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COMPREHENSIVE REVIEW AND CRITICAL SYNTHESIS OF THE LITERATURE ON RECOVERY OF ECOSYSTEMS FOLLOWING DISTURBANCE

(FISH AND SHELLFISH)

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FINAL REPORT

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EXECUTIVE SUMMARY

This report presents a review of the scientific literature pertaining to the recovery of marine fish and commercially important shellfish populations following anthropogenic or natural disturbances. The types of disturbance include pollution such as oilspills and pesticides, effects of weather and climate change and physical processes such as floods and earthquakes. In each case we have evaluated the rate, extent and duration of recovery of populations, and attempted to identify abiotic and biotic factors that affect recovery times. This information was used to suggest management practices to enhance the recovery process and to identify indicator species to be used to monitor recovery.

There is an extensive literature on the effects of overfishing on marine fish populations and recovery of those stocks. Recovery can range from several years to decades and is generally enhanced by complete bans on fishing for some years. Species with short life cycles and high fecundity tend to recovery most quickly. However, recovery may be more dependent upon physical oceanographic and climatic conditions that are variable and unpredictable than upon biological processes. Recovery from other factors ranges from a few days for behavioral changes caused by weather disturbances to years for disturbances that significantly alter habitat such as channelization of

streams or flood damage. In all cases the rates of recovery depend upon the availability of colonizing individuals to reoccupy the area after the disturbance.

Shellfish populations display significant natural fluctuations in population size that are often exacerbated by overfishing. Recovery times ranged from 3 to 30 years but for some species fluctuation could be reduced and total production increased by the appropriate application of aquaculture. Shellfish populations typically recover more rapidly from other types disturbance than from overfishing. Recovery is primarily dependent upon the availability of juvenile, or adult, stages for recruitment.

Recovery time depends upon the particular parameter that is chosen to indicate recovery. Individuals of an affected species may reappear quickly but establishing a stable age distribution or comparable assemblages of species will require several years. Shellfish populations recover more slowly than finfish because the individuals are generally less mobile. Therefore, they cannot avoid the disturbance as easily and recruitment is generally restricted to juveniles rather than mature individuals.

We suggest that fishery statistics collected by state or federal agencies should be used to monitor the recovery of finfish populations. The best indicators of shellfish recovery are the common bivalves, mussels, clams and oysters. We do not recommend any intervention to enhance the finfish populations since the most important commercial species have had record catches since the spill. In addtion the scientific literature indicates that recovery generally occurs naturally and efficiently without intervention.

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We depended upon many individuals in many organizations and in a number of countries for providing information, reprints, reports, and other literature for this study. We are indebted to each of these individuals and to each of these organizations for the help they have given us over the course of this study.

1.0 INTRODUCTION

Background: In the early morning hours of 24 March 1989, the tanker EXXON VALDEZ ran aground and ruptured her tanks on Bligh Reef in Prince William Sound, Alaska. This resulted in the spilling of approximately eleven million gallons of North Slope crude oil into one of the nation's most sensitive ecosystems. The spill occurred during the normal outmigration of pink salmon (*Oncorhynchus gorbuscha*), the most abundant salmon species in the area (Koering and Noerengerg 1976). There is concern regarding the impact of the oil spill to different components of the Prince William Sound ecosystem. This report considers the potential effects of the spill on fish and shellfish populations and the expected rates of recovery of those populations.

Ecosystems are continually changing in response to natural phenomena and anthropogenic perturbations. Some natural events such as meteorite impacts, volcanoes, and Tsunamis produce significant, rapid, and sometimes catastrophic effects. At the opposite extreme, events like long-term shifts in climate and continental drift, cause ecosystem modifications at extremely slow rates. Similarly, the impingement of man's activities on natural ecosystems may be slowly causing widespread, long-term, and perhaps nonspectacular degradation of the biosphere. Or, there may be events that produce immediate, apparently catastrophic consequences, such as large explosions, and chemical or oil spills. The immediate effects that result from these events will generally moderate with time, although it is difficult to predict either the time required for recovery or the extent of recovery which may occur.

Objectives: The objective of this project was to conduct a thorough review of the available literature on the recovery of finfish and commercially important shellfish (bivalves and crustacea) populations following disturbances in marine and estuarine environments, including information on the impacts of various physical and chemical factors that affect the recovery processes. Particular emphasis was given to the types of marine ecosystems that are common in Prince William Sound, Lower Cook Inlet and the Western Gulf of Alaska.

The specific objectives of the project were:

1. Review the literature on the recovery of finfish and commercially important shellfish following disturbances

2. Prepare a synthesis document of this literature that is pertinent to Prince William Sound, Lower Cook Inlet, and the Gulf of Alaska and:

- Describes the rates of recovery, duration and degree of recovery of fish and shellfish populations following disturbance

- Identifies abiotic factors that affect recovery rates;

- Estimates potential degree of recovery and expected rates of recovery;

- Considers the influence of management practices on the rate of recovery;

- Identifies indicator species, as well as population, community or species-specific parameters that can be used cost effectively to monitor the recovery.

3. Provide an annotated bibliography of the references used in the literature review.

2.0 TECHNICAL APPROACH

Information Retrieval: Computer searches of on-line data bases were conducted using the University of Washington libraries. Searches were conducted for oil spill effects on fish and shellfish, for fish and shellfish recolonization, and for ecosystem recovery and restoration using the following key words:

Oil spill and Fish
Oil Spill and Clam
Oil Spill and Shrimp
Oil Spill and Crab
Oil Spill and Ecological Recovery
Fish and Recovery
Fish and Restoration
Fish and Recolonization
Fish and Storm
Fish and Hurricane
Salmon and Recovery
Salmon and Restoration
Salmon and Recolonization
Salmon and Tsunami
Trout and Recovery
Trout and Restoration
Trout and Recolonization
Shellfish and Recovery
Shellfish and Recolonization
Shellfish and Restoration

The abstracts from computer searches were obtained as printouts and as ASCII text files on floppy disks which were edited as MS-DOS files or with the word processing program

Microsoft Word 5.0. It was very convenient and efficient to work with "downloaded" references and eliminates unnecessary re-typing of citations. After the data base searches were completed, the printouts were reviewed to remove unnecessary and duplicate citations Abstracts from grey literature publications (eg. Technical memorandum, agency reports, dissertations) were generally transferred to ASCII files on floppy disks directly from the publications by use of a visual scanner.

Source of Data: The data bases searched and the number of relevant citations found in each data base are summarized in Table 1. Searches of the on line data bases have been very successful, sometimes generating in excess of 1000 references if we search on oil or oilspill. When we restricted the search to the keywords listed above, considerably fewer, but more directly pertinent, references were obtained. The Oil Spill Public Information Center provided several references that are directly applicable to the Prince William Sound area. We were unable to successfully obtain information from NODC, NGDC or NOAA/NESDIS data centers and information services.

Analysis and Synthesis: An initial analysis of the data was made by reviewing the citations and assigning each citation to one of several subject categories based on the contents of the abstracts and professional judgement of the investigators. After this initial classification articles in each category were reviewed and narrative texts were prepared for each subject from the appropriate references.

Table 1. Data bases searched and the number of relevant citations found in each data base.

Data Base	Number
Aquatic Science and Fisheries Abstract	185
Biological Abstracts	0
Chemical Abstracts	0
Conference Papers Index	0
Dissertation Abstracts	0
Life Sciences Collection	20
NTIS (National Technical Information Service)	10
Oceanic Abstracts	0
Science Citation Index	0
Selected Water Resource Abstracts	89
Arctic and Antarctic Regions	33
Oil Spill Public Information Center	38

3.0 REVIEW OF READILY AVAILABLE INFORMATION ON RECOVERY

We reviewed the literature on recovery of fish and shellfish populations following natural or anthropogenic disturbances. Although we are specifically concerned with recovery following an oilspill, most of the literature discusses the response of populations following overfishing. Therefore, we have included specific sections on recovery from overfishing and recovery from oilspills. All other information has been combined into a section on recovery from other environmental perturbations. For convenience, fish populations and shellfish populations are reviewed separately.

3.1 RATE, DURATION, AND DEGREE OF RECOVERY OF FISH POPULATIONS FOLLOWING DISTURBANCE

3.1.1 Recovery from Overfishing

Fisheries is a practical profession and from a fisherman's perspective recovery has occurred when the catch per unit effort (CPUE) reaches the predisturbance levels. Recovery is considered partial if CPUE is only a fraction of predisturbance levels. Professional judgement of fisheries managers is required to distinguish between a stable recovery and short term fluctuations. It should be noted that the direct CPUE data are not always available but may be calculated from landings and other statistical data.

Cod (Gadus morhua) and **Haddock** (Melanogrammus aeglefinus): This classic example of the North Sea bottom fisheries is discussed in detail by Gulland (1977). Catch statistics for the North Sea fisheries are available since 1906 and stocks have been heavily fished throughout this century except during the first and second world wars. Cod and haddock stocks recovered (Fig. 1) during the wars, because of the short respite from fishing. The break of 4-5 years in fishing produced a significant recovery of the stocks and immediately following the wars the catch jumped to higher levels than the pre-war values. The increased landings during the 1950's and 1960's probably resulted from a change in fishing methods and increased effort (Gulland 1977) or from major changes in the hydrographic circulation patterns in the North Atlantic (Cushing 1982).

Similar trends in catch and fishing effort of cod occurred in the Northeast Arctic (Fig. 2). After the second world war the catch jumped to pre-war levels, although fishing effort was quite low. Again, a break in fishing of 4-5 years resulted in recovery of the population.

Plaice (Pleuronectes platessa): Like cod and haddock, the North Sea plaice populations recovered during the two world wars (Gulland 1977). The trends in annual landings

(Fig. 3a) indicate that there were high populations immediately after the wars that decreased rapidly due to increased fishing efforts. Comparisons of fishing effort and estimates of stock abundance (Fig. 3b) indicate that the stock tripled in size between 1938 and 1946. Both before and following the war the catch is dominated younger (less than 5 years old) fish (Fig.4). However, there is a significant increase in the abundance of older fish following the war. Because older females produce more eggs, this change in the age structure increases the fecundity of the population and allows the population to expand more rapidly.

Alaska plaice have usually been taken as incidental catches in the yellowfin sole fishery. Zhang et al. (1991) used total catches (Fig. 5a) and biomass estimates for age 6 and older Alaska plaice to model stock production in the Eastern Bering Sea (Fig. 5b). The model indicates that under the fishing and environmental conditions that existed during the 1970-1990 period it took about 7 years for the biomass of age 6 and older fish to stabilize.

Yellowfin Sole (Limanda aspera): The yellowfin sole fishery in the eastern Bering Sea was fully developed by 1959 and both catch and population abundance declined precipitously in the early 1960's (Fig. 6). As fishing continued throughout this period the populations did not recover for more than 20 years. In fact the catch has never returned to previous levels although the population biomass (Fig. 6b) is estimated to have surpassed the biomass of the 1960's (Zhang et al. 1991). It took about 12 years of steady increase for the biomass of sexually mature individuals, age 7 and older, to stabilize.

It should be noted that both yellowfin sole and Alaska plaice in the eastern Bering Sea are characterized by a separation of a shallow (<30 m) nursery area from the fishing grounds inhabited by the exploitable population (Zhang and Gunderson 1990). This enhances recovery because the nursery area is not affected directly by the fishery.

Pacific Halibut (Hippoglossus stenolepis): Pacific halibut are found on the continental shelf of the North Pacific Ocean. Halibut move from deep water along the edge of the continental shelf to shallow banks and coastal waters during the summer and return to deep water in winter. Most males are sexually mature by the time they are 8 years old, whereas the average age of maturity for females is 12 years (IPHC [International Pacific Halibut Commission] 1987).

The catch of halibut gradually increased from about 44 million pounds in 1931 and exceeded 70 million pounds in 1962 (Fig. 7). However, the catch then declined and fell to below 25 million pounds in 1974-1979. Pacific halibut are inadvertently captured by gear types targeting on other species. Historically, incidental catches of halibut were relatively small until the early 1960's when there was a sudden influx of foreign fishing vessels targeting on ground fish (Fig. 8.) The combination of fishing and incidental mortalities resulted in the gradual decline of the stock.

The catch increased from 1975 until 1985 although it never regained its highest historical levels and has been declining again since 1985. The IPHC has regulated the catch by setting annual catch limits, a minimum size limit, and limiting the fishing season. The fishing season of 250 days originally was reduced to less than 150 days in the 1960's and 1970's, to less than 40 days in the 1980's (Fig. 9) and 1 day per area in 1992.

The IPHC's goal is to maintain the halibut population at levels which produce optimum yield (IPHC 1987). Models by Zhang et al. (1991) suggest that biomass of halibut age 8 and older decreased steadily during the period of declining catch from about 170,000 metric tons (mt) in the 1960's to a minimum of less than 80,000 mt in the mid 1970's (Fig. 10B) and reached a value of about 150,000 mt in the mid 80's. After 10 years of steady increase, the biomass reached a new maximum that was still 20 thousand tons short of 1960's levels. However, the annual catch of halibut reached the 1960 maximum of about 70 thousand tons around 1988 after a period of 28 years (Fig. 10A).

Japanese Sardine (Sardinops melanosticta): Kondo (1980) described the recovery of the Japanese sardine which includes four separate local stocks distributed around Japan. There were large catches in the early eighteenth and nineteenth centuries and fishery data have been collected systematically since 1905. The fish catches increased gradually from the early part of this century until 1925, then increased rapidly to reach a peak of 2,600,000 tons in 1936. After that, the catch started to decline in 1938 and finally reached its lowest level, less than 10,000 tons, in 1965 (Fig. 11). The catch of sardine remained at a low level from the later half of the 1940's to the early 1970's. The population started to recover in 1972 and the rapid increase in the sardine stock after 1972 is attributable to the occurrence of the dominant 1972 year class. After that, the population of sardine created many strong year classes to support the high level of production. Rondo (1980) estimated that a catch in excess of 1 million tons could be maintained for over 10 years.

The ability of the Japanese sardine to recovery is thought to result from a shift in the location of the Kuroshio current. The shift increased the area available for spawning with a subsequent increase in the number of eggs. In addition, the nursery grounds were better quality so the survival rate in the post-larval stage increased. Thus, the production of a strong year class and the reversal of the trend in population abundance resulted directly from an unexpected, and unpredictable, change in the physical environment.

Canadian Pacific Herring (Clupea harengus pallasi): Commercial fishing for herring on Canada's west coast began in 1877 with the first recorded catch (0.7mt) in 1888. The catch increased from below 600 tons before 1902 to the maximum of 219,000 tons in 1964/1965. Because of overfishing, the herring population declined and spawn deposition decreased, especially for the heavily exploited coast population. Fishermen had difficulty locating fish and the proportion of immature fish in the catch rose noticeably in 1965. Because of the low catch, the herring fishery was closed earlier in 1968, and remained closed during the following four years, except for the traditional subsistence fisheries and a bait fishery. The fishery experienced poor year classes from 1966 through 1970. After the fishery was closed for 4 years, however, the stocks of herring on Canada's west coast recovered and had record or near-record spawning escapements in 1974. The fishery was reopened again in 1974 and the catch has ranged between 70,000 and 85,000 tons since 1976. Although, the herring population recovered significantly in the six year period between 1968 and 1974 (Hourston 1980) the catch did not return to its previously high levels.

Small Shoaling Pelagic Fish: Small shoaling fish stocks such as anchovies, sardines, and herrings are highly variable fish stocks and are very vulnerable to unrestrained fishing (Csirke 1988). Many small shoaling pelagic stocks have collapsed, after highly profitable fisheries had developed, and then recovered afterwards. These stocks typically are short-lived, pelagic species with a more direct link between the physical environment and the adult fish stock. Therefore, the populations respond more guickly to environmental change and effects are readily observable. Large fluctuations of population size and total catch are common in well-developed fisheries for small shoaling pelagic populations with differences of 10 to 100 times between the maximum and minimum catch and stock sizes occurring in less than a decade.

Peruvian Anchovy (Eugralis ringens): Estimates of total biomass of Peruvian anchovy are available at monthly intervals (Fig. 12). During the 1960's the biomass fluctuated considerably about an average of around 15 million tons, with a peak of more than 20 million tons in 1967 and a record catch of 13 million tons in 1970; the stock and the fishery collapsed after 1970 as a consequence of heavy fishing combined with adverse environmental conditions. There was a substantial recovery 12 years after the 1970 crash, although there were significant fluctuations in population abundance during that period. Following the crash in 1955, recovery occurred in 6 years. Recovery is dependent upon both the size of the breeding population and the specific environmental conditions which result from changes in major oceanographic processes, such as upwelling and current patterns.

California Sardine (Sardinops caerulea): The spectacular collapse of the California sardine fishery is a classical example of a fishery that did not recover for more than 40 years after the crash (Gulland 1977). At one time the California sardine fishery was among the biggest fisheries in the world. The peak catch was 800,000 tons in the 1936/37 season. Within 15 years the catch dropped to less than 50,000 tons (Fig. 13). It now seems fairly certain that the decline can be attributed to overexploitation, although the continuation of low population densities coincided with a rise of the anchovy population.

Other Stocks of Shoaling Fish: The annual nominal catches of the South American sardine, Pacific bonito, and the south African sardine are shown in Figures 14-16, respectively. The time series available for these fisheries are too short to determine if the changes are periodic or episodic. However, based on the available data, one can tentatively conclude that the time span (Fig. 14) for South American sardine populations to recover from a minimum to maximum was about 13 years (1972-1985) and the time between successive peaks is greater than 20 years. For Pacific bonito (Sarda chiliensis) the population declined over a 25 year period (Fig. 15) and has not yet recovered. Similarly, monthly estimates of population biomass and annual landings of the South African sardine were depressed for more than 20 years compared to their peak values in 1962 (Fig. 16). Both Peruvian anchovy and the South African sardine apparently went through pulses of high abundance shortly before their collapse.

An interesting feature of these changes is the number of cases in which similar species have undergone parallel changes at the same time. Figure 17 shows long term variability of three species of sardine occurring in the Pacific. The 50 years period between the two successive maxima seems unlikely to be pure coincidence for all three species. Francis and Sibley (1991) have recently argued that some common environmental factor, rather than fishing pressure or purely biological processes, must affect the catch and the size of all three stocks.

SUMMARY - RECOVERY FROM OVERFISHING: We have reviewed several case histories of fish populations that declined due to overfishing. Some significant features of these fisheries are summarized in Table 2. In some cases (cod, haddock, plaice, herring) recovery appeared to occur relatively quickly (4 - 7 years) simply as a result of decreasing the fishing pressure. For other populations, recovery is measured in decades (Japanese sardine, halibut, Yellowfin sole), or has not yet occurred (Pacific bonita, California sardine). In general, recovery occurs more quickly if fishing is completely restricted for a period. Species with short life cycles that reach sexual maturity at early ages and broadcast large numbers of eggs are most likely to recover quickly. For longer-lived species it is important to maintain a stable distribution of reproductive individuals. Zhang et al (1991) showed that it takes about 10 years of sustained recovery to develop such populations. Finally the population recovery of some populations is closely associated with specific environmental conditions which may occur at unpredictable frequencies. Therefore, the spectacular recovery of the Japanese sardine and the South American sardine was unexpected because it occurred more than 40 years after the initial recorded decline of the population. It is becoming increasingly clear that the population abundance of many marine fish populations is dependent upon physical oceanographic conditions that may be quite variable and unpredictable (Francis and Sibley 1991).

3.1.2 Recovery from Oil Spills

Fish are generally mobile species that are able to avoid areas with significant oil contamination (Royce et al, 1991). The impacts of oilspills are much more serious on shellfish populations. Therefore, our major discussion of the impacts and recovery from oilspills is in Section 3.2.2. In this section we discuss the major impacts to fish populations following 2 major spills, Exxon Valdez and Amoco Cadiz.

Exxon Valdez: Baker et al. (1990) reviewed the natural cleaning and recovery of ecosystems following oil spills in cold water regions. The recovery of an ecosystem damaged by petroleum hydrocarbons begins when the toxicity or other adverse properties of the oil decline to a level that is tolerable to the most robust colonizing organisms. Adult fish are rarely killed by oil although pelagic eggs and fish larvae may be damaged during an oil spill. However, the loss of pelagic eggs and fish larvae has no immediate impact on the fish stocks that are available to the fishing industry, and is not expected to have long-term effects since catch and climatic changes are the main factors that determine the annual recruitment of fish stocks (Baker et al. 1990).

Maki (1991) described the initial environmental impact of the Exxon Valdez oil spill. The oil spill occurred approximately three weeks prior to the peak of the Pacific herring spawn. The "miles of spawn" reported for herring in 1989 and 1990 were lower than in 1988, but the spawning activity of herring in Prince William Sound in 1989 and 1990 ewas comparable to the historical averages (Figure 18). This author concluded that herring spawning activity was not impaired or delayed during the Exxon Valdez oil spill. Similarly, the all-time record for the commercial catch of pink salmon occurred in 1990. Because pink salmon has a two-year life cycle, the catch in 1990 reflects the population of salmon that spawned in 1988 and left their native streams in 1989. Therefore, Maki (1991) concludes that the Exxon Valdez oil spill did not have significant effects on the population of pink salmon. Since herring and pink salmon are considered to be the most vulnerable species, it is unlikely that other finfish species have been adversely affected (Royce et al. 1991).

Amoco Cadiz: Direct mortality to fish and shellfish occurred immediately following the Amoco Cadiz oil spill (Conan 1982). About 10^4 dead fish, mainly wrasses (Labridae), sand eels (Ammodytes spp.), and pipe fishes (Syngnathidae) were found dead along the shore within a 10 km radius of the Amoco Cadiz wreck during the first week. Cockles (Cardium edule) and other bivalves (Solenidae, Mactridae, Veneridae), as well as large crustaceans (Cancer pagurus, Portunus puber, Carcinus maenas) and shrimps (Crangon crangon, Leander serratus) were killed in the same area. The effect on the population of large crustaceans and coastal fishes was less than for bivalves. Fin rot disease caused by the spill was reported in plaice, sole and mullet. Three years after the spill, populations had not recovered to their former level and the time of the recovery could not be predicted (Conan 1982).

Because population recovery depends upon the life strategy of each species, the recovery of stable age distribution and population density are dependent upon the life expectancy, fecundity and the ecology of larvae. Full recovery may require several generation times (Conan 1982). Because clams and fishes have life expectancies of 5-10 years, Conan (1982) estimated that 30 years, 3-6 generations would be required for a complete recovery of the stable age distribution.

Gundlach et al. (1983) reported that following the Amoco Cadiz oil spill several well-known finfish species were rarely found in the Bay of Morlax or Bay of Lannion. However, many species returned to normal population densities 9 months after the spill. Because of the high natural variability of the catch data, Gundlach et al. (1983) concluded that the changes in fish catches could not be attributed to the Amoco Cadiz spill.

3.1.3 Recovery from Other Environmental Disturbances

Numerous other natural and anthropogenic factors can disrupt fish populations. This section discusses recovery of populations that were affected by weather, habitat alterations or pollution. The examples that are discussed for weather disturbances emphasize tropical marine fish populations while habitat alterations and pollution are solely concerned with freshwater streams and rivers.

Weather: A hurricane (or typhoon), a tropical cyclone, has a great amount of energy that can destroy habitats along the shoreline and cause large scale fish kills. Typical responses of fish include changes in the normal activity cycles, and changes in territorial, social, reproductive and feeding behaviors and may include changes in population size.

Woodley et al. (1981) investigated the impact of Hurricane Allen on Jamaican coral reefs and found an increase in damselfish density after the hurricane. Also, cryptic fishes such as squirrel fish, moray eels, hawfish and triple-fin blenny were more often seen than before the hurricane. Threespot damselfish was found to relocate to deeper water after Hurricane Allen. After one year, fish assemblages on high- and low- reef patches differed in species composition and behavior (Kaufman 1983). However, in a study of the responses of fishes to typhoon 20, Tribble et al. (1982) found that wrasse (Pseudolabrus japonicus) and damselfish (Eupomacentrus altus) did not shift their distribution to deeper areas after the typhoon.

The behavior of damselfishes was also changed by the hurricane. After the hurricane, damselfishes apparently did not have a territory or home range and displayed submissive coloration. The school of striped parrot fish (Scarus croicensis) was smaller, less stable in composition and nonreproductive after the hurricane (Woodley et al. 1981). Similarly, Tribble et al. (1982) found female wrasse (Loris dorsomaculata) changed social groups and wrasse (P. japonicus) and damselfish (E. altus) changed territorial behavior after typhoon 20 in Igaya Bay, Japan.

Coral fishes recovered very quickly following the hurricane. For example, the territorial behavior of damselfishes was restored within 2 to 9 days. The normal reproductive behavior of striped parrot fish returned in 12 days and the recovery of schooling behavior was observed 3 weeks after the hurricane (Kaufman 1983; Woodley et al. 1981).

Walsh (1983) investigated the response of fish during a severe 3-day storm that struck the coral reef of Kona, Hawaii. He found that the storm changed the abundance of species and individuals, and shifted habitats. Abundance of sixteen fish species were significantly increased after the storm while the abundance of five other species decreased. The relative abundance of these species, according to a

Spearman Rank Correlation Analysis, had a high degree of similarity before and after the storm. However, the overall fish abundance was significantly lower. In addition, a large number of fishes moved from shallower to deeper areas in response to the storm. For example, before the storm over 100 territories of yellow-eyed damselfish (Stegastes fasciolatus) were found above the reef break, compared to 22 territories below. After the storm 54 territories of yellow-eyed damselfish were found above the break, compared to 109 below. Similarly, hawfish (Paracirrhites arcatus and Cirrhitops fasciatus) and damselfish (Chromis vanderbilti) increased significantly in deeper water after the storm. The recolonization of the shallower areas was rapid in the weeks following the storm. Many areas regained their prestorm appearance within 16 months (Walsh 1983).

Cyclones also disrupt the structure of shallow water assemblages of fishes. Turbulence caused by cyclones could restrict the feeding activities of fishes. Lassig (1983) reported that a cyclone in Great Barry had little effect on adult fishes but caused high mortality on juveniles, presumably because juveniles were unable to resist the water movement of the cyclone. The cyclone also redistributed the sub-adult individuals. Because recruitment was affected, the cyclone changed the structure and size of fish populations in the area for the subsequent year (Lassig 1983)

Cold spells that cause a significant drop in temperature are another kind of natural disturbance. Bohnsack (1983) reported that mean number of fish species and mean number of individual fishes per reef were significantly reduced after a cold spell on the Florida Keys, although the biomass per reef was not significantly changed. The response of the fish communities persisted until the following summer. In the following summer mean number of species and mean number of individuals were higher than either the year before or after the cold spell. Because of the apparent reduction in predation and competition, juvenile recruitment was very successful. This change in community measures returned to predisturbance conditions within one year (Bohnsack 1983).

Habitat Alterations: The habitat in rivers can be damaged by both natural (flood or erosion) and human (dredging or toxins) disturbances. Dredging operations in the Camowen River, North Ireland initially reduced salmonid population densities (Kennedy et al. 1983) followed by a progressive downstream recovery. Immigration was the most important factor for recovery. The 1+ and older fishes recovered more rapidly than fry. Trout fry density at the upper sections recovered 4 years after dredging, compared to 6 years at the lower sections. This progressive recovery, extending gradually downstream, was related to the gradual stabilization of the substratum. Recovery time for the river is directly related to the intensity and extent of the dredging operation and the adequate immigration of fish from undisturbed areas. For some sections of the Camowen River, recovery time was estimated to be longer than 6 years. The dredging also changed the population structure at the affected sites. The structure of the fish population was related to the depth of the habitat. The sites that were deepened by dredging contained many more 1+ and older fish than prior to the dredging. In contrast, sites that were shallower after dredging contained more fry after repopulation (Kennedy et al. 1983).

Cederholm and Koski (1977) investigated the physical and biological effects of stream channelization on Big Beef Creek, Kitsap County, Washington during summer for five years. The density of juvenile salmonids was reduced for at least the first two summers following channelization. After five summers, the population of coho salmon was higher than before channelization, but the population of steelhead trout was lower. Therefore, channelization of lower Big Beef Creek resulted in a highly unstable stream environment that had not fully recovered after five years. The different recovery times between coho salmon and steelhead trout may be related to the difference in habitat preference. Coho salmon avoid areas of dense shade and prefer the open glide pools during their rearing period. However, steelhead trout prefer areas of dense vegetative cover during summer rearing (Cederholm and Koski 1977).

Lamberti et al. (1991) described the recovery of cutthroat trout (Oncorhynchus clarki) following a catastrophic debris flow in Quartz Creek, Oregon. The debris flow in February 1986 changed channel geomorphology and destroyed riparian vegetation for 500 m. The cutthroat trout population was locally damaged by the disturbance, however trout density in the upstream reach was unaffected. Trout density was 100 fish/100 m of stream length after the disturbance and remained at that level for the entire 3-year study. The fish density in the debris flow reach decreased from 146 fish/100 m of stream length before the disturbance to about 10 fish/100 m one month after the disturbance. A downstream reach that was also affected by the debris flow had trout density between the upstream and debris flow reaches after the disturbance. One year after the disturbance, however, trout densities increased markedly in both the debris flow and downstream reaches. Trout density in the debris flow reach were about twice those of the upstream reach after two and half years.

Lamberti et al. (1991) found that adult cutthroat trout (1+ and older fish) had a different response to the debris flow than fry. The density of adult fish in the upstream reach was highest during the first and second years after the disturbance. However, the density of adult fish in disturbed reaches increased sharply after 2 years so that adult fish density in the downstream reach exceeded those upstream. Production of fry was stable in the upstream reach during the three year study. The production of fry in the debris flow reach was low, compared to normal in the downstream reach during the first year after the disturbance (Lamberti et al. 1991).

Lamberti et al. (1991) compared the number of 0+ trout in the fall with the number of 1^+ trout the following spring, and concluded that fish immigrated into these reaches after the debris flow. Because cutthroat trout spawn at age 2^+ and older, fry density in the debris flow reach was high after one year; immigration of 1^+ trout during the first year after the disturbance enhanced recruitment of fry in the second and third years. Two years after the disturbance, trout populations in the debris flow and downstream reaches had recovered to levels equal to or exceeding those in the upstream reach. The recovery of the trout population was dependent upon the size and time of disturbance. Trout population in the downstream reach recovered more rapidly than in the debris flow reach since it had a smaller disturbance and more reproductive adults.

Wilzbach (1986) discussed the effects of logging on trout populations. When surrounding forests and in-channel debris are removed in clear-cut logging operations, trout populations in small streams have been found to increase in abundance and biomass over the short term. Food is the most important factor in the increase of trout population. However, the increase in trout production that follows logging is short-lived. When second growth vegetation shades the channel, food supply decreases. In addition, wood inputs into the channel from second growth vegetation are not large or abundant enough to provide cover or stabilize the channel. The burst in trout numbers shortly after logging is followed by a decline to levels that characteristically are lower than for mature forested streams. In general, increased fish production immediately following logging may be restricted to mountainous streams with a coldwater fish fauna. In lower reaches of a stream-river system logging may produce significant deleterious changes. This change will produce a decline in numbers or total loss of sensitive fish species and replacement with more tolerant and often non-native species (Wilzbach 1986).

Milner and Bailey (1989) discussed the colonization by salmonid species of recently deglaciated streams in Glacier Bay National Park, Alaska. The salmonids had marked differences in numbers and in spatial and temporal distribution. For example, there were no salmonids in turbid meltwater streams such as Wolf Creek. Coho (Oncorhynchus kisutch), sockeye (O. nerka), chum (O. keta) and pink (O.

gorbuscha) salmon, and Dolly Varden (Salvelinus malma) were found in the youngest clearwater stream (Nunatak Creek) although pink and chum salmon were only found in the last year of the 8 years survey. Water temperature, sediment loading and stream discharge were the primary factors that governed the establishment, species diversity composition and abundance of salmonids in Glacier Bay streams. In addition, the presence of pools in clearwater streams increased the abundance of coho salmon. However, the abundance of Dolly Varden was higher than coho in the absence of pool habitat.

Hanson and Waters (1974) studied the standing crop, growth, and reproductive rate of a brook trout population in Valley creek, Minnesota for 6 years after a heavy flood. The fish density increased from 498/ha to a maximum of 10,822/ha within 3 years after the disturbance. A succession of strong year classes after the flood moved through the age structure during the recovery years. The population size and age structure of brook trout completely recovered 4 to 5 years after the flood. In addition, rainbow trout that did not live there before flood damage immigrated into the study section from downstream and became permanently established.

Klassen and Northcote (1988) reported that tandem V-shaped gabion weirs improved the spawning habitat in Sachs Creek, Queen Charlotte Islands, British Columbia by increasing the intragravel dissolved oxygen and intragravel permeability. Therefore, they suggested that the intragravel environment of damaged streams can be restored within one year by use of gabions .

Naslund (1989) discussed the effect of stream deflectors, boulder dams, boulder groupings and a combination of boulder reflectors and dams on the brown trout (Salmo trutta) population in Laktabacken Creek, Sweden. The density of age 0^+ fish was not significantly different in altered sections than unaltered section, although 2^+ and older trout were affected. The density of brown trout increased threefold, 3 years after the setting of boulder dams. Total standing crop of fish increased 5 times in the boulder dams section. Deflectors, boulder groupings and combinations of boulder deflectors and dams did not change the density or standing crops of trout, except for an increase of standing crops in the deflector section. Since the density of brown trout is correlated with the amount of cover, more suitable cover in altered sections have affected densities and standing crops of the trout in Laktabacken Creek. The full effect of the habitat restoration in Laktabacken Creek had not been determined 3 years after the alteration.

Fuchs and Statzner (1990) described the recovery of benthic macroinvertebrate communities following restoration projects in small streams in Germany. In one stream (Lower Schierenseebach) the ecological communities in upstream and downstream reaches of the stream were completely intact and recovery of macroinvertebrate fauna occurred within one year. However, recovery in the second stream (Giebbach) did not occur within 5 years because the stream was isolated and populations of recolonisers were unavailable. Because of the loss of many species and isolation from other communities, Fuchs and Statzner (1990) estimate that recovery of the Rhine river will require more than 12 years.

Pollution: Workman (1981) studied the recovery of rainbow trout and brown trout following a spill of toxaphene-base cattle dip into Sixteenmile Creek, Montana. The composition of the cattle dip was 44.15% toxaphene, 1.32% lindane, 10.00% petroleum distillate, 28.00% aromatic petroleum derivatives and 16.53% inert ingredients. Rainbow trout and brown trout numbers at the pesticide discharge point (source) were 7% and 32% of the total numbers at a control site during the first year after the spill. In sections 8 and 24 miles below the source, trout numbers were near zero. Recovery of the trout population was related to the location of sites. Recovery seemed to occur within 5 months at the source of the spill but required 3 years at a site 24 miles downstream. Immigration of yearling and 2-year-old trout from unaffected portions of the stream was the initial factor for restoring rainbow and brown trout in Sixteenmile Creek (Workman 1981) followed by natural recruitment within the area. A rise in the number of 3 year and older rainbow trout was found 2 years after the poisoning, compared to 3 years for brown trout. In general, the initial stages of repopulation occurred very rapidly and later stages occurred at a steadily decreasing rate. Recovery of the fish populations was dependent upon survival, available habitat and reproductive success.

Olmsted and Cloutman (1974) investigated the rate of reestablishment of a fish community following a pesticide spill in Mud Creek, Arkansas that eliminated 29 species of fish from the study area. Repopulation of fishes began soon after the pesticide dissipated. For example, bigeye shiners (Notropis boops) and blackspotted top-minnows (Fundulus olivaceus) returned within 5 days after poisoning. Immigration from Scull Creek, an undisturbed tributary, was the source for initial repopulation. Except for bigeye shiners, immigrants were primarily young-of-the-year or immature individuals. Because species had repopulated the disturbed zone and the populations were similar to predisturbance abundances, it was concluded that recovery occurred within one year after the poisoning. The rate of repopulation was influenced by the existence of undamaged areas nearby and the abundance of fishes in those areas. In addition, the season of the year when the damage occurred was an important factor for the immigration of fish from unaffected areas. Olmsted and Cloutman (1974) concluded that a stream fish community has a remarkable ability to reestablish itself after a catastrophe as long as there is no permanent damage or significant alteration of habitat.

Phinney (1975) reported on the repopulation of brook trout in the North Fork Musselshell River in central Montana after the stream was treated with rotenone to remove large populations of white sucker (Catostomus commersoni) and longnose sucker (C. catostomus). The brook trout population in the treated sections was low compared to the control section after the treatment. However, brook trout occurred 8 km upstream from the treated area. Repopulation of brook trout began 21 days after the treatment in the upper sections and the fish population gradually increased after the treatment. Displacement of fry from upstream areas was the primary source of fish so the percentage of age-0 trout (fry) was higher in the treated sections than in the control section during the first summer after the treatment. The brook trout population reached its peak one year after the treatment and the population was considered to have recovered at that time.

Turnpenny and Williams (1981) investigated the recovery of fish in River Ebbw Fawr, an industrial river of southeast Wales, after pollution controls were installed at coal washeries and steelworks on the river. The installation of an effluent treatment plant reduced the concentration of toxic materials and increased the dissolved oxygen and pH. The treatment plant reached its full capacity after 3 years of operation and fish returned to the river within 6 months after full operation started. Brown trout (Salmo trutta) was the first species to return. Eel (Anguilla anguilla) was found within one year after the treatment plant's full operation. Flounder (Platicthys flesus), stoneloach (Noemacheilus barbatulus), and stickleback (Gasterosteus aculeatus) were found the next year and bullhead (Cottus gobio) returned 3 years after the plant was fully operational. The population of fishes increased steadily over the study period, but the minnow (Phoxinus phoxinus), a resident of other parts of the river, did not recolonize during the study. The recolonization of fish was influenced by water quality in the river and the order in which species returned was associated with differential tolerance of pollution. Because immigration was the main source of recolonization, the availability and mobility of the species also influenced the recovery time for individual species of fish (Turnpenny and Williams 1981).

3.1.4 Recovery of Lotic Ecosystems

Cairns and Dickson (1977) and Cairns (1990) developed an index to predict recovery in lotic ecosystems after a pollution event:

Recovery index = (a) (b) (c) (d) (e) (f)

Where:

a is the existence of nearby epicenters to provide organisms for reinvading the damaged system.

b is transportability or mobility of dissemules. The dissemules may be spores, eggs, larvae, flying adults that lay eggs, or other stages in the life history of an organism that permit it to move either voluntarily or involuntarily to a new area.

c is the condition of the habitat following pollution stress.

d is the presence and persistence of residual toxicants following pollution stress.

e is chemical-physical environmental quality following pollution stress.

f is the potential of management agencies or other organization to assist in remediation of the damaged area.

Each factor has a rating system from 1 to 3 with good conditions for recovery having a higher rating. If the recovery index is higher than 400, the chance of rapid recovery is excellent. When the recovery index is less than 55, chance of rapid recovery is poor. Recovery time for stream or river ecosystems is dependent upon: 1) the severity and duration of the stress, 2) the number and kinds of stresses, 3) residual effects on nonbiological units (e.g., substrate), 4) presence of epicenters for recolonizing organisms, 5) the innate vulnerability, 6) inertia, and 7) resiliency of the systems (Cairns and Dickson, 1977). This index provides a numerical estimate of the likelihood of recovery. However, it is difficult to precisely predict the outcome of recovery because the precise sequence of events affecting the recovery process may be unique events and the interactions among species generally do not follow deterministic models (Cairns 1990). Our inability to make accurate predictions reflects the fact that ecology is not yet a predictive science.

SUMMARY - RECOVERY FROM OTHER DISTURBANCES: Several types of disturbance other than overfishing have been discussed in sections 3.1.2 and 3.1.3. The most significant aspects of these studies are compiled in Table 3. Recovery times range from a few days for behavioral changes caused by weather disturbances to several years for disturbances that significantly alter habitat, such as channelization of streams or flood damage. In all cases the rates of recovery depend upon the availability of colonizing individuals to reoccupy the area following the disturbance.

3.2 RATE, DURATION, AND DEGREE OF RECOVERY OF SHELLFISH POPULATIONS FOLLOWING DISTURBANCE

3.2.1 Recovery from Overfishing

Alaskan King Crab: (Paralithodes camtcschatica) is a large crab, reaching a weight of 10 kg. It lives in water depths to about 200 m around the North Pacific from northern Japan to southeastern Alaska. It is a long-lived, around 15 years, animal that reaches sexual maturity after five years. Prior to 1947 the king crab fishery was virtually unknown, with no recorded production. Fishing for crabs started in the late 1940s in the western part of the Gulf of Alaska, principally out of Kodiak, and expanded exponentially (Fig. 19) as the stock was explored and markets developed. Production increased steadily until 1967, when the trend reversed and fell to about one-third of the peak by 1970. The large accumulated stock of older crabs had been decimated, and the slow growing crabs did not sustain the fishery, even though some restrictive fishing regulations were applied.

Later, the fishing area expanded westwards to new grounds near the Aleutian Islands and in the Bering Sea (Royce 1984). The catch gradually increased again to a new record in 1980, only to collapse even more rapidly to about one-fifth of the second peak by 1982 (Fig. 19). The production of king crab has failed to recover significantly from this devastating crash.

Figure 19 shows trends in total production of the Alaskan king crab but detailed information is available on the history of individual stocks for several areas. Figures 20 - 25 show the historical trends for the commercial catch, CPUE in number of crabs per pot lift, and the National Marine Fisheries Service (NMFS) survey estimates of the abundance of legal male crab (Otto 1989). There is generally a very strong correlation between these values.

Figure 20 shows the historical trends of red king crab from Bristol Bay. The production and CPUE gradually declined through 1970-1971. From 1972 through 1978 stock abundance and CPUE increased. It took about 8-10 years for the stock to recover from overfishing and natural causes, but it then crashed again to below 1970 levels within 2 years. Currently, the stock remains at low abundance and shows no definite sign of recovery.

The blue king crab of the Pribilof Islands declined steadily until about 1977 (Fig. 21). Between 1977 and 1980 a slight improvement in the stock was observed, but then all three indices - abundance of legal male king crab, the catch, and CPUE - declined through 1988.

The historical trends of blue king crab from St. Matthew Island, golden king crab in the western Aleutian Islands, tanner crab from eastern Bering Sea, and snow crab from eastern Bering sea are shown in Fig. 22 - 25, respectively. These data show different responses of individual stocks including continuous decline, steady state, and rapid and slow recoveries. Although none of these stocks is at an historically high value of abundance, the trends with time are quite different among the different stocks.

The number of crabs per pot or CPUE is an index of the stock population density. When the CPUE returns to precrash value, it is an indication that the stock has recovered. The time required for CPUE to return to the original value is the recovery time. Depending on the combined impact of overfishing and natural mortality rates, the recovery time may be rapid or very slow. Slow recovery of crab populations is partly due to the slow growth rate of crabs (Fig. 26 & 27), and partly due to the length frequency distribution of male and female king crab that put additional restrictions on reproduction and recovery of the stocks (Fig. 28 & 29).

Dungeness Crab: (Cancer magister): Dungeness crab has traditionally been fished commercially in California, Oregon, Washington and British Columbia. In recent years these stocks have declined while the Dungeness fishery of Alaska has increased. The biology and management of Dungeness crab relative to its recent decline was reviewed in the third Lowell Wake ield Fisheries Symposia Series (Alaska Sea Grant 1985). Excerpts from this symposium are given in the following:

In California, Dungeness crabs are commercially harvested from Morro Bay in the south to Crescent City in the north. Production of crab in northern California has been characterized by 6 or 7 years of good fishing followed by 4 years of poor fishing (Warner 1985). Until the early 1960s, San Francisco Bay produced significant quantities of crabs, but since then has experienced a major decline in abundance (Fig. 30). Comparison of the crab catch in San Francisco with the catch in northern California (Fig. 30 & 31) shows that the catch in Crescent City and Fort Bragg follows the general pattern for the west coast but production in San Francisco Bay has never recovered from the crash of late 1950s. This is likely due to factors other than fishing, since the production for the past 25 years has been about one-fourth of the precrash landings. Pollution in the bay is thought to be responsible for these persistent effects because pollution impacts the larvae and juveniles more severely than the adult crabs.

