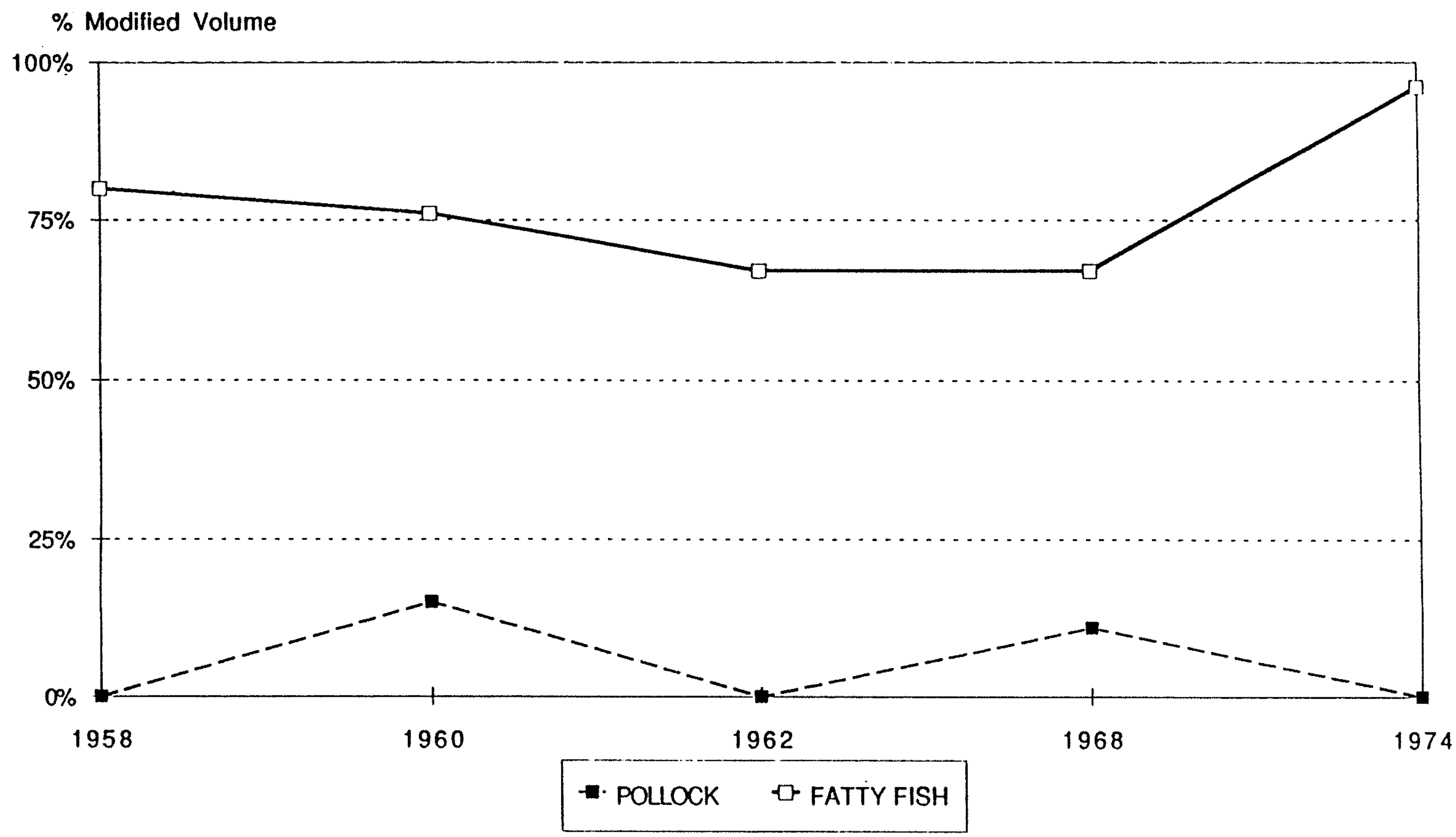


Exhibit 47. Proximate composition of fish and shellfish. Source: Marine Fisheries Review Paper 1198, September 1976, pp. 3-4.