In Oregon, catch records date from 1889 when 6,000 pounds of crab were landed. Annual landings remained under one million pounds until 1933. Since 1937, annual catch has ranged from 3 to 18 million pounds. Obvious cycles began in 1963 with 7-10 year intervals (Fig. 32). State agencies have managed the crab harvest since 1947. Initially, the management policy was maximum sustained yield, but recently became optimum yield. Future management strategies will include effort control and fleet reduction.

In Washington, Oregon, British Columbia, and Alaska the cyclical patterns of dungeness crab catch is similar to Oregon. The overall catch for the West Coast and Alaska show the highs and lows occurring at 7-10 year periods for a period of 20 years (Fig. 33).

Dramatic fluctuations in commercial landings which reflect real fluctuations in crab abundance have occurred for Dungeness crabs throughout the Pacific Northwest for the past several decades. Proposed explanations for these fluctuations include: upwelling induced effects, ocean water temperature, predatory effects, cannibalism by older crabs, and sunspots (Fig. 34). Discussions on the causes of the crab population fluctuations are beyond the scope of this study. However, it is important to recognize that recovery will vary with the severity of the impact from an oil spill, chemical spill, or natural disaster on the crab population and on the phase of the cyclical fluctuation in abundance. If a spill or disaster occurs when the crab population is at its minimum, it may take much longer to recover from the impact than if it occurs when the population is at its maximum abundance.

Surf Clam (Spisula solidissima): Murawski and Serchuk (1989) divided the history of the surf clam fishery of the eastern United States into five relatively distinct phases: the early period (1870-1942), the developmental period (1943-1949), the expanding period (1950-1965), full development and overcapitalization period (1966-1976), and intensive management period (1977-present). Surveys of surf calm abundance began in 1965. Between 1965-1986 the abundance and age structure of surf clam were significantly different among the Mid-Atlantic assessment areas. The resource was relatively stable and the abundance of fishable surf clams was at moderate to low levels during 1965-1970. Only a small portion of clam biomass was produced in the southern Virginia-North Carolina region during this period. Following the discovery of a large concentration of a single year class of clams off the entrance to Chesapeake Bay, the landings in southern Virginia-North Carolina peaked in 1974.

After that, the abundance decreased rapidly. The entire fishable resource of surf clam in the Mid-Atlantic reached its lowest levels during 1976-1978. At the same time, fishing efforts were concentrated on the limited Delmarva resource. In 1976, a clear authority and mandate for conservation and management of fisheries resources in offshore waters was established. Because of strong year classes in the northern New Jersey (1976) and Delmarva (1977) subareas, total biomass of the Mid-Atlantic offshore surf clam recovered to levels observed during the mid-1960s.

Tinsman (1981) reported that clam reproductive success was quite variable during the past forty years but that long-term population cycles may be normal rather than induced by man's activity. The decrease of the commercial catch may reflect the declining population cycle. Predation, especially by crab, is the main factor that influences clam recruitment.

Scallop (Patinopecten yessoensis): The life span of scallop in Mutsu Bay, Japan is 10-12 year with an optimum temperature for growth between 10^{o} and 15^{o} (Aoyama 1989). In Mutsu Bay, scallop production formerly fluctuated greatly. High production depended on unusually high survival following a period of abnormally high fecundity. Peak production of more than 10,000 tons annually was typically maintained for 2-5 years and followed by extended periods with production as low as 200-300 tons (Fig. 35a). The cycle varied between 10 and 20 years before the mid-1960s. Since the development of seed collection in 1963-64, the production of scallop has dramatically increased with the highest production of 47,000 tons in 1974. Poor environmental conditions, overpopulation, disease and genetic defects caused production to decrease to 16,000 tons in 1977 (Fig. 35b) when the total number of scallop spat was limited to 700 million in order to control overpopulation. Aquaculture operations have both increased annual production and stabilized the fluctuating production cycles.

Queen Conch: Between 1904 and 1989 the queen conch fisheries in the Caribbean (Fig. 36) cycled between very high landings and virtual elimination of the resources (Berg and Olsen 1989). Extensive harvesting of pre-reproductive individuals produced a collapse of the fishery. The time between two peak landings was between 20-30 years.

California Abalone (Haliotis spp.): Annual landings of abalone exceeded 1,800 tons from 1951 to 1968 (Tegner 1989). Because of the reduction in the legal size of red (1959) and green (1969) abalone, landings of these species increased, while an increase in the minimum size of pink (1970) abalone decreased the landing of this species. Major trends in abalone landings in California include: (1) A south-ward shift of the major fishing grounds, (2) Episodic changes in species composition, and (3) A sharp decline in total landings beginning in 1969. Because of the complete exploitation of accumulated stocks, loss of some very productive area, environmental degradation and closure of some island sites, annual landings declined to less than 400 tons and have not recovered since 1974.

SUMMARY - RECOVERY FROM OVERFISHING: As we observed for finfish, natural populations of shellfish may undergo significant natural fluctuations in population abundance that are often exacerbated by overfishing. Recovery times for shellfish populations range from 3 to 30 years (Table 4). The short recovery times observed for surf clams resulted from the production of a particularly strong year class, all other populations required approximately 10 years to recover. It is significant that the natural fluctuations observed in scallop populations were reduced and total production was increased with aquaculture. It is also important to note that the temporal trends for individual stocks may be quite different than the catch record for the overall fishery.

The above recovery rates are appropriate to populations that have been overfished because fishing generally targets mature individuals. Mortalities caused by pollution, oil spills, and other agents will heavily impact the larvae and juveniles. Hence, recovery of the stocks may take much longer.

3.2.2 Recovery from Oil Spills

Although large spills from tankers and oil well blowouts are more spectacular, most of the oil in the oceans comes from river runoff, coastal refineries, deballasting of tankers, offshore exploration, and natural seepage. For this review no distinction was made between different sources and their associated effects. For completeness we discuss some aspects of the biogeochemistry of oil in marine ecosystems and the effects of petroleum products on fish and shellfish before we concentrate on the recovery of fish and shellfish populations. Although these topics have been considered previously as subjects for extensive reviews, they are considered here in terms of the recovery process. Ultimately recovery requires that the oil is removed from the system, detoxified or immobilized to be biologically unavailable.

Oil in Water and Sediment: Oil dispersion in water depends upon the specific characteristics of the oil as well as environmental conditions. In the Amoco Cadiz oil spill, the total oil content in the water column was estimated at 30,000 tons, 13.5% of the amount spilled. Oil concentrations in the water column ranged from 30 to 7,000 ppb following various oil spills (Ekofisk, Amoco Cadiz, Arrow, Argo

Merchant, Ixtox-1). This oil can be degraded or dispersed by dissolution, biodegradation, emulsification, evaporation, photochemical oxidation, agglomeration and settling to the bottom. In an enclosed marine mesocosm (CEPEX), Lee et al. (1978) found the concentration of lower weight aromatics (naphthalenes, anthracene, benzopyrene, benz(a)anthracene and fluoranthene) decreased exponentially in the water column due to evaporation, photochemical oxidation, microbial degradation and sedimentation. Similarly, sedimentation and photochemical oxidation decreased the concentrations of higher weight aromatics. According to Gundlach et al. (1983), concentration of oil in the offshore region decreased from initial values of 3 to 20 $ug\text{-}L^{-1}$ to background values (< 2 $ug\text{-}L^{-1}$) one month after the Amoco Cadiz oil spill. However, the water around the beach did not return to background values until 300 or 400 days after the beaches became visually clean (Blackman and Law 1981).

The transfer of oil to the sediments is a significant concern in most oil spills. Following the Ixtoc-1 blowout, nearly 120,000 metric tons of oil sank to the bottom (Jenelov and Linden 1981). The distribution of oil in the sediment varies with sediment type and depth. Because coarse-grained beaches respond more rapidly to changes in the incoming wave conditions, the depth and extent of oil burial increased with grain size. Following the Ixtoc-1 blowout, oil was buried 40 cm deep along the shell beaches of Texas, although it only reached a depth of 7 cm on the fine-grained sand beaches (Gundlach et al. 1981). The physical movement of sand as part of the natural erosional-depositional beach cycle, and downward migration of sediment by tidal action can change the distribution of oil in the sediment. For the Ixtoc-1 blowout, approximately 3,900 tons of oil washed onto exposed beaches of fine-grained sand and mixed sand and shell in south Texas. However, more than 90% of the beached oil was removed after a tropical storm (Gundlach et al. 1981).

The persistence of oil in the sediment depends on the oil characteristics, location of sediment, and microbial biodegradation. Oil at the surface of coarse sediments decreased by 82-88% after 100 days, compared to a 21% reduction in a mixture of oil and finer substrate (Anderson et al. 1978). The biodegradation rate was estimated to be 0.5 ug of oil per day per gram of sediment following the Amoco Cadiz oil spill (Gundlach et al. 1983). Because microbial hydrocarbon biodegradation is an oxygen dependent process, low concentrations of oxygen decrease the potential for biodegradation. Therefore, oil in the anaerobic zones will persist for a longer time.

Erosion, or self-cleaning half-life, defined as the time required for the hydrocarbon concentration to be reduced by 50% was estimated to be 2 years for n-alkanes in natural sediment, compared to 10 years for aromatics (Vandermeulen 1977). Asphalt reefs on sand and gravel beaches still existed two years after the Amoco Cadiz spill (Gundlach et al. 1981). After the Arrow spill, tar reefs persisted for 6 years in the intertidal region of Chedaducto Bay, Nova Scotia (Keizer et al. 1978). According to estimates of Gundlach et al. (1981), the residence time for the Metula oil spill in the Strait of Magellan in 1974 was 15-30 years in low energy sand and gravel beaches, and over 100 years for sheltered tidal flats and marshes (Teal and Howarth 1984).

Following sedimentation, chemical composition of oil may be altered due to differential degradation after the spill. In the Florida oil spill of No 2 fuel oil in Buzzards Bay Massachusetts, only a small amount of n-alkanes persisted after two years, but isoprenoids and alicyclic and aromatic hydrocarbon were retained in the polluted sediment (Blumer and Sass 1972). Similarly, the half-life of the n-C18/phytane ratio in the sediment of a marine microcosm (MERL) was estimated to be 58 days (Gearing et al. 1980).

The sedimentation of oil primarily affects the benthic fauna. Following the Amoco Cadiz spill, a sharp decrease in numbers of both individuals and species was observed in the seagrass community (Jacobs 1980). Similarly, a drastic decrease of the total Fucus biomass occurred along the shore that was first hit by the Tsesis oil spill. Notini (1980) found that faunal density within the algal zone was 8-10% of the prespill density two weeks after the spill. For hydrocarbon concentrations less than 50 ppm population densities sometimes declined with no apparent change in species composition. Between 100 and 1,000 ppm, species of small polychaetes, mostly Cirratulids and Spinonids, appeared. At concentrations above 10,000 ppm, only the opportunistic Cirratulids and Capitellids were present (Teal and Howarth 1984). Overall, higher concentrations of oil in the sediment were more detrimental to the benthic communities.

Recovery of macrofauna has been studied for oil spills (Jacobs 1980), refinery plant outfall abatement (Leppakoski and Kindstrom 1978), laboratory, and in situ experiments (Atlas et al. 1978; Vanderhorst et al. 1980; Oviatt et al. 1982; Kalke et al. 1981). The recovery of macrofauna varies with habitat, species, and season. For example, following the Amoco Cadiz spill, direct deposit feeders such as Maddamidae and capitellidae showed rapid recovery. However, the filter feeders responded more slowly and only recovered when the dissolved fraction of oil in the interstitial water declined (Jacobs 1980).

Bioaccumulation: Hydrocarbon levels in the tissues of animals are related to the concentration of hydrocarbons in the media that the animal contacts and the feeding strategy of the animal. Boehm et al. (1982) determined the difference in hydrocarbon concentrations between clams (Macoma balthica) and mussels (Mytilus edulis) following the Tsesis oil spill. These authors explained the difference in hydrocarbon uptake of the two species by their different feeding strategies. Mytilus is a sedentary suspension feeder that can accumulate hydrocarbons through water and particulates. Macoma is a detritovore that feeds primarily at the sediment-water interface. Hydrocarbon concentrations in Mytilus indicated a rapid depuration of fresh oil during the time immediately following the spill. After one year hydrocarbon concentration in tissue had generally returned to background levels. Macoma, however, accumulated hydrocarbons in the tissues after the initial exposure to the oil spill, apparently depurated during the winter, and then had a second accumulation. The second contact with the oil occurred due to a landfall followed by sinking of the shoreline, offshore transport of oil and redistribution of the petroleum residues. Blackman and Law (1981) observed that concentrations of hydrocarbons in Mytilus tissue returned to background levels of 10 ppm between 300-400 days after the impacted beach from the Eleni V spill was visually clean.

Roesijadi et al. (1978) compared the uptake of hydrocarbons from sediments contaminated with Prudhoe Bay crude oil by two deposit feeders (Macoma inquinata and Phascolcosoma agassizii) and one suspension feeder (Protothaca staminea). They observed that the naphthalenes in the oiled sediments were not readily accumulated, and that benzo(a)pyrene was quite persistent in the tissues. The compounds directly associated with particulate matter were less available for uptake than the fraction released to the surrounding water. Interstitial water was suspected to be the prime source for hydrocarbon uptake as opposed to the sediments.

Gilfillan and Vandermeulen (1978) analyzed soft shell clams (Mya arenaria) off Nova Scotia that were exposed to Bunker C oil from a spill six years earlier. Clam tissues were found to contain up to 200 ppm and the sediment contained up to 3,800 ppm. Neff et al. (1985) observed oysters impacted by the Amoco Cadiz oil spill over a 27 months period following the spill. They observed concentrations up to 200 ppm dry weight aliphatic hydrocarbons and up to 1,000 ppm aromatic hydrocarbons in oyster tissue and noted that depuration can be confounded by storm induced resuspension of sediments containing residues. Laseter et al. (1981) observed concentrations of hydrocarbons in cultured oysters (Crassostrea gigas and Ostrea edulis) from the area of the Amoco Cadiz spill that were 10-20 times higher than from reference areas up to 3 months after the spill. Four years after the spill hydrocarbon concentrations in oysters from impacted areas were still 10 times higher than for control areas. Contaminant concentrations were reported to decrease from 1978 to 1981 but to have stabilized by 1982.

Bioaccumulation of petroleum hydrocarbons in bivalves tends to be slow but constant, whereas uptake in shrimp, crabs, and other crustaceans appears to be very rapid and reaches maximum tissues concentrations within a few hours, (Anderson et al. 1980). Likewise, uptake of soluble petroleum hydrocarbons in fish is very rapid and reaches maximum blood concentration within an hour (Lee et al. 1978).

Effects on Behavior: Olla et al. (1983) observed shallower distribution and slower burrowing rates for juvenile hard clams (Mercenaria mercenaria) in oiled sediments. The concentration of oil in the sediments was not considered to be acutely toxic but the behavior effects could cause increased accessibility to predation. Pearson et al. (1981a) set up experiments to test for increased predation of littleneck clams (Protheca stamina) by dungeness crabs (Cancer magister) and observed higher predation for clams from oiled sediments than from clean sediments. This was caused by the shallower burrows and slower burrowing rates in the oiled sediments. The clams avoidance behavior might be considered an adaptive response to oil exposure, but avoidance may lead to increased predation (Olla et al. 1983). Decreased burrowing rates could also decrease the clam feeding rate (Linden 1975).

Dow (1978) investigated soft shell clams (Mya arenaria) in an area in Maine where oil migrated to a level below the sediment surface. The young clams on the surface grew well but as they grow larger they burrow deeper until they reach the oiled layer where high mortality was observed. Nearly all of the dead clams were faster growing and larger than those that had survived for a longer period of time. This long-term effect of oil contamination may lead to changes in the age distribution of clam populations.

Recovery: Vandermeulen (1977) investigated the self-cleaning processes and recovery of biota after the Arrow oil spill in Nova Scotia. Oil coverage decreased with time. Self cleaning occurred remarkably quickly during the first two years, although the rate of recovery was dependent upon environmental conditions within particular habitats. It was fast on high-energy beaches but slow on low-energy shores of lagoons and estuaries. Six years after the Arrow oil spill, clam (Mya arenaria) populations were still greatly reduced in numbers, had an altered age distribution, and showed a distinct break in the six-year age class. Biological recovery was closely linked to the self-cleaning pattern. In areas of rapid cleaning, recovery had a half-life of around four years, but in areas of slow cleaning, recovery was correspondingly slower with a half-life in decades. Recovery half-life was considered to be the time required for a population to reach one half of the abundance in non-oiled (control) areas and estimated to be 10 years for *Mya arenaria*, compared to 4 years for *Fucus* and 3 years for cordgrass *Spartina* (Vandermeulen 1977)

Gilfillan and Vandermeulen (1978) reported on the alterations of carbon flux on shell and tissue growth and on population structure and recruitment of soft-shell clams (*Mya arenaria*) from chronically oiled sediments 6 and 7 years after the Arrow spill in Nova Scotia. Because the oiled lagoon sediments contained up to 3,800 $ug\text{-}g^{-1}$ oil, clams contained up to 200 $ug\text{-}g^{-1}$ hydrocarbon in their tissues. The population structure of soft-shell clams in the oiled lagoon was different from that in an unoiled lagoon. Total numbers and the number of mature adult clams in the oiled lagoon were lower than in the unoiled lagoon. In the oiled lagoon, the population remained nearly 60% below normal population density 6 years after the spill. In addition, the population in the oiled lagoon had a slower growth rate, a 1-2 year lag in tissue growth, and a reduced carbon flux with a lower assimilation rate than in the unoiled population. The residue of oil in the sediments was the main factor affecting the growth of adult clams. The oiled populations remained under stress and the recovery potential of *M. arenaria* in the oiled sediments remained low even 6 years after the spill.

After the Amoco Cadiz spill the catch of edible crabs (*Cancer pagurus* and *Lithodes maia*) was lower in the Bay of Morlax and Bay of Lannion during the first year (Gundlach et al. 1983). The catches of crabs, lobsters (*Homarus vulgaris*) and rock lobsters (*Palinurus vulgaris*) returned to normal during the second year after the spill. But the low percentage of egg-carrying female lobsters during the first two years after the spill, reduced the recruitment of lobsters for 4-6 years after the spill.

Linden et al. (1979) described the impact of the Tsesis oil spill on the coastal ecosystem of the Baltic Sea. The population of bivalves (mainly *Mytilus edulis*) and crustaceans were drastically reduced along the shores of Toro and parts of Liso after the spill. However, the population recovered after 12 months. The immigration and subsequent reproduction of individuals from refuge areas were the main sources of recovery. The time of recovery was influenced by the distance to refuge areas, the toxicity of the spilled oil, the time of year, the degree of exposure of the affected areas and the methods used to clean up the oil (Linden et al. 1979).

Chan (1977) described the recruitment of marine life following the 1971 San Francisco oil spill. Between 4.2 to 7.5 million intertidal invertebrates were estimated to be smothered by the oil spill. Five years after the spill, the population densities of some marine species had significantly increased in intertidal zones at Sausalito and Duxbury Reef in the San Francisco Bay. Barnacles (Balanus glandula and Chthamalus dalli) and mussels (Mytilus californianus) showed a steady rise after the spill. Similarly, limpet (Collisella spp.) populations were threefold higher than pre-oil counts 5 years after the spill. Barnacles, limpets, mussels, periwinkles, starfish, turban snails, and shore crabs in the study areas reached steady population recruitment within five years after the spill. In addition to the effect of the oil spill, the population densities of barnacles, mobile crabs, snails, and starfish showed a marked cyclical variation caused by natural ecological forces such as large waves.

3.2.3 Recovery from Other Environmental Disturbances

Hypoxia: Garlo (1982) reported an increase in a surf clam population after an hypoxic disturbance off Little Egg Inlet, New Jersey. The hypoxic water conditions occurred intermittently from mid-July through late September 1976; dissolved oxygen concentrations ranged from 0.4 to 7.1 ppm during this period. The population increased 7-fold one year after the hypoxic conditions and the biomass increased by a factor of 1.4. Because of the high survival of clam and the reduction in the predatory species of echinoderms and crustaceans, the surf clam population recovered rapidly. However, the age structure was still significantly different one year after the disturbance.

Surface Clearing: Hewatt (1935) studied ecological succession in the mussle (Mytilus californianus) habitat in Monterey Bay, California. Initially, a square yard of rock surface was cleared off, scraped, and brushed with a steel brush until no living animals or plants was left. Mussels appeared 5 months after the area was cleared off but recovery on the rock surface by the mussels and their associated fauna was not complete after two and one-half years. Ecological succession in the Mytilus habitat progressed in the following manner: (1) A clean area first becomes covered with a film of algae; (2) Those species which feed on this algal growth, such as limpets, are the first animals to appear in the area; (3) During their respective spawning seasons the mussels, goose barnacles and rock barnacles attach themselves to the cleaned surface; (4) These sessile forms gradually come to occupy the greater part of the surface and make the habitat unfavorable for the larger specimens of limpets; (5) The limpets then move to a higher zone in which the mussels and barnacles cannot exist.

Castenholz (1966) described the recovery of M. californianus on the Oregon coast after a major disturbance. A vertical strip over a meter wide on a cliff was cleared in the summer 1960 and 1961, but recovery by Mytilus was not yet complete by 1966.

Earthquake: The Alaska earthquake of 1964 changed the land elevation and altered the intertidal zone of Prince William Sound (Baxter 1971). The habitat of Mytilus edulis was uplifted and destroyed after the earthquake. However, young-of-the-year M. edulis were found in all suitable areas one year after the earthquake. Baxter (1971) predicted that M. edulis population should return quickly to pre-earthquake levels. A decrease in molluskan predators after the earthquake was a major reason for the rapid recovery of M. edulis.

SUMMARY - RECOVERY FROM OTHER DISTURBANCES: Table 5 summarizes the response of shellfish populations to a variety of disturbances including several oilspills. The recovery periods are typically faster than those that were observed following overfishing (Table 4). However, recovery from overfishing is correlated with natural fluctuations in population abundance. Recovery from other disturbances is primarily associated with the availability of juvenile, or adult, stages for recruitment. The time to recovery also depends upon the particular parameter that is chosen to indicate recovery. Typically some individuals representing the most affected species reappear within 1 year but the stable age distribution of comparable assemblages of species may require 5 or more years. Recovery of population abundance tends to take longer for shellfish than for finfish because the individuals are less mobile. Therefore, they cannot avoid the disturbance as easily and recruitment only occurs for juveniles, rather than mature individuals.

3.2.4 Recovery of Seagrass and Salt Marsh Ecosystems

Salt-marsh vegetation that was partially destroyed by the Amoco Cadiz oil spill was significantly restored by natural processes by 1980 (Levasseur and Jory 1982). In situ regeneration of perennial individuals and germination of seeds produced near or on the site accounted for most of the recovery.

Lee et al. (1981) reported that addition of heavy oil to Spartina salt marsh resulted in high concentration of polycyclic aromatic hydrocarbons in sediment and benthic animals. However, the concentration rapidly decreased during a 20 week period following the spill. The times for certain hydrocarbons to decrease to 50% of their highest value were approximately 100, 70, and 30 days in sediment, mussels, and oysters respectively. Benthic macrofauna species showed varying responses to oil addition. Fiddler crabs, oysters, and mussels showed no changes. Mud snails increased in density due to migration of adult snails from untreated areas to scavenge on animals killed by the oil. Many of the adult periwinkles (Littorina irrorata) were killed by oil. However, in the spring juvenile periwinkles recolonized the oiled areas as a result of larval settling.

Marsh surface sediments, cores, and organisms were analyzed for hydrocarbons from one to seven years after the 1969 No. 2 fuel oil spill at West Falmouth, Massachusetts (Burns and Teal 1979). All organisms showed oil contamination initially. Fundulus were nearly free of oil after one year but Uca remained heavily contaminated for at least four years. The authors reported that alkanes disappeared in sediments after about four years while heavy aromatics and naphthalenes persisted throughout the study.

The impact of Esso Bayway oil spill on macrofauna of a brackish-freshwater marsh was investigated by Neff et al. (1981) for nine months. They reported that the macrocrustacean and fish populations were very similar at both oiled and reference stations. Also, post larval penaeid shrimp were equally abundant at oiled and reference stations. Webb et al. (1981) observed the effects of a No.6 fuel oil spill on a coastal marsh near Galveston, Texas. They reported complete regrowth of the plants that were removed as part of the cleanup. They also noticed that the oil killed the aboveground portion of a plant only when oil covered most of the plant. They added that the plants, regardless of the extent of oil coverage, produced new growth in the following spring. Peckol et al.(1990) investigated the effects of the World Prodigy oil spill on kelp response along the Rhode Island coast and found no evidence of adverse effects on growth rates.

Bodin and Le Moal (1982) discussed the short-term effects of the dispersant, Finasol OSR-5, on meiofauna and macrofauna. The dispersant was used for cleaning a beach polluted by an oil spill and the variations of meio- and macrofauna were observed during one month. The authors reported significant reductions of densities after the cleaning. Bodin and Boucher (1981, 1982) investigated the recovery of meiobenthos and microphytobenthos on beaches touched by the Amoco Cadiz oil spill. They found a changed seasonal cycle of meiofauna and an imbalance of harpacticoid copepods. They reported that recovery on exposed beaches was nearly complete. The authors concluded that temporal variations of meiofaunal density and quantity of chlorophyll pigments are more sensitive to ecological factors than to oil pollution. Hartog and Jacobs (1980) evaluated the effects of the Amoco Cadiz oil spill on mobile benthic fauna of an eelgrass community at Roscoff. They reported that the spill had a profound but selective effect on various animal groups. Some groups disappeared while others were apparently unaffected. The very diverse amphipod fauna disappeared and was replaced by a population of Pherusa fucicola. While rapid recovery of some species had taken place, this was not observed for filter feeders. A four year survey of the microphytobenthos (cell number and chlorophyll content) of a mud flat polluted by Amoco Cadiz spill was conducted by Riaux-Gobin (1985) who reported a noticeable peak of microphyte biomass 7 months after the spill. He concluded that the spill affected the long-term trend of the biocenosis.

Fleeger and Chandler (1983) reported that meiofauna were highly tolerant of hydrocarbon stress and no mortality could be identified in any taxon following an experimental oil spill in a Louisiana salt marsh. Densities of some taxa (nematodes and copepods) responded positively to oil application. Hampson and Moul (1978) assessed the immediate effects of the Bouchard oil spill on marine invertebrates and three year growth and recovery of a salt marsh after the spill. They reported an extreme reduction in the number of individuals and species in the impacted area.

Seagrass Ecosystem: The effects of oil on seagrass ecosystems were reviewed by Zieman et al. (1984). That review is condensed in the following paragraphs.

Seagrasses require high light levels for photosynthesis and sediments for both attachment and nutrition. Hence, they are restricted to a narrow band of shallow coastal waters. Seagrass meadows stabilize sediments and provide habitat for filter feeding invertebrates, fish, and a number of other species. It has been reported that up to 20 cm of sediment erode from unvegetated sand banks following a single storm in Chesapeake Bay. Observations indicate that near the edge of eelgrass meadows there is a decreasing density of plants and an increasing amount of sediment removed by currents and a positive correlation between sediment stability and invertebrate infaunal diversity (Orth 1977).

Petroleum products can cause direct mortality due to fouling, asphyxiation or poisoning or indirect damage (death of food sources, destruction of habitat and sensitive juvenile forms, etc.) to seagrass ecosystems. The most serious oil spill damage has been observed on seagrass beds that are intertidal or marginally subtidal. During the Santa Barbara oil spills, Phyllaspadix growing in the intertidal zone was severely damaged while subtidal plants, and some extremely low intertidal, were undamaged because they did not come in direct contact with the oil. Similar effects were observed on the Washington State coast in 1972 following the wreck of a military troop transport (Clark et al. 1973, 1975). Following the Amoco Cadiz oil spill, Hartog and Jacobs (1980) observed that Zostera marina in a station that was only 0.5 m lower than other stations was almost unaffected. Following the spill, these authors noted a variety of changes in the abundance and structure of the associated fauna. For example, gastropods were an abundant and diverse fauna that were not significantly affected by oiling. In contrast, the diverse and ecologically important amphipods were devastated. Observation of an oil spill off the Florida Keys showed no direct damage to Thalassia beds, but mass mortalities of pearl oyster, a grass bed inhabitant (Chan 1977).

Based on the study of past oil spills, it seems seagrass beds have suffered relatively little damage, and the primary impact has been on the associated faunal communities. In part, this may be due to the submerged nature of the system, although seagrass beds that have been exposed to oil at low tide also have not suffered greatly. Since seagrass beds have the bulk of their biomass (50-85%) in the sediments they are capable of rapid regeneration but are extremely susceptible to disturbance of the sediments.

When the sediments and seagrass rhizomes are not severely disturbed, the probability of recovery is greatly increased. Restoration of seagrass beds by transplantation of anchored and unanchored shoot, plug, and seed has been described by Phillips (1980). While the seagrass beds may recover rapidly either naturally or by transplantation, the associated fauna may not recover as quickly. Similarly, monitoring the recovery of seagrass beds can be achieved easily by measuring the biomass, but monitoring faunal recovery requires long term sampling and observation of the faunal density and composition.

Salt Marshes: The followings sections are condensed from a review by Getter et al. (1984) on the recovery and restoration of salt marshes and mangroves following an oil spill.

Salt marshes are a part of marine wetlands that are largely temperate in distribution and occur up to the limit of tidal influence. Oil spilled on salt marsh plants can lead to a reduction in photosynthesis, respiration, or transpiration, while absorption of toxic components through the leaves or roots can cause poisoning of the plants. There is considerable variation in the sensitivity of plants to oil components. It seems that perennials with large root systems are more resistant to oil than other species (Baker 1971). In addition, seasonal changes in salt marsh populations may considerably alter the extent of oil damage. In some cases, a major problem following oil damage to vegetation has been loss of sediment stability followed by erosion. Where extensive rhizomatous root mats exist or vegetation cover is continuous recovery may be rapid, even when vegetation has been killed. Salt marshes generally support large populations of invertebrates and waterfowl that are more susceptible to oil spills than the plant community.

The recovery of salt marshes from the effects of oil spills in terms of structural changes such as distribution and density of biomass, characteristics of sediments, and other factors can be followed more easily than functional responses such as interaction among species, productivity, and the role of the salt marsh in the wider context of the coastal ecosystem. According to Getter et al. (1984) the key factors in recovery of salt marsh are: (1) Reduction in toxicity, retention, or availability of oil to plants and animals, (2) Availability of propagules, (3) Stability of sediments, and (4) Biotic interactions which depend on oil tolerance of many species and other environmental factors.

Creating and restoring salt marshes has been reported for several coastal areas (eg. Dicks and Iball 1981). The recovery of plants can be achieved by seeding, transplanting greenhouse-grown seedlings, fertilization and other techniques. The recovery can be monitored by measuring biomass, species diversity, and other conventional techniques.

3.3 ABIOTIC AND BIOTIC FACTORS AFFECTING THE RECOVERY RATE

Platt (1977) considered the factors that affect recovery of stream ecosystems to include: 1) The existence of nearby epicenters of reinvading organisms, 2) Appropriate conditions for transport of dissemules, 3) Habitat for invading species following the stress, 4) Concentrations of residual toxicants, 5) Chemical-physical water quality, 6) The number of indigenous organisms that are resistant to the stress, 7) The extent of structural and functional similarity between invading and displaced species, 8) Flushing capacity, 9) The distance from other ecological stresses, and 10) Management capabilities for control and recovery of damaged systems. These factors are also important for the recovery of fish and shellfish populations following a disturbance. In essence recovery requires a suitable habitat and potential invading organisms to occupy that habitat. Numerous examples presented above indicate that the availability of reinvading individuals is the most important factor affecting recovery time.

Following oilspills, suitable habitat requires that the oil be removed or detoxified. For fish species in the water column, detoxification and removal begins immediately as oil is volatilized, mixed in the water column and dispersed. The most important factors affecting the loss of oil are temperature, exposure to sunlight and turbulence in the upper water column. For shellfish, especially immobile bivalves, the extent of clean up in the habitat may be significantly more important than for finfish. The principal factor affecting the clean up rate appears to be the exposure to wave action with oil dissipating from high energy environments much faster than from low energy environments.

Fluctuations in fish populations are strongly correlated with fluctuations in climate and physical oceanographic processes including El Nino, seawater temperature, and the distribution of upwelling and currents. For example, variation of Peruvian sardine populations is related to the El Nino phenomena (Csirke 1988). Japanese sardine populations recovered after a shift in the position of the Kuroshio current (Kondo 1980). An increase in the populations of pollock and Greenland herring was related to an increase of seawater temperature (Bulatov 1989; Jones 1982). Davydov (1989) and Bulatov (1989) suggest that the fluctuations of fish population may be related to variations in the extent of solar activity. Therefore, natural processes may develop cycles of 40-60 years (Davydov 1989). If disturbances are superimposed on those natural cycles, the rate of recovery will depend upon the particular point in the cycle when the disturbance occurred.

An important factor for the recovery of fish populations is the development of one or more strong year classes. For example, Japanese sardine recovered after the strong 1972 year class (Kondo 1980) and Canadian west coast herring recovered after a strong 1973 year class (Hourston 1980). Because strong year classes also depend on random fluctuations in climate and weather (Cushing 1982) it is difficult to predict when they will occur.

3.4 DEPENDENCY OF RECOVERY ON HABITAT PROTECTION, CHANGES IN MANAGEMENT PRACTICES, AND OTHER RESTORATION APPROACHES

In order to estimate recovery times it is important to define recovery. Cairns et al (1977) provided three definitions of recovery: (1) Restoration to usefulness as perceived and defined by the general public, (2) Restoration to original functional and structural conditions although the species present may be significantly different than those present originally, and (3) Restoration to the original functional and structural condition with original species. When an ecosystem has been degraded, either deliberately or accidentally, restoration to the original condition may not be possible. Because ecosystems change through time and specific patterns are unlikely to be repeated, the system generally would not persist in the pre-disturbance conditions even without the disturbance. Furthermore, we generally have insufficient information about previous conditions to determine when such a recovery has occurred. In addition, if some species are lost due to the disturbance, the cost of restoration may be prohibitive. Sometimes the basic ecological knowledge about the system is insufficient or the physiochemical environment and biological habitat may have changed to such a degree that restoration to the "original" state is not practical and restoration options may be restricted to some alternative condition. Therefore, recovery must be defined as the ecosystem reaching new equilibrium conditions rather than returning to pre-disturbance conditions (Cairns 1990). Determining the type of recovery that is desired is an important management decision that will determine when recovery has occurred.

The principal management practice for restoring fish populations has been to restrict or close fishing seasons. We provide several examples of finfish and shellfish populations recovering when fishing pressure was reduced. However, there are other examples in which reduced fishing pressure did not restore the population. In most cases the recovery of marine fish populations appears to be associated with environmental conditions rather than management practices. Enhancement of fish and shellfish populations by the use of aquaculture methods also has a long history. Generally this includes spawning under controlled conditions and rearing the juveniles in protected environments (eg. hatcheries) until they are released into the natural environment. Enhancement has been most productive in freshwater lakes and streams, and much less valuable in marine systems. Although salmon hatcheries have been established in many countries for long periods of time, it is difficult to show that they have significantly improved population abundance (Hilborn 1992).

4.0 EXTRAPOLATION TO INJURED ALASKAN ECOSYSTEM

4.1 IDENTIFICATION OF MOST PRACTICAL AND COST EFFECTIVE INDICATORS OF RECOVERY TO MEASURE

Indicator Species: Generally, indicator species refers to organisms that can best represent the impact, recovery, and health of an ecosystem. The most important indicator species from the stand point of fisheries are those that are widely exploited as fisheries resources. For finfish, these include salmon, Dolly Varden, cutthroat trout, herring, and bottom fish. Mature salmon and herring are integrators of large scale pelagic processes while the juveniles may be affected by disturbance in local habitats. Similarly, cutthroat trout and Dolly Varden are representatives of coastal waters, whereas, bottom fish are indicators of benthic community.

Bivalves are also useful as sensitive bioindicators of persistent oil contamination. Shellfish can contact hydrocarbons associated with the sediments years after an area appears to be free of oil. Boehm et al. (1982) showed that Macoma exhibits two stages of contamination; an initial exposure from a spill and a later exposure from the sedimented oils. Concentrations of hydrocarbons in the organism are also persistent in bivalves and may be a sensitive indicator of petroleum contamination (Roesijadi et al. 1978). By selecting clams and mussels it is possible to determine if only those species in the sediment are being affected or if the oil is still being released into the water column.

Management Recommendations: We do not recommend any attempts to enhance the recovery of finfish and shellfish populations in Prince Williams Sound. The most important commercial fisheries, pink salmon and herring have had record returns since the spill. Since a fishery is considered to have recovered from the impact of a disturbance when the catch per unit effort reaches the predisturbance level, these species have recovered already, if they were ever impacted. Thus, on practical grounds attempts to restore these resources are unnecessary.

Specific intervention to restore the ecosystem or particular species within an ecosystem is similarly unjustified from a theoretical perspective. According to Cairns (1990), "the field of ecology has not yet matured as a rigorous predictive science; and the precise sequence of events, including climatic occurrences, affecting the recovery process may be unique events and thus rarely or never repeated". Hence, it is not possible to predict when and how the recovery will occur and what biotic and abiotic factors are the most important parameters for recovery. Furthermore, review of available literature on the impact of disturbances on populations and communities indicates that in most cases the "recovery" occurs naturally and efficiently without intervention.

It may be important, however, to monitor the rate of the recovery using indicator species and the selected indices for each species. For finfish the data used to evaluate recovery should be the fishery statistics collected by management agencies but for shellfish populations additional survey and monitoring programs may be required.

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Table 2. Recovery of finfish stocks from overfishing. The time interval between succcessive maxima is considered the recovery period

Fish species	Regions	Recovery Period (years)	Remarks
Cod & Haddock	North Sea	4 - 5	Recovery resulted from reduced fishing pressure
Plaice	North Sea Alaska	4 - 5 7	Recovery resulted from reduced fishing pressure Incidental catch in yellowfin sole fisheries
Pacific Bonito	Pacific	>25	Still no recovery
Canadian Pacific Herring	Canada's west Coast	6	Strong year classes
South American Sardine	Pacific	>20	
Peruvian Anchovy	Pacific	6-12	Large natural fluctuations in abundance
South African Sardine	Atlantic	>20	Still no recovery
Japanese Sardine	Pacific	50	Response to change in current patterns
Pacific Halibut	North Pacific	28	Severe fishing restrictions
California Sardine	Pacific	>50	Still no recovery
Yellowfin Sole	Alaska	25	Tentative

Table 3. Recovery of finfish from disturbances other than overfishing.

Disturbance	Location	Species	Impact	Recovery Studied	Recovery Time	Remarks
Hurricane Allen	Jamaican coral reefs		Detroy habitat, Fish kill			
		Damselfishes & other fish	Increased density, Changed territory and home behavior	Schooling behavior Territory behavior	3 wks 2 - 9 days	Cryptic fishes were more often seen after the storm
		Threespot damselfish	Relocated to deeper water	Species composition and behavior	>1 year	High- and low-relief patches were still different after 1 year
Typhoon 20	Igaya Bay, Japan	Wrasse	Did not relocate, Female changed social groups			
		Damselfish	Changed territory behavior			
Storm	Hawaii	Damselfish	Changed abundance, Hawfish moved to deeper water	Full recovery	16 month	Recolonization within weeks
Cyclone	Great Barry	Damselfish	Changed structure and population size			
Cold Spell	Florida		Fewer species Reduced abundance	Species and number	1 year	Biomass was not affected

Table 3. Recovery of finfish from disturbances other than overfishing (continued).

Disturbance	Location	Species	Impact	Recovery Studied	Recovery Time	Remarks
Oil Spill Exxon Valdez	Alaska	Pink salmon Herring	No impact Lower spawn miles in 1989 & 1990			Record high catch in 1990 Spawn miles still within average
Oil Spill Amoco Cadiz	France	Wrasse, sand pipe fishes, eels	Immediate mortality			
		Plaice, sole, mullet	Increased fin rot, Decreased abundance		3 years	Estimated recovery time 5 -10 years for clam, 30 years for fish
Channeliz-ation	Camowen River, North Ireland	Salmonids	Reduced density, Changed fish structure	Recovery	4 years 6 years	Upstream section Downstream section Dredging intensity and extent, consolidation of substrate, and Immigration were the main factors 1+ and older recovered rapidly
	Big Beef Creek Washington	Salmonids Steelhead trout	Fewer juveniles Fewer juveniles	Density Recovery	5 years >5 years	Not fully recovered after 5 years, Related to habitat preference

Table 3. Recovery of finfish from disturbances other than overfishing (continued).

Disturbance	Location	Species	Impact	Recovery Studied	Recovery Time	Remarks
Pesticide Damage	Sixteenmile Creek, Montana	Rainbow trout Brown trout	Reduced abundance Reduced abundance	Fully recovered Fully recovered	2-year 3 years	Immigration and reproductive success were the main factors affecting recovery
	Mud Creek, Arkansas		29 species was eliminated Bigeye shiners	Return	5 days	Immigration is the main factor
				Fully recovery	one year	
	Musselshell, Montana	Brook trout		Repopulation	21 days	Fry displaced from upstream
				Completely recovery	1 year	
Debris Flow	Quartz Creek, Oregon	Cutthroat trout	Damaged local population	Density recovery	2 years	Size and time of disturbance, and immigration of 1+ trout are the main factor.
Flood Damage	Valley Creek, Montana	Brook trout	Density reduced	Density recovery Population size and age structure	3 years 4-5 years	Immigration Strong year class

Table 4. Recovery of shellfish stocks from overfishing. The time interval between successive maxima is considered the recovery period.

	Regions	Recovery Period (years)	Remarks
King Crab Red King Crab	Eastern Bering Sea	8 - 10	Variation caused by fishing & natural mortalities
Blue King Crab	Eastern Bering Sea	8 - 10	Slow recovery time related to slow growth rate, and low male & female mating frequency
Dungeness Crab	Oregon	7 - 10	Recovery time depends upon fluctuation of crab abundance, low ocean water temperature, upwelling induced effects, and predatory effects
	Washington		
	British Columbia		
	Alaska	7 - 10	
Scallop	Mutsu Bay Japan	10 - 30	The stock population after 1964 was changed by culture
Queen Conch	Caribbean	20 - 30	
Surf Clam	Mid-Atlantic	3	Fishing restriction for 3 years, 1978 returned to the 1960's levels

Table 5. Recovery of shellfish from disturbances other than overfishing.

Disturbance	Location	Species	Impact	Recovery Studied	Recovery Time	Remarks
Hypoxic water	Little Egg Inlet NJ	Surf clam	Population decreased	Abundance	1 year	Much reduced predation
Oil spill Arrow	Nova Scotia	*Mya arenaria*	Changed population structure Reduced number Delayed shell growth Reduced carbon flux Loss of year class	Half-life*	>6 years	Recovery potential in oiled sediment still low after 6 yrs
Oil spill San Francisco	San Francisco Bay	Mussels		Steady recruitment	5 years	
Oil spill Amoco Cadiz	Morlax & Lannion Bay France	Crabs, lobsters rock lobster		Catch	2 years	Returned to normal in second year, reduced lobster recruitment during 4-6 years after spill
Oil spill Tsesis	Baltic Sea	Bivalves, crustaceans	Reduced population	Abundance	<12 months	Immigration and subsequent reproduction were the main source
Cleared surface	Monterey Bay, CA	*Mytilus californianus*		Return	5 months	
				Complete rehabilitation	>2.5 years	
	Oregon	*Mytilus californianus*		Complete recovery	> 5 years	
Land uplift	Alaska	*Mytilus sp.*		Return	1 year	Young-of-the-year were found in suitable areas

*: A recovery half-life is the time required for a population to reach one half of the abundance in a non-oiled control area.

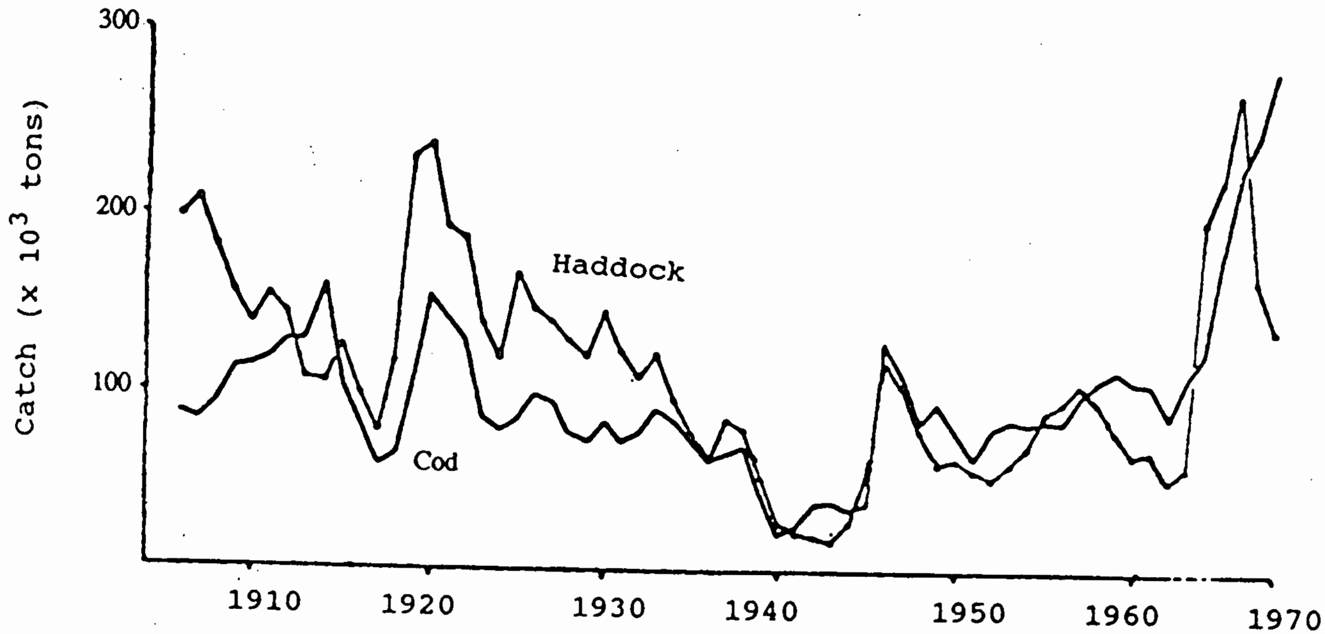

Figure 1. Total international catches of cod and haddock from the North Sea, 1906-69. Note drop in catches during the two Wars, and absence of any long trend.

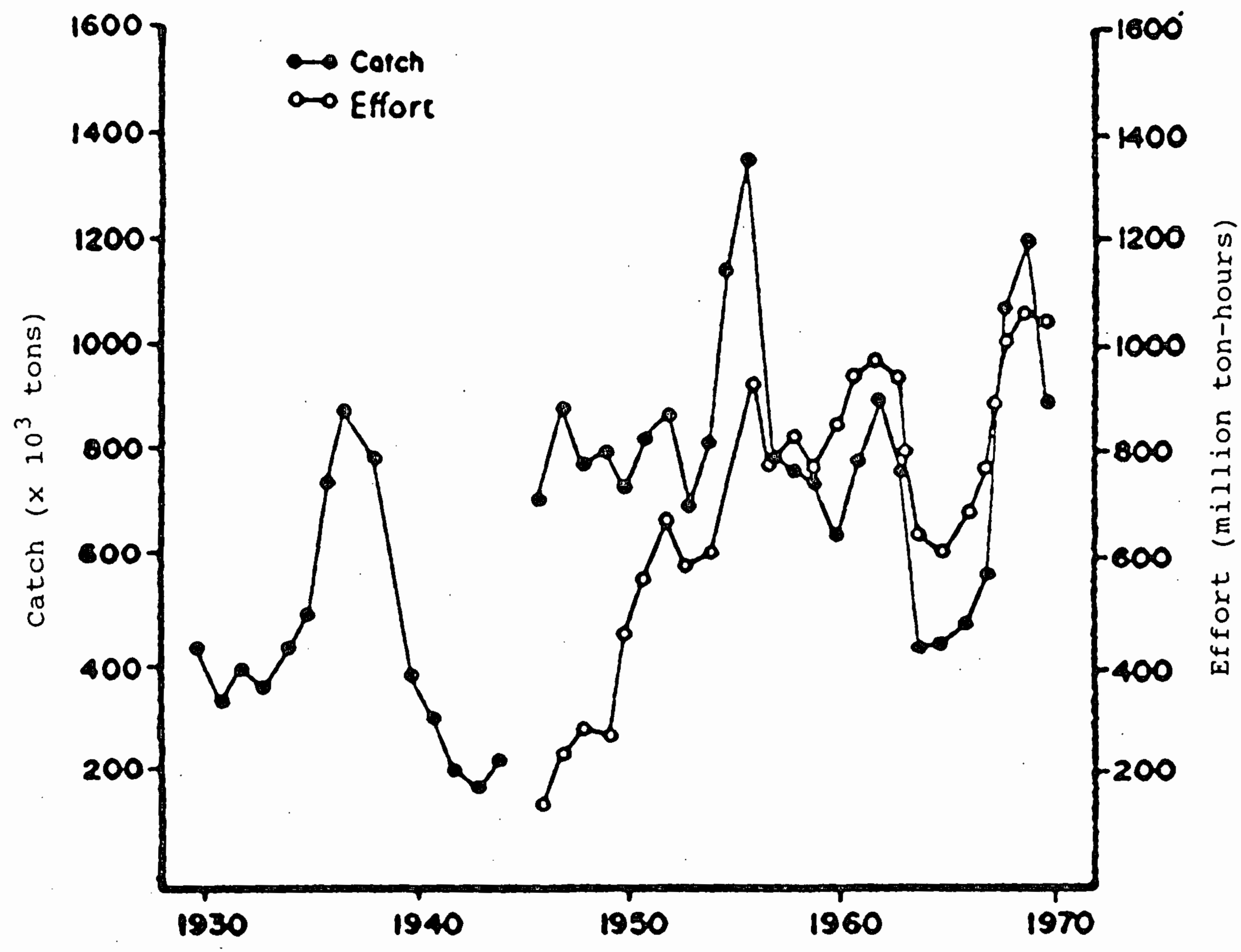

Figure 2. Trends in catches (full circles) and fishing effort (open circles) of cod in the north-east Arctic. Note little change in catch from 1947 onwards, despite increasing effort. (Data from I.C.E.S. reports)

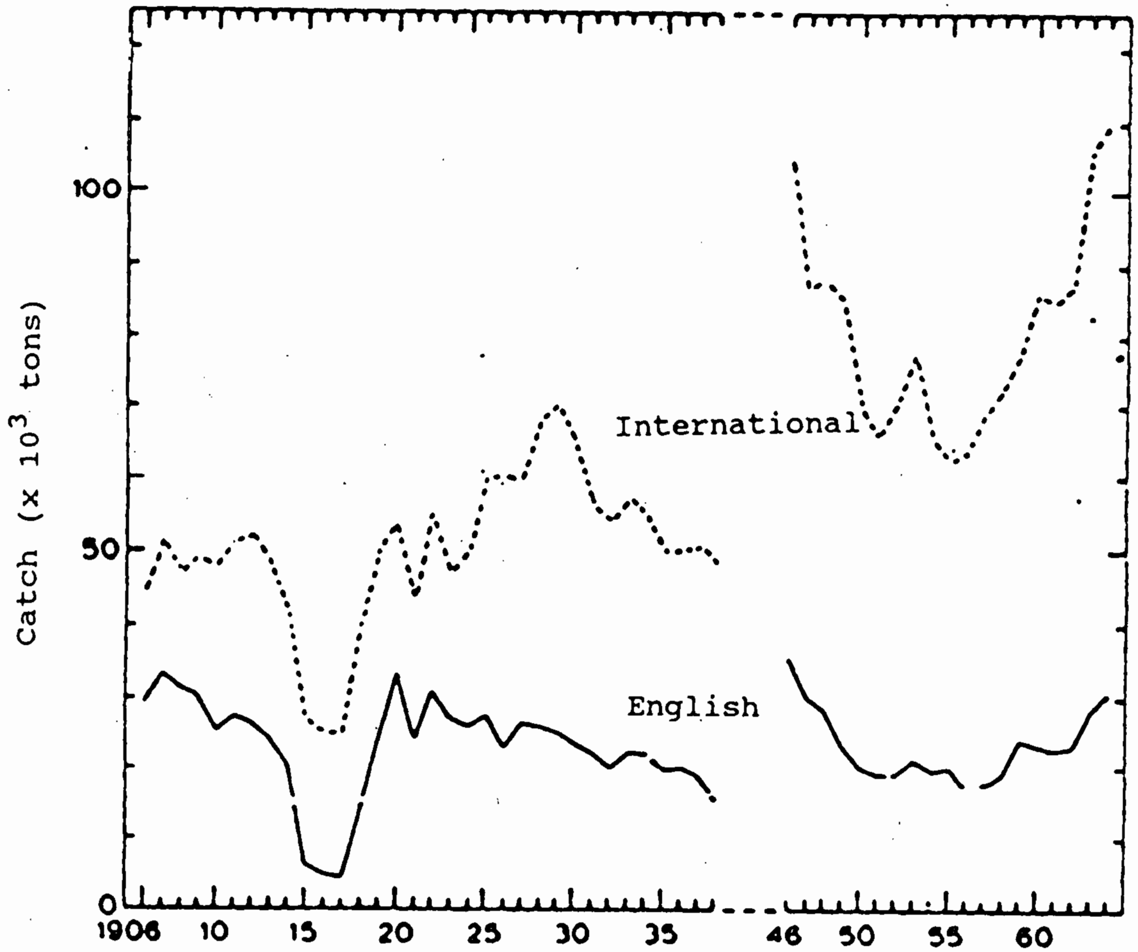

Figure 3A. Annual landings of North Sea plaice, 1906-64.

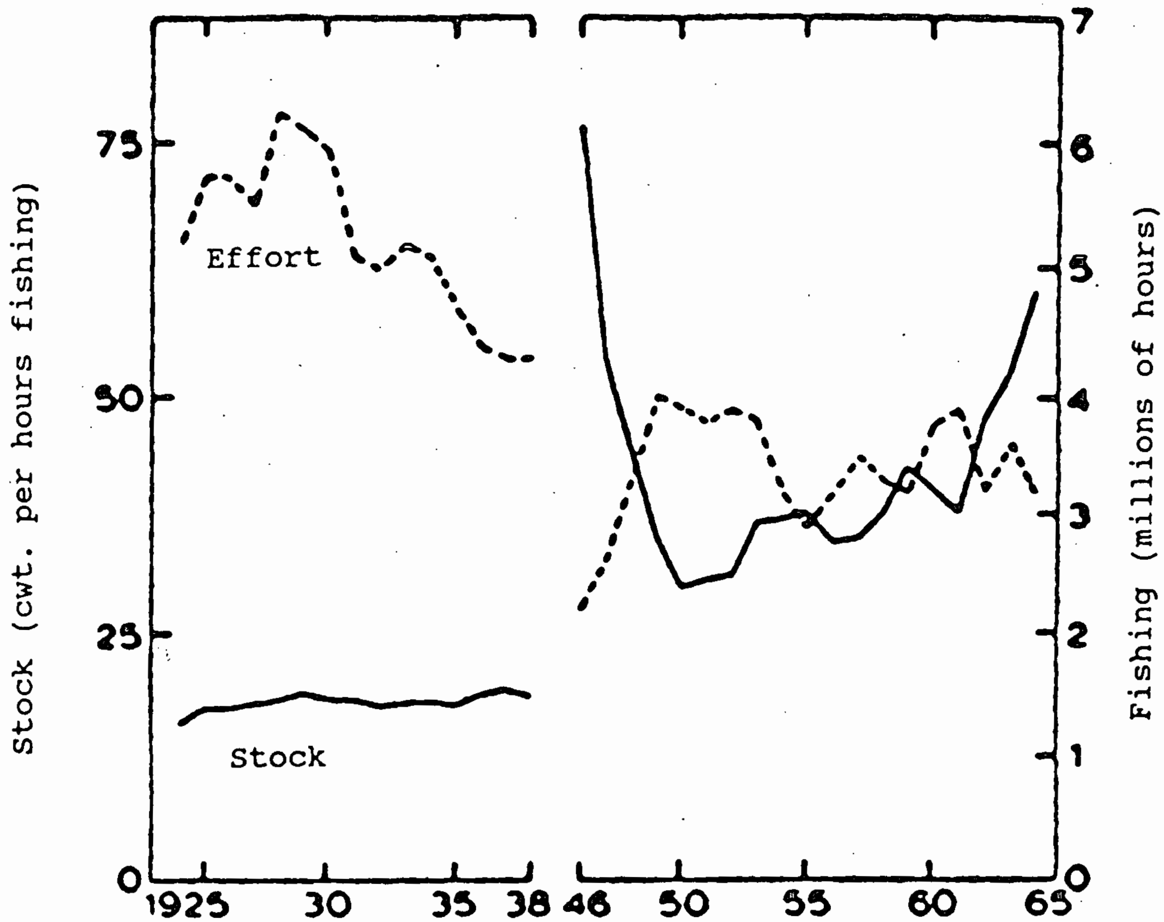

Figure 3B. Corresponding fishing effort (broken line) and estimated stock abundance (catch per 100 hours fishing) of North Sea plaice by English trawlers. (From Gulland 1968)

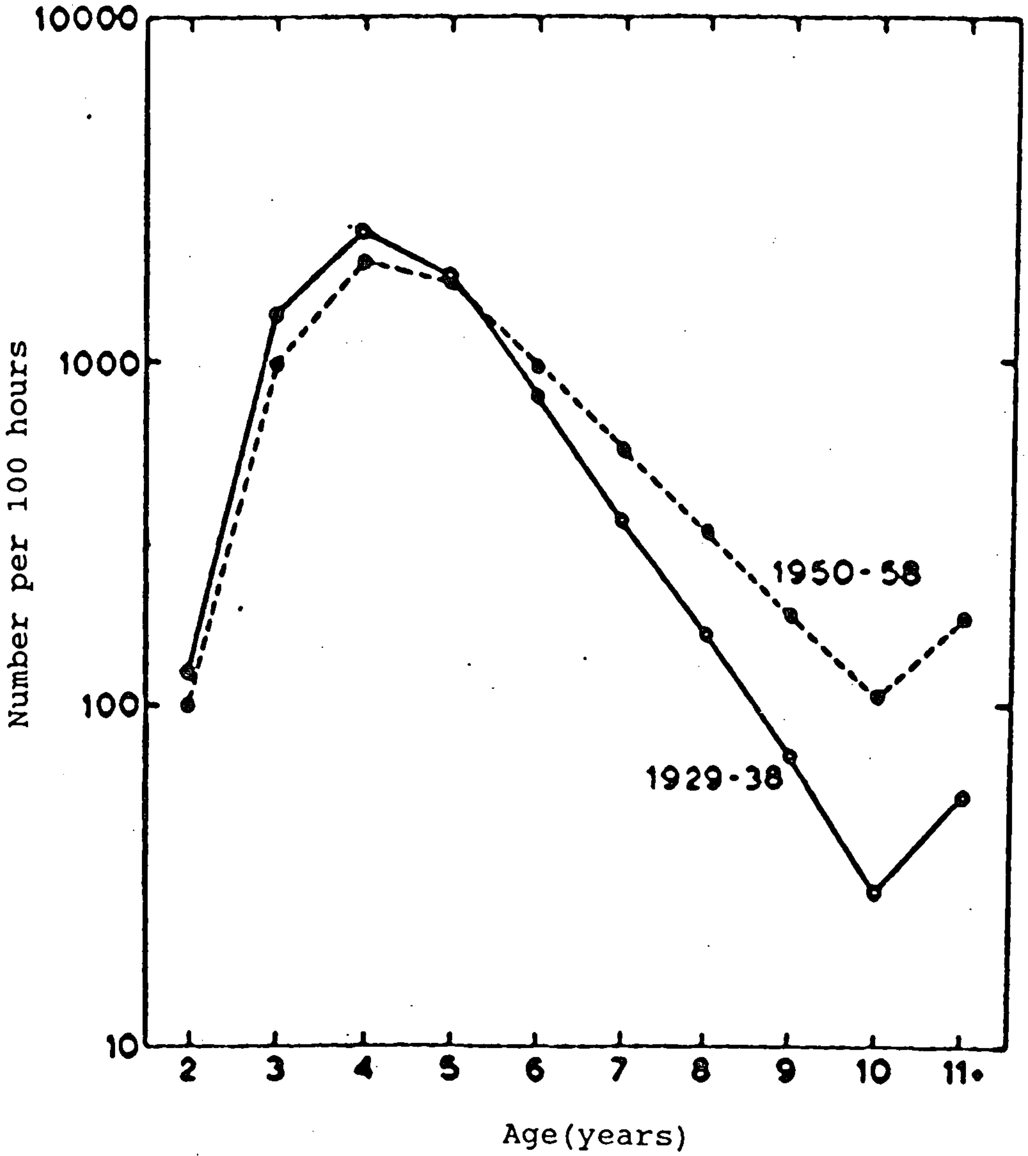

Figure 4. Numbers of plaice of successive ages caught in 100 hours fishing by English trawlers (logarithmic scale) to show better survival in post-war years. (From Gulland 1968)

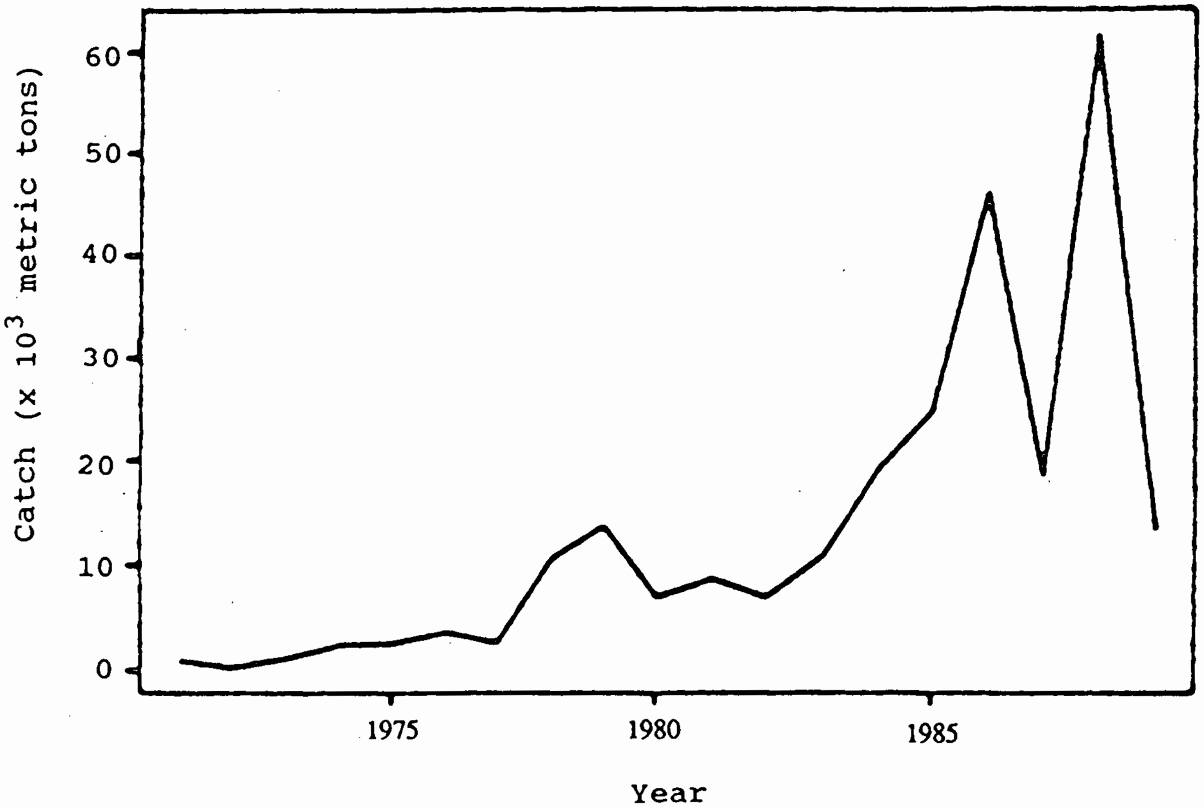

Figure 5A. Annual catch of Alaska plaice in the eastern Bering Sea, 1971-89.

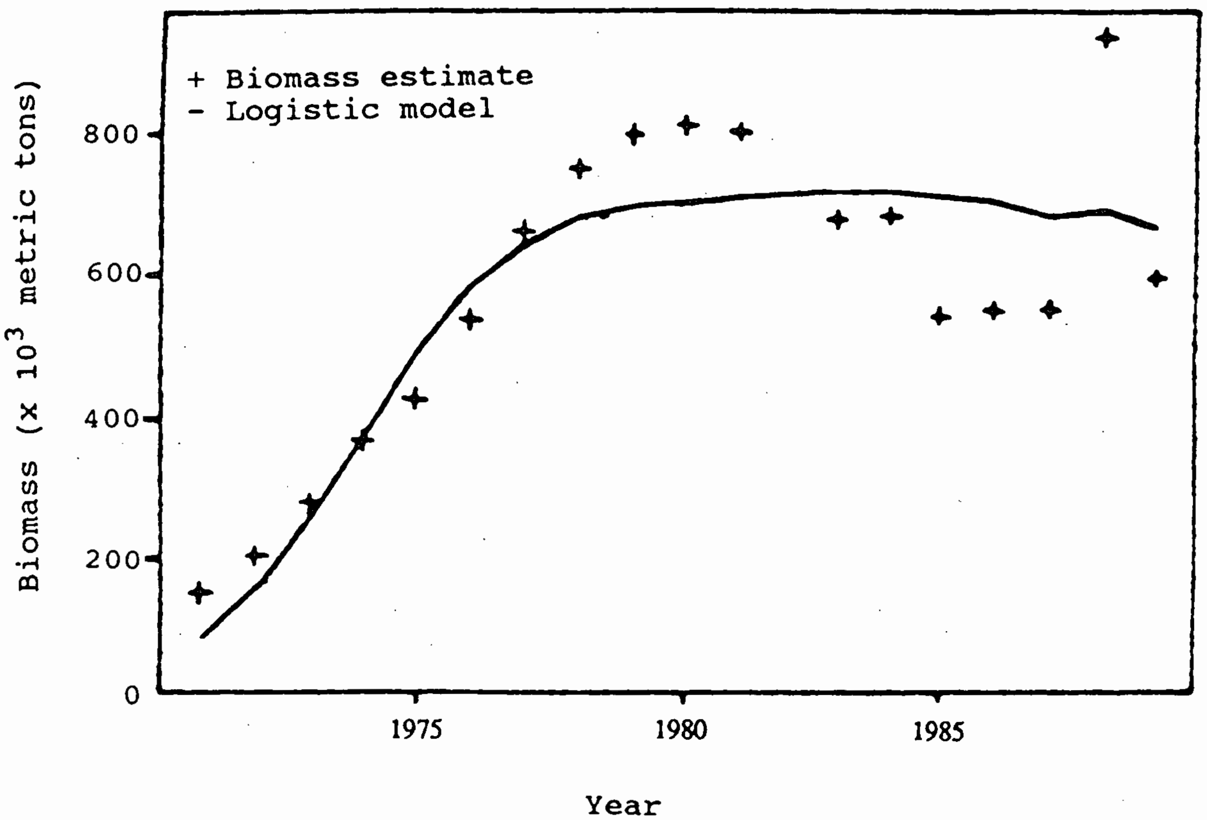

Figure 5B. Estimates of biomass(+) and predicted trajectories using the Logistic model (solid line) for Alaska plaice in the eastern Bering Sea, 1971-89.

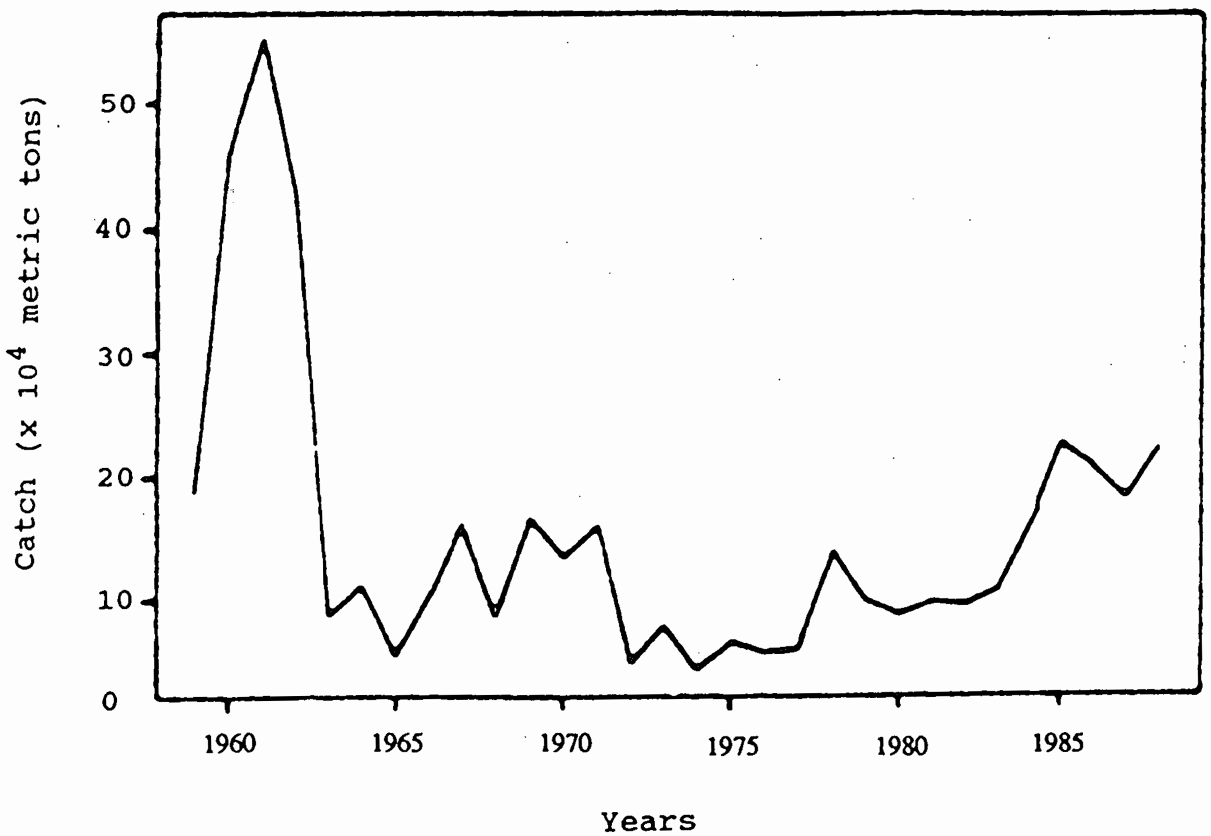

Figure 6A. Annual catch of yellowfin sole in the eastern Bering Sea, 1959-88.

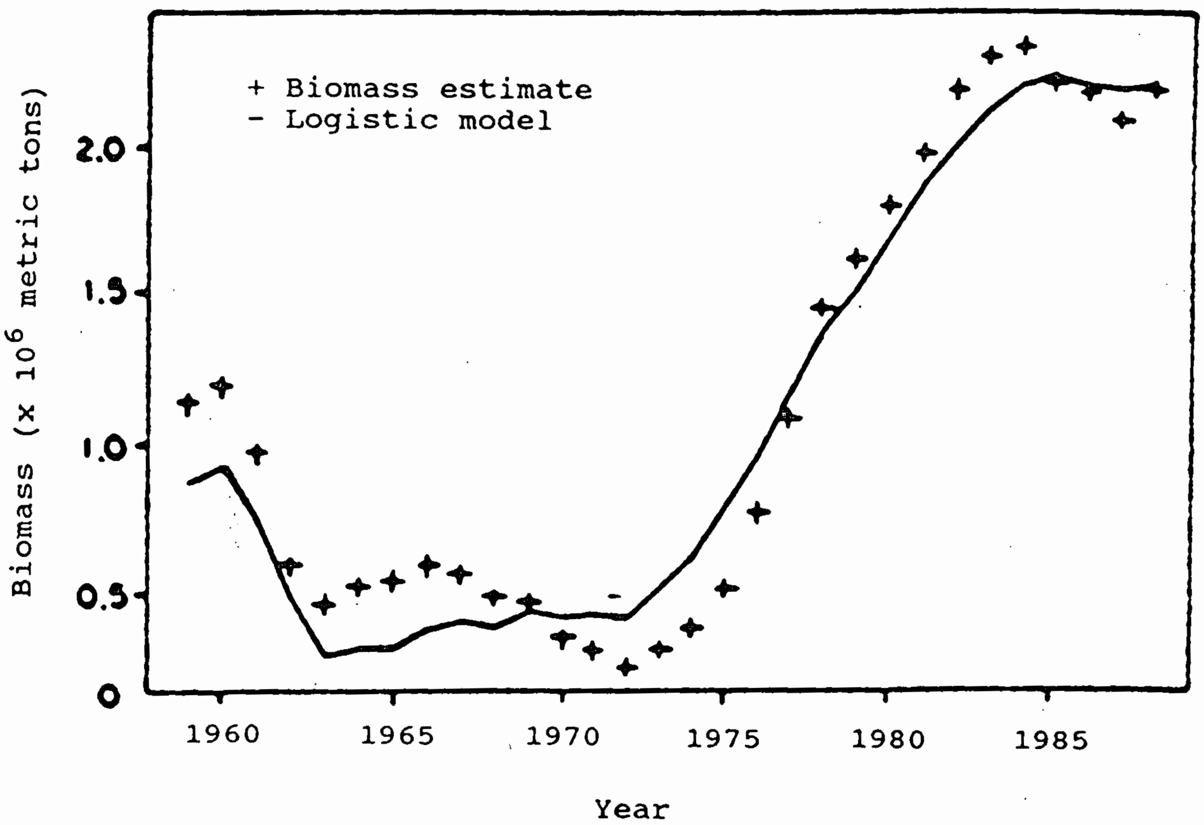

Figure 6B. Estimates of biomass(+) and predicted trajectories using the Logistic model (solid line) for yellowfin sole in the eastern Bering Sea, 1959-88.

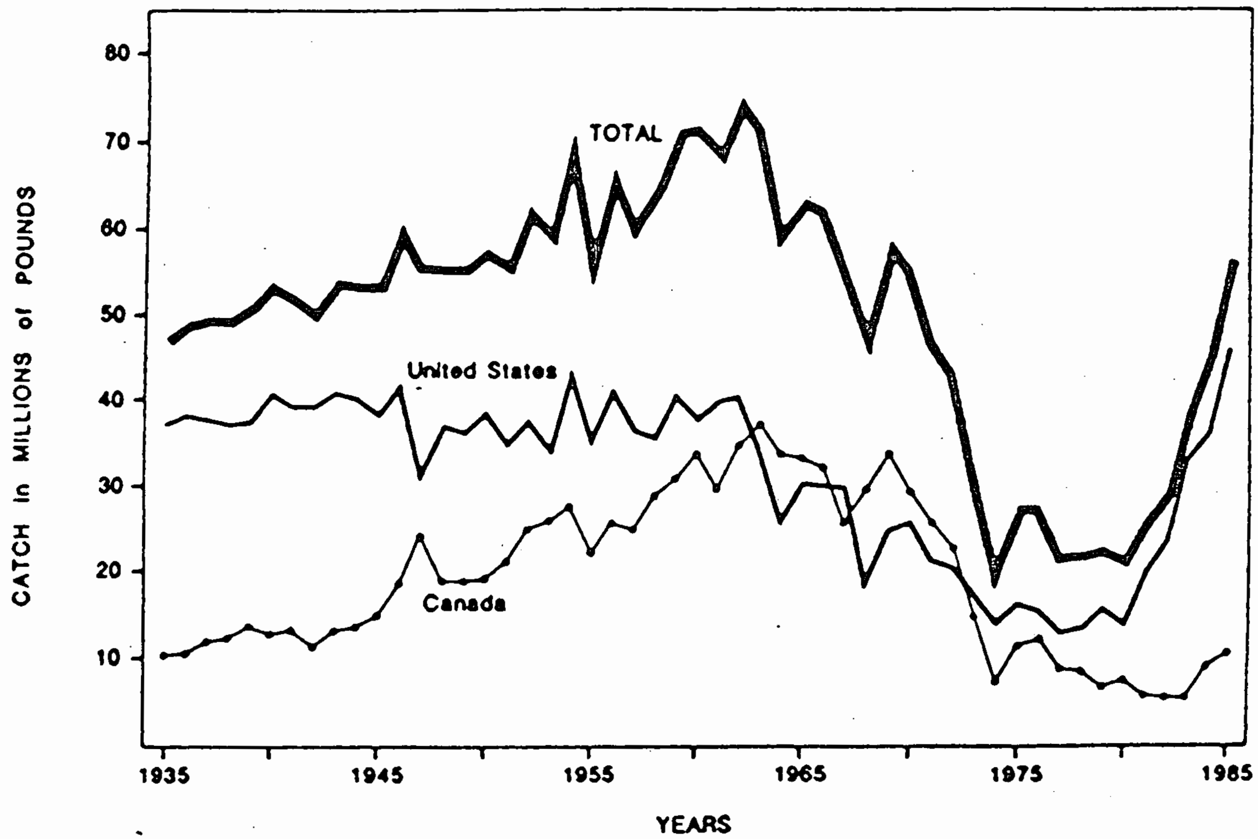

Figure 7. Total Canadian and United States catch of Pacific halibut, 1930-1985 (head-off, Eviscerated weight)

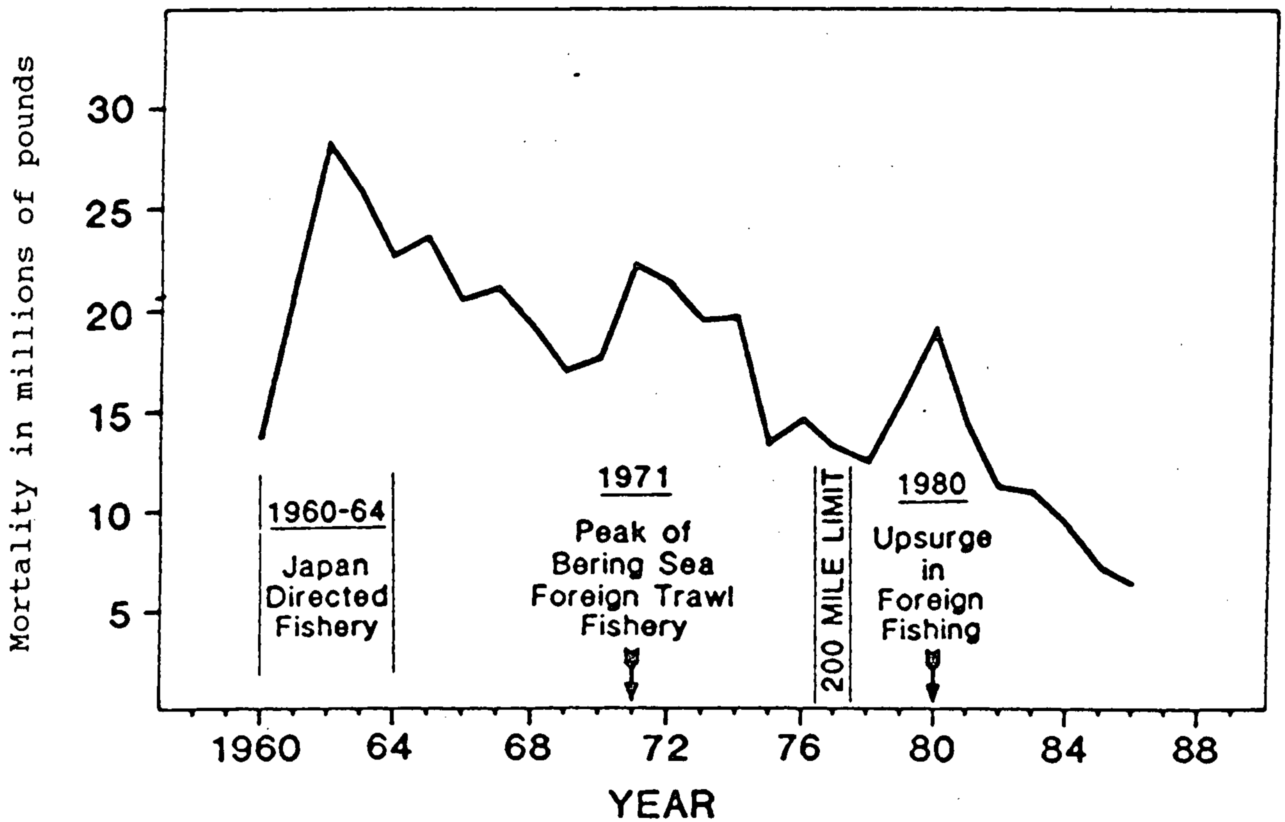

Figure 8. Historical trend in incidental mortality of Pacific halibut.

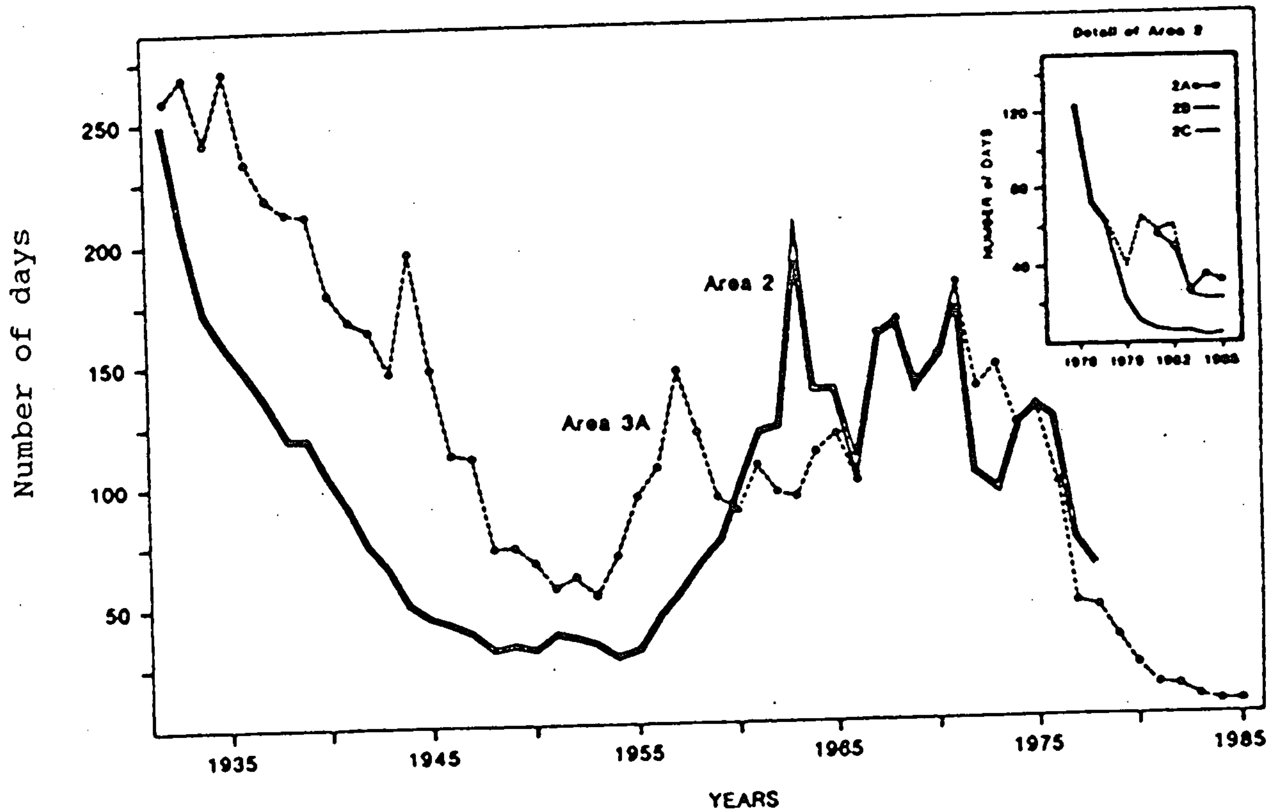

Figure 9. Length of fishing seasons in Area 2 and 3A, 1932-86.

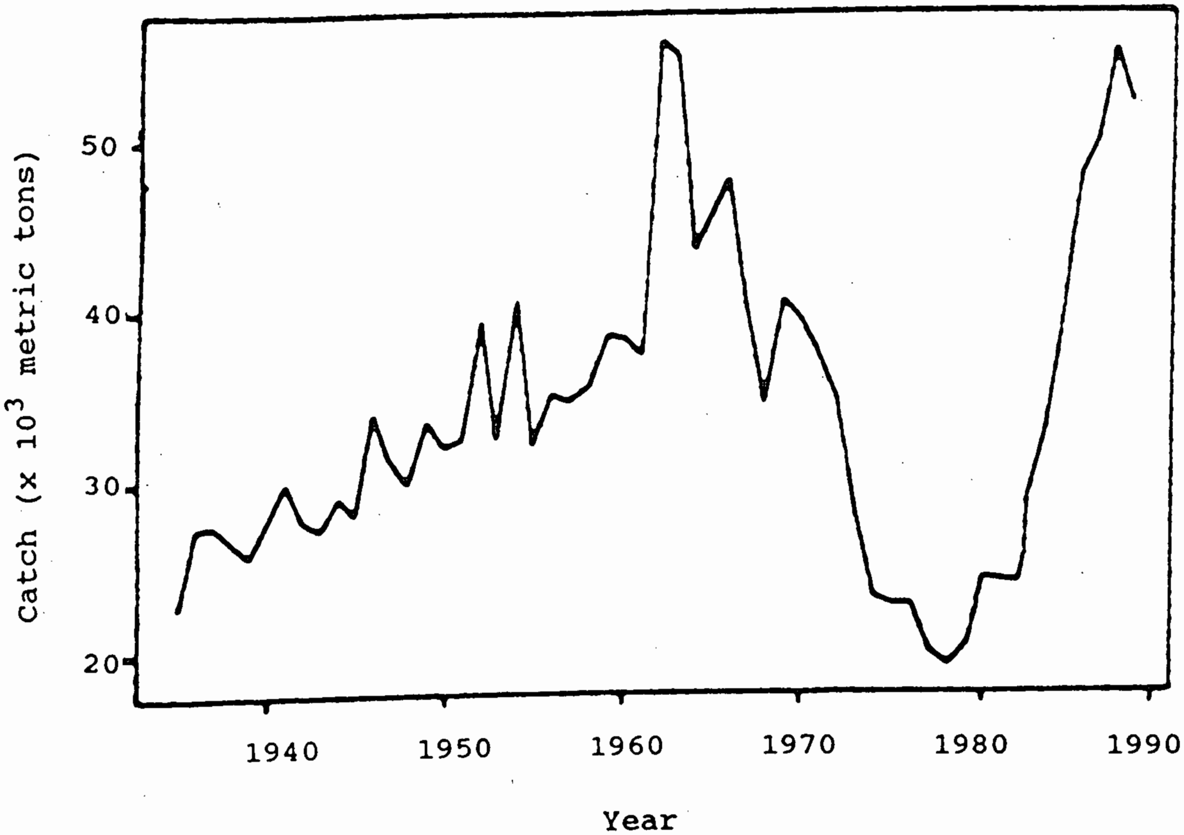

Figure 10A. Annual catch of Pacific halibut in the eastern Bering Sea and Gulf of Alaska, 1935-89.