SPECIES	ORIGIN OF SAMPLE	NUMBER OF LOTS	NUMBER OF FISH	NUMBER OF ANALYS.	OIL			PROTEIN		
					MAX.	MIN.	AVG.	MAX.	MIN.	AVG.
Grey cod	AK, WA, OR	12	113	113	1.10	0.21	0.66	19.10	16.30	17.90
Euchalon	Colum. River	1	16	16	8.98	4.59	6.25	15.30	13.20	14.60
Flounder										
Arrowtooth	SE AK, WA, OR	3	31	31	4.52	0.78	2.30	18.80	16.30	17.70
Starry	SE AK, WA, Pug. Sd.	9	40	31	3.40	0.40	1.40	20.60	13.40	17.30
Pac. halibut	OR, WA, AK	26	29	29	3.32	0.39	0.79	22.50	18.10	20.70
Herring (flesh)	BC, Pug. Sd.	2	14	2	13.10	10.80	12.50			16.00
Herring (whole)	Kodiak, Pr. Wm. Sd., SE AK, BC	13	210	69	23.70	2.20	12.80	19.50	14.20	16.40
Pac. pollock	Bering Sea, NE Pac.	4	60	8	1.30	0.60	0.98	19.30	16.40	18.90
Rockfish										
Black	SE AK	2	32	32	3.62	0.57	1.84	18.90	16.20	18.70
Blackmouth	SE AK	1	12	2	2.28	2.09	2.19	18.90	20.60	19.80
Blacktip	SE AK	1	3	1		(1.27)			(19.30)	
Bocaccio	WA	1	15	15	1.62	0.80	1.04	19.50	17.60	18.60
Chilipepper	N CA	1	12	12	2.90	1.55	2.35	21.60	19.60	20.80
Flag	WA	1	6	2	1.95	1.60	1.78	18.40	17.90	18.20
Greenstriped	WA, OR	2	30	16	0.74	20.20	0.73	20.80	19.60	20.30
Idiot	WA, OR	1	13	13	3.38	0.57	1.67	18.30	16.30	17.30
POP	WA, OR, N CA	17	210	200	4.03	0.36	1.43	20.70	15.10	19.00
Red	SE AK	4	9	4	0.23	0.19	0.20	18.10	16.40	17.20
Sablefish	SE AK, WA, OR	13	108	107	22.90	2.76	15.10	16.60	10.60	13.80
Salmon										
Chum	Pug. Sd.	7	7	7	7.33	2.18	3.86	23.30	20.20	21.30
Chinook	OR	3	3	3	15.70	7.20	11.50	21.20	17.80	19.50
Pink	SE AK, WA, Pug. Sd.	15	73	44	12.10	7.40	4.76	23.20	15.20	19.00
Coho	WA, OR, Pug. Sd.	14	86	86	12.50	1.63	5.31	22.80	20.00	21.70
Sockeye	BC, WA, OR, Col. Riv.	12	42	42	13.70	1.26	8.55	23.40	17.20	21.30
Sole										
Dover	WA, OR, N CA	11	103	103	3.32	0.39	0.95	22.50	7.10	16.80
Flathead	Ber. Sea, BC, WA, OR, Pug. Sd.	4	28	8	1.50	0.55	1.10	19.70	14.90	19.20
Rex	WA, OR	4	58	58	3.09	0.35	0.71	18.10	13.90	16.70
Rock	Ber. Sea, Pug. Sd.	4	15	15	1.30	0.49	0.77	19.80	15.90	19.20
Yellowfin	Ber. Sea	1	78	1		(1.25)			(17.00)	

Exhibit 48. Estimated comparative energy values (wet mass) for raw, whole prey species fed to the captive animals referenced in this study. Source: Perez et al. (1990).