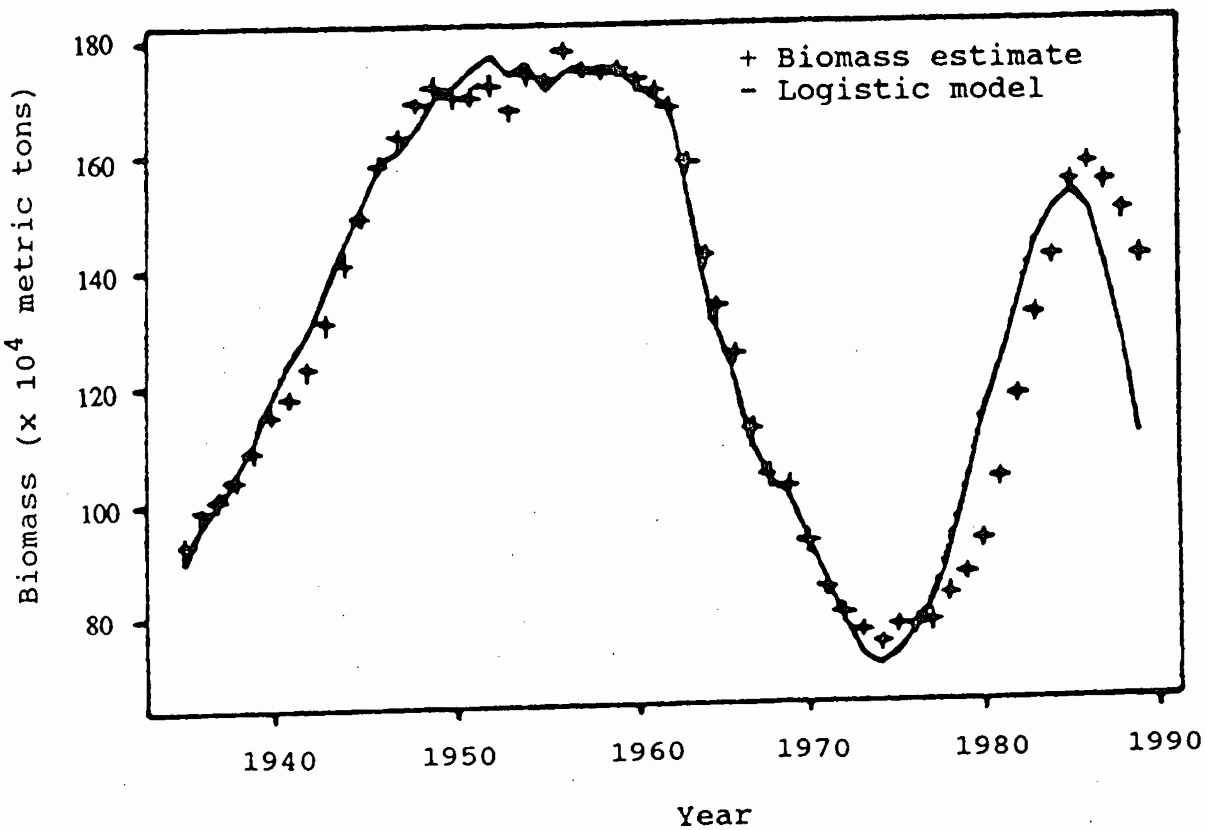

Figure 10B. Estimates of biomass (+) and predicted trajectories using the Logistic model (solid line) for Pacific halibut in the eastern Bering Sea and Gulf of Alaska, 1935-89.

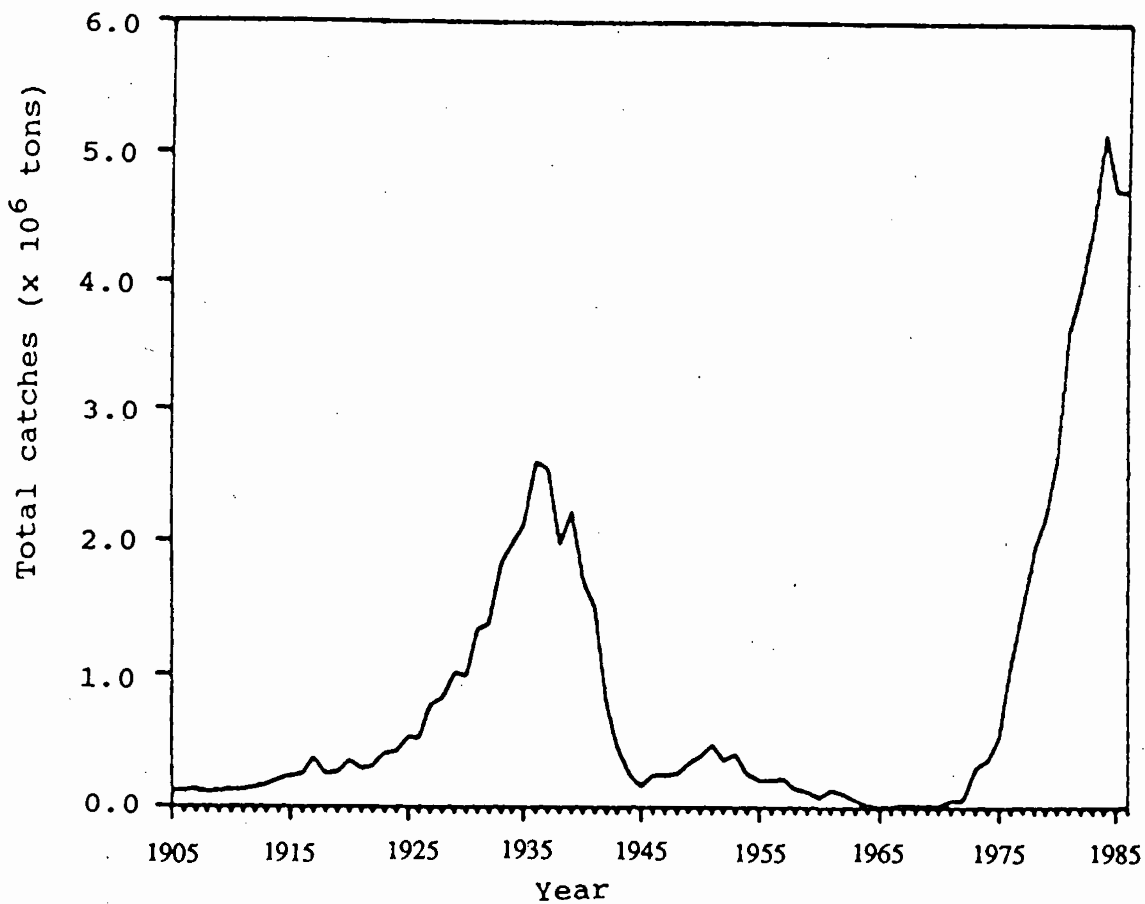

Figure 11. Nominal catches of Japanese sardine (*Sadinops melanostictus*) in the northwest Pacific. (Adapted from Kondo 1980, with data from Murphy 1977 and FAO Yearbook of Fishery Statistics)

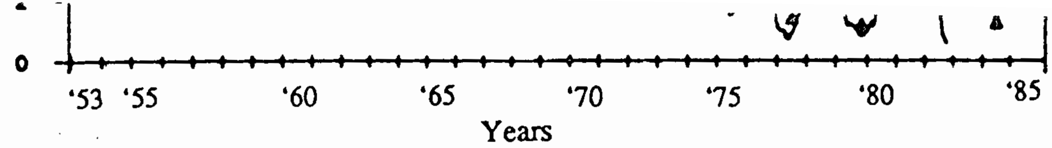

Figure 12. Fluctuations of the northern and central stock of Peruvian anchovy (*Engraulis ringens*) and occurrence of 'El Nino' phenomena between 1953 and 1985 (Adapted from Pauly et al. 1987). The continuous line represents monthly YPA biomass estimates (Data from pauly, Palomares and Gayanilo 1987); the solid triangles represent various independent biomass estimated made by IMARPE (Data from IMARPE 1974, 1974a, 1975, 1981, 1986; Johanesson and Robles 1977; Johannesson and Vilvhez 1981; and Zuta, Tsukayama and Villabueva 1985); solid horizontal bars represent the relative intensity of the 'El Nino' phenomena following the classification of Rivera (1987).

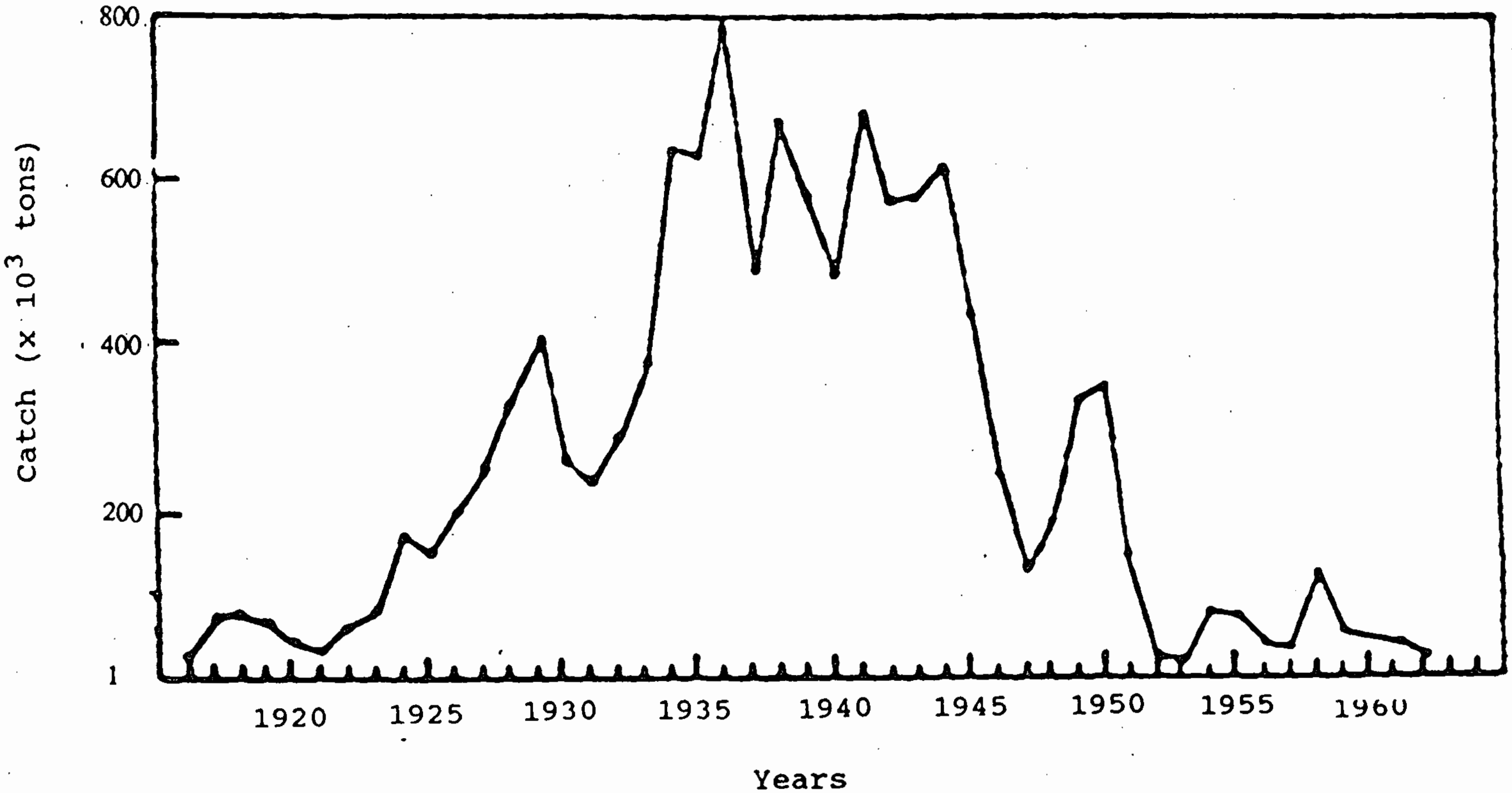

Figure 13. Catches of sardine along the Pacific coast of the United States. (Data from Murphy 1966).

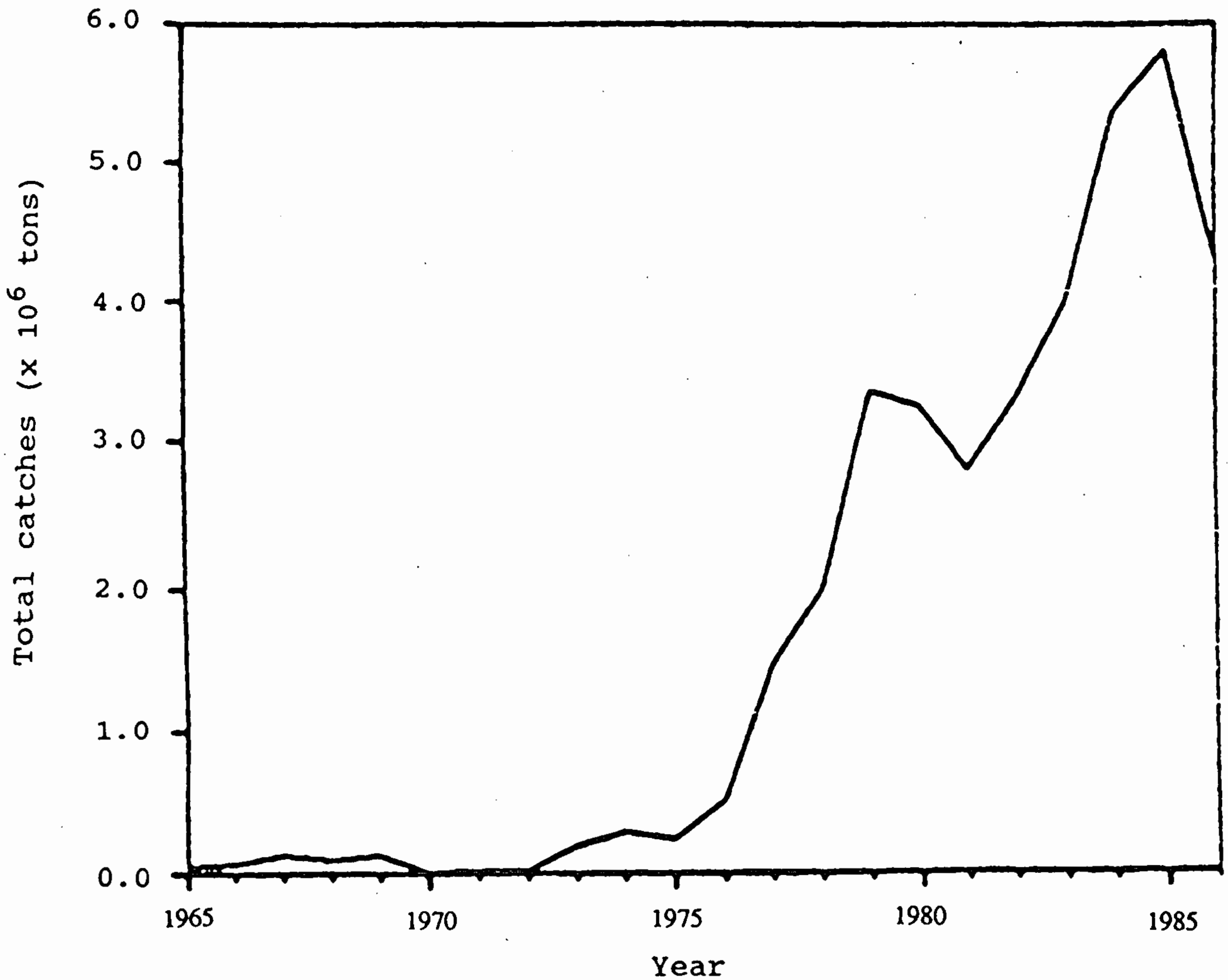

Figure 14. Nominal catches of the South American sardine (*Sardinops sagax*) in the southeast Pacific. (Data from FAO Yearbook of Fishery Statistics)

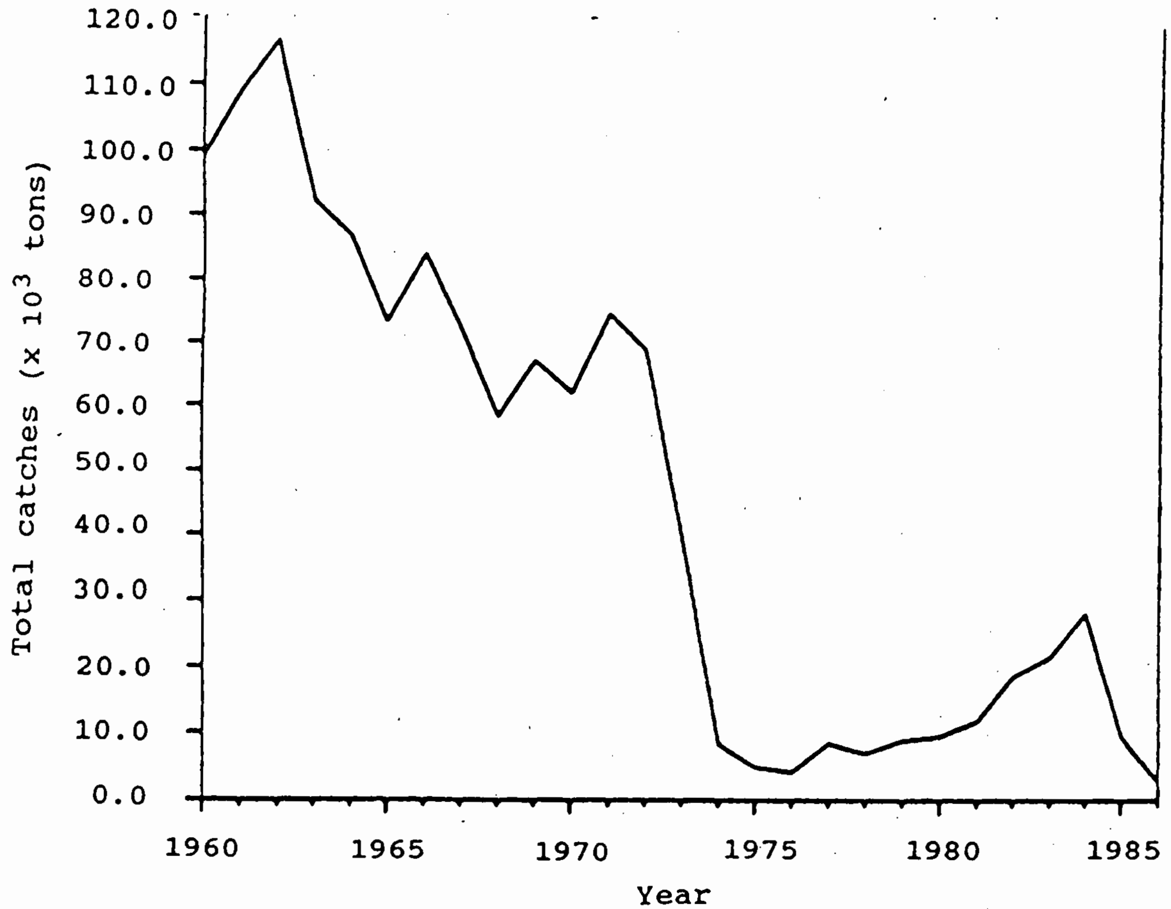

Figure 15. Nominal catches of Pacific benito (*Sarda chiliensis*) in the southeast Pacific. (Data from FAO Yearbook of Fishery Statistics)

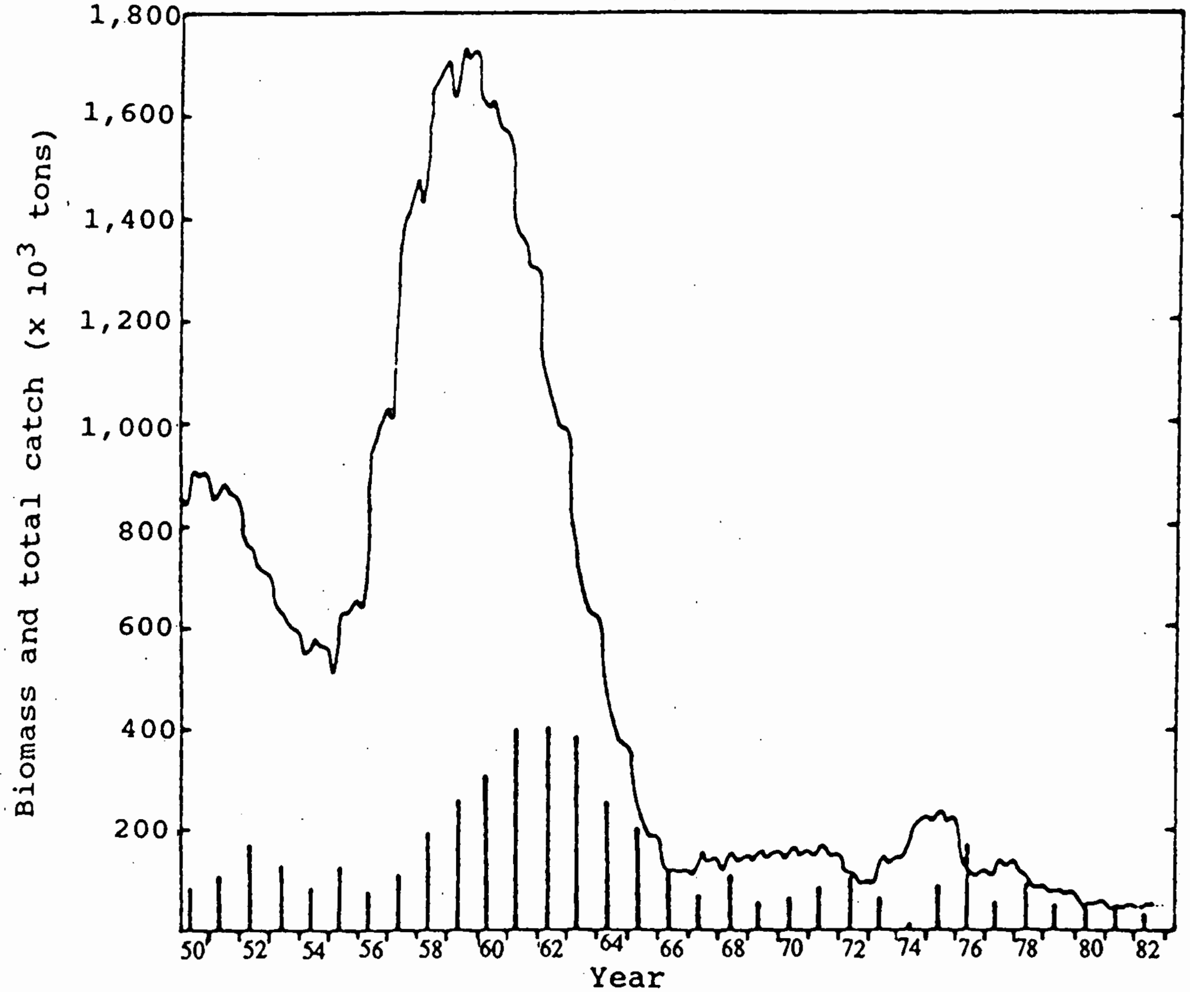

Figure 16. Monthly VPA biomass estimates (continuous line), and annual landings (vertical bars) of the South African sardine (*Sardinops ocellatus*). (From Butterworth 1983)

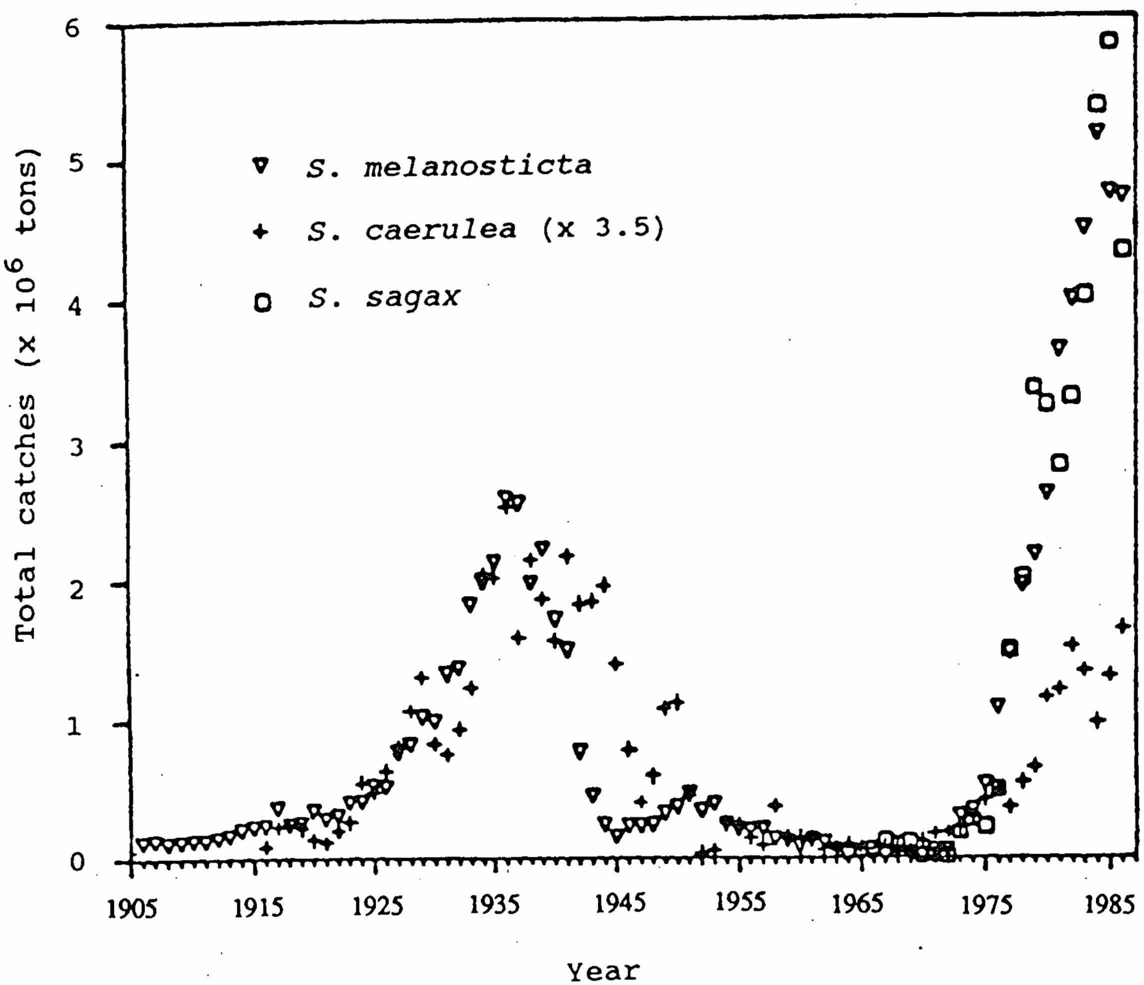

Figure 17. Long-term variability in the annual catches of three main species of sardine, the Japanese sardine (*Sardinops melanosticta*), the California sardine (*S. caerulea*) and the South American sardine (*S. sagax*) in the Pacific Ocean. (Adapted from Kawasaki 1983, with the data from Murphy 1977 and FAO Yearbook of Fishery Statistics)

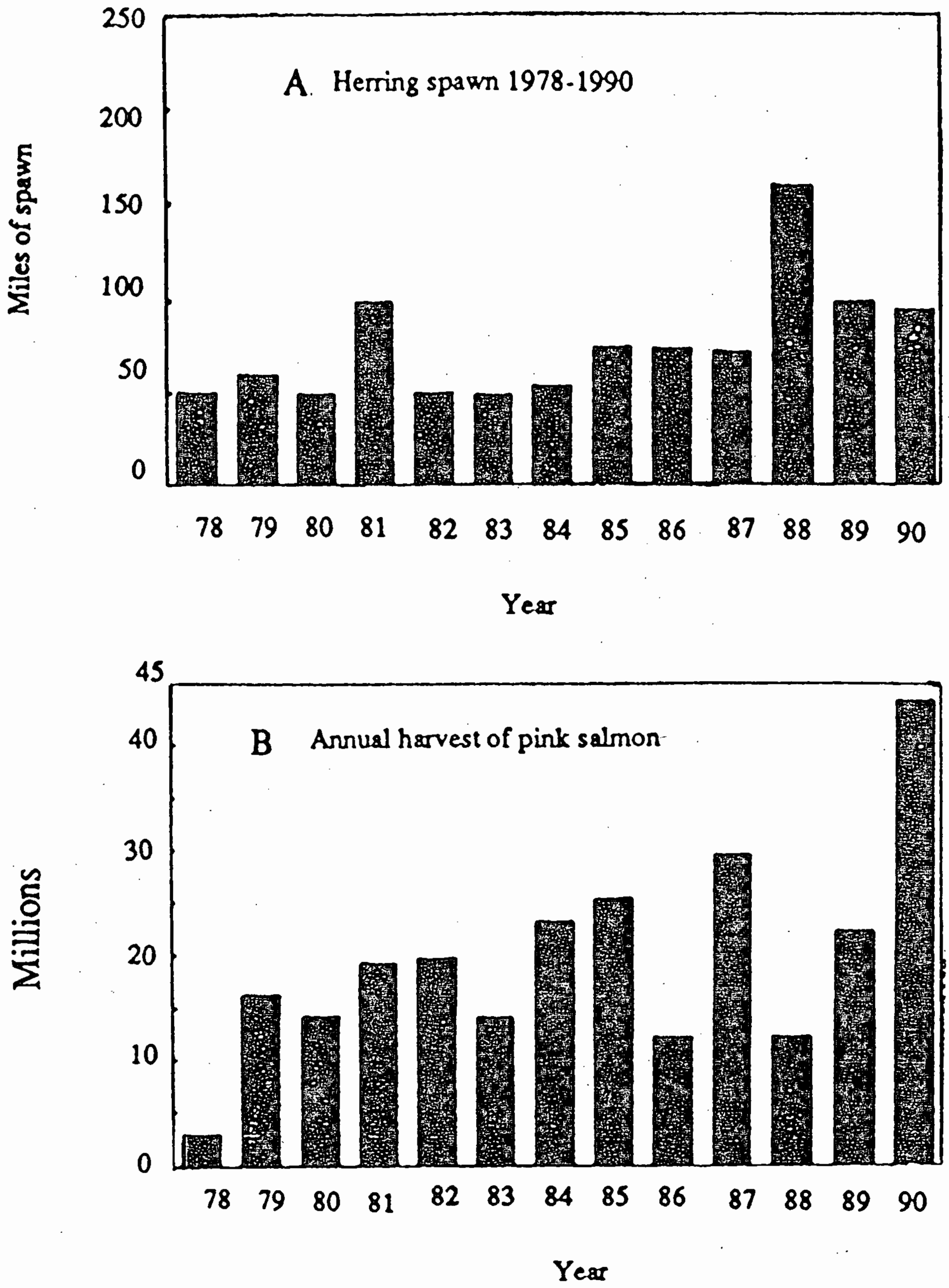

Figure 18. Prince William Sound fish production. Herring spawn (A) and annual harvest of pink salmon (B) for the period of 1978-1990.

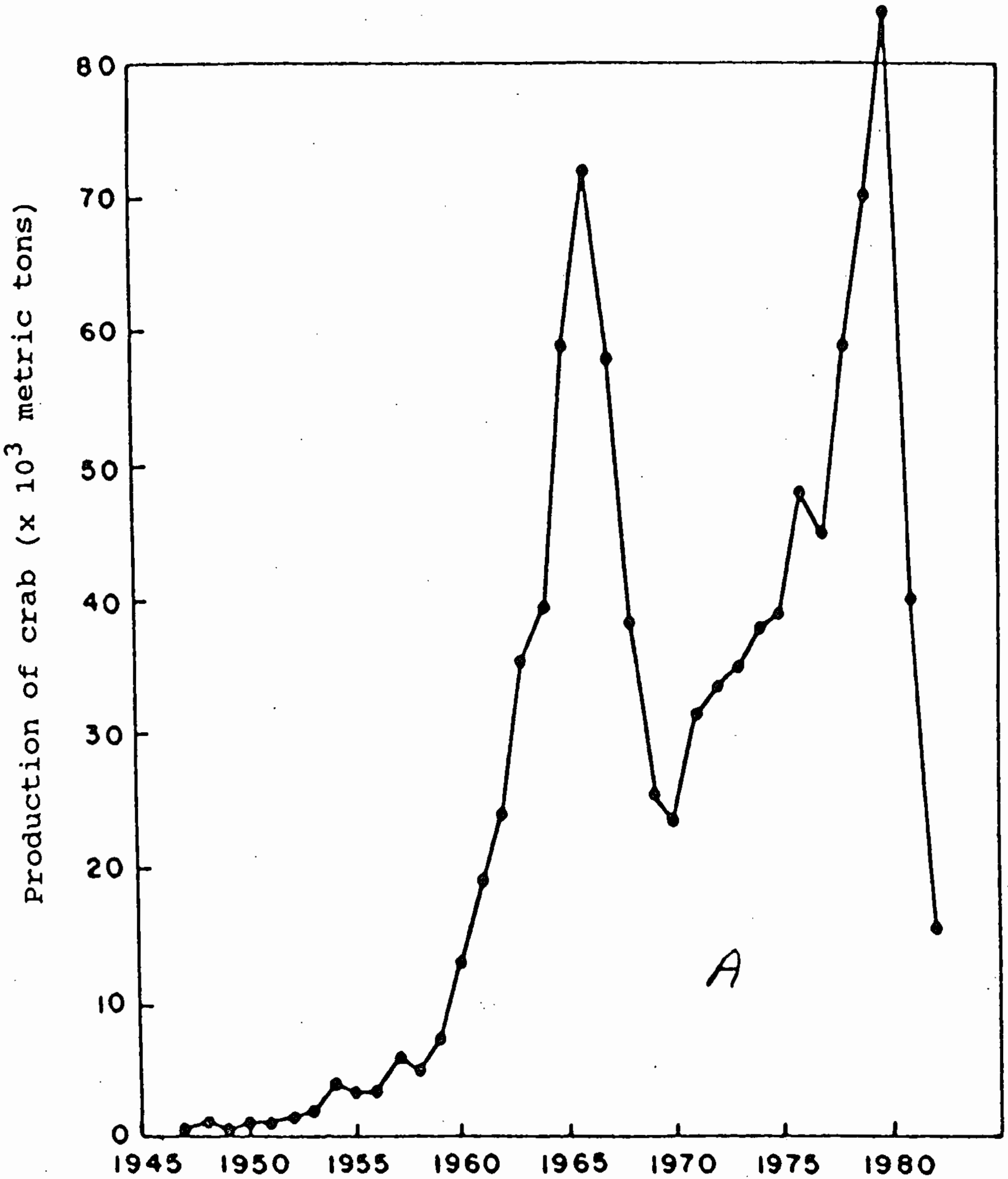

Figure 19A. Trends in U.S. production of Alaskan king crab. (Data from U.S. Department of Commerce, 1945-1980)

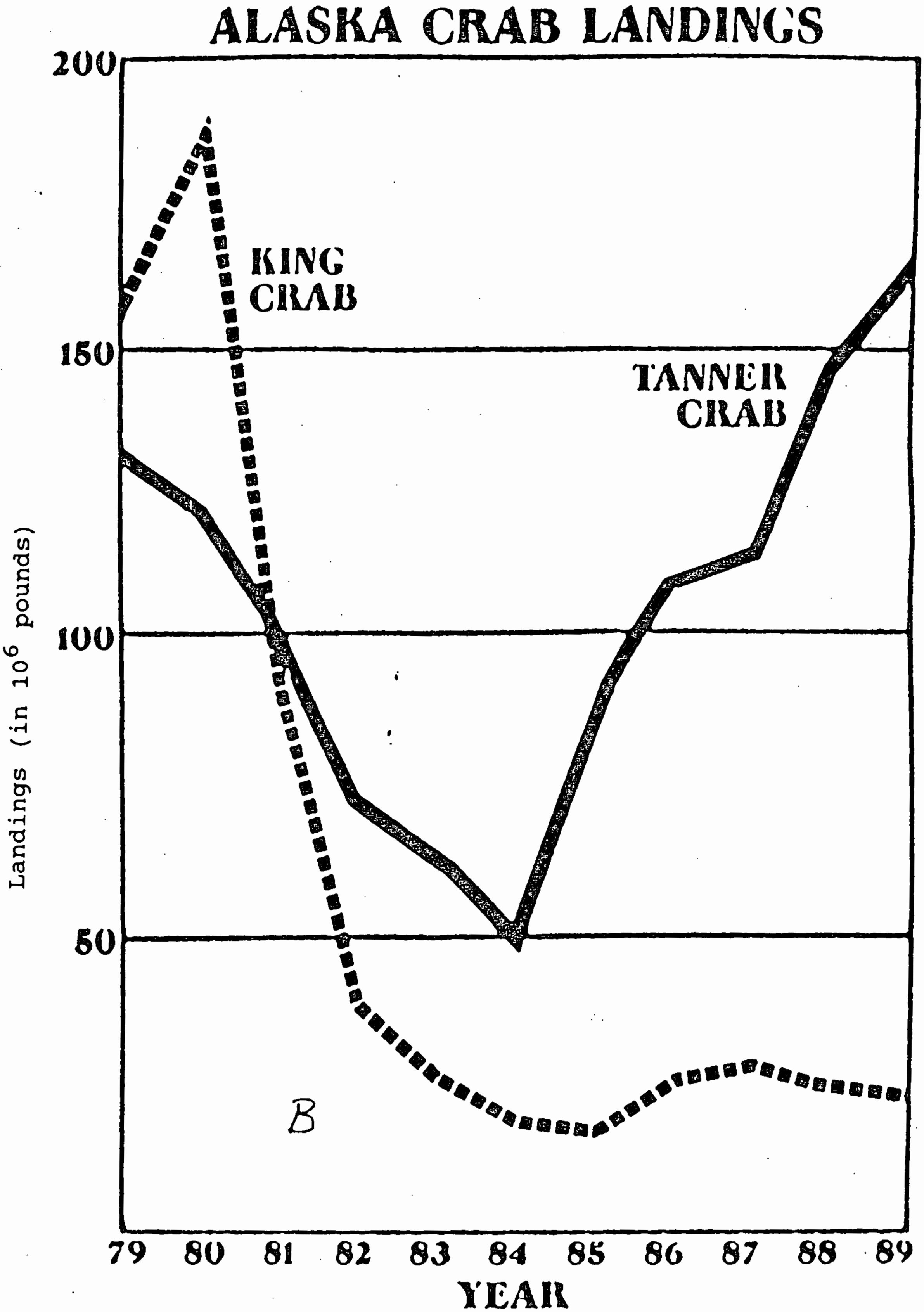

Figure 19B. Trends in Alaska carb landings, 1979-89.

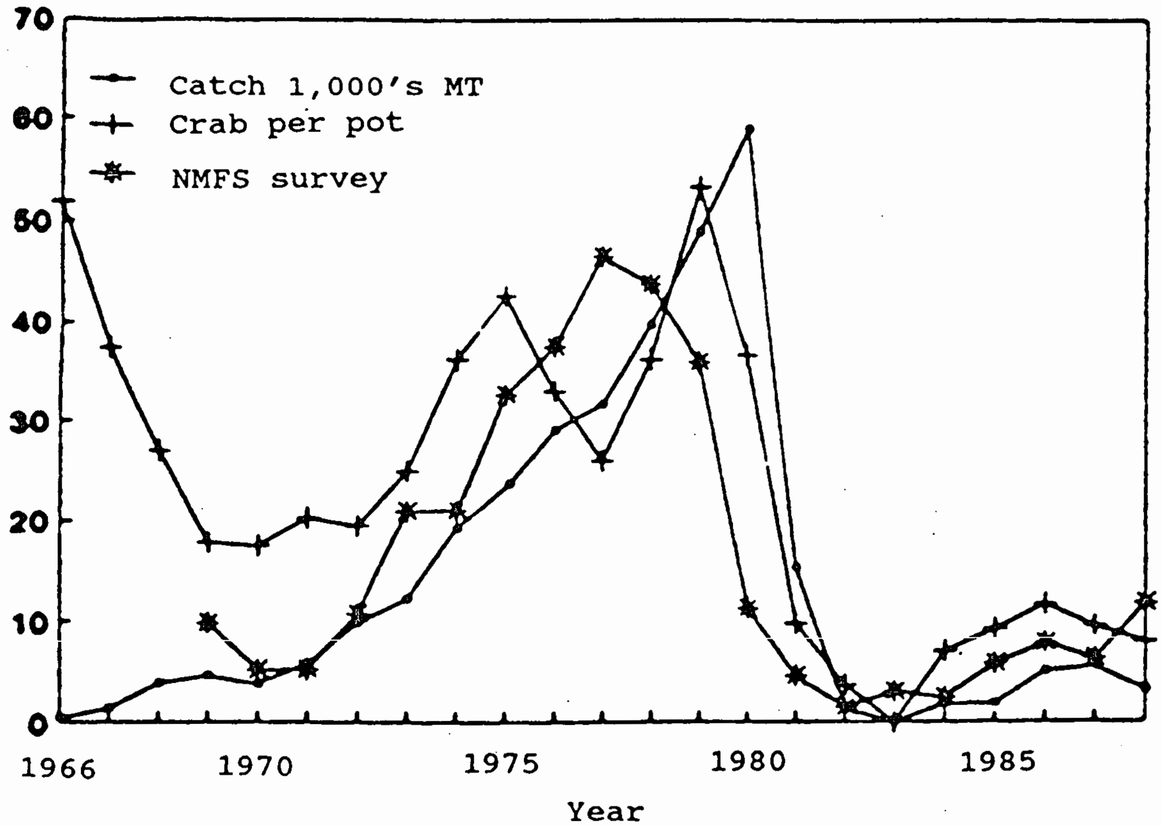

Figure 20. Comparison of U.S. commercial catch and crab per pot lift (CPUE) with NMFS survey estimates of the abundance of legal male red king crab (millions) from Bristol Bay. Note that the fishery was closed in 1983.

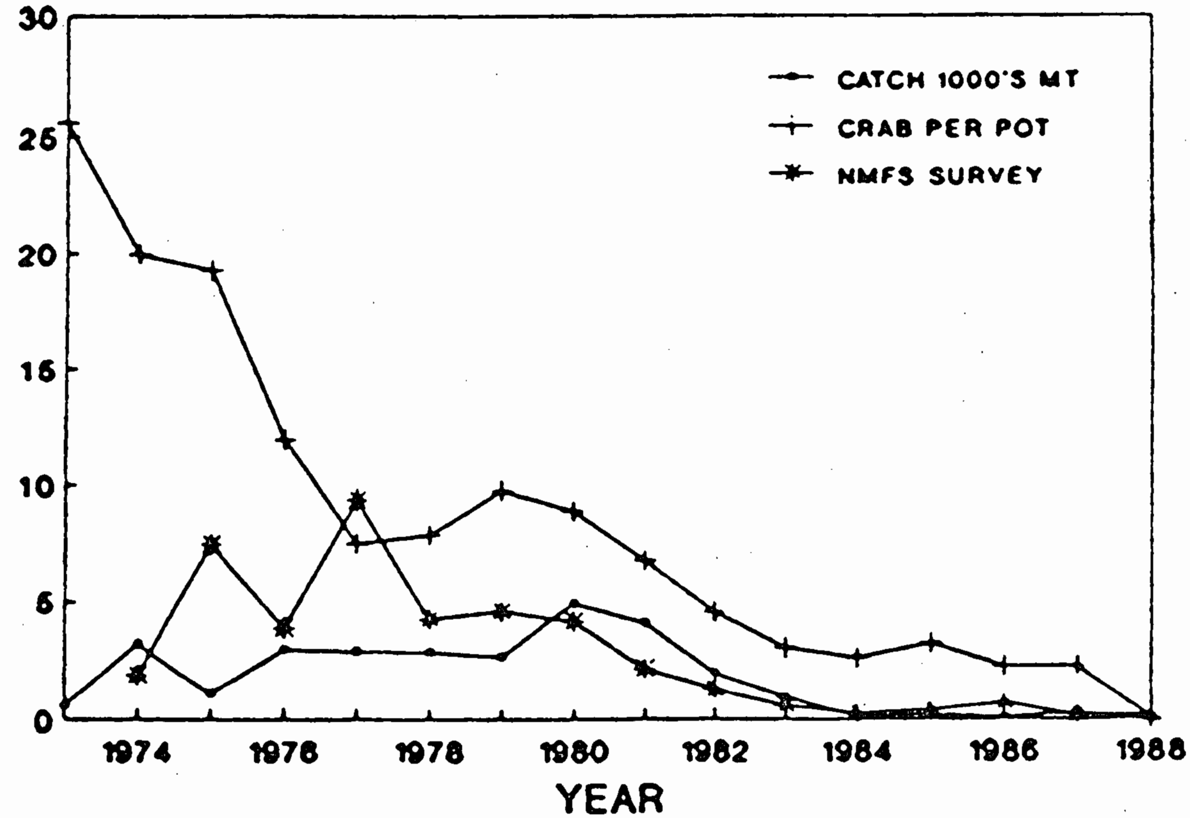

Figure 21. Comparison of U.S. commercial catch and crab per pot lift (CPUE) with NMFS survey estimates of the abundance of legal male blue king crab (millions) from Pribilof Islands. Note that the fishery was closed in 1988.

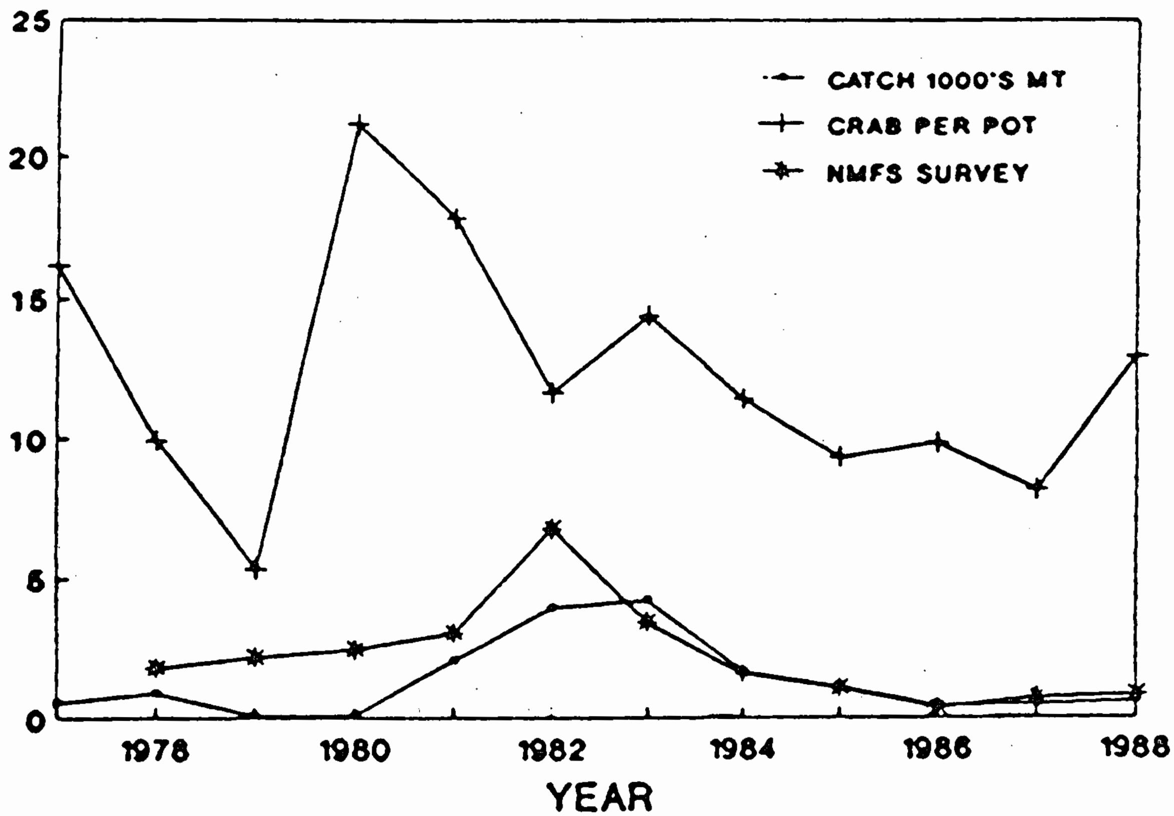

Figure 22. Comparison of U.S. commercial catch and crab per pot lift (CPUE) with NMFS survey estimates of the abundance of legal male blue king crab (millions) from St. Matthew Island.

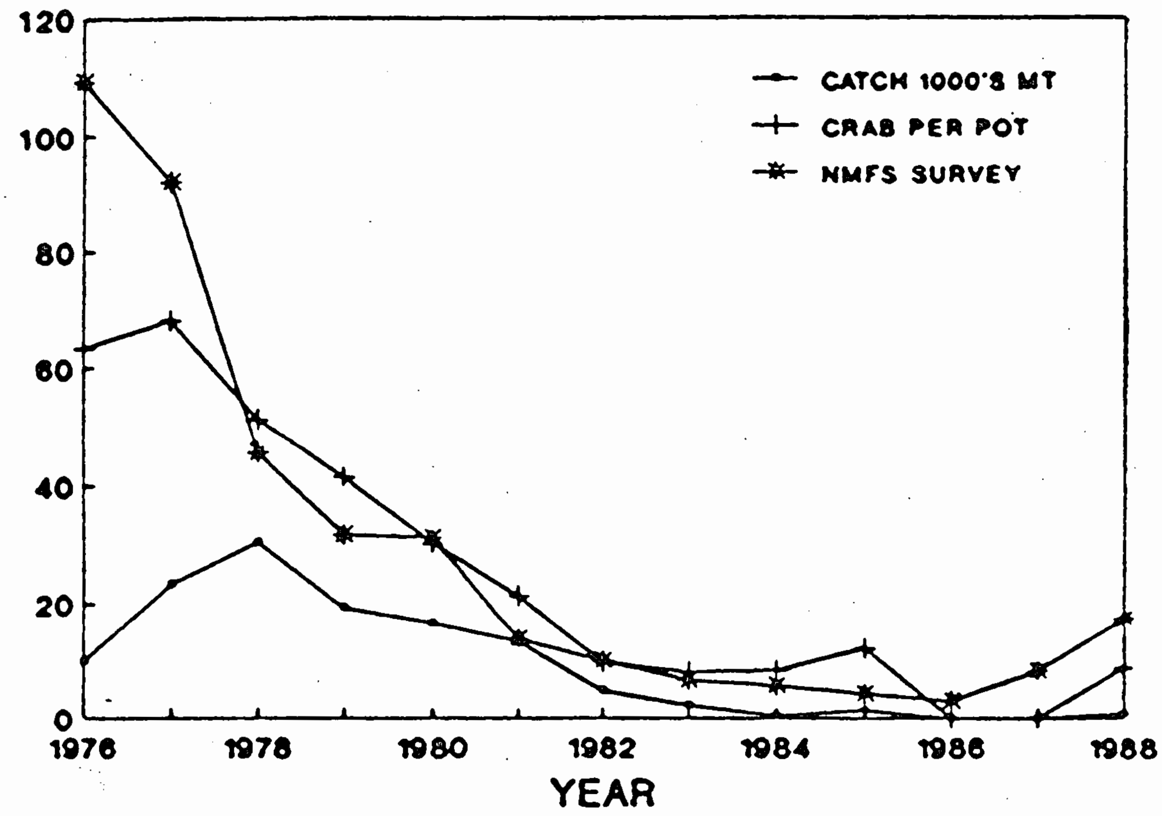

Figure 24. Comparison of U.S. commercial catch and crab per pot lift (CPUE) with NMFS survey estimates of the abundance of legal male tanner crab (millions) from the eastern Bering Sea. Note that the fishery was closed in 1986 and 1988.

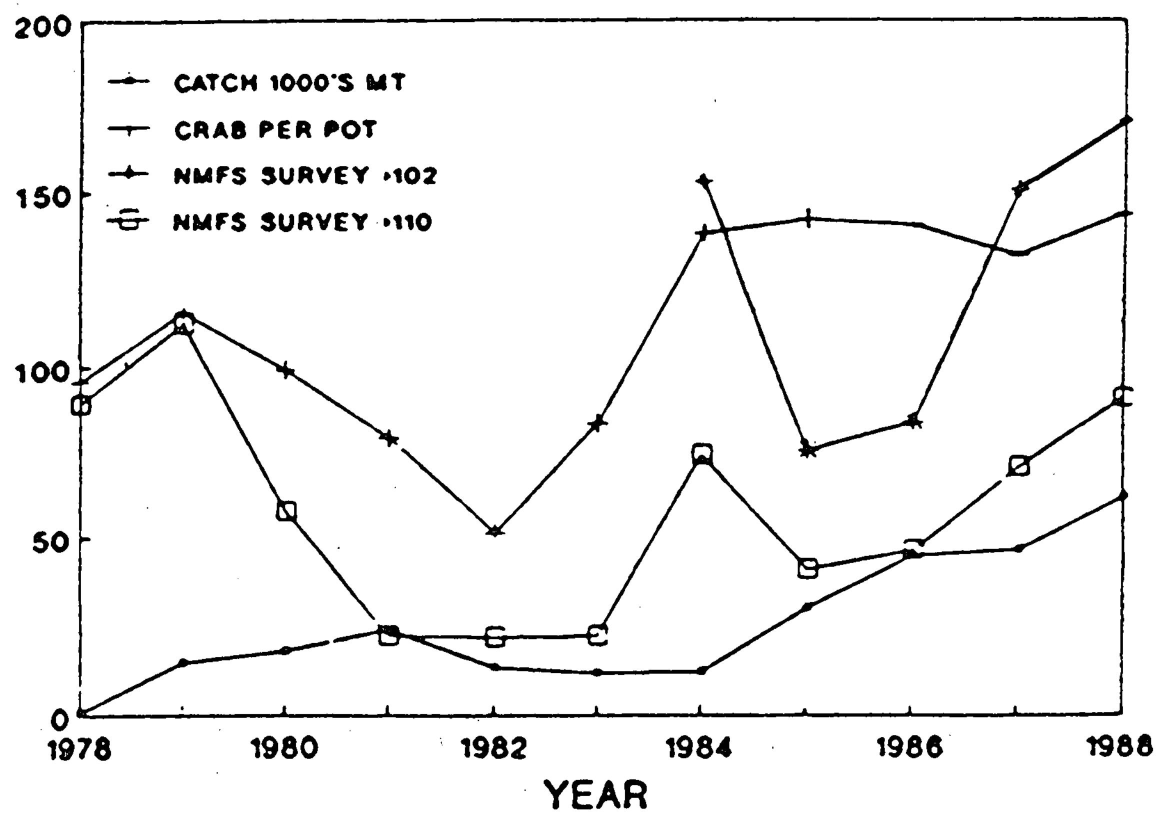

Figure 25. Comparison of U.S. commercial catch and crab per pot lift (CPUE) with NMFS survey estimates of the abundance of commercial size male snow crab (millions) from the eastern Bering Sea. Crab of 110 mm carapace width are approximately average for the history of the fishery but processors have refused to purchase smaler than 102 mm in recent years.

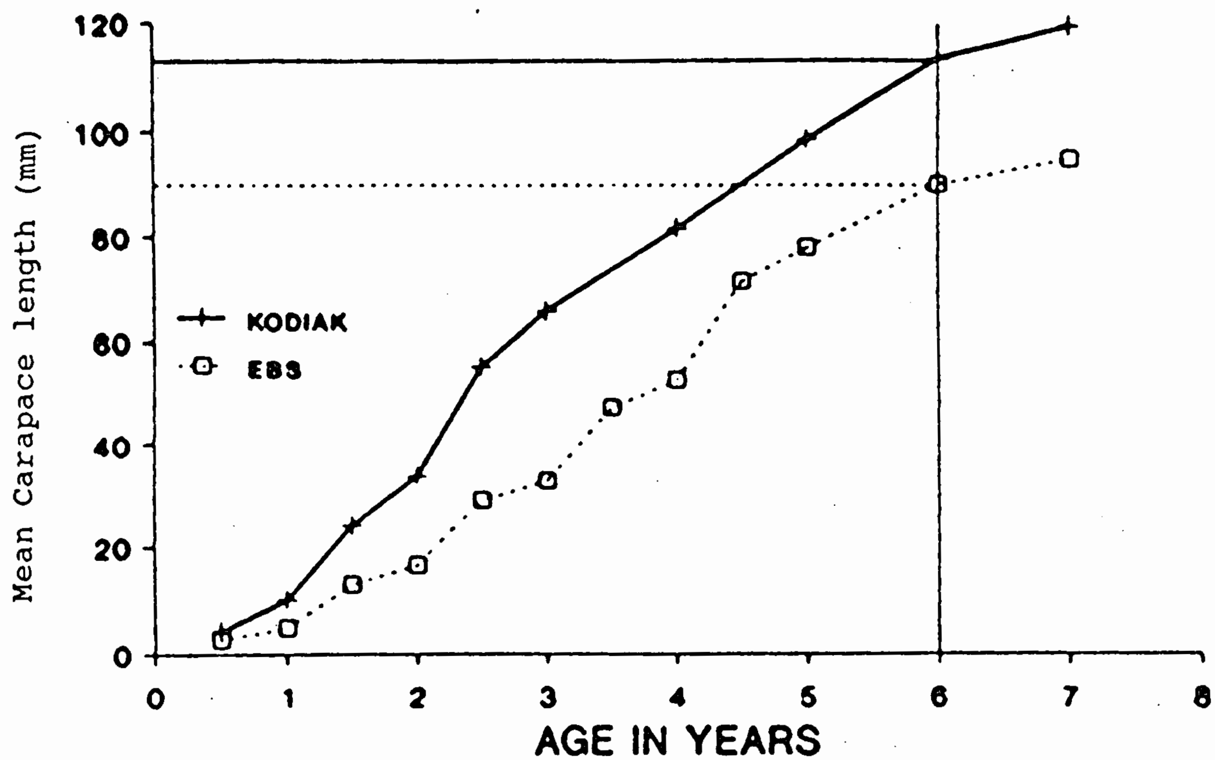

Figure 26. Growth of female red king crabs in Kodiak and Bristol Bay, eastern Bering Sea, as predicted by model. Model includes early growth according to temperature regression, and secondary growth by annual molting increments assumed to be different for each location.

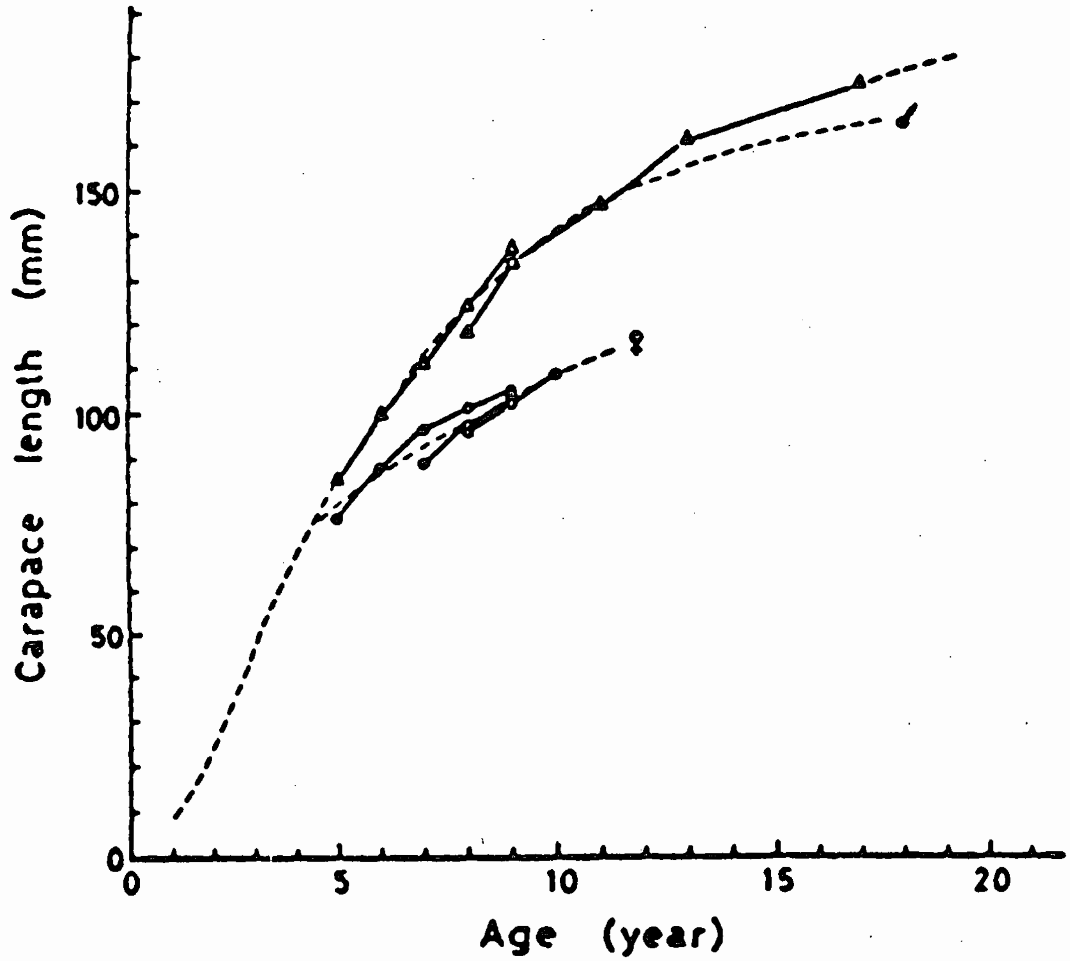

Figure 27. Growth of the laboratory reared Kamchatka red king crabs. Curve for male is calculated using the growth model by Weber and Miyahara (1962). Curve for immature is derived from Kurata (1961). Curve for female is derived from Matsuura et al. (1972).

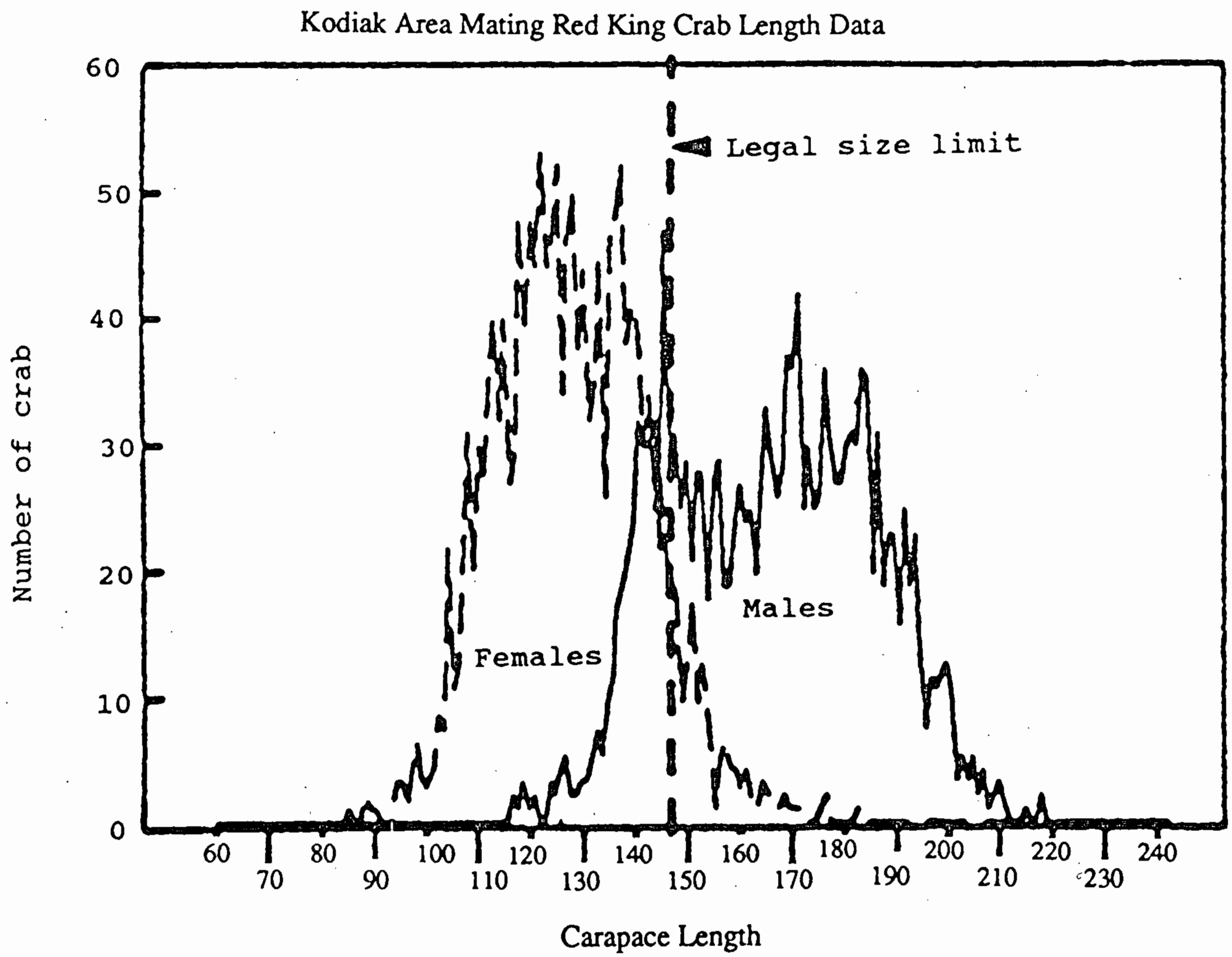

Figure 28. Length frequencies of male and female red king crab collected from the Kodiak area, 1964 through 1971. Only pairs in which both the male and female had shell ages of approximately 12-months are included.

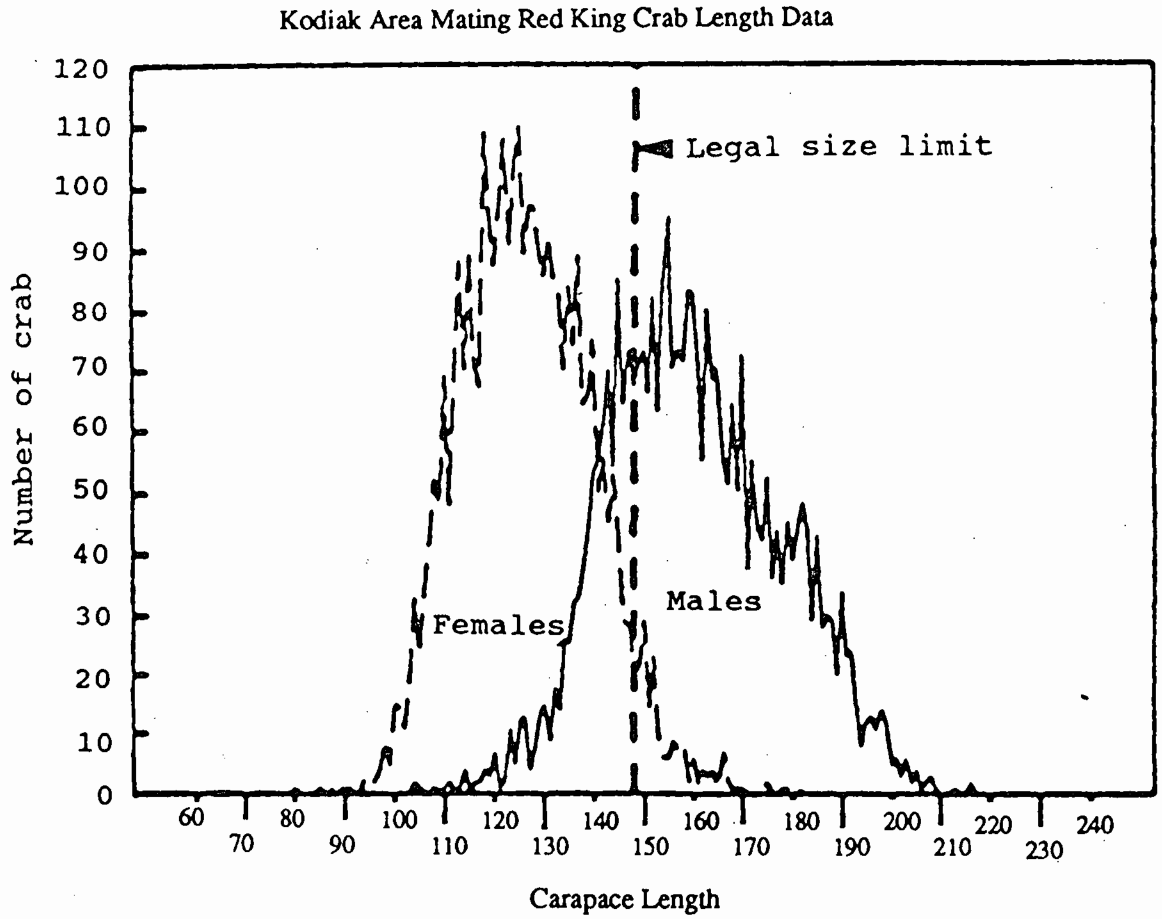

Figure 29. Length frequencies of male and female red king crab mating pairs collected from the Kodiak area, 1964 through 1971. Pairs of all shell ages are included.

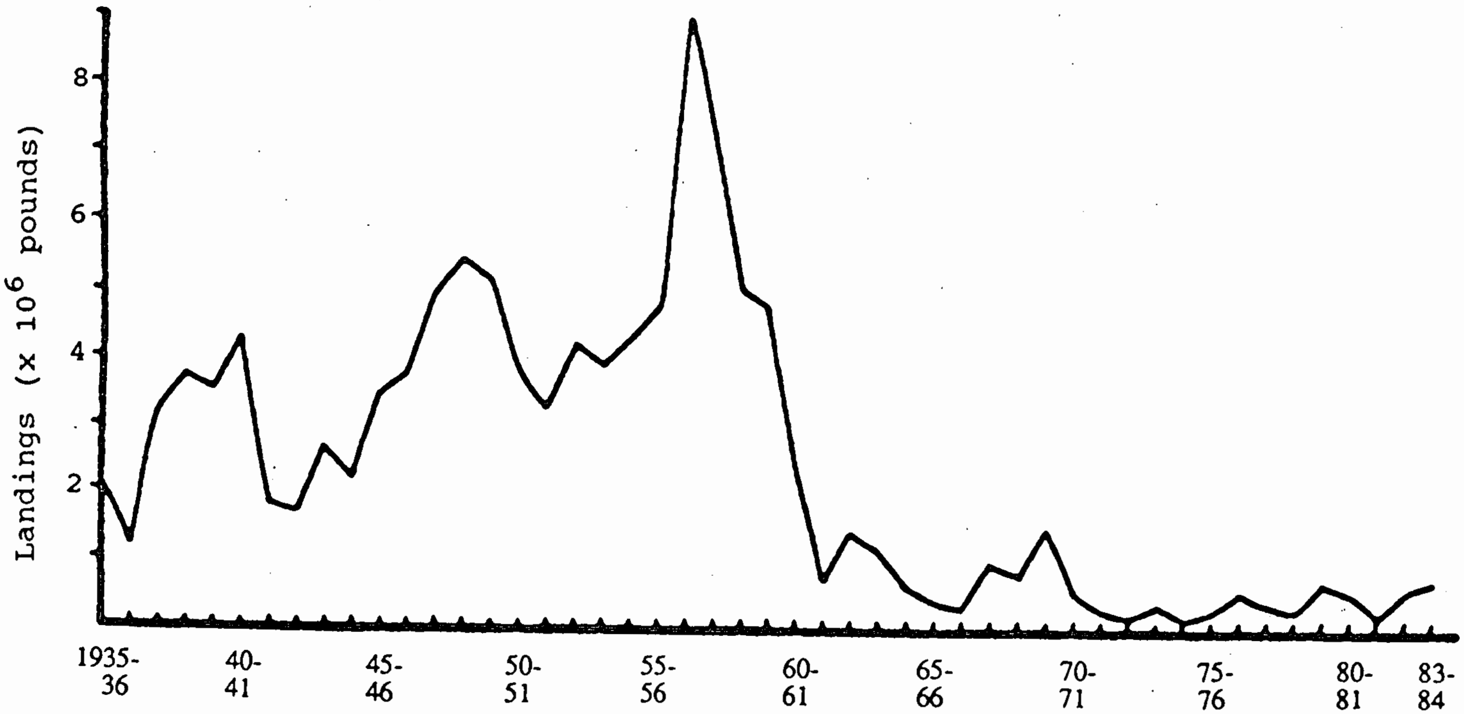

Figure 30. Dungeness crab commercial fishery landings in San Francisco.

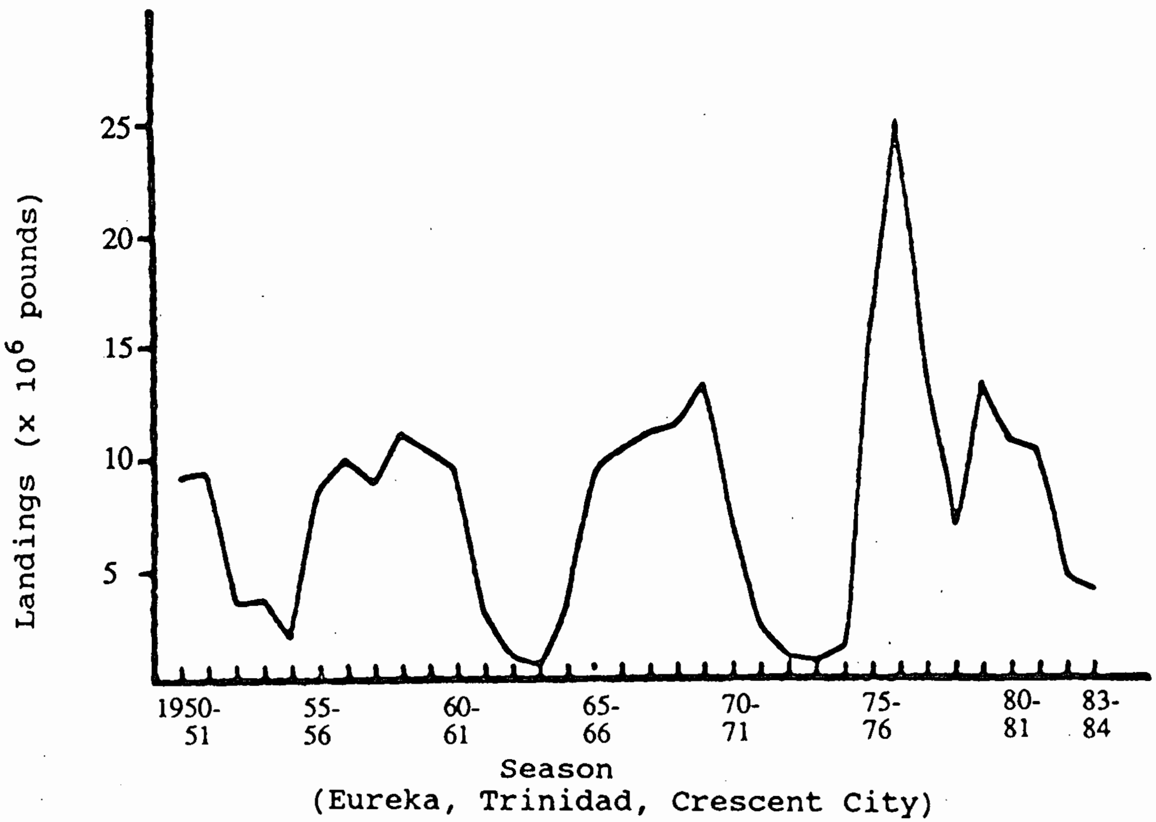

Figure 31A. Dungeness crab commercial fishery landings in Northern California.

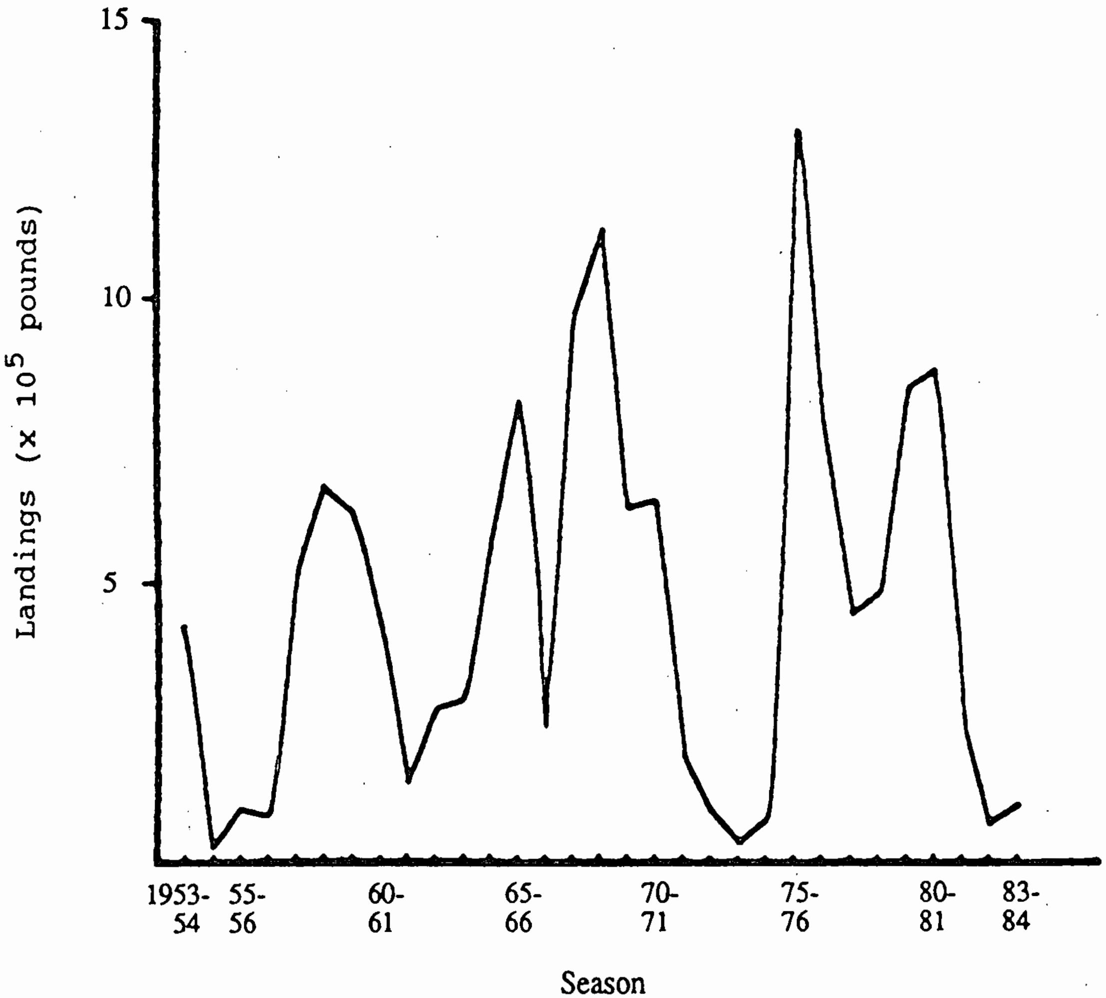

Figure 31B. Dungeness crab commercial fishery landings in Fort Bragg, California.

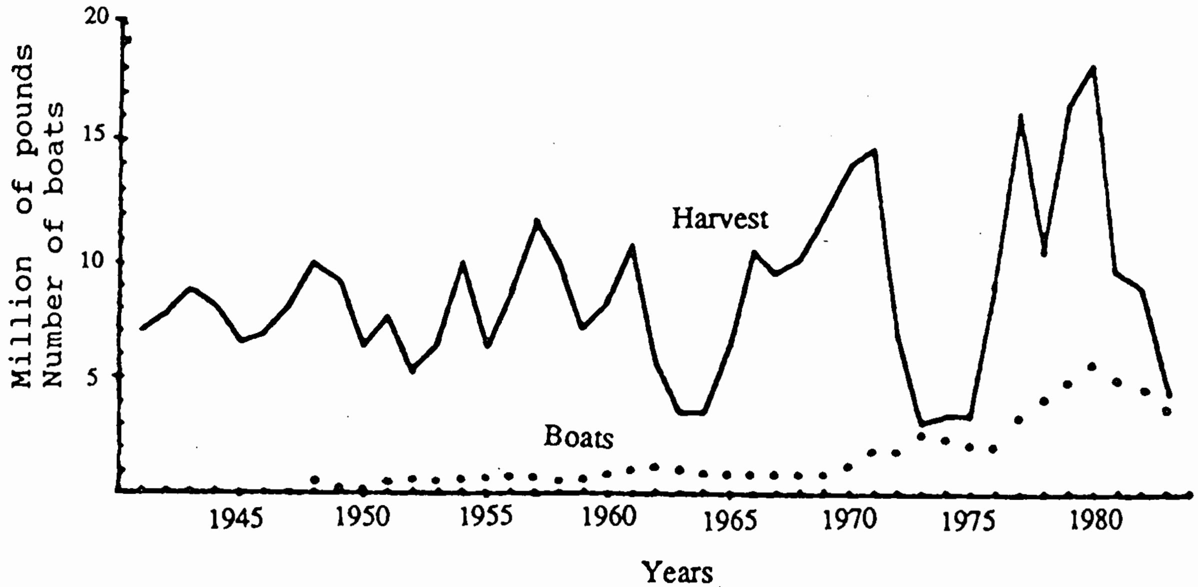

Figure 32. Oregon dungeness crab harvest and number of boats.

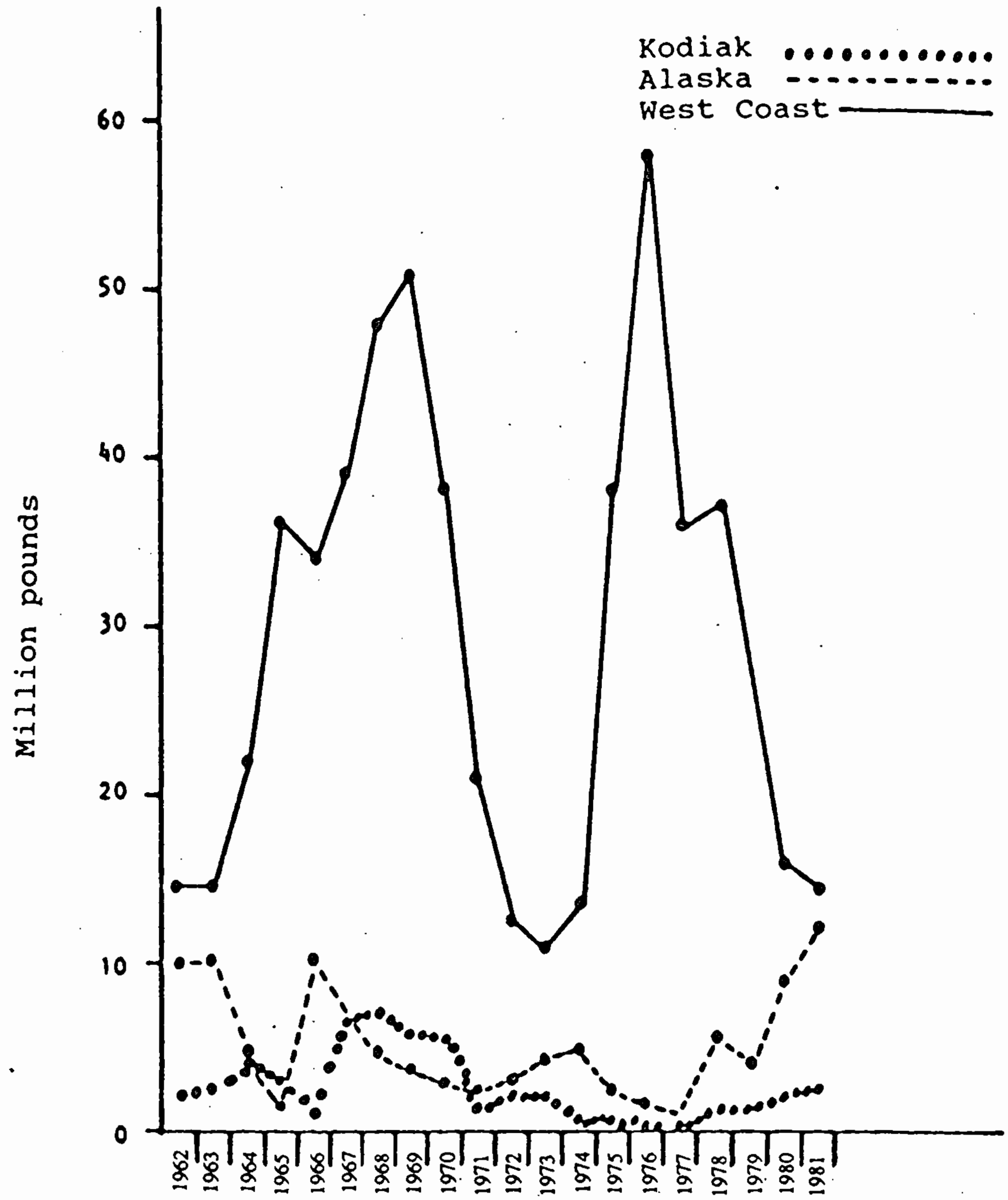

Figure 33. Alaska's dungeness catch production compared to West Coast catch production 1962-1981.