Prey species	Energy value (kcal/g)[a]	Analysis and tissue[b]	Data sources[c]	Estimated comparative energy value (kcal/g)[d]
Yellowtail amberjack (*Seriola quinqueradiata*)	2.36	P, muscle	1, 2	2.60
Bluefish (*Pomatomus saltatris*)	1.47	P, muscle	2, 3	1.62
Capelin (*Mallotus villosus*)	1.81	P, whole	2, 4, 5	1.81
Cod (*Gadus* spp.)	1.10	P, muscle	1, 2	1.21
Atlantic herring (*Clupea harengus harengus*)	2.53	P, whole	2	2.53
Pacific herring (*Clupea harengus pallasi*)	2.17	P, whole	2, 5, 6, 7	2.17
Herring (Clupeidae)[e]	2.10	P, whole	2	2.10
Atlantic mackerel (*Scomber scombrus*)	2.35	P, muscle	2, 8	2.59
Chub mackerel (*Scomber japonicus*)	2.40	P, muscle	1	2.64
Spanish mackerel (*Scomberomorus maculatus*)	1.82	P, muscle	2, 3, 5	2.00
Mackerel (Scombridae)	2.04	P, muscle	2	2.24
Mullet (Mugilidae)[f]	1.95	P, whole	9	1.95
Walleye pollock (*Theragra chalcogramma*)	1.25	C, P, R. whole	1, 2, 10, 11, 12	1.25
Blue runner (*Caranx crysos*)	1.42	P, muscle	2	1.56
Salmon (Salmonidae)[g]	1.90	P, muscle	1, 2	2.09
Blue mackerel scad (*Decapterus maruadsi*)[h]	1.46	P, muscle	1	1.61
Scad (Carangidae)[i]	1.52	P, muscle	1, 2	1.67
Smelt (Osmeridae)[j]	1.20	P, whole	2, 13	1.20
Sole (Pleuronectidae)[k]	1.14	P, whole	2	1.14
Sprat (*Sprattus sprattus*)	1.81	P, whole	2	1.81
Whiting (Gadidae)	1.12	P, muscle	2	1.23

[a]The values given in column 1 represent the average of range values obtained from the data in the cited references. Values based on proximate composition data, including estimates calculated from relative proportions of total body mass represented by different body parts, were calculated with the following energy factors (representing heats of combustion) derived from Watt and Merrill (1963): 9.50, 5.65 and 4.20 kcal g^{-1}, respectively for fat, protein and carbohydrate.

Exhibit 48—cont.

[b]Analysis: C = bomb calorimetry combusion value; P = proximate composition data averaged (to the extent possible) over the seasonal range of values for the percentage of protein, fat and carbohydrate in the tissue sample; R = value estimated from data on the relative proportions of body parts and their respective energy value based on proximate composition data. Tissue: muscle = raw flesh material only; whole = raw material from entire specimen.

[c]Please refer to Perez et al. (1990) for additional information on the following sources: (1) Kizevetter (1971), (2) Sidwell (1981), (3) Gooch et al. (1987), (4) Jangaard (1974), (5) Krzynowek and Murphy (1987), (6) McBride et al. (1959), (7) Bigg et al. (1978), (8) Leu et al. (1981), (9) Vlieg (1984a), (10) Kizevetter et al. 1965, (11) Miller (1978), (12) Ashwell-Erickson and Elsner (1981), (13) Geraci (1975), (14) Croxall and Prince (1982), (15) Vlieg (1984b), (16) Perez and Bigg (1986).

[d]Where data were not available for whole fish, the comparative energy value of edible whole specimens was estimated at 1.1 times the muscle tissue value. This factor was estimated based on data for capelin, herring, walleye pollock and smelt in Sidwell (1981).

[e]Includes round herring species.

[f]Based on data for striped mullet, *Mugil cephalus*, and yellow-eyed mullet, *Aldrichetta forsteri.*

[g]Average of values for chinook salmon, *Oncorhynchus tshawytscha*, chum salmon, *O. keta*, coho salmon, *O. kisutch*, pink salmon, *O. gorbuscha*, and sockeye salmon, *O. nerka.*

[h]Based on data for *Decapterus* spp.

[i]Average of values for species of four genera: *Caranx, Decapterus, Selar,* and *Trachurus.*

[j]Based on the energy value for rainbow smelt, *Osmerus mordax.*

[k]Average of values for Dover sole, *Microstomus pacificus*, petrale sole, *Eopsetta jordani*, and rex sole, *Glyptocephalus zachirus.*