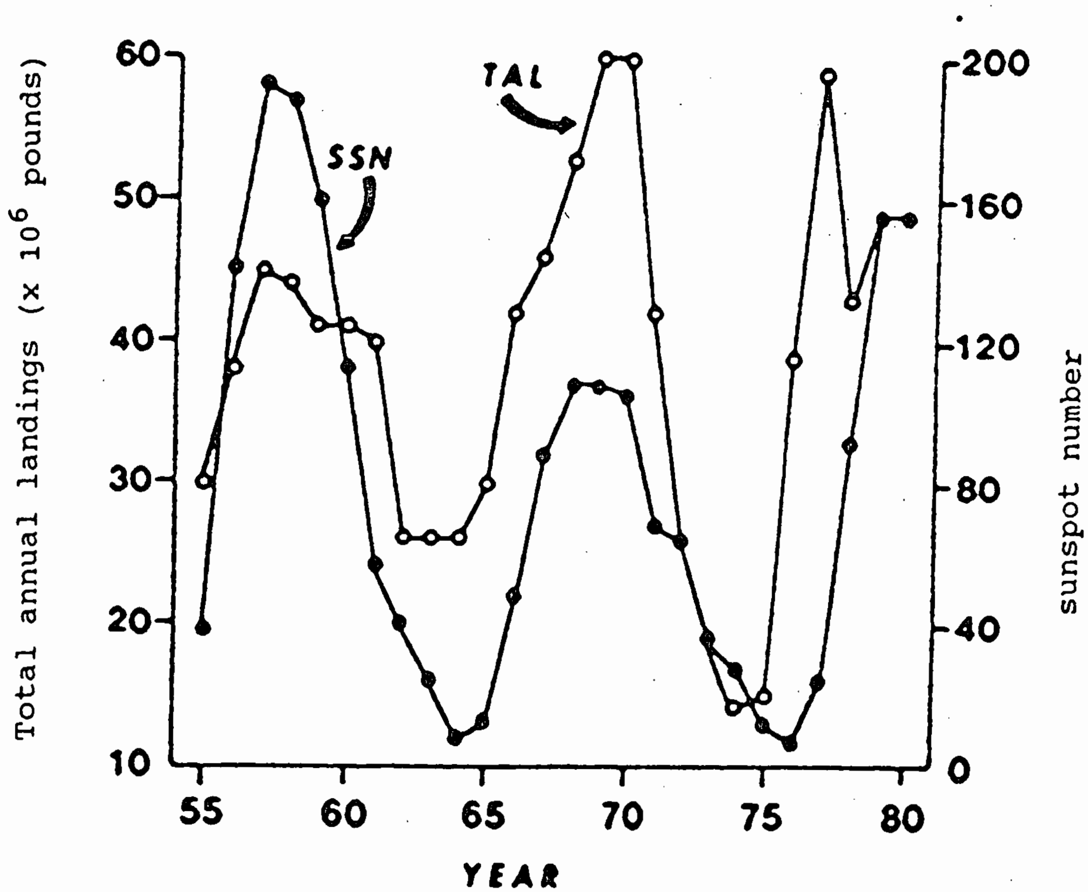

Figure 34. Total annual West Coast dungeness crab landings and mean annual sunspot numbers for the period 1955-1980. Redrawn from Love and Westphal (1981).

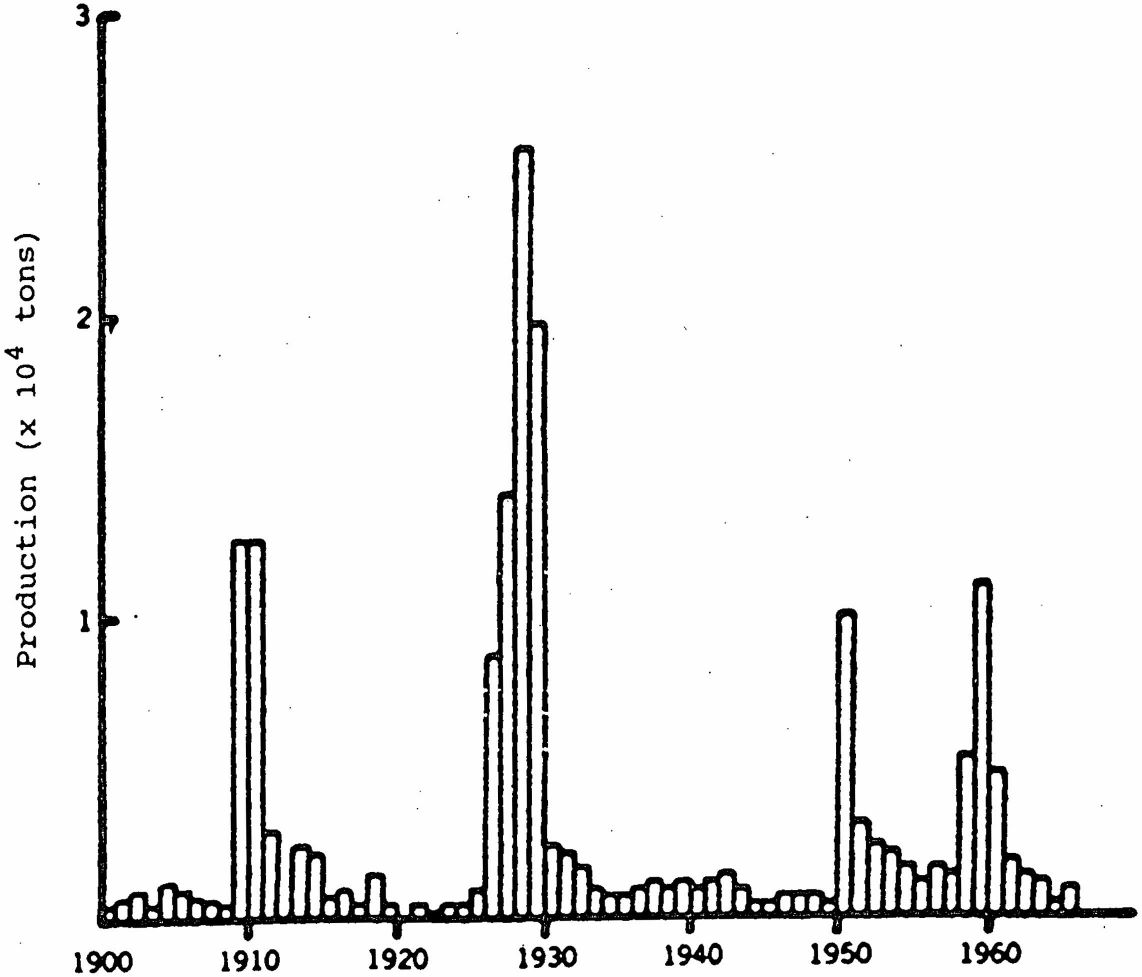

Figure 35A. Historical production of scallops in Mutsu Bay prior to culture method.

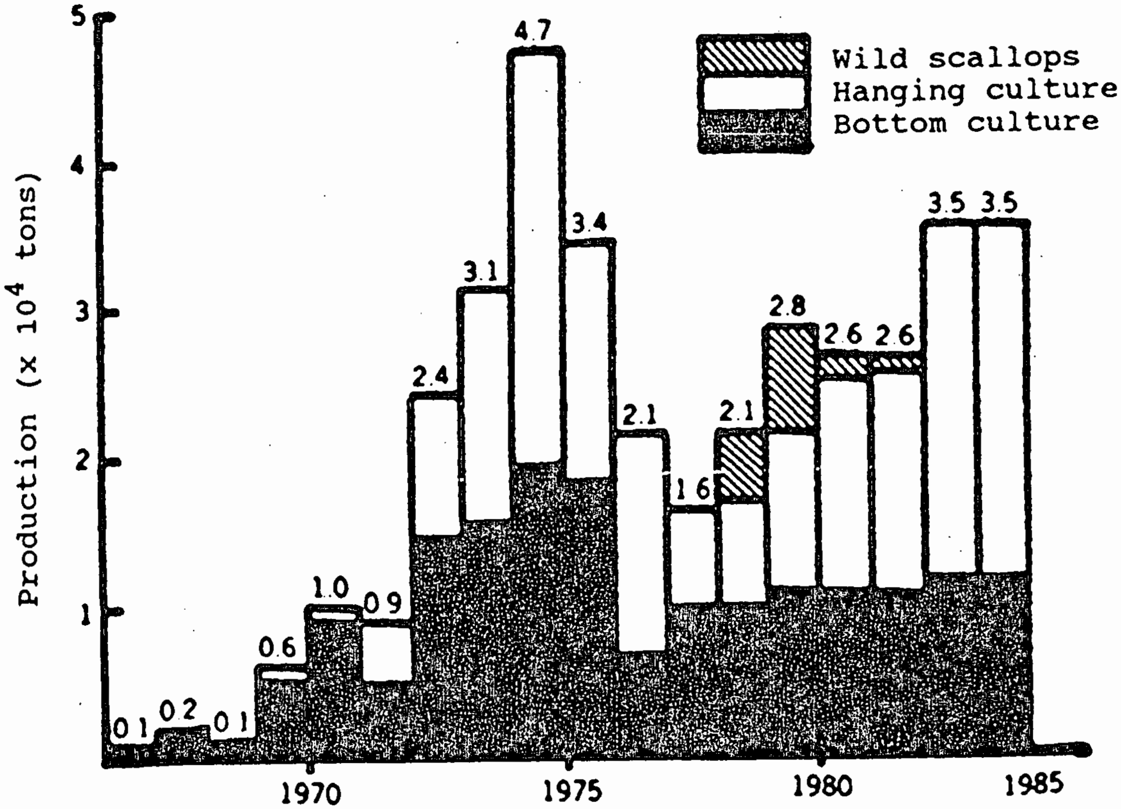

Figure 35B. Annual production of scallops in Mutsu Bay after introducing culture method.

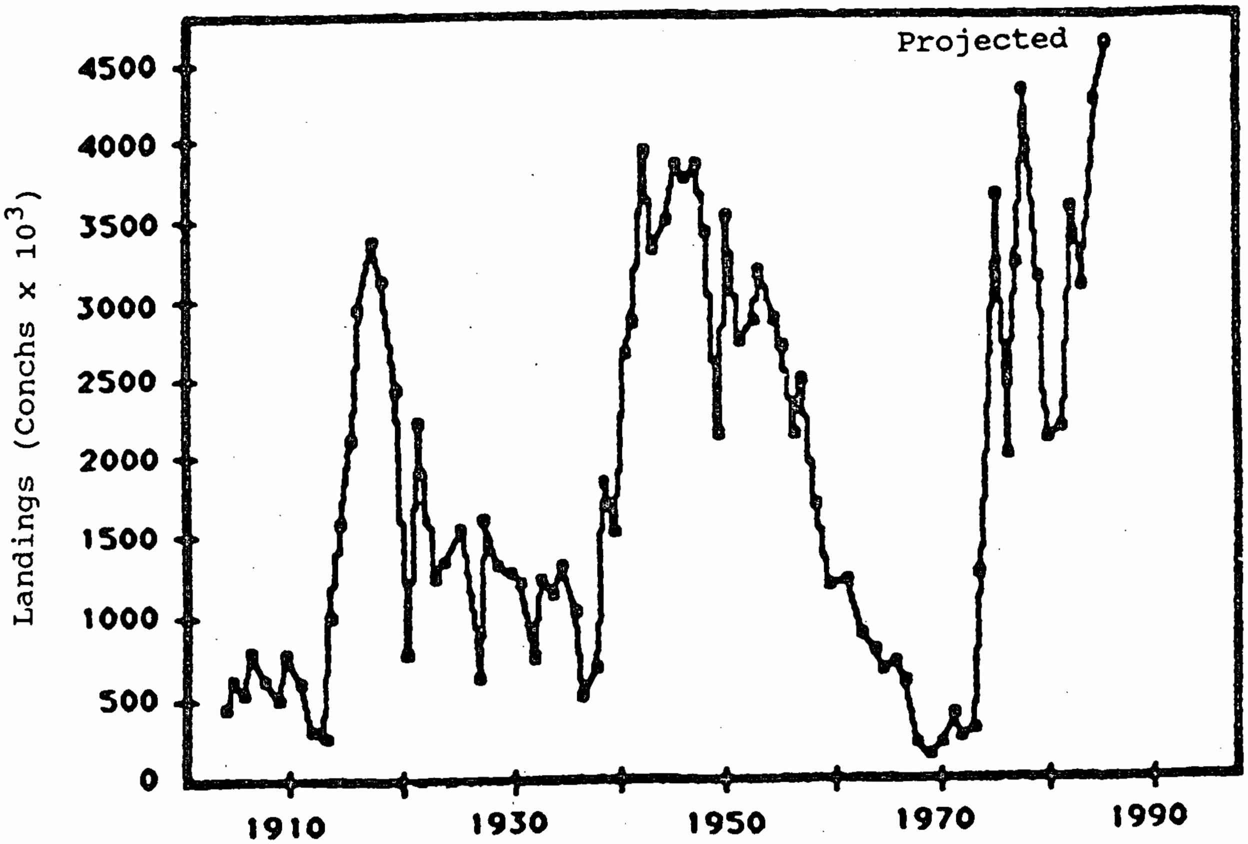

Figure 36. Conch landings (primarily export figures) in the Turks and Caicos Islands from 1904 to 1986. Values were given in thousands of conchs. The 1985-1986 landing was projected from April to August landings when normally 67% of the total annual figures was landed.

Akintonwa, A. and Ebere, A. G. (1990)

Toxicity of Nigerian Crude Oil and Chemical Dispersants to Barbus sp. and Clarias sp.

Bulletin of Environmental Contamination and Toxicology 45:729-733.

ABSTRACT:

During an oil spill, contingency arrangements are made to limit environmental damage. One method is the use of chemical dispersants which break up the oil slick into oil and water emulsions. Some of these dispersants have been shown to cause damage to the respiratory epithelium of fish gills. In order to estimate the environmental impact of oil spillage and of chemicals used in cleanup operations, the toxicities of crude oil and chemical dispersants alone and in combination were investigated. Asabo 16c crude oil and the chemical dispersants Teepol and Conco-k were tested using fish of the genera Clarias and Barbus. The LC_{50} was estimated by graphical interpolation and an approximate nomographic method. The calculated crude oil LC_{50} was 21.5, 16.5, and 8.6 $ml\text{-}L^{-1}$ for 24, 48, and 96 hour test periods, respectively. Conco-k had LC_{50}s of 11.5, 7.6, 5.7 $ml\text{-}L^{-1}$ and Teepol had LC_{50}s of 7.8, 6.0, and 5.9 $ml\text{-}L^{-1}$ for the same test periods. Combinations of crude oil and oil dispersant were more toxic than each chemical alone. Therefore, the use of an oil dispersant in the event of an oil spill calls for caution and evaluation of the impact on the fauna in the area.

Anderson, J. W., Kiesser, S. L. and Blaylock, J. W. (1980)

Cumulative effect of petroleum hydrocarbons on marine crustaceans during constant exposure

Rapports & Proces-Verbaux Reunions Conseil Int Explor. Mer. 179:62-70. (Paper presented at ICES Workshop Biological Effects Marine Pollution and Problems of Monitoring, Beaufort, N. C. 1979)

ABSTRACT

A constant hydrocarbon exposure system was used to obtain mortality and hydrocarbon accumulation data for three species of marine crustaceans. Extracts of Prudhoe Bay crude oil containing 98% aromatics, which were largely (94%) monoaromatics, produced 50% mortality in mysids (Neomysis awatschensis), and two shrimp species (Hippolyte clarkii and Pandalus danae) in periods of 0-5 to 9 days at concentrations ranging from 0.36 to 6-35 ppm total hydrocarbons. The product of time (in days) and LC_{50}

concentration (in ppm) was used as a "toxicity index" for a given species. These values (in ppm-days), plotted on a log-log regression, produce a linear (r = 0.86-0.92) relationship with a common slope of -1.27. The formula, X_1 $d._{27}Y = C$, described the sensitivities of the three species, where C varied from 2-6 for mysids to 8-14 for Hippolyte. This relationship allows prediction of mortality over intervals likely associated with oil spills

Anderson, J.W., Kiesser, S.L., McQuerry, D.L. and Fellingham, G.W. (1985)

Effects of oil and chemically dispersed oil in sediments on clams

Proceedings - 1985 Oil Spill Conference: Prevention, Behavior, Control, Cleanup: American Petroleum Institute, pp. 349-353.

Abstract:

Several field experiments with natural sediments in the intertidal zone were conducted over a two-year period to compare the effects of Prudhoe Bay crude oil and this same oil dispersed with Corexit 9527 (1 part Corexit to 10 parts oil) on the clams, Protothaca staminea and Macoma inquinata. Exposure periods ranged from one to six months. In a one-month exposure to about 2,000 parts per million (ppm) total oil in sediments, survival of P. staminea was two to three times greater than that of M. inquinata, and both species exhibited lower tolerance to oil alone than dispersed oil at the same concentration. However, uptake of naphthalenes and phenanthrenes by M. inquinata was greater from sediments mixed with dispersed oil than oil alone. Dispersed oil in this 30-day exposure also produced a decrease (compared to field controls) in the concentration of some of the free amino acids in the tissues of M. inquinata. Four- and six-month field exposures of small P. staminea to sediment containing oil or dispersed oil (about 2,000 ppm) reduced growth in both treatments (four-month exposure) or the chemically dispersed oil treatment (six-month exposure). In the latter experiment initial petroleum concentrations in the surface sediments (top 3 centimeters) were higher (about 3,000 ppm) for the dispersed oil than for oil alone. Surface layers in both conditions were free of contamination (down to 6 cm) after six months.

Anderson, R.C. and Meade, N.F. (1981)

Measuring the Economic Impacts of the Amoco Cadiz Oil Spill: Overview and Status Report. (In French)

Amoco Cadiz : Fates and Effects of the Oil Spill. Proceedings of the International Symposium. Centre Oceanologique de Bretagne, Brest. (November 19-22, 1979) pp. 849-854

ABSTRACT

NOAA in cooperation with several French and American universities and research institutions sponsored an economic damage assessment of the Amoco Cadiz oil spill to develop and test a series of methodologies for measuring the most significant economic costs associated with major oil spills. Categories for which cost estimated were made include: cleanup operations; market valued social costs such as commercial fishing, kelp production, tourism and aquaculture; and non-market social costs such as recreation and esthetis. No attempt was made to establish economic values for damages to wildlife except to the extent that it was indirectly included in the above categories. This paper describes the methodologies used to establish the economic damages in each of the above categories and discusses some practical problems that were encountered in carrying out the assessments.

Aneer, G. and Nellbring, S. (1982)

A SCUBA-diving investigation of Baltic herring (Clupea harengus membras L.) spawning grounds in the Askoe-Landsort area, northern Baltic proper.

J. Fish. Biology 21:433-442;

ABSTRACT

In a spawning area survey in the Askoe area, northern Baltic proper, transects established at the beginning of summer were sampled and studied by diving. Herring spawn was found at 45 of the transects. The eggs were usually found on Pilayella littoralis, a filamentous brown algae, at the more exposed transects. Eggs were only found down to a depth of 11 m. In a neighbouring oil spill area spawn were found at only four out of 20 transects. Of eggs taken to the laboratory for hatching, 54% of those from the unaffected area hatched but only 25% of those from the oil spill area.

Anon, P. (1987)

Oil spill into the marine ecosystem. (in Spanish) Original title: (Derrame de petroleo en el ecosistema marino)

Pesca 48:33-36

ABSTRACT
The effects of the spill of 16,800 barrels of crude oil off Conchan (Peru) beaches were studied. Results showed that in sandy beaches the oil affected the benthic and intertidal communities, while in the rocky beaches, oil had a continuum effect on the algae. The oil remains in the open sea 18 days after the spill affecting the artisanal fishing. Mollusks, crustaceans and echinoderms showed oil traces ranging from 0.10-0.20 micrograms per organism.

Appeldoorn, R. S. (1981)

Response of soft-shell clam (Mya arenaria) growth to onset and abatement of pollution.

J. Shellfish Res. 1:41-49

ABSTRACT
Length-frequency analysis was used to generate age-length curves for six populations of the soft-shell clam Mya arenaria exposed to a sudden pollution event. Five populations were each subjected to a single oil spill. A sixth population was subjected to the onset and subsequent abatement of the effluent from heavy metals mining. With one exception, the onset of pollution was accompanied by a noticeable break in the age-length curve representing a decrease in growth rate following the event. At the site where abatement occurred, the age-length curve showed a second break indicating resumption of near-normal growth. An attempt is made to relate severity and persistence of the pollution effect on growth to the degree of deflection in the age-length curve. A method that estimates prepollution growth is presented and applied to two populations.

Atlas, R.M. (1982)

Microbial hydrocarbon degradation within sediment impacted by the Amoco Cadiz oil spill.

Ecological Study of the Amoco Cadiz Oil Spill: Report of the NOAA-CNEXO Joint Scientific Commission (Gundlach ER and M Marchand eds) pp. 1-25

ABSTRACT
The wreck of the Amoco Cadiz in March 1978 released over 210,000 tons of oil into the marine environment. As much as one third of the spilt oil may have been washed into the intertidal zone. The spill occurred during storm

surges, thereby spreading the oil throughout the intertidal zone. Two years after the Amoco spill, the wreck of the tanker Tanio resulted in another oil spill that contaminated much of the same Brittany shoreline impacted by the Amoco Cadiz . This study was undertaken to determine the fate of petroleum hydrocarbons within surface sediments along the Brittany coast with reference to the role of microorganisms in the oil weathering process.

Atlas, R.M.A, Horowitz, A. and Busdosh, M.

Prudhoe Crude Oil in Arctic Marine Ice, Water, and Sediment Ecosystems: Degradation and Interactions with Microbial and Benthic Communities'

J. Fish. Res. Board Can. 35:585-596.

ABSTRACT:
A variety of in situ models were used to simulate oil spills in different arctic ecosystems. Numbers of oil-degrading microorganisms increased after oil contamination. Oil contamination of sediment resulted in mortality of indigenous invertebrates. Recolonization of oil-contaminated sediments began shortly after oil contamination but benthic communities were significantly different in oil-contaminated sediment compared with the control, 2 months later. Petroleum hydrocarbons were degraded slowly. Ice greatly restricted losses of light hydrocarbons. Following initial abiotic losses, biodegradation of oil was limited and did not significantly alter the relative percentages of hydrocarbons in the residual oil. The authors concluded that petroleum hydrocarbons will remain in arctic ecosystems for prolonged periods after oil contamination.

Badin, P. H. and Boucher, D. (1983)

Medium-term evolution of meiobenthos and chlorophyll pigments on some beaches polluted by the Amoco Cadiz oil spill. (in French)
Original Title: (Evolution à moyen terme du meiobenthos et des pigments chlorophylliens sur quelques plages polluees par la maree noire de l'Amoco Cadiz)

Oceanol. Acta. 6:321-332

ABSTRACT
The ecological monitoring undertaken after the Amoco Cadiz oil spill (16 March 1978), on the beaches Brouennou and Corn ar Gazel (mouth of Aber Benoit) and Kersaint (near Portsall), was continued monthly until November 1980.

Chlorophyll pigments were found to have suffered little, quantitatively, from the direct effect of pollution, but the study of temporal variations in meiofaunal densities revealed disturbances in seasonal cycles. Other factors, e.g. hydrodynamic fluctuations and macrofaunal predation, may have acted as regulating mechanisms on the evolution of the populations. The effects of pollution are particularly evident in certain faunistic imbalances, as the study of harpacticoid copepods showed. However, particular evolutionary trends between and within ecological groups of species implied that recovery was nearly complete, at least on exposed beaches.

Baker, J.M, Clark, R.B., Kingston, P.P. and Jenkins, R.H. (1990)

Natural Recovery of Cold Water Marine Environments After an Oil Spill

Presented at the Thirteenth Annual Arctic and Marine Oil Spill Program Technical Seminar 111pp.

ABSTRACT

This review of the published literature examines natural cleaning and natural recovery of ecosystems and biological communities following oil spills in cold water regions of the world. The scientific literature permits generalisations to be drawn; but oil spills in exceptional circumstances may produce exceptional effects. In a number of cases, long-term studies of recovery processes are incomplete, and recovery time scales suggested involve some extrapolation.

Barry, M. and Yevich, P.P. (1975)

The Ecological, Chemical and Histopathological Evaluation of an Oil Spill Site, Part III: Histopathological Studies

Marine Pollution Bulletin 6:171-173

ABSTRACT:

In July 1971 when approximately 25% of the clams in Long Cove, Searsport, Maine, had been killed by the March 1971 oil spill, collections of surviving clams were made for histological examination. These studies were continued through 1974 and revealed a high incidence of gonadal tumours in clams contaminated by the oil. The area of highest oil impact correlated with the highest per cent of tumours. The tumours were found to be malignant neoplasms.

Baxter, R.E. (1971)

Earthquake Effects on Clams of Prince William Sound

The Great Alaska Earthquake of 1964, Vol. 3, Biology. National Research Council, National Academy of Sciences, Washington, DC.

ABSTRACT:

The changes in land elevations associated with the Alaska earthquake of 1964 affected the intertidal populations of hard-shell clams in Prince William Sound. Mortality was estimated at 36 percent. Studies established that 29 percent of the surviving hard-shell clams were in the optimum habitat zone between mean low water and lowest low water; before the earthquake 82 percent of the hard-shell clams were in the optimum zone. No species of hard-shell clam is in danger of disappearing from the fauna of Prince William Sound. Ninety-nine species of pelecypods were tentatively identified during studies in the Sound.

Bayliss, R. and Spoltman, R. (1981)

The wreck of the Lee Wang Sin

Proceedings - 1981 Oil Spill Conference: Prevention, Behavior, Control, Cleanup American Petroleum Institute, Washington, D.C. pp. 221-226.

ABSTRACT

Environmental effects and cleanup efforts involved in Alaska's largest (length of shoreline affected) marine oil spill are recounted. Some 2,381 to 7,143 barrels of heavy bunker fuel and diesel oil were released during high winds into Alaskan and Canadian waters as a result of the 1979 Christmas Day capsize of the Taiwanese ore freighter, M/V Lee Wang Sin, off the southern edge of the Alaska anhandle. Over 350 miles (mi) of shoreline were contaminated within a week of the accident, and oil slicks identified as products of the spill were sited a month later, 210 mi north of the vessel's grounding site off the southeast tip of Prince of Wales Island. While being towed to a deep-water burial site, the vessel unexpectedly sank 8 mi from an internationally known sea bird sanctuary. Overall, many sensitive fish, mammal, bird, and shellfish resources were potentially impacted, furbearers and waterfowl, probably most seriously. Moreover, severe weather conditions and rugged terrain presented unique problems for cleanup operations, access, and logistics.

Belkhir, M. and Hadj Ali Salem, M. (1986)

Oil Spill Dispersant Toxicity on Fish and Mollusc

Bulletin de l'Institut National Scientifique et Technique d'Oceanographie et de Peche BNSSEE, 13:13-18

ABSTRACT:
The toxicity of dispolene 32S (an oil spill dispersant) was tested on three kinds of fish (Mugil ramada, Atherina hepsetus, Aphanius fasciatus) and two kinds of Mollusks (Mytilus gallanrovincialis and Tanes decussatus). Determination of LC_{10}, LC_{50} and LC_{90} shows that dispolene 32S is very toxic and can be considered as a harmful product even when used at low levels. The reaction time differs from one test organism to another; Mugil and Atherina were more sensitive than Aphanius and the mollusks were the most resistant of the organisms tested.

Blackman, R.A.A. and Law, R.J. (1981)

The Eleni V Oil Spill: Return to Normal Conditions.

Marine Pollution Bulletin 12:126-130

ABSTRACT
The fate and effects of Eleni V oil spilled in May 1978 was followed until May 1980. At a mechanically-cleaned and exposed beach the hydrocarbon concentrations of inshore water and mussel tissue returned to background values between 300 and 400 days after the beaches became visually clean. Oil remaining on the surface of a protected beach still showed little degradation compared to oil buried in a disposal pit. Even on mobile beaches subject to high wave-energy, mechanical retrieval and clean-up of such a persistent heavy fuel oil is considered necessary unless its redistribution by wave action over adjoining beaches and into sediments is considered acceptable.

Blumer, M., Sanders, H.L., Grassle, J.F. and Hampson, G.R. (1971)

A Small Oil Spill

Environment 13(2):2-12

ABSTRACT:
Oil pollution of the ocean is an increasingly serious global problem. The oils in petroleum are different in composition and toxicity from those occurring naturally in living marine organisms. These differences present a threat to ocean life and ultimately to human welfare, particularly in view of the scope of today spills in coastal waters and harbors of the world produce chronic pollution much larger in volumn and probably more severe in biological consequences. Chronic oil pollution contaminates nearshore waters that are the key to the survial of most marine animals that are taken for man's food. Over a long period of time, this persistent pollution may interfere with the normal life processes of the organisms, as well as killing them outright at high concentrations. The result may be progressive disappearance of usually abundant fish and shellfish. Their decline would be accompanied by an increase in pollution-tolerant species that generally indicate an unhealthy state of biological affairs. Furthermore, remaining organisms of food value to man may be permanently contaminated with petroleum hydrocarbons that could be hazardous to health.

Blumer, M. and Sass, J. (1972)

Oil Pollution: Persistence and Degradation of Spilled Fuel Oil

Science 176:1120-1122

ABSTRACT
In September 1969, approximately 600 metric tons of number 2 fuel oil were spilled in Buzzards Bay, Massachusetts. Two years later, fuel oil hydrocarbons still persisted in the marsh and in offshore sediments. Hydrocarbons degradatioon is slow, especially below the immediate sediments surface and appears to proceed principally through microbial utilization of alkanes and through partial dissolution of the lower-boiling aromatic hydrocarbons. The boiling ranges of the spilled oil and the relative abundances of homologous hydrocarbons (for example, phytane and pristane) have been well preserved. The findings are in agreement with the known geochemical stability of hydrocarbons. Fuel oil is an appreciable fraction of whole crude oil. This fact suggests that oil product and crude oils have a considerable environmental persistence.

Bodennec, G., Pignet, P., and Caprias, J.C. (1983)

The Tanio oil spill. Chemical survey of the oil pollution in water and sediments from March 1980 to August 1981(French) Original Title: (Le Tanio - Suivi chimique de la pollution petroliere dans l'eau et les sediments)

Rapp. Sci. Tech. 52, 108 pp CNEXO; Paris

ABSTRACT

After the Tanio wreck (March 1980) in northern Brittany, oil pollution was surveyed during 3 months in seawater, and during 16 months in intertidal sediments. Dynamic processes (wind and tides) and coastal geomorphology have controlled pollution of the coast line. Sediments were analyzed by glass capillary gas chromatography and contained oil residue for a long time. Bunker C oil weathering is slower than for a light crude oil. Microbial degradation appeared to be a major weathering process.

Bodin, P. (1988)

Results of ecological monitoring of three beaches polluted by the `Amoco Cadiz' oil spill: development of meiofauna from 1978 to 1984

Mar. Ecol. Prog. Ser. 42:105-123

ABSTRACT.

Following the `Amoco Cadiz' oil spill, time-series sampling of the meiofauna was carried out from 1978 to 1984 in the intertidal zone of 3 sandy beaches on the northern Finistere coast (Brittany, France). Quantitative analysis documented 2 principal phases in the development of the main taxa (Nematoda and Copepoda). First came a degradation phase leading to impoverishment in density and diversity of the populations. This first phase could be subdivided into several stages corresponding mainly to the toxicity period and. on one beach (Kersaint), to a summer `bloom'. Then came a recovery phase corresponding to a quantitative and qualitative reconstitution of the meiofaona. Each phase lasted a greater or lesser time according to station exposure and the considered taxon. A qualitative analysis of harpacticoid copepods illustrated the development of population diversity and `ecological groups'. During the first phase, replacement of the original populabon by a substitute fauna was observed. Correspondence factorial analysis on the development of harpacticoid communities allowed a better understanding of the main pollution and recovery factors such as toxicity, organic matter. hydrodynamism and zoological groups Meiofauna. particularly harpacticoid copepods, are significant bioindicators of ecological disturbances.

Bodin, P. and Boucher, D. (1982)

Mid-term evolution of meiobenthos and microphytobenthos on beaches touched by the Amoco Cadiz oil spill. (in French) Original Title: (Evolution a moyen-terme du meiobenthos et du microphytobenthos sur quelques plages touchees par la maree noire de l'Amoco-Cadiz)

Ecological Study of the Amoco Cadiz Oil Spill: Report of the NOAA-CNEXO Joint Scinetific Commission pp. 245-268

ABSTRACT

The ecological follow-up undertaken after the Amoco Cadiz oil spill, on the beaches Brouennou and Corn ar Gazel (mouth of Aber Benoit) and Kersaint (near Portsall), was continued until November 1980. Chlorophyll pigments have suffered little quantitatively from the direct effect of pollution, but the study of temporal variations in the meiofaunal densities revealed disturbances in seasonal cycles. Other factors, e.g. hydrodynamic fluctuations and macrofaunal predators, could act as regulating mechanisms on the evolution of the populations. The effects of pollution are particularly obvious in some faunistic imbalances, as the study of harpacticoid copepods showed. However, particular evolutionary trends between and within ecological groups of species implied that recovery was nearly complete, at least on exposed beaches. The conclusions drawn to date are tentative because of the lack of reference data, and it is intended to continue the survey annually in spring.

Bodin, P. and Boucher, D. (1981)

Temporal Evolution of Meiobenthos and Microphytobenthos on Some Beaches Polluted by the Amoco Cadiz Oil Spill (French). Original Title: (Evolution Temporelle du Meiobenthos et du Microphytobenthos sur Quelques Plages Touchees par la Maree Noire de l'Amoco Cadiz)

Amoco Cadiz: Fates and Effects of the Oil Spill. Proceedings of the International Symposium. (Centre Oceanologique de Bretagne, Brest, France; November 19-22, 1979) pp. 327-345

ABSTRACT

Meiobenthos and chlorophyllian pigments from the beaches of Corn ar Gazel and Brouennou (mouth of Aber Benoit) were studied from Sept. and Nov. 1978. Meiofauna was sampled regularly from March 1978, on the beach of Kersaint, near Portsall. Temporal variations of density of meiofauna and quantity of chlorophyllian pigments seem to show that microphytobenthos and meiofauna are more sensitive to the main ecological factors: hydrodynamism and climatic variations than to the oil pollution of Amoco Cadiz .

Bodin, P. and Le Moal, Y. (1982)

Short-term effects on meiofauna and macrofauna, of the clearing of a beach polluted by hydrocarbons with utilization of an oil spill dispersant.(in French) Original Title: (Effets a court terme, sur la meiofaune et la macrofaune, du nettoyage d'une plage polluee par les hydrocarbures avec utilisation d'un dispersant)

Acta Oecol. 3:263-280

ABSTRACT

At the opportunity of a field experimental cleaning on a polluted beach by a recent oil spill dispersant (Finasol OSR-5), variations of meio- and macrofauna were observed during a month. Effects have resulted in an important reduction of densities, with complex fluctuations the modalities of which are discussed. A month after the cleaning, the population has not completely recovered.

Boehle, B. (1986)

Avoidance of petroleum hydrocarbons by the cod (Gadus morhua).

Fiskeridir. Skr. (Havunders.) 18(3):97-112. (Paper presented at national symposium on the behavior of marine animals, Solstrand, Norway, 9-10 Feb. 1983.

Abstract

The experimental fish (G. morhua) were held in two different aquaria, one with three and one with two compartments. Water containing water soluble fraction of Fuel Oil No. 2 was introduced in one of the compartments. By means of light- and sound-based detectors, the amount of time spent by the fish in the various compartments was recorded. Although the results were somewhat contradictory, it seems that the fish avoided water containing more than 100 ug-L^{-1} of the petroleum hydrocarbons.

Boehm, P.D. (1982)

AMOCO Cadiz Analytical Chemistry Program

Ecological Study of the AMOCO Cadiz Oil Spill pp. 35-99.

ABSTRACT:

As part of the NOAA/CNEXO research program to examine the longterm fates and effects of the AMOCO CADIZ oil spill, samples of frozen intertidal surface sediment, sediment cores, oysters, flatfish and macroalgae were examined by gas chromatography and mass spectrophotometry to study the weathering of AMOCO CADIZ oil, persistent marker compounds residues in tissues and environmental variability of oil pollution. Results showed that oil was weathered rapidly by biodegradation and evaporation. Oil was buried in most sedimentary environments with burial and/or penetration down to 15 cm in fine-grained sediments and 20-30 cm in sandy sediments. Offshore sediments were impacted after the shoreline impact through leaching, sorption on intertidal sediments and offshore transport of these sediments. The presence of unresolved material, pentacyclic triterpanes, and alkylated phenanthrene and dibenzothiophene compounds is characteristic of AMOCO CADIZ oil in sediments. Identifiable AMOCO CADIZ oil residues persisted at the Ile Grande marsh. Oysters were initally heavily impacted by the spill and contained residues of AMOCO CADIZ oil even after 2 yr. Fish do not appear to have been directly impacted chemically by the oil spill to any significant exctent. Compositional profiles traceable to AMOCO CADIZ oil are likely to disappear from all sediments by the fourth year after the spill.

Boehm, P.D., Barak, J.E., Fiest, D.L., and Elskus, A.A. (1982)

A Chemical Investigation of the Transport and Fate of Petroleum Hydrocarbons in Littoral and Benthic Environments: The Tsesis Oil Spill.

Mar. Environ. Res. 6:157-188.

ABSTRACT

The fate of saturated and aromatic hydrocarbons discharged into the coastal Baltic Sea environment from the Tsesis oil spill was studied in the acute and post-acute (one year) phases of the spill. Samples of <u>Mytilus edulis</u> from littoral zone stations and <u>Macoma balthica</u> from soft bottom stations were obtained as well as sediment trap samples and surface sediment samples. Sediment trap samples indicated that sizable quantities of chemically and microbially weathered oil were sedimented, and available for benthic uptake shortly after the spill. After initial uptake of sedimented oil (500 to 1000 ug/g dry weight), Macoma populations appear to have begun slow depuration through the first winter after the spill, but Tsesis oil was again introduced to the benthic stations studied during the following summer. Mytilus populations were severely impacted by the oil.

Bohnsack, J.A. (1983)

Resiliency of reef fish communities in the Florida Keys following a January 1977 hypothermal fish kill.

Environ. Biol. Fish. 9:41-53

ABSTRACT

In January 1977, a record breaking cold spell caused fish kills at Big Pine Key, Florida. Census data collected before and after the cold spell from a series of model reefs constructed in 1975 showed a significant drop in mean number of reef fish species and individuals. Following this disturbance, high recruitment of juveniles occurred, presumably due to reduced competition, predation, or a combination of these. Model and natural patch reef communities examined the summer following the cold spell (1977) were significantly different from those examined the summer before (1976) and the second summer following the cold spell (1978). During the summer of 1977, a significantly smaller mean fish size and a significantly greater mean number of species and individuals were observed. Increased species richness following the cold spell is consistent with the intermediate disturbance hypothesis. Contrary to some theoretical predictions, results suggest reef fish communities are highly resilient to some regional disturbance.

Bonsdorff, E. (1981)

The Antonio Gramisci Oil Spill Impact on the Littoral and Benthic Ecosystems.

Mar. Pollut. Bull. 12:301-305

ABSTRACT

On 27 February 1979 the tanker Antonio Gramsci grounded off Ventspils (USSR) in the Baltic Sea. Some 5000-6000 t of crude oil were spilled, and drifted towards the archipelago of Stockholm (Sweden) and Aaland (Finland). About 500 t oil was mechanically recovered in Aaland area. The immediate effects were small in the uppermost littoral (the Cladophora

belt), but in the lower littoral (the Fucus belt) severe effects were recorded. Meiofaunal densities decreased in crustacean and mollusc species, but remained stable for the total community. Macrofaunal long- term changes could not be linked to the oil spill.

Brannon, E.L., Quinn, T.P., Whitman, R.P., Nevissi, A.E., and Nakatani, R.E. (1986)

Homing of Adult Chinook Salmon after Brief Exposure to Whole and Dispersed Crude Oil

Trans. Amer. Fish. Soc. 115:823-827

ABSTRACT:

Adult chinook salmon Oncorhynchus tshawytscha that had returned to the University of Washington, Seattle, hatchery were exposed for 1 h to either whole Prudhoe Bay crude oil, a chemical dispersant, or chemically dispersed oil in fresh water. The oil exposure concentrations were higher than under oil spill conditions measured in the field. Members of the treatment groups and similarly handled controls were held for 1 day after exposure and then displaced downstream. Neither frequency of homing (72% overall) nor days to return to the hatchery (mean = 3.2 d) were affected by the treatments. Retention of some treated fish at the hatchery determined that longevity was sufficient to prevent significant bias in estimates of homing. Later in the season, homing speed increased and longevity decreased, but homing frequency remained relatively constant.

Broome, S.W., Seneca, E.D., and Woodhouse, W.W., Jr. (1988)

Tidal salt marsh restoration.

Aquat. Bot. 32:1-22

ABSTRACT

Coastal salt marshes occur in the intertidal zone of moderate to low energy shorelines along estuaries, bays and tidal rivers. They have ecological value in primary production, nutrient cycling, as habitat for fish, birds and other wildlife and in stabilizing shorelines. Disturbance by development activities has resulted in the destruction or degradation of many marshes. Awareness of this loss by scientists and the public has led to an interest in restoration or creation of marshes to enhance estuarine ecosystems. Recovery of marshes after human perturbation such as dredging, discharges of wastes and spillage of petroleum products or other toxic chemicals is often slow

under natural conditions and can be accelerated by replanting vegetation.

Brown, D.W., Friedman, A.J., Prohaska, P.G., and MacLeod, W.D., Jr. (1981)

Investigation of Petroleum in the Marine Environs of the Strait of Juan de Fuca and Northern Puget Sound. Part 2: Second-Year Continuation.

NOAA Tech. Memo. NOAA/OMPA; BOULDER, CO., 43 pp

ABSTRACT

An investigation was initiated in February 1977 to measure existing levels of petroleum hydrocarbons in the Strait of Juan de Fuca and Northern Puget Sound, and to investigate spatial and temporal trends in occurrence, concentration, and composition of petroleum-related hydrocarbons. Sediment and mussel samples from 19 stations located along shipping lanes in the Strait of Juan de Fuca and Northern Puget Sound were analyzed for alkanes and aromatic hydrocarbons. Although the sites were relatively free from petroleum contamination, hydrocarbons indicative of petroleum were found at Cherry Point, Sandy Point, March Point, False Bay, Dungeness/Three Crabs, Ediz Hook, Kydaka Point, and Baadah Point. A small oil spill in Port Angeles Harbor on 13 May 1979 afforded an opportunity to evaluate the premise that hydrocarbon concentrations in intertidal sediment and mussels can be used to monitor for spilled oil in this region.

Brown, R.S., Wolke, R.E., Brown, C.W. and Saila, S.B. (1979)

Hydrocarbon pollution and the prevalence of neoplasia in New England soft-shell clams (Mya arenaria).

Animals As Monitors Of Environmental Pollutants. Symposium On Pathobiology Of Environmental Pollutants: Animal Models And Wildlife As Monitors. pp. 41-51

ABSTRACT

Ecological, chemical, and pathological analyses were made on soft-shell clams from 10 New England sites of varying types and degrees of hydrocarbon pollution (nominal, oil spill, industrial and domestic sewage, and heavy metal). To date, over 1,300 clams have been histopathologically examined. Of these, 162 had neoplastic lesions. Clams from one site had predominately gonadal neoplasms, while the majority were of hematopoietic origin. Cells of both types

were markedly anaplastic, invasive, and appeared to have metastasized. The amounts of hydrocarbons found in both clams and sediments were in agreement with the ecological histories of the sites. The amount of hydrocarbons in clams was related to the amount in the associated sediments.

Brown, S. and Cooper, K.R. (1978)

Histopathological analyses of benthic organisms from the vicinity of the Argo Merchant wreck.

In the Wake of the Argo Merchant, Proceedings of a symposium. University of Rhode Island, Kingston, R. I. pp. 96-102.

ABSTRACT

An examination of marine life 2 mo after the spill found the following: a dead Cancer crab with a thick deposit of Argo Merchant oil coating the remnant gut; a moribund hermit crab; 1 Modiolus with mantle lesions of round, raised calcified nodules several mm in diameter adjacent to patches of Argo oil deposited on the internal shell surface; and 1/250 starfish with tarballs in the buccal cavity. Seven months following the spill, no oil was seen in 8 Cancer and 10 hermit crabs, 44 starfish, and 5 sea cucumbers, collected alive. One Modiolus, also visibly uncontaminated, had extensive calcium nodule formation on an adductor muscle and surrounding mantle. The effect of the Argo oil on marine life was minor, within the physiological tolerance limits of the macrobenthos.

Brown, B.J.; Evans, D.R. (1989)

Restoration of anadromous fish -- not as simple as it sounds.

Proceedings of Wild Trout, Steelhead And Salmon in the 21st Century (Guthrie D., ed.) Oregon State University Sea Grant. pp. 61-74

ABSTRACT

Restoration implies the recovery or rebuilding of something lost or destroyed. Once lost, genetically unique stocks of wild fish can never be recovered. To discuss restoration in a manner pertinent to management of wild salmon and steelhead, one must review the causes of habitat loss and destruction, because these must be reversed or their effects mitigated before reestablishment of fish runs becomes feasible.

Bulatov, O.A. (1989)

The Role of Environmental Factors in Fluctuations of Stocks of Walleye Pollock (Theragra chalcogramma) in the Eastern Bering Sea

Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models (R.I. Beamish and G.A. McFarlane, eds.) Can. Spec. Publ. Fish. Aquat. Sci. 108:353-357

ABSTRACT

Two periods of high abundance of walleye pollock have been observed between 1904-86: one in 1966-69 and another in 1983-85. Analysis of water temperature and solar activity patterns in the period after spawning indicated that the most abundant yearclasses appeared during the first years of warm periods, at the start of the ascending limb of the solar activity pattern. There was no relation between recruitment and abundance of spawners. It is anticipated that unfavourable environmental factors will result in a continual decline in pollock abundance from 1990 onward. Abundant year-classes will likely not occur until 2005 at the earliest.

Bunch, J. N. (1987)

Effects of petroleum releases on bacterial numbers and microhetero-trophic activity in the water and sediment of an Arctic marine ecosystem

Arctic 40(Suppl. 1):172-183

ABSTRACT

The effects of a petroleum slick and chemically dispersed petroleum on bacteria numbers and microheterotropic activity (uptake of glutamic acid by heterotrophic microorganism) were monitored in the water column and sediments of selected bays at Cape Hatt Northwest Territories. Observations were made between 1980 and 1983 as a component study of the Baffin Island [Canada] Oil Spill (BIOS) Project. These data were augmented by measurements of chlorophyll a, particulate and dissolved organic carbon and inorganic nutrients in the water column, while total organic carbon (TOC) was measured in the sediments in some years. Petroleum was released on two occasions in 1981. In the first release. nondispersed petroleum moved across the surface of test Bay 11 and adhered to the intertidal sediments at low tide. No significant effects were seen in chemical or microbiological variables measured in 1981 or 1982. During the second release in 1981, dispersed petroleum was carried by the current through the water of test Bays 9 and 10 and into the channel beyond. Measurements of Vmax (maximum velocity) of glutamic acid uptake in water samples taken in these bays during the release showed a transient decrease in Vmax compared with control Bay 7. Bacterial numbers were unaffected, as were variables measured in the sediment of test Bays 9 and 10 during and after the release. In vitro experiments with water samples demonstrated that a combination of petroleum and dispersant alone reduced the Vmax of glutamic acid uptake to a greater extent than petroleum alone. A bay-year analysis of variance between 1981 and 1982 demonstrated that TOC and bacterial numbers increased in the sediments of test Bay 9 over 1981, while the Vmax, of glutamic acid uptake remained constant. In control Bay 7 and test Bay 11, all variables decreased over 1981 except TOC in Bay 11. In 1983. trends in the sediments of Bay 9 were similar to those of Bay 7. In test Bay 11. petroleum beached on the intertidal one in 1981 was observed entering subtidal sediments between 1981 and 1983 and forming a decreasing gradation of petroleum concentrations from nearshore to offshore areas. TOC increased between 1982 and 1983. Microheterotrophic activity remained constant in Bay 11, although it decreased in Bays 9 and 7. Bacterial numbers increased in Bay 11 but decreased in Bays 9 and 7. It was concluded that the changes in Bay 9 in 1982 and in Bay 11 in 1983 were a consequence of perturbations by petroleum. Effects on the benthic macrofauna and flora increased the levels of detritus, and hence TOC, in the sediments. This caused changes in bacterial numbers and microheterotrophic activity.

Bunch, J.N., Harland, R.C., and Laliberte, J. (1981)

Abundance and activity of heterotrophic marine bacteria in selected bays at Cape Hatt, N.W.T. 1980. First report to the Baffin Island Oil Spill (BIOS) Project.

Can. Manuscr. Rep. Fish. Aquat. Sci., no.1611, 81 pp

ABSTRACT

On the basis of bacterial abundance and activity, three bays at Cape Hatt, N.W.T., were judged to be similar and therefore suitable for comparative microbiological studies during and after experimental petroleum spills in 1981. Variations in values between the sediments of stations and bays for Vmax, total count and total viable heterotrophs were attributed to changes in the areas of sediment sampling and methods of collection. Mean total counts of bacteria appeared to reach a peak early in the open water season and then slowly decline, whereas the means of Vmax increased slowly across the sampling period to mid- September. Glutamic acid uptake at the sediment-water interface was

found to be different from uptake in the water immediately above the sediment.

Burns, K.A. and Knap, A.H. (1989)

The Bahia las Minas oil spill. Hydrocarbon uptake by reef building corals.

Mar. Pollut. Bull. 20:391-398

ABSTRACT

The authors report the analyses of hydrocarbons in the tissue of reef building corals, reef sediments and seawater samples collected in September 1986 as part of the initial impact assessment of a major oil spill in Panama. The patterns of gas chromatograms indicated the oil residues were highly modified in comparison with the oil spilled only 5 months before: volatile fractions and predominant n-alkanes were missing.

Burns, K.A. and Teal, J.M. (1979)

The West Falmouth Oil Spill: Hydrocarbons in the Salt Marsh Ecosystem

Estuarine and Coastal Marine Science 8:349-360

ABSTRACT:

Marsh surface sediments, cores, and organisms were analysed for hydrocarbons from one to seven years after the spill in September 1969 of No. 2 fuel oil at West Falmouth, Massachusetts. All organisms analysed showed contamination initially. Fundulus were nearly free of oil after one year but Uca remained heavily contaminated for at least four years. Alkanes disappeared in sediments after about 4 years while heavy aromatics and naphthenes persisted throughout the study.

Butler,, M.J.A. and Berkes, F. (1972)

Biological Aspects of Oil Pollution in the Marine Environment, A Review

Manuscript Report no.22, Marine Sciences Centre, McGill University Montreal (Quebec) 122pp.

ABSTRACT

A synthesis of some of the most significant research done on oil pollution and its biological effects is presented. The report includes farily extensive sections on petroleum hydrocarbons, solvent-emulsifiers, effects of oil pollution on birds, mammals, fish, sediment and marine communities and case studies of oil pollution including the Torrey Canyon disaster, the Santa Barbara oil spill and the Arrow accident. The geography of oil pollution is explored in such areas as the Baltic Sea, North Sea and Arctic Ocean. The study also aims to analyze the environmental implications of a series of hypothetical incidents that would be associated with activities involving oil exploration, exploitation, export and import, coastal movement and marine transportation activities and facilities.

Cabioch, L., Dauvin, J.C., Mora Bermudez, J.and Rodrigruez Babio,C.
(1980)

Effects of the Amoco Cadiz oil spill on the sublittoral benthos, north of Brittany. (in French)
Original Title: (Effects de la maree noire de l'Amoco Cadiz sur le benthos sublittoral du nord de la Bretagne)

14th European Marine Biological Symposium on Protection Life in the Sea. (Kinne, O.and H.P. Bulnheim, eds.) Helgol. Meeresunters. 33:192-208

ABSTRACT

Effects of hydrocarbons on the sublittoral macrobenthic communities have been observed through (1) studies of population dynamics of selected communities, conducted prior to the spill by the tanker "Amoco Cadiz" in spring 1978 and (2) comparisons between the situation in summer 1978 with that in earlier years, with continuation of the observations in some selected sites. The effect of the spill has been selective, involving a limited number of species, mainly crustaceans, molluscs and the sand urchin <u>Echinocardium cordatum</u>. The spill mainly affected communities on fine sediments and, to a lesser degree, those on mixed sediments. Notably, the destruction of the dominant populations of <u>Ampelisca</u>, in areas of fine sands in the Bay of Morlaix, has led to a marked decrease of biomass and production. Moreover, repopulation will be difficult because of the isolation of such communities on the southern side of the English Channel.

Cabioch, L., Dauvin, J.C., Gentil, F., Retiere, C. and Rivain, V. (1981)

Disturbances in the Composition and Functioning of Sublittoral Benthic Populations with the Impact of Amoco Cadiz Hydrocarbons. (in French)
Original Title: (Perturbations Induites Dans La Composition et le Fonctionnement des Peuplements Benthiques Sublittoraux, Sous l'Effet des Hydrocarbures de L'Amoco Cadiz)

Amoco Cadiz: Fates and Effects of the Oil Spill. Proceedings of the International Symposium. pp. 513-525

ABSTRACT

A quantitative and dynamic study of the populations undertaken one year before the Bay of Morlaix became polluted, provided a guide to bring together the interpretations. An essential part of the project was the study of the communities of fine sediments, most affected by the oil. The results obtained from the study of the first annual cycle after the pollution led to the following conclusions: All areas were impacted by a brief immediate phase of selective mortality, which affected a limited number of species (principally Crustaceans, Molluscs and Echinocardium) and which mainly disturbed the communities of the fine sediments; In the moderately disturbed sites, most of the surviving species followed afterwards an apparently normal annual cycle. Nevertheless, we observed some interruptions to the recruitment of some species; A transient proliferation or a more lasting rise in the density of certain Polychaetes (particularly the Cirratulidae and Capitellidae) was observed; At the end of the first annual cycle, recolonization by the most important species that had been eliminated had not yet taken place.

Cairns, J. Jr.

Lack of Theoretical Basis for Predicting Rate and Pathways of Recovery

Environmental Management 14:517-526

ABSTRACT

An inadequate basis for precisely predicting the outcome of lotic ecosystem recovery, whether due to unaided natural processes or management techniques or both. exists because: (1) The field of ecology has not yet matured as a rigorous predictive science; (2) The precise sequence of events, including climatic occurrences, affecting the recovery process may be unique events and thus rarely or never repeated; and (3) Even when attempts are made to

control the recolonization process through introduction of species, etc. the interaction of these species may not follow deterministic models. Although this symposium focuses on lotic ecosystems, such systems are influenced strongly by exports from the surrounding land mass and. under certain circumstances, this may be the overriding influence on the recovery process. Therefore, unless the boundary conditions are determined realistically, the recovery process may not follow desirable pathways. Despite the lack of a robust theoretical support base for lotic ecosystem recovery, some remarkable and rapid recoveries have occurred to either a close approximation of the original condition or to a condition ecologically superior to the damaged condition. In some cases, the recovery was due entirely to natural processes and, in others, often followed relatively straightforward management practices. There is evidence indicating that lotic ecosystem restoration is both cost effective and likely to produce satisfying results relatively rapidly. It is both fortunate that this is the case, since society is likely to support such efforts when the results have been extraordinarily successful, and unfortunate since restoration ecology needs a predictive capability.

Cairns, J. Jr. (ed.)

The recovery process in damaged ecosystems , Ann Arbor Science Publishers Inc.

ABSTRACT

Change is one characteristic of an ecosystem. Species composition, various rate processes, degree of complexity and the like all vary with time. Displacements in ecosystem structure and function may result from fire, floods, glaciation, changes in rainfall and a variety of other natural causes. Additionally, displacements may result from societal stresses such as toxic chemicals, clear cutting, dams and erosion. Ecosystems may recover from both types of displacement, although the recovery process will rarely produce a system identical to the original when societal stress is involved. Case histories of recovery from human-induced displacements exist for an array of ecosystems. Since displacement results when an environmental change occurs for which the organisms are unprepared, one might assume that the recovery process would be the same for both natural and societal stresses. It is also possible that the types of stresses produced by an industrial society inhibit recolonization more than naturally occurring stresses for which evolutionary adjustment has been possible. The symposium from which this volume emanates was organized to explore some characteristics of the recovery process. Since it was limited to one day of the Ecological Society of

America's portion of the American Institute of Biological Sciences annual meeting in Athens, Georgia, both breadth and depth were necessarily limited. The purpose of the symposium was to stimulate interest in restoring damaged ecosystems. The ESA meeting was an appropriate place to hold the symposium because without a sound ecological basis, restoration efforts will surely be less effective.

Cairns, J. Jr. (ed.)

Rehabilitating damaged ecosystems, Volume I-II CRC Press, Inc. Boca Raton, Florida

ABSTRACT

These volumes provide a series of case studies to describe the current status of ecosystem restoration. Future management options will be dramatically affected by the degree of skill used in providing research opportunities in ecosystems that industry is charged with rehabilitating or in derelict ecosystems where some level of government must accept this responsibility since it is legally impossible to assign this to an individual or a private institution. The young and rapidly developing field of restoration ecology has evolved to a sufficient degree to enable cost-effective and ecologically interesting restoration of ecosystems damaged by mining and other anthropogenic activities. However, it is abundantly clear that regulatory measures may impede the generation of an adequate scientific base for further development of the field. It is important for research investigators, regulators, industries, and other organizations charged with rehabilitation to realize that they have a common interest but that all will have to adjust to the needs of the others in order to achieve the desired results. These desired results should be (1) a cost-effective means of fulfilling the responsibility of rehabilitating the damaged ecosystems so that those charged with this responsibility meet the legal requirements for doing so; (2) the regulators must be able to demonstrate that they have fulfilled their responsibility to the public and to their superiors in the government at whatever level of government they represent; and (3) the research investigators must derive sufficient new information to justify publication in a peer-reviewed scholarly journal. It is apparent from wetlands and water management on mined lands, that, while we might do much better in this regard, a heartening degree of success has already been achieved.

The number of management options that can be implemented is a direct function of the size and reliability of the information base available. The scientific information base is not likely to increase at an acceptable rate unless a substantial amount of the money comes from nontraditional sources. Ecosystem rehabilitation is a major

undertaking and will require a level of funding not likely to become available from the National Science Foundation, the National Institutes of Health, or many of the other traditional sources. On the other hand, research investigators are not likely to solicit funds from nontraditional sources unless they can get the most critical of their needs met by them, namely (1) the ability to carry out experiments that can be published in scholarly peer-reviewed journals and (2) recognition by their peers that these efforts represent good science. Without this research effort, regulators will be enforcing requirements which in the present state of knowledge have a highly uncertain ecological outcome and may, in fact, frequently fail totally. In the absence of an adequate information base, industry is faced with a higher degree of uncertainty regarding rehabilitation costs and probable success than most industrial managers consider desirable. Therefore, both regulators and industrial groups can increase the certainty of the successful outcome of a rehabilitation effort and simultaneously satisfy the needs of research investigators if there is skillful communication about the needs that each group needs to have satisfied. This will not be an easy task because the basis of a satisfactory working relationship is mutual trust, and the three groups just mentioned have often been in contention rather than working effectively together. Nevertheless, industrial and university ties are increasing and, while there are some dangers to this process, there are also many opportunities. There has been a less significant development in interactions between regulators and universities, but even here there are some grounds for optimism. Many of the chapters in this book will show the state of the art methodology that will markedly influence present management options for rehabilitation of damaged ecosystems. The degree to which this relationship just described flourishes will, in large part, determine the future management options.

Cairns, J. Jr. and A.L. Buikema, Jr. (eds.)

Restoration of habitats impacted by oil spill Butterworth Publishers and Ann Arbor Science Book

ABSTRACT

Before general strategies for the recovery or restoration of damaged ecosystems can be discussed, a number of problems must be considered when attempting to restore ecosystems to original condition.

These problems include the following:

(1) Inability to define the "original condition of ecosystems long exposed to societal stresses,
(2) Inability to define long-term or genetic changes in populations that may preclude restoration to a previously known original condition,
(3) Lack of understanding of the natural variability in ecosystems,
(4) Lack of knowledge of ecosystem recovery processes, and
(5) Need to consider the cost/benefit ratio of restoring an ecosystem to its original condition or the return of selected amenities (e.g., recreation) at a substantial reduction in costs.

Case histories of the restoration and recovery of damaged ecosystems illustrate that restoration or rehabilitation of damaged ecosystems is within the biological and technological grasp of society, and alternatives are accepted by a public educated in the problems and cost/benefit ratios. The ability of an ecosystem to respond to perturbation depends on three characteristics: inertia (ability to resist change), elasticity (ability to recover), and resiliency (ability to recover after successive perturbations). These characteristics will vary from site to site. Consequently, management strategies will also vary on a site-specific basis. Unfortunately, we do not have the data base to quantify and qualify these characteristics adequately.

From reports on investigations with oil spills, we were able to rank habitats as to their vulnerability to oil spills and cleanup operations. Most marine habitats are highly vulnerable because their ability to resist change (inertia) is low; the same is true for the tundra and taiga. Many of these habitats are simple, with low species diversity and/or a high degree of specialized life strategies. For a similar reason, we considered fast-flowing freshwater systems to be vulnerable. Ponds were classed vulnerable because of their small size. In most instances, the recovery process for these systems is expected to be quite long.

The second crucial characteristic in ecosystem recovery and restoration is elasticity, or the ability to recover. The potential for recovery depends on at least five factors: (1) existence and proximity of biological epicenters; (2) dissemination potential of propagules; (3) habitat condition following stress; (4) presence of residual toxicants; and (5) the physical-chemical quality of the environment. The implementation of a management strategy should emphasize methods to enhance elasticity in the recovery process.

The last crucial characteristic is ecosystem resilience. Few data are available on the ability of an ecosystem to recover from frequent perturbation, especially with oils. Until data are generated, we must assume that the resiliency of many aquatic ecosystems is low. The first concern of an oil-related industry should be to inventory the aquatic ecosystems in the vicinity of drilling operations, shipping lanes, transport and refining facilities, etc. This inventory should also identify ecosystems some distance away that could also be affected during a spill because of prevailing winds, currents, or any factor capable of inducing oil transport. Once these ecosystems have been identified, they should be cataloged according to (1) size, (2) degree of shelter or wave energy; (3) proximity to similar ecosystems; (4) ecologically and/or economically important species that live in, or rely on, that ecosystem; (5) species that have long life cycles; (6) species that may be sensitive or tolerant to potential toxicants; (7) role of that habitat, i.e., erosion control or secondary productivity; and (8) estimate of the current ecological state of the ecosystem, i.e., is it stressed or how does it compare to similar sites nearby? This latter instance may be very difficult to estimate because little is known about the natural variability of healthy ecosystems.

Once this inventory has been completed, those ecosystems that are of little ecological value should be identified. Small ecosystems not near biological epicenters are more susceptible to perturbation effects, and recovery is expected to be slow because invasion by new organisms will be slow. These may not be worth restoring to their original condition. Ecosystems under long-term chronic stress may have changed so drastically that recovery to an original condition is impossible or not cost-effective. In any event, alternative plans should be established for these habitats so that cost-effective rehabilitation strategies can be established. The intent here is to return some amenities that are acceptable to society. This may include development of fishery reefs, recreation areas, etc.

The next concern should be to determine if mechanical, physical, or chemical means of preventing oil contamination are possible to protect the remaining ecosystems. This is most important for ecologically important ecosystems such as marshes, mangrove swamps, seagrass beds, coral reefs, and soft-bottom subtidal areas. In most instances, cleanup activities should not be used because the potential damage may be greater than if the system is allowed to recover naturally.

If protection of these ecosystems by mechanical, physical, or chemical means is not possible, then management strategies must be directed to facilitating the recovery process of damaged ecosystems. This can occur by a combination of restoration of habitat and/or organisms. One requirement for close, but discontinuous, ecosystems or for a large ecosystem is the establishment of appropriate biological epicenters so that reinvasion of existing flora and fauna can occur rapidly. This may require the establishment and maintenance during a spill of ecological preserves within the ecosystem in question. This may simply be an area that can be fenced off.

If ecological preserves within ecosystems are not possible, a more expensive alternative would be the establishment of ecological preserves, zoos, gardens, and nurseries where important species could be cultivated for the express purpose of restocking damaged areas. This concept could require only the culture of important indigenous species. However, the cultivation of early successional or pioneer species (especially plants) would be most important. These species could be used rapidly to stabilize a damaged area for subsequent recolonization by indigenous or climax species.

Whenever ecological preserves, gardens, or nurseries are established, emphasis must be placed on those species that can be easily transplanted and the life stage that can be most easily disseminated. For various similar plants and animals, the propagule may be different. This information, if known, must be inventoried so that cultivation methods are employed to guarantee an abundance of propagules in a timely manner.

Strategies for restoration must include an analysis of the habitat condition and methods for stabilizing these habitats. Most important is the prevention of erosion in those habitats that recover slowly. Other mechanisms for restoring habitat condition are also important, e.g., aeration may be necessary to prevent lethal effects due to a high biological oxygen demand.

Lastly, the most important factor in regulating recovery and restoration is the residual toxicity factor. Sediment particles readily pick up oils and, in the anaerobic environment of marshes, oxidation of oils is severely retarded.

Many information gaps were identified in this workshop, and the ubiquitous call for more research was not taken lightly. Information on recovery clearly is lacking because many postspill studies were not carried out for long periods of time, and these studies were not adequately designed to address the issues of quantification and qualification of impact. Most notable was the lack of studies on freshwater systems. While a number of attempts have been made to facilitate restoration and recovery of damaged ecosystems, the success rate has been variable because of the multitude of unknown or poorly understood factors affecting growth and reproduction of transplanted species. Research and our lack of information on ecosystem structure and function needs on the ecological requirements of critical species have been identified. Development of oil resistant strains of plants and animals would also enhance ecosystem recovery.

Cairns, J. Jr., K. L. Dickson, and E. E. Herricks, eds. (1977)

Recovery and Restoration of Damaged Ecosystems Proceedings of the International Symposium on the Recovery of Damaged Ecosystems University Press of Virginia, Charlottesville

ABSTRACT
A major concern in this country as well as the rest of the world is the environmental degradation caused by man's activities. Despite protective measures, environmental risks are steadily increasing. While countless discussions and innumerable papers have dealt with the causes and consequences of our damaging activities, this volume explores a different aspect of the topic: the prospects of recovery if damage does occur. An experienced group of international scientists contributed case histories, presented theories, and raised important questions related to the restoration and recovery of damaged ecosystems. The book focuses on three major topics: the nature of recovery processes for various ecosystems; identification of the elements common to the recovery process for all ecoystems, as well as the unique attributes in different kinds of ecosystems; and the prospects for accelerated recovery and restoration by human intervention and management. Individual chapters discuss the recovery of streams and lakes by natural and artificial methods; the reintroduction of plants and wildlife to damaged ecosystems; the role of fire in the natural growth of forests; environmental factors in surface mine recovery; the effects of oil spills and recovery from them; the recovery of tropical forest systems, tundra, and taiga surfaces; the recovery of cities; and the political problems inherent in environmental protection legislation.

Chan , G.L. (1975)

A Study of the Effects of the San Francisco Oil Spill on Marine Life, Part II: Recruitment

Proceedings 1975 Confeerence on Prevention and Control of Oil Pollution pp. 457-461

ABSTRACT
A study of marine organisms on intertidal transects was made to observe the effects of the San Francisco Bunker C oil spill of January 18, 1971. From a comparison of pre-oil and post-oil transect data, it was estimated that 4.2 to 7.5 million marine invertebrates, chiefly barnacles (Balanus glandula, Chthamalus dalli, and Pollicipes polymerus) were smothered by the oil. Other invertebrates included sea anemone, crabs, chiton, sea mussel and boring clam. In subsequent observations from 1972 to 1974, the sample counts of invertebrates had returned to , and in some cases surpassed pre-oil transect levels. No lingering effects of the oil spill were noted in any of the marine species.

Chan, G.L. (1977)

The Five-year Recruitment of Marine Life after the 1971 San Francisco Oil Spill

ABSTRACT

On January 18, 1971 two Standard Oil tankers collided underneath the Golden Gate Bridge, releasing about 840,000 gallons of Bunker C fuel. An estimated 4.2 million to 7.5 million intertidal invertebrates, chiefly barnacles, were smothered by the oil. Five-year observations of marine life recruitment following the spill indicate that population densities of some marine species have significantly increased in the San Francisco Bay area intertidal zones at Sausalito and Duxbury Reef. With some fluctuations, the barnacles Balanus glandula and Chthamalus dalli have increased from July 1971 to May 1976 from 93 to 189 barnacles per dm^2 at Sausalito and from nine to 34 per dm^2 at Duxbury Reef. The large bed of mussels, Mytilus californianus, showed a steady rise from 5.9 dm^{-2} in April 1971 to 14.0 dm^{-2} in July 1976. The density of mobile organisms such as limpets, snails and crabs all show cyclical variations: some show an overall increase. The limpet, Collisella spp. which suffered high mortality during the spill have increased threefold over pre-oil counts.

In 1975, some significantly low sample means were recorded for barnacles in Sausalito and for 18 composite species at Duxbury Reef, probably due to natural ecological forces. The five year recruitment (1971-76), however, shows no evidence of lasting detrimental effects of Bunker C oil on the populations of marine life within the transect sites.

Chasse, C. (1978)

The Ecological Impact on and Near Shores by the Amoco Cadiz Oil Spill

Marine Pollution Bulletin 9:298-301

ABSTRACT:

By comparison with previous pollution accidents and taking into account the enormous quantity of oil spilled at Portsall, the provisional balance sheet indicates rather less damage to the marine environment than might have been expected. There is now evidence that intertidally and close inshore direct mortalities have been localized, seldom heavy and always selective and partial. Contamination of organisms and products of commercial fisheries at sea have been transitory. Oyster culture alone has been badly damaged. The algal crop is now exploitable for industrial

use. The general cover of macro-algae has survived the incident.

Conan, G. (1982)

The long-term effects of the Amoco Cadiz oil spill.

Philos. Trans. Roy. Soc. Lond., Ser. B. 297:323-333; 1982

ABSTRACT

The supertanker Amoco Cadiz wrecked on the coast of northern Brittany in April 1978. The resulting spill of 223,000 t of crude oil polluted some 360 km of rocky or sandy shores, salt marshes and estuaries. Three to six generations may be necessary before populations retrieve their stable age distribution. Delayed effects on mortality, growth and recruitment were still observed up to 3 years after the spill. Estuarine flatfishes and mullets had reduced growth, fecundity and recruitment and were affected by fin rot disease. Populations of clams and nematodes in the meiofauna declined one year after the spill. Weathered oil is still present in low-energy areas. Species with short life cycles tend to replace long-lived species. A fauna of cirratulid and capitellid polychaete worms now prevails in sandy to muddy areas. For several clam populations, recruitment remains unstable. Three years after the spill it is still premature to decide how long it will take before populations and ecosystems reach their former or new equilibria.

Courtot, P. (1985)

Hydrocarbons evolution after the Amoco Cadiz oil spill. Observations and modelization. (in French)
Original Title: (Evolution des hydrocarbures apres l'echouage de l'Amoco Cadiz)

Strategies and Advanced Techniques for Marine Pollution Studies in the Mediterranean Sea (Giam C.S. and Doll H., eds.) p.8

ABSTRACT

After the crash of the super-tanker Amoco-Cadiz on March 17th 1978, on the reefs of the North Coast of Finistere (Portsail, Brittany, France), a three year program was established to follow the evolution of petroleum hydrocarbons at sea first and then in the sediments of a highly polluted river, Aber-Benoit. Infra-red for total hydrocarbons and capillary column gas chromatography for individual compounds were used, necessitating two liters seawater samples and 50 g sediment. Water and sediment of Aber Benoit were found to contain both petroleum and recent biogenic hydrocarbons. Resuspension of particles play an important role in redissolution of hydrocarbons in water and a study was undertaken of the influence of different parameters on physico-chemical absorption conditions (porosity, size and type of clays and sands-salinity and temperature). The main results of this study will be given.

Clark, R.C., Jr., Finley, J.S., Patten, B.G., Stefani, D.F., and DeNike, E.E. (1973)

Interagency Investigations of a Persistent Oil Spill on the Washington Coast

Prevention and Control of Oil Spills, Proceedings of Joint Conference, Washington DC, pp. 793-808.

ABSTRACT

An interagency team of biologists, chemists, oceanographers and engineers investigated the long-term effects of oil spilled by the grounding of the troopship General M.C. Meigs January 6, 1972, on an ocean coast intertidal community of plants and animals. Oil was released from the 440,000 liters of Navy Special Fuel Oil carried by the vessel. A series of sites, forming a vertical profile of the rocky shelf area from the upper intertidal zone to the lowest low tide level in Wreck Cove was studied. This report describes the preliminary findings of the first ten months (January-October, 1972) of the investigation. Abnormal and dead urchins indicated that this species was affected. Loss of fronds and bleached thalli not evident in control areas were observed in the plant community in the immediate vicinity of the hulk. Petroleum hydrocarbons were taken up in the intertidal community. The normal paraffin hydocarbon patterns and content over the range n-C14H30 to n-C37H76 of healthy-appearing barnacles, crabs and alga display the same basic characteristics as the released fuel oil.

Cox, G.A., Barnett, A., Gould, J.R., Hay, K.G., Hirota,J., McAuliffe, C.D. and Michael, A.D. (eds). (1979)

Oil spill studies: Strategies and techniques

Journal of Environmental Pathology and Toxicology 3, 146 pp.

ABSTRACT

An Oil Spill Studies: Strategies and Techniques Workshop (055) convened to organize and summarize current

techniques and suggest samping strategies to study the effects of oil spills on marine and estuarine biota. 055 was designed to provide marine scientists with the collective field and analytical experience of researchers in this field. Massive petroleum releases to the marine environment, not continual, chronic spillage was addressed. 055 participants strongly endorsed the concept of a few comprehensive studies of oil spillages rather than many inconclusive studies which are the current norm. The following research areas were covered information management, chemistry, plankton, benthos, and fish, birds, marine mammals and sea turtles. Individual study recommendations are given for each study area.

Cretney, W.J., Green, D.R., Fowler, B.R., Humphrey, B., Engelhardt, F.R., Norstrom, R.J., Simon, M., Fiest, D.L. and Boehm, P.D. (1987)

Hydrocarbon biogeochemical setting of the Baffin Island Oil Spill experimental sites. 3. Biota.

ARCTIC 40:71-79

ABSTRACT
A baseline for petroleum residues in the Cape Hatt region of Baffin Island in arctic Canada was obtained in anticipation of controlled oil releases of the Baffin Island Oil Spill (BIOS) Project. Tissue hydrocarbons in a variety of arctic marine species were dominated by biogenic hydrocarbons. UV/F analysis of tissues indicated an upper limit of petroleum residues in the low to sub microgram concentration range. PAHs were detected in samples in the low ng concentration range and revealed a distribution of the combustion type. The hydrocarbon baseline in the BIOS study area was found to be as low as might be found anywhere on each and therefore ideally suited to the BIOS study.

Crutchfield, J.A.Jr. (1979)

Oil Interactions with Fisheries

Proceedings of Marine Sciences and Ocean Policy Symposium; A Definition of the Issues and a Search for a Consensus on Multiple Uses pp. 235-242

ABSTRACT
Fish and shellfish feeding on oil-tainted materials gradually build up hydrocarbons in the tissues, especially in the liver and gut. Though taste effects may be detectable for only a relatively short time, the marketing of

contaminated products could cause a severe reaction among fish consumers. Since much of the actual or potential damage to fisheries from oil operations involves inshore waters, there is a real likelihood that recreational fishing may suffer. A number of reasonable firm policy conclusions emerge. First, for identifiable and quantifiable damages, full liability of the responsible party seems the appropriate remedy. Second, for specific, quantifiable damages for which no responsibility can be established, both equity and incentive would appear to favor a cooperative indemnification scheme with oil companies providing a repayment pool and with well-defined procedures for arbitration of claims. Third, there is urgent need for fast response capability in areas subject to high risk of oil spill, including immediate availability of biological assessment procedures and of personnel; activation of cleanup techniques; and advisory services to the fishing industry as to the limits within which the fishing must be curtailed. Finally, the need for national and international authority is emphasized to influence investment choices in the production, transportation, and transfer of oil at sea.

Cushing, D.H. (1979)

The monitoring of biological effects: the separation of natural changes from those induced by pollution

Phil. Trans. Royal Soc. London B. 286:597-609.

ABSTRACT
An added mortality rate of eggs, larvae and juveniles of fish populations, or impact, is assumed to be density independent. The total mortality from hatching to recruitment is represented by the fecundity, and any increment in density independent mortality implies a decrement in density dependent mortality. At high stock the consequence is an increase in stock towards a position of less resilience: at low stock less resilience is found with a decrease in stock. In general impact generates a shift of K-strategy, the self-stabilizing strategy, to r-strategy, an opportunistic one. In a fish-population very little impact should be tolerated at low stock because it would prevent recovery, to a management objective such as maximum sustainable yield. At high stock, impact may generate more stock at an unknown risk.

Dauvin, J-C. (1982)

Impact of Amoco Cadiz oil spill on the muddy fine sand _Abra alba_ and _Melinna palmata_ community from the Bay of Morlaix.

Estuar. Coast. Shelf Sci. 14:517-531

ABSTRACT

Thirteen quantitative quarterly samples of the Abra alba - Melinna palmata community from the Bay of Morlaix (France) were taken from August 1977 to August 1980. The quantitative and qualitative changes in the community subsequent to the Amoco Cadiz oil pollution (March 1978) could thus be studied. Hydrocarbons were present in the sediments in exceptionally high quantities for more than a year after the oil spill, and then they decreased sharply. The numbers of species in the community increased as a whole during the 3 years' observation. Some species that disappeared after April 1978 have not yet reappeared. Density and biomass showed important seasonal variations, with summer maxima and winter minima and with a net dominance by the polychaete populations. During the first annual cycle after the pollution, there was a sharp increase in the density of some species which were present in very low or very high numbers before the pollution.

Dauvin, J-C.; Gentil, F. (1990)

Conditions of the peracarid populations of subtidal communities in northern Brittany ten years after the Amoco Cadiz oil spill.

Mar. Pollut. Bull. 21:123-130

ABSTRACT

Peracarid populations were greatly reduced in 1978 by oil from the Amoco Cadiz . Ten years after the spill, a benthic survey was conducted in the soft-bottom infralittoral communities of the bays of Morlaix and Lannion and the Aber Wrac'h channel to study the state of recovery of peracarid populations. Living in isolated populations in fine sand and muddy sand communities with low potential for immigration, the recolonization and the reconstitution of these perturbed populations was expected to be slow. The amphipod populations from the subtidal channel of Aber Wrac'h, which were initially the most affected by the oil spill, were in the least advanced state of recovery. Some species present in abundance before the oil spill were not rediscovered. Nevertheless, ten years after the oil spill, most of the populations had completely recovered.

Davies, W.P., Scott, G.I., Getter, C.D., Hayes, M.O., and Gundlach, E.R. (1980)

Methodology for environmental assessments of oil and hazardous substance spills.

Proceedings 14th European Marine Biological Symposium on Protection of Life in the Sea (Kinne O. and H.P. Bulnheim, eds.). Helgol. Meeresunters. 33:246-256

ABSTRACT

Ecological assessment of oil and hazardous material spills has been divided into three distinct phases: (1) First-order response studies conducted at the time of the initial spill event, (2) Second-order response studies conducted two months to one year post-spill, which document any delayed mortality and attempt to identify potential sublethal impacts in sensitive species, and (3) Third-order response studies conducted one to three years post-spill, to document chronic impacts (both lethal and sublethal) to specific indicator species. The need for contingency planning before a spill is discussed along with the use of the Vulnerability Index, a method in which coastal environments are classified on a scale of 1-10, based upon their potential susceptibility to oiling. A study of the lower Cook Inlet section of the Alaskan coast illustrates the practical application of this method.

Davies, W.P., Hoss, D.E., Scott, G.I., and Sheridan, P.F. (1984)

Fisheries resource impacts from spills of oil or hazardous substance

Restoration of Habitats Impacted by Oil Spills (J.Cairns Jr. and A.L. Buikema, eds.) Butterworth Publishers, Stoneham, MA pp.157-172

ABSTRACT

Oil pollution is a potential impact to fisheries resources for three reasons: a direct (lethal or sublethal) effect to fisheries stocks may occur, oil may render the fisheries products unacceptable to the consumer, and fishing operations may be directly affected by the presence of oil. These reasons may be extended to other hazardous or toxic materials. Examples have been documented for each of these reasons. High mortalities occurred among oysters in the estuaries of Brittany, France during the 1978 Amoco Cadiz spill. Oysters and other fisheries resources elsewhere have acquired hydrocarbon taint from spills or seepages. The vast areas covered by oil released from the Ixtoc 1 well blowout

near Campeche, Gulf of Mexico in 1979 caused shrimpers and other fishermen to change location of their operations.

Davydov, I.V. (1989)

Characteristics of Development of Atmospheric Circulation in the Northern Pacific Ocean and Their Role in Determining Long-Term Changes in the Abundance of Certain Fishes

Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models (R.J. Beamish and G.A. McFarlane, eds.) Can. Spec. Publ. Fish. Aquat. Sci. 108:181-194

Abstract
The two contrasting types of atmospheric pressure and circulation patterns that determine the type of water regime in various far-eastern seas develop due to the geographical position and intensity of high-altitude pressure ridges and troughs in the northwestern Pacific. This sea area may be treated as a single environmental system with interrelated development of hydrometeorological conditions and biological processes. The trends in the occurrence of specific types of pressure and circulation conditions, and related trends in fish abundance, change both in 10-11-yr periods and also over longer intervals. The former may be related to the 22-yr cycle of solar activity, while the latter may depend on the geoeffectiveness of the times of transition of solar activity (Wolf numbers) through their long-term average level in the centennial cycle (approximately 100-yr), and on the maximum of the centennial cycle of frequency of sun spots, which usually occurs in the 11 yr cycle following the centennial minimum of solar activity. As a result, natural processes may develop cycles of 40-60 yr (depending on the length of a particular centennial cycle of solar activity).

Dicks, B., and Iball, K. (1981)

Ten years of saltmarsh monitoring- The case history of a Southhampton water saltmarsh and chaning refinery effluent discharge

Proceedings of the 1981 Oil spill Conference (Prevention, Behavior, Control, Cleanup) American Petroleum Institute pp. 361-374.

ABSTRACT
One of the largest refinery and petrochemical plants in the U.K. has been discharging its effluents into the creek system of a Spartina anglica-dominated saltmarsh in

Southhampton water since 1953. This resulted in extensive damage to the marsh system up to 1971. At that time, a program of effluent quality improvement commenced that has resulted first in recolonization of small areas of damaged marsh followed by extensive recovery. Changes in the marsh vegetation have been studied frist by transect surveys in 1969 and 1970 (to assess damage) and subsequently by twice-yearly vegetation mapping resurveys from 1972 to the present. This paper summarizes the data from the 10 yr survey. The recovery/recolonization has continued progressively to the present day, with improvements in several annual and perennial marine species that have been successful colonizers; the original dominant Spartina anglica has recolonized only poorly. In addition to vegetation mapping, several series of Spartina transplantation experiments have been carried out to precisely define areas of continued effluent impact. These have formed a nucleus for Spartina recolonization in some parts of the marsh and may well speed up the return of this species in these areas. Using these relatively simple techniques it has been possible to identify differences in toxicity between different outfalls. This has been taken into account in site effluent management policy. Research programs have recently been extended to include recolonization of the marsh by intertidal animals and detailed analyses of hydrocarbon contents of sediments over the marsh. Preliminary results from these programs are described. These additional techniques improve monitoring sensitivity and provide valuable information for interpreting long-term continued effluent improvements being undertaken by the refinery.

Doe, K.G., Wells, P.G.

Acute Aquatic Toxicity and Dispersing Effectiveness of Oil Spill Dispersants: Results of a Canadian Oil Dispersant Testing Program (1973 to 1977)

Chemical Dispersants for the Control of Oil Spills, ASTM STP 659, (L. T. McCarthy Jr., C.P. Lindblom and H. F. Walter, eds) American Society for Testing and Materials, pp. 50-65

ABSTRACT

An oil spill dispersant testing program was initiated in 1973 to evaluate the toxicity and dispersing effectiveness of dispersants submitted to Fisheries and Environment Canada for approval prior to use in Canadian waters. Screening toxicity tests with rainbow trout (Salmo gairdneri) were performed initially on 19 dispersants. Thirteen were considered sufficiently nonacutely toxic to justify further evaluation using methods and criteria of the Canadian Guidelines on the use and acceptability of oil spill dispersants. The dispersants BP1100X, Corexit 8666, Drew Chemical OSE 71, Drew Chemical OSE 72, Oilsperse 43, and Sugee 2 passed both the toxicity and effectiveness criteria and were placed on the Canadian standard list of acceptable oil spill dispersants. Acute lethal toxicity tests with BP1100X and Sugee 2 showed that rainbow trout in fresh water were more sensitive than two marine fish, Fondulus heteroclitus and Menidia menidia, while fourthstage larval lobsters, Homarus americanus, were the least sensitive.

Dow, R.L. (1975)

Reduced growth and survival of clams transplanted to an oil spill site

Marine Pollution Bulletin 6:124-125.

ABSTRACT

Production of soft clams fell 20% in two years following oil pollution although in adjacent mudflats production increased by 250%. Transplanting uncontaminated clams into this area confirmed poorer survival and slower growth in polluted mud.

Dow, R. L. (1978)

Size-Selective Mortalities of Clams in an Oil Spill Site

Marine Pollution Bulletin 9:45-48

ABSTRACT

Mixed No. 2 fuel oil and JP 5 jet fuel, following an oil spill into Long Cove, Searsport, Maine, U.S.A. in March 1971 was concentrated locally at levels up to more than 250 ppm in intertidal sediments from 15 to 25 cm below the surface and continued until 1976 to kill successive year class juvenile clams as in normal growth behaviour they burrowed down through redistributed overlying clean sediments into the oil concentration beneath.

Dow, R.L. and Hurst, J.W.Jr. (1975)

The Ecological Chemical and Histopathological Evaluation of an Oil Spill Site, Part I: Ecological Studies

Marine Pollution Bulletin 16:164-166.

ABSTRACT
An oil spill into Long Cove, Searsport, Maine, began on 16 March and lasted until at least 30 June 1971. It resulted in immediate and continuing soft clam mortalities which, based on before and after biological surveys, had by August 1974 exceeded 85% of the estimated 50 million market-size clams occupying the area.

Ebeling, A.W., Laur, D.R., and Rowley, R.J. (1985)

Severe storm disturbances and reversal of community structure in a southern California kelp forest.

Mar. Biol. 84:287-294

ABSTRACT
Regular observations made over a period of 5 yr in 4 permanent transects provided data on plant, sea urchin, and fish densities which indicate that 2 unusually severe winter storms in 1980 (Storm I) and 1983 (Storm II) had different effects on a southern California kelp-forest community. Storm I removed all canopies of the giant kelp Macrocystis pyrifera, but spared most understory kelps, mainly Pterygophora californica . Hence, the previously large accumulation of detached drift kelp, mostly M. pyrifera, disappeared. Denied their preferred diet of drift kelp, the sea urchins Strongylocentrotus franciscanus and S. purpuratus then emerged from shelters to find alternative food. Without effective predators, they consumed most living plants, including the surviving understory kelps. This weakened the important detritus-based food chain. In 1983, Storm II reversed the process by eliminating exposed urchins, while clearing rock surfaces for widespread kelp settlement and growth.

Elkaim, B. (1981)

Amoco Cadiz Oil Spill Effects on Sublittoral Populations of the Penze Estuary (in French).
Original Title: (Effects de la Maree Noire de l'Amoco Cadiz sur le Peuplement Sublittoral de l'Estuaire de la Penze)

Amoco Cadiz: Fates and Effects of the Oil Spill. Proceedings of the International Symposium. pp. 527-537

ABSTRACT
The effects of Amoco Cadiz hydrocarbons on the subtidal fauna of Penze (North Brittany) have been studied from

samples collected before (1976, 1977) and after pollution (1978). The following conclusions can be drawn: A selective effect on the Crustaceans notably Peracarids (Amnelisca, Anseudes, Bathynoreia, Urothoe) and at the dominance level of zoological groups: A reduction in the populations and density of several marine species (Gibbula, Nassa, Eunaaurus). These effects of the oil spill limited to the outer six kilometers of the estuary did not bring about a profound modification of the fauna pattern: the subtidal population presents a greater tendency for a mosaic distribution of facies: The effects observed appear to be reversible, with the possible exception of repopulation by some species (Anseudes, Urothoe), which have no pelagic larval stage whose recolonisation may be delayed. At the estuary level, the stress effect though limited in space has evolved rapidly with time.

Elmgren, R., Hansson, S., Larsson, U., Sundelin, B., and Boehm, P.D. (1983)

The Tsesis oil spill: acute and long-term impact on the benthos

Marine biology 73:51-65

ABSTRACT:

The Tsesis oil spill in October 1977 resulted in the release of over 1,000 tons of medium grade fuel oil in an Archipelago in the brackish Baltic Sea. Considerable oil quantities reached the benthos by sedimentation. Within 6 d benthic amphipods of the genus Pontoporeia, as well as the polychaete Harmothoe sarsi Kinberg, showed reduction to less than 5% of pre-spill biomasses at the most impacted station. The clam Macoma balthica (L.) was more resistant, and showed little or no mortality, but was heavily contaminated by oil (about 2,000 ug/g dry wt total hydrocarbons). Not until the second summer after the spill were the first signs of recovery noted at the most heavily impacted station. Three years after the spill Pontoporeia spp. biomass was still depressed in the most affected area, while H. sarsi showed normal biomass, and M. balthica abundance was inflated. Recovery was thus underway, but the lifespan of M. balthica implies that the disturbed community composition may persist for many years at this station. Full recovery is likely to require more than 5 yr and may take a decade or more.

Farrington, J.W., Davis, A.C., Frew, N.M., and Rabin, K.S. (1982)

No. 2 fuel oil compounds in Mytilus edulis : Retention and release after an oil spill.

Mar. Biol. 66:15-26

ABSTRACT

M. edulis contaminated by a brief 2-d exposure to a slick from a No. 2 fuel oil spill in the Cape Cod Canal, Massachusetts, USA were sampled six times during an 86-d post-spill period to study the rate of release of fuel oil compounds under field conditions. Typical half-lives were n-alkanes, 0.2-0.8 d; pristane, 1.5 d; C-2 (dimethyl or ethyl) napthalenes, 0.9 d; methyl phenanthrenes, 1.7 d. Changes in relative ratios of C-2 phenanthrenes during the release period were observed. The evidence available to date strongly supports the rold of molecular weight and accompanying properties of water solubility as the main controlling factors in the rate of release of fuel oil compounds by M. edulis . However, the data for the rapid release of n-alkanes and C-2 phenanthrenes also indicate molecular type and molecular configuration as additional key factors.

Feder, H.M., Naidu, A.S., and Paul, A.J. (1990)

Trace element and biotic changes following a simulated oil spill on a mudflat in Port Valdez, Alaska.

Mar. Pollut. Bull. 21:131-137

ABSTRACT

A mudflat in Port Valdez, Alaska, was examined to determine effects of experimental additions of Prudhoe Bay crude oil on metal chemistry and harpacticoid copepod abundance. Hydrocarbon concentrations were at background levels 30 days after final addition of oil. The short residence time of oil added to sediments is attributable to physical removal of oil by tides, low sediment permeability, and low affinity of hydrocarbons for periglacial clay surfaces. Elemental concentrations, except Si, were lower in oiled than in unoiled sediments. Elemental depletion in oil-impacted sediments is attributable to mobilization of metals from oxide/hydroxide sediment phases or to desorption from clay due to lowering of Eh-pH of sediments subsequent to oil addition. In oiled sediments, abundance of harpacticoid copepods was similar to or higher than values within unoiled plots.

Fleeger, J.W., and Chandler, G.T. (1983)

Meiofauna responses to an experimental oil spill in a Louisiana salt marsh.

Mar. Ecol. Prog. Ser. Il:257-264

Abstract

To determine the potential impact of an oil spill on Louisiana salt marsh meiofauna, 21 m^{-2} South Louisiana crude oil was applied to 4 randomly assigned experimental plots in a Spartina alterniflora marsh. Four unoiled plots served as conrols. All plots were sampled 1 to 3 before and on Days 2, 5, 10, 20, 30, 60, 95 and 144 following oil application. Meiofauna were sorted to major taxon, and copepods identified to species. Surpirsingly, these meiofauna were highly tolerant of hydrocarbon stress as no oil-induced mortality could be identified in any taxon even though >13,000 ug oil g^{-1} dry sediment was applied. Densities of several taxa did respond positively to oil application. Nematodes were significantly more numerous in oiled plots on days 5 and 20; copepods on Days 30 and 60. The increase in copepod numbers was due largely to a significant increase in Enhydrosoma woodini which reached densities of 180 10 cm^{-2} in oiled plots. Copepods displayed only slight changes in community structure and no successional sequence was identified.

Fuchs, U, and Statzner, B. (1989)

Time scales for the recovery potential of river communities after restoration: Lessons to be learned from smaller streams.

Proceedings of the fourth International Symposium on Regulated Streams: Regul. Rivers: Res. Manage. 5(Suppl.):77-87

ABSTRACT

German politicians have promised that the River Rhine will be sufficiently restored within twelve years to permit salmon to live there again. Obviously the large rivers in Central Europe are more isolated from each other than smaller streams, and communities donating potential colonizers (if they exist at all) are further apart for possibly restored large rivers than for smaller streams. Thus, recovery can be expected to be faster in small streams than in big rivers after restoration (or reduction of detrimental human influence). Therefore, two restoration projects in German lowland streams, which differ in their degree of isolation, can serve as indicators to the time periods which could at least be expected for the recovery of

Central European rivers. Sufficient recovery of benthic macroinvertebrate fauna could be achieved in relatively short periods. However, in a rather isolated stream reach in the Upper Rhine valley (closest intact lotic ecosystems of a comparable type were found 20-25 km away) a sufficient recovery of benthic macroinvertebrate fauna was not achieved within five years after restoration, although there was high diversity of physical habitats and the water quality was acceptable (except for two oil accidents in the fourth and the fifth year).

Ganning, B., Reish, D.J. and Strughan, D. (1984)

Recovery and restoration of rocky shores, sandy beaches, tidal flats, and shallow subtidal bottoms impacted by oil spills.

Restoration of Habitats Impacted by Oil Spills (J. Cairns Jr. and A.L. Buikema, eds.) 736

ABSTRACT
The authors use a modified definition where recovery comprises the return of the ecosystem to within the limits of natural variability. Natural variability may include alternative components of the ecosystem or even a modified one, but it is a natural and functional ecosystem for the area. Restoration in this context is the return of the ecosystem to within limits of natural variability by natural and/or artificial means. Discussion of the ecological effects of oil and possible cleanup actions in different types of habitats necessitates defining the types of oil. This discussion deals with three different main types of petroleum: (1) heavy black oil that includes most crude oils and heavy fuel oils, (2) light refined products such as diesel and light fuel oils, gasoline, etc., and (3) the water-in-oil emulsion called mousse. This division is based largely on physical characteristics because these tend to dictate the methods of cleanup and/or restoration.

Garlo, E. van (1982)

Increase in a surf clam population after hypoxic water conditions off Little Egg Inlet, New Jersey

J. Shellfish Res. 2:59-64

ABSTRACT
From July through September 1976, intermittent hypoxic water conditions occurred off Little Egg Inlet, New Jersey, The following year, the estimated number of surf clams in

the 100 km^2 area had increased seven fold, due to the increased number of 1+ year-old clams. The high survival of the 1976 cohort indicated that the population had the ability to make a rapid recovery after intermittent hypoxia. Apparently, a reduction of the number of predatory echinoderms and crustaceans during the period when the 1976 cohort set, contributed to its success.

Garrity, S.D., and Levings, S.C. (1990)

Effects of an oil spill on the gastropods of a tropical intertidal reef flat.

Mar. Environ. Res. 30:119-153

ABSTRACT

The effects of an oil spill on the molluscs of an intertidal reef flat were examined. At least 8,000,000 liters of medium weight crude oil were spilled on 27 April 1986 from the refinery at Isla Payardi on the Caribbean coast of the Republic of Panama. The severity of effects on a nearby reef flat varied with the amount of oil deposited in a given zone of the reef. Immediate mortality of snails occurred in zones with heavy accumulations of oil and abundances further decreased in some zones after the activities of a cleanup crew. Overall density and species number decreased over time. Recruitment appeared reduced in some zones more than two years after the spill. No such patterns were observed at an un-oiled control site until a small spill of diesel fuel in May 1988 similarly reduced mollusc populations. However, this spill had no long term effects. Effects of oil spills on these types of reef flats depend on the pattern of tidal emersion at the time of the oil spill, because water levels determine the distribution of oiling across the reef flat.

Getter, C.D., Cintron, G., Dicks, B., Lewis, R.R. III and Seneca, E.D. (1984)

The recovery and restoration of salt marshes and mangroves following an oil spill.

Restoration of Habitats Impacted by Oil Spills (J. Cairns Jr and A.L. Buikema, eds.) pp.65-114

ABSTRACT

This chapter reviews briefly those portions of these studies that are relevant to determining the effects of oil on marine wetlands. Also, the literature is synthesized to

allow an evaluation of methods of protection, cleanup, and restoration attempts that have been carried out in marine wetlands. This chapter accomplishes these two objectives by: providing a brief review of the effects of oil spills and related cleanup activities on salt marshes and mangrove ecosystems; reviewing methods of protecting marine wetlands from being oiled; reviewing successful means of cleaning marine wetlands following oil spills; reviewing and presenting techniques that have proven successful in restoring marine wetlands damaged by oil spills and/or cleanup operations; establishing a set of criteria and discussing guidelines for decisions on means of protecting susceptible areas, and for cleaning and restoring oiled marine wetlands.

Gilfillan, E.S., and Vandermeulen, J.H. (1978)

Alterations in Growth and Physiology of Soft-Shell Clams, Mya Arenaria, Chronically Oiled with Bunker C from Chedabucto Bay, Nova Scotia, 1970-76

J. Fish. Res. Board Can. 35:630-636

ABSTRACT

Two populations of soft-shell clam, Mya arenaria, one from a chronically oiled lagoon (since the Arrow oil spill in 1970) and the other from a nonoiled lagoon, were compared as to population structure, growth, and metabolism. The oiled lagoon sediments contained up to 3800 ug/g oil (UV determination), and clams up to 200 ug/g hydrocarbon in their tissues (fluorescence). The oiled population of clams differed from the nonoiled population in lower total numbers with fewer mature adults, a 1-2 yr lag in tissue growth, a lower shell growth rate, and a reduced carbon flux with a lower assimilation rate. Results are interpreted to indicate that the recovery potential of M. arenaria in these oiled sediments is low and that these oiled populations remain under continued stress 6 years after the Arrow spill.

Glemarec, M. (1986)

Ecological Impact of an Oil Spill: Utilization of Biological Indicators

Water Science and Technology 18:203- 211

ABSTRACT

The effects of the Amoco Cadiz oil spill on the fine sand ecosystem are evaluated by means of macrofauna which represent medium hydrodynamic conditions. Different species were classified in ecological groups according to their sensitivity to hydrocarbons and to organic matter overload. The two parameters, specific richness and abundance per square meter, indicate the structure of the macrofauna population, while a third parameter, the biomass, can also be used. The study of these factors and their evolution in time, as well as the ecological groups, enables definition of the degradation, recolonization and restructuring conditions. Finally, predators such as fish juveniles, regulate these communities. Six years after the Amoco Cadiz oil spill, even if this fine sand ecosystem reaches a new equilibrium, it is still too early for the regulation processes by predators to take place.

Glemarec, M., Hussenot, E. and Moal, Y.E. (1982)

Utilization of biological indications in hypertrophic sedimentary areas to describe dynamic process after the Amoco Cadiz oil spill.

Atlantica 5:48

ABSTRACT
An ecological survey was conducted for 4 yr in the area which is the most affected by the Amoco Cadiz oil-spill i.e., Abers Wrac'h and Benoit, to define chronological processes which were confirmed by another oil-spill two years later. The approach taken was to recognize taxonomic groups. These groups were used as biological indicators. The successive appearance of these various groups, their relative importance, and their disappearance, are the key features of this dynamic approach. This temporal succession is studied along two different gradients of decreasing hydrodynamism, the Abers, where the chemical decontamination and the biological process are not synchronized. Patterns of temporal evolution and succession are discussed. This type of analysis indicates that biological perturbations can persist within the ecosystem well beyond the time when most physical and chemical factors have apparently returned to normal.

Gourbault, N.E. (1987)

Long-term monitoring of marine nematode assemblages In the Morlaix Estuary (France) following the Amoco Cadiz oil spill.

Estuar. Coast Shelf Sci. 24:657-670

ABSTRACT

In March 1978 the coast of Brittany was heavily polluted with oil from the Amoco Cadiz. Marine nematode assemblages from the Morlaix estuary were regularly monitored at three sites from October 1978 to November 1984. Differences among the assemblages and indications of the effects of oil contamination were detected by diversity, corrspondence analysis and fits to empirical models. Clearest evidenced effects were seen at the shallowest upstream site, and were detectable four years after the spill. It was concluded that by 1984 the fauna had recovered at all sites to situation similar to that pertaining in October 1978.

Griffiths, R.P. and Morita, R.Y. (1981)

Study of microbial activity and crude oil-microbial interactions in the waters and sediments of Cook Inlet and the Beaufort Sea.

Environmental Assessment of the Alaskan Continental Shelf. Final Reports of Principal Investigators. Volumne 10- Biological Studies.; NOAA/OMPA; Boulder, Co (Usa) 417-784

ABSTRACT

It has been found that crude oil alters microbial function in marine sediments. This altered function will have three major impacts on normal biological activity. (1) It will reduce overall productivity by interfering with the normal flow of food through the detrital food chain. Recent estimates show that 50-80% of food available to all animals present is ultimately derived from this source. (2) Crude oil will interfere with the processes that convert the nitrogen and phosphorous in organic material into inorganic forms which are required for plant growth. Without these inorganic nutrients, plants can not produce the new organic material required to feed the animals present. (3) Crude oil changes microbial activity in the sediments so that the chemical environment of the sediment surface is changed. It seems quite likely that these changes will remain long after the initial crude oil toxicity has abated and could greatly alter the normal recruitment of animals back into the impacted area. It is believed the most vulnerable environment in Alaskan marine systems is the soft-fine grained sediments such as those found in the St. Georges Basin in the southern Bering Sea, Shelikof Strait, and the major bays of Cool Inlet. These are the regions predicted to have the greatest long-term perturbation in the case of a large scale oil spill.

Gulliksen, B. and Taasen, J.P. (1982)

Effect of an Oil Spill in Spitzbergen in 1978.

Mar. Pollut. Bull. 13:96-98

ABSTRACT

The oil content in the sediment and the marine life along the arctic shores of Van Mijenfjord, Spitzbergen were investigated about two years after a spill from diesel storage tanks. High values of oil were recorded in the sediment along the shore near the tanks. The shore fauna is generally poor in these areas and the only biological effect detected was the disappearance of the amphipod _Gammarus setosus_ from the surface layers.

Gundlach, E.R., Fischer, I.A. and Stein, R.J. (1977)

The black tide of La Coruna

Oceans 10:56-60

ABSTRACT

The supertanker Urquiola. carrying 107,000 tons of crude oil and 3,000 tons of Bunker C. fuel oil, struck bottom while entering La Coruna Harbor, the major port of Galicia, May 12 1976. Spain was not prepared for a spill of this magnitude and an estimated 25,000-30,000 tons of oil washed ashore the following weeks. Oil was spread over 215 km of coastline, with 60 km having moderate to heavy oil coverage. Shellfish fatalities on a sandy tidal flat at the Playa de Santa Cristina were dramatic. There were high mortalities of bivalves and snails in the top 15 cm of fine sediment. Nearly 70% of the edible cockle (_Cerastoderma edule_) population, the dominant species of the area, was killed. Other species of clams, such as _Scrobicularia plano_, _Tellina tenuis_, and _Venepurus decussata_, were reduced 10-30%. Evidence of behavioral impairment was obvious in many still living. Mortality at the marsh behind Santa Cristina was not as immediately evident as on the sand flat. The benthic invertebrates most sensitive to this spill were the edible, commercially valuable cockle and the sandworm. However, the oilsoaked cordgrass (_Spartina_) and local shore crabs (_Carcinus maenas_) did not seem to suffer great damage.

Guzmao del Proo, S.A., Chavez, E.A., Alatriste, F.M., de la Campa, S., De la Cruz, G., Gomez, L., Guadarrama, R., Guerra, A., Mile, S. and Torruco, D. (1986)

The impact of the Ixtoc-1 oil spill on zooplankton.

J. Plankton Res. 8:557-581

ABSTRACT

Zooplankton data on seven cruises in the southern part of the Gulf of Mexico between 1979 and 1982 show a decrease in biomass levels of almost four orders of magnitude, lower than previously observed, when mean biomass reached 389 mg m^{-3}. Seasonal biomass changes observed before and after the spill show the same pattern, with maximum in summer and minimum in spring; together with species diversity, the highest heterogeneity of the community was present in the spring and the lowest diversity in the fall. Changes in the organization and structure of the zooplankton community occurred after the spill, reaching a lower level of stability. Most samples appear to be contaminated by hydrocarbons, but the role of the Ixtoc-1 oil spill as a factor in this is hard to determine.

Hampson, G.R. and Moul, E.T. (1978)

No. 2 fuel oil spill in Bourne, Massachusetts: Immediate assessment of the effects on marine invertebrates and a 3-year study of growth and recovery of a salt marsh

J. Fish. Res. Board Can. 35:731-744.

ABSTRACT

On October 9, 1974 the oil barge Bouchard 65 loaded with 73,000 barrels of oil spilled what was initially thought by the Coast Guard to be a few barrels and later raised to an undetermined amount of No. 2 fuel oil off the west entrance of the Cape Cod Canal in Buzzards Bay, Massachusetts. Within the following 2-wk period, oil from the barge was found contained along the west side of Bassett's Island and inner Red Brook Harbour, a distance of 5.0 km from the site of the spillage. Qualitative samples of dead and moribund marine invertebrates were collected in tide pools and slight depression along the beaches. A collection consisting of 4360 invertebrates comprising 105 species, plus 2 species of fish were found in 8 samples. Noticeable effects of the oil on the salt-marsh plant community were also observed. A detailed quantitative examination was begun to determine the effects of the oil on various components of the affected salt-marsh community in Winsor Cove compared to a selected control site. From data collected in September 1977, the marsh grass in the lower intertidal zone in Winsor Cove has shown an inability to reestablish itself by either reseeding or rhizome growth. The associated sediments show a correspondingly high concentration of petroleum hydrocarbons impregnated in the peat substrate. Erosion rates measured in the affected area, as a result of the 3-year period of marsh degeneration, were 24 times greater than the control site. Microscopic algae

were considered least sensitive to environmental changes. Examination of the interstitial fauna found in the study area in the summer of 1977 showed an extremely reduced number of individuals and species.

Hanson, D.L. and Waters, T.F. (1974)

Recovery of Standing Crop and Production Rate of a Brook Trout Population in a Flood Damaged Stream

Trans. Amer. Fish. Soc. 103:431-439

ABSTRACT
The brook trout (Salelinus fontinalis Mitchill) population in Valley Creek, Minnesota, recovered from heavy flood damage in 1965-66 in terms of standing crop, growth, and production rates over a period of 4 to 5 years. Standing crops of brook trout increased numerically by 20-fold from a low of 498/ha in 1966 to 10,882/ha in 1969, and in biomass by 6-fold from 25kg/ha in 1966 to a maximum of 148 kg/ha in 1970. Growth rate early in the recovery period was high due to the low density of trout but decreased in successive years as fish density increased. Annual production was about 50 kg/ha during the flood years but increased during the recovery years to a maximum of 167 kg/ha in 1969. Cohort production for the 1965 year class, the one most seriously affected by the floods, was about 15 kg/ha, whereas cohort production for the 1961 year class, the last one that could be completely followed in this study, was about 190 kg/ha. After the floods, rainbow trout (Salma gairdneri Richardson) immigrated into the study section from downstream; although variable in year class strength, the rainbow contributed substantially to total salmonid standing crop and annual production in some years. It has apparently become permanently established, even after total recovery of the brook trout population.

Harger, J.R.E. and Straughan, D. (1972)

Biology of Sea Mussels (Mytilus califronianus (Conrad) and M. edulis (Linn.)) before and after the Santa Barbara Oil Spill (1969)

Water, Air , and Soil Pollution 1:381-388

ABSTRACT
Effects of the 1969 Santa Barbara oil spill on sea mussels were investigated by comparing biomass characteristics of mussel populations in polluted and clean areas before, during, and after the discharge. The

following null hypotheses were tested: (a) mussels collected in August 1969 from areas experiencing oil pollution were not lighter in body weight than those collected from the same locations in previous years. (b) mussels collected from areas experiencing oil pollution in August 1969 were not lighter in body weight than those collected in subsequent years from the same locations. Animals in exposed areas were not significantly lighter in body weight than those in clean areas. Likewise no deleterious effect in the form of lowered body weights could be detected in mussels from polluted areas in three successive years subsequent to the oil spill. Mussels were not sampled until 7 mo after the initial spill so that any immediate deleterious effect generated by the oil could have been compensated for by the time of examination. It is noted that the spill in question occurred at a time of minimal growth response might have resulted if the oil had washed ashore during a period of heightened growth.

Harrel, R.C. (1985)

Effects of a crude oil spill on water quality and macrobenthos of a southeast Texas stream.

Hydrobiologia 124:223-228

ABSTRACT
On December 6, 1981 an oil spill of 160 barrels (25,440 liters) occurred in a small southeast Texas stream. Water quality changes, other than the presence of oil, were not evident until six months later when water temperature increased and stream flow ceased. This resulted in decreased dissolved oxygen and increased carbon dioxide concentrations. Responses of the benthic macroinvertebrate community include an increase in density of oligochaetes, decrease in numbers and taxa of chironomids, with eventual complete elimination, and low community diversity. Decrease in oil concentration resulted in reversal of these responses. No clean water taxa were collected and complete recovery had not occurred 26 months after the spill when the study was terminated.

Hartog, C. den and Jacobs, R.P.W.M. (1980)

Effects of the Amoco Cadiz oil spill on an eelgrass community at Roscoff (France) with special reference to the mobile benthic fauna.

14th European Marine Biological Symposium on Protection of Life in the Sea (O. Kinne and H.P. Bulnheim, eds.) Helgol. Meeresunters. 33:182-191

ABSTRACT

In October 1977 an investigation was initiated of the qualitative and quantitative composition of the fauna of the eelgrass (Zostera marina) beds at Roscoff. Samples were taken in 2 seagrass beds at different tidal levels in order to follow numerical changes in the course of the year. In March 1978 the area of study was struck by the oil slick of the tanker Amoco Cadiz . For this reason, sampling has been continued at the same frequency. The tabulated results show clearly that the oil slick had a profound but selective influence on the various animal groups; some of them disappeared while others were apparently unaffected. Rapid recovery of some species has taken place, but re-establishment of other species, particularly the filter feeders has not been observed. The very diverse amphipod fauna has disappeared, and has been replaced by a population of Pherusa fucicola and Gammarus locusta ; the latter was absent in the year before the oil disaster took place.

Hiyama, Y. (1979)

Survey of the Effects of the Seto Inland Sea Oil Spill in 1974

Proceedings 1979 Oil Spill Conference (Prevention, Behavior, Control, Cleanup), American Petroleum Institute, Washington, D.C. Publication No. 4308. pp699-707.

ABSTRACT

On December 18, 1974, a fuel oil tank in Mizushima Refinery of Mitsubishi Oil Co. ruptured. About 50,000 barrels of fuel oil spilled and spread in the Seto Inland Sea, where there were intensive fisheries and heavy marine traffic among various industrial settlements. Coastal fisheries and fish culture fell into confusion, but, according to this survey, marine life quickly recovered by the summer of 1975 and the effect of the oil on the natural environment was not so large as suspected, the reason being mainly the quick and energetic work to recover the spilled oil. This paper is a report of the outline of the accident and a survey of its influence on the marine environment.

Horn, M. H. (1974)

Fishes

A Summary of Knowledge of the Southern California Coastal Zone and Offshore Areas, Vol 2, pp. 11.1 - 11.124

ABSTRACT

The marine environment off southern California with its diverse chemical, physical, and geological characteristics provides a wide variety of habitats for fishes. Although numerous natural oil and gas seeps occur in the region and although oil drilling wastes are among the major wastes dumped in the study area, very little information is available on the effects of these materials on fishes of fisheries in southern California marine waters. In a survey of the effects of the Santa Barbara Channel oil spill, it was reported that fish were still present after the spill and that sampling in the area by the California Department of Fish and Game indicated no adverse effects. An analysis also did not reveal any abnormal conditions of fish and macroplankton populations. The reduction in the fish catch following the spill was said to be due to reduced fishing effort in the oily waters and to harbor closure at Ventura (because of flood damage) and at Santa Barbara (because of the oil spill). More research is needed on the effects of petroleum hydrocarbons on fishes especially in an area such as southern California where the biota is subject to both natural and man-caused contamination.

Hourston, A.S. (1980)

The Decline and Recovery of Canada's Pacific Herring Stocks

Rapp. P-v Reun. Cons. int. Explor. Mer. 177:143-153.

ABSTRACT

Prior to the 1960s, the catch of herring from the nine major stocks was limited primarily by the available markets and the catching and processing capacity. Apparent annual mortality rates, from 75% to over 90% in the 1950s, did not depress the abundance of the stocks. In the mid-1960s, eight of the nine stocks experienced poor recruitment in three out of four years and abundance dropped. With better vessels and new technology, fishermen were able to maintain catches at close to former levels for two or three years until rather gross stock assessment procedures were able to demonstrate that stocks had been reduced to a fraction of their former level. Because the next two year classes to be recruited had already been depleted when the fishery was closed, spawn deposition remained at a low level for four years before showing an improvement in the fifth year and recovery in the sixth year. The timing of the decline varied among the stocks over a period of five years and, because the populations are made up of a mixture of stocks, the low period ranged from five to ten years for different

populations. Two of the populations have not recovered to their former strength. The establishment of procedures for more precise monitoring of the stocks and of management strategies based on achieving optimum escapements should preclude a repeat of the 1960s for Canada's west coast herring stocks.

Humphrey, B, Boehm, P.D., Hamilton, M.C. and Norstrom, R.J. (1987)

The fate of chemically dispersed and untreated crude oil in Arctic benthic biota.

Arctic 40:149-161.

ABSTRACT

Subtidal benthic biota were monitored for petroleum hydrocarbons following two experimental oil spills at Cape Hart, N.W.T., Canada. In one spill oil was chemically dispersed into the water column, and in the other oil was released onto the water surface and allowed to land on the shoreline. In addition to baseline samples, samples were collected immediately after the oil releases, two to three weeks after and one and two years after. Initial observations did not distinguish between effects of the surface and dispersed releases. Total oil content and hydrocarbon compositional analyses were conducted to investigate partterns of uptake and depuration for five different arctic species: Astarte borealis, Macoma calcarea, Mya truncata, Serripes poenlandicus and Strongylocentrotus droebachiensis. Filter-feeding species took up oil rapidly from the water column, while deposit-feeding species took up oil less rapidly from the sediments. All species depurated most of the oil after one year, but after two years the deposit feeders appeared to be taking up more oil from sediments contaminated by stranded oil from the surface oil release.

Jackson, J.B.C., Cubit, J.D., Keller, B.D., Batista, V., Burns, K., Caffey, H.M., Caldwell, R.L., Garrity, S.D. and Getter, C.D. (1989)

Ecological effects of a major oil spill on Panamanian coastal marine communities.

Science 243:37-44

ABSTRACT

In 1986 more than 8 million liters of crude oil spilled into a complex region of mangroves, seagrasses, and coral

reefs just east of the Caribbean entrance to the Panama Canal. This was the largest recorded spill into coastal habitats in the tropical Americas. Many populations of plants and animals in both oiled and unoiled sites had been studied previously, thereby providing an unprecedented measure of ecological variation before the spill. Intertidal mangroves, seagrasses, algae, and associated invertebrates were covered by oil and died soon after. More surprisingly, there was also extensive mortality of shallow subtidal reef corals and infauna of seagrass beds. After 1.5 years only some organisms in areas exposed to the open sea have recovered.

Jones, R. (1982)

Population fluctuations and recruitment in marine populations

Phil. Trans. R. Soc. Lond. B. 297:353-368

ABSTRACT

This paper is not concerned with the effect of oil pollution as such, but sets out to consider the range of natural variation and the extent to which this might mask the effects of other factors such as possible pollutant effects. To detect the effect of a pollutant (or a change in fishing effort) it is necessary to allow for natural variations, both random and periodic. Some examples are given to illustrate the extent of natural variations, in a variety of marine populations. For Arcto-Norwegian cod, information is available on catches from about the middle of the last century to the present day. Large catches are about 36 times the size of small catches. The difference between large and small catches is about equal to the mean catch. Further, the time taken to change from a small to a large catch level is very variable. The Greenland cod provides an example ofa stock that increased very considerably due to a northerly increase of the limits of distribution of the species. This increase was associated with a warm period in the North Atlantic and with increased catches. Many fish stocks and in particular many species of pelagic fishes, exhibit much larger fluctuations in stock size, e.g. the Hokkaido herring, the Japanese sardine, the Bohuslan herring, the Atlanto-Scandian herring and the Califonian anchovy and sardine. Fluctuations also occur in invertebrate species and evidence is given of changes that have occurred in North Sea phytoplankton and zooplankton. The Peruvian anchovy provides an example of a stock that decreased very considerably, due partly to fishing and partly to changes in the hydrographic regime that caused the fish to become more available for exploitation. Fluctuations in fish stocks are primarily due to

fluctuations in recruitment. The factors affecting recruitment are not yet fully understood but are known to be determined during the first year of life and probably during the larval or early juvenile stages. Whatever the mechanism, however it is the variations in recruitment that determine a very large part of the variations in adult fish stocks and hence it is variations in recruitment and the causes of these that are important. In conclusion, the examples show that natural communities can exhibit large natural fluctuations, of varying periodicity, in the long term. Apart from incidents where there is gross pollution, an effect of pollution can therefore only be convincingly demonstrated for those species for which background information is available for a long enough period to allow for longterm periodicity as well as for short-term and irregular variability.

Kaufman, L.S. (1983)

Effects of Hurricane Allen on reef fish assemblages near Discovery Bay, Jamaica.

Coral Reefs 2:43-47

ABSTRACT

On 6 August 1980, Hurricane Allen pounded the north coast of Jamaica with its heaviest seas of this century. The resulting destruction of fish habitats was followed by changes in predator abundance, herbivore behavior, and the distribution of territorial damselfishes. One year later, fish assemblages differed between patches of reef more or less severely damaged by the hurricane. Hurricanes of this magnitude could have an important influence on local patterns of behavior and species interactions, by redistributing fish habitats and their associated key species.

Kemp, P.F.; Swartz, R.C.; Lamberson, J.O (1986)

Response of the phoxocephalid amphipod, Rhepoxynius abronius , to a small oil spill in Yaquina Bay, Oregon.

Estuaries 9:340-347

ABSTRACT

A spill of approximately 284,000 liters of Bunker C and diesel fuel oils occurred at the entrance of Yaquina Bay, Oregon, following the wreck of the freighter Blue Magpie on

19 November 1983. A portion of this oil entered the lower estuary and was deposited on subtidal benthic habitats occupied by the phoxocephalid amphipod Rhepoxynius abronius. Bioassays with Rhepoxyvnius abronius showed that the oil globules were not acutely toxic unless mixed into the sediment at concentrations of 1.0 parts per thousand or greater. A series of 10-d bioassays before and after the spill showed that sediment collected from oiled subtidal sites did not become acutely toxic to this species. Although the density of the R. abronius population declined by 75% after the spill, similar declines of the same population were observed at this site in fall 1980. Although mean fecundity was greater in 1984 than in 1981, recruitment following the spill was lower than in the 1980-1981 study. Thus, there is limited evidence for a small impact of the oil spill on this sensitive amphipod.

Kennedy, G.J.A., Cragg-Hine, D, Strange, C.D. and Stewart, D.A. (1983)

The effects of a land drainage scheme on the salmonid populations of the River Camowen, Co. Tyrone.

Fish. Manage. 14:1-16

ABSTRACT

Annual electrofishing surveys were carried out over an 11-year period at five sites on an upland river which was subject to dredging operations in connection with a land drainage scheme. Four of the sites were dredged 3 years after the start of the survey and one control site remained undredged throughout. The results indicated that dredging operations initially reduced salmonid densities and that there was subsequently a progressive downstream recovery. Yearling and older fish recovered to pre-drainage scheme levels more rapidly than fry. Changes in population structure were also observed at three of the dredged sites. Two sites were considerably deepened and finally contained larger numbers of older fish than prior to the drainage scheme. The opposite effect was found to have taken place at a site which became shallower as a result of drainage works, and contained larger numbers of fry at the end of the survey.

Kirby-Smith, W.W. and Ustach, J. (1986)

Resistance to hurricane disturbance of an epifaunal community on the continental shelf off North Carolina.

Estuar. Coast. Shelf Sci. 23:433-442

ABSTRACT

Hurricane Diana was stalled over the continental shelf of central North Carolina on 11-13 September 1984 in the vicinity of a previously studied epifaunal community (30 m depth). Two research cruises following the hurricane used still camera and TV transects to obtain data which allowed an evaluation of storm related effects on taxa of algae, sponges, corals, echinoderms and fish. Analysis of 35-mm slides suggested no effects attributable to the hurricane except observations on damaged coral heads and dead mussels. Analysis of television transects indicated no storm related changes from the previous study in frequency of occurrence of large epibenthic taxa. Hurricane damage was much less than anticipated.

Kittredge, J.S. (1975)

Effects of Crude Oil on Marine Invertebrates

Final Report to Office of Naval Research - Available from the National Technical Information Service, Springfield, VA 22161 as AD-A017 921

ABSTRACT

A brief summary of research on the effects of crude oil on the behavior of marine invertebrates, principally crustaceans. Behavior patterns examined was the feeding response. Polyaromatic hydrocarbons were probably the potentially dangerous component of oil pollution.

Kirkwood, R.C., Henderson, A.R. and Hamilton, J.D. (1986)

The status of fish populations in the Clyde Estuary.

The Environment of the Estuary and Firth of Clyde. Proc. R. Soc. Edinb. Sect. B. 90:157-170

ABSTRACT

Changes in the status of fish populations in the Clyde Estuary between Woodhall and Glasgow since 1978 are described and data presented on species composition and distribution, temporal and spatial fluctuations in abundance and biomass and length frequency data for certain species are analysed. The seaward part of the estuary is colonised by marine and euryhaline marine species dominated by flounder, while the city reaches have a fresh water component dominated by three-spined stickleback and eel in addition to several euryhaline species, e.g. sand-goby and

saithe. The extent of biological recovery of the estuary from severe organic pollution can be gauged from the presence now of thirty-four species, including nineteen in the city reaches which were virtually fishless in the mid nineteenth century.

H.D.Klassen, H.D. and Northcote, T.G. (1988)

Use of Gabion Weirs to Improve Spawning Habitat for Pink Salmon in a Small Logged Watershed

North American Journal of Fisheries Management 8:36-44

ABSTRACT

Tandem V-shaped gabion weirs for improving spawning habitat for Pacific salmon Oncorhynchus spp. were installed to replace large organic debris at three sites in Sachs Creek, Queen Charlotte Islands, British Columbia. Intragravel conditions were compared between three gabion weir pairs and six nearby reference sites. Survival of eggs of pink salmon O. gorbuscha was compared between one gabion pair and two reference sites. The improvement in intragravel dissolved oxygen depression (surface intragravel concentrations) after gabion installation (a decrease from 5.4 mg/L before to 2.5 mg/L after installation) was significant ($p < 0.05$) when compared to changes found at nearby reference sites. Intragravel permeability also improved significantly ($p < 0.05$) after gabion installation in the low-gradient (1%) reaches of Sachs Creek (from 870 cmffl before to 2,400 cm/h after installation). Pink salmon egg survival calculated by two indices at one gabion site in its first year of operation did not differ significantly ($p>0.05$) from survival at two nearby reference sites. Gabions appear to be useful tools for the restoration of damaged streams.

Kondo, K. (1980)

The Recovery of the Japanese sardine- The biological Basis of Stock-size Fluctuations

Rapp. P-v. Reun. Cons. int. Explor. Mer 177:324-354

ABSTRACT

The habitat of the Japanese sardine is the mixing area between the coastal water masses and the Kuroshio Current, or between the Kuroshio and Oyashio Currents, but it is located slightly nearer the Oyashio domain off the Pacific coast of Japan. The sardine never live within the Kuroshio or Oyashio. The living conditions they require, according to

developmental stage, lead to a change of habitats. Fish in the younger stages live in the neighbouring area of the Kuroshio Current, while later they migrate to the coastal water mass or the mixing area of the Oyashio Current and feed from spring through surmmer. It takes one, or two years before they reach the adult stage. During the period of immaturity they migrate for wintering whereas in the adult stage they migrate for spawning. The adult sardine return to the mixing area of Kuroslio Current to spawn.

The subpopulations living in the East China and Japan Sea area have life conditions similar those of the Pacific subpopulation, but the ocean graphic backgrounds are replaced by the Tsush Warm Current, the East China Sea and Yellow cold water masses, and the Liman Cold Current. Therefore, the habitat of this species is not geographically restricted, but the fish adapt to the wide range of oceanographic conditions in the Far East area, including the seas surrounding Japan. Japanese sardine have increased their population size everywhere within the habitat, through adaptation during the evolution of the species.The present prosperity of the Japanese sardine stock is most evident in the Pacific subpopulation, but other subpopulations living in the East China Sea and Japan Sea have also increased. The causes of such an increase in the Pacific subpopulation are: (1) maximum survival rate in the critical period caused by the shift of the Kuroshio Current, which created good foraging conditions for the postlarvae, and (2) suitable conditions during the feeding phases within the life cycle of the sardine alters These suitable conditions are found in the mixing area, influenced by the Oyashio Current and coastal water masses because sardine feed on phytoplankton as the dominant food.
Consequently, in the Pacific subpopulation the 1972 year class, which reached the adult stage in the spring of 1974 and has spawned most successfully since 1975 in the sea area around Izu Islets, near the Kanto District, has been a very large one.

The abundance of the 1974 year class was three to five times that of the 1972 year class. During the years from 1975 to 1977 these year classes with high adult stocks had high levels of reproduction, resulting in the creation of many strong year classes. Recently annual catches of Japanese sardine have ranged from several hundred thousand tonnes to over one million tonnes. It is estimated that these high levels of catch, of over one million tonnes, will continue for several years, or for more than ten years since 1972.

Koons, C.B. and Wheeler, R.B. (1978)

Oil spill has minimal effect on environment of oil. The effects of oil dispersants on seagrass communities are not known. Inert absorbents present little hazard to seagrass systems if properly used. The normal recovery of seagrass systems from oiling depends on the extent of damage to sediments. Efforts of restoring oil-damaged seagrass systems by transplanting plugs or shoots have met with variable success. It is suggested that research be carried out on the toxicity levels of the major hydrocarbon substances on the major seagrass species in laboratory and fiels tests.

Zitko, V., Burridge, L.E., Woodside, M. and Akagi, H. (1984)

Low contamination of fish by hydrocarbons from the uniake G-72 (Shell Oil, Vinland) wellsite blowout in February 1984.

Can. Tech. Rep. Fish. Aquat. Sci., no. 1305.

ABSTRACT

Cod (Gadus morhus) and haddock (Melanogrammus aeglefinus) fillet and liver were analyzed for hydrocarbons by spectrofluorometry and by gas chromatography-mass spectrometry. Fluorescence emission, di-, tri-, and tetramethyl benzenes, naphthalene and its methyl- and dimethyl homologues were used to detect contamination by gas condensate. Increased fluorescence and dimethylbenzenes were detected in the livers. It appears that fish were exposed to the gas condensate but the exposure was very low and did not affect the fish. The condensate was readily accumulated by juvenile Atlantic salmon in the laboratory. The excretion half-life was of the order of days. The potential of gas well blowouts to contaminate fish is higher than anticipated previously.

Northern Offshore 7:24-25

ABSTRACT

The estimated petroleum input into the North Sea and northeastern Atlantic is 400,000 TPY. The estimated standing crop of dispersed hydrocarbons in the North Sea alone is 1.6 million t. On this basis, the 12,000-20,000 t of petroleum - spilled in the Ekofisk Bravo blowout is rather insignificant compared to this total. There are many physical, chemical, and biological processes acting on spilled petroleum at any given time following an incident. Some processes are more important immediately folowing the spill: others have more long-range effects. Evaporation and biodegradation, both important processes for hydrocarbon removal, are discussed, as well as the impact of marine animals on hydrocarbon uptake. The effect of oil pollution on birds, fish, and benthic organisms is discussed.

Kuhnhold, W.W. (1978)

Impact of the Argo Merchant Oil Spill on Macrobenthic and Pelagic Organisms

Proceedings of Conference on Assessment of Ecological Impacts of Oil Spills, American Institute of Biological Sciences. pp. 153-179.

ABSTRACT

Abundance studies in benthic and pelagic communities including commercial fish species were done but did not suggest a major adverse impact. Zooplankton was, at some stations, fouled with oil. At some stations within the slick area and close to the margin lower densities of ichthyoplankton were found; pelagic fish eggs of the only two species present were contaminated and found moribund to a high degree. Laboratory experiments with cod eggs and young larvae were conducted with a no. 6 fuel oil to determine toxic levels of dissolved hydrocarbon concentrations. Very few of the fish examined, showed traces of Argo Merchant oil in stomach contents or muscle tissue. Prey-predator relationship seemed to have remained normal. Shortcomings in sampling methodology and evaluations are discussed.

Lamberti, G.A., Gregory, A.V., Ashkenas, L.R., Wildman,R.C. and Moore, K.M.S. (1991)

Stream Ecosystem Recovery Following a Catastrophic Debris Flow

Can. J. Fish. Aquat. Sci. 48:196-208.

ABSTRACT
We studied recovery processes for 3 yr in Quartz Creek (Cascade Mountains, Oregon), a third-order stream catastrophically impacted by a February 1986 debris flow for which both predisturbance data and an upstream control reach were available. The debris flow altered channel geomorphology and destroyed riparian vegetation for 500 m, resulting in a reach with short, disordered channel units, low hydraulic retention, and an open canopy. High irradiance levels and reduced grazing by macroinverTebrates contributed to rapid accrual of benthic algae in the disturbed reach, which formed the bioenergetic basis for ecosystem recovery. Macroinvertebrates (mostly herbivores) recovered to upstream densities and taxonomic richness within 1 yr, although effects on community structure persisted into the second year. cutthroat trout (<u>Oncorhynchus clarki</u>) populations were locally decimated by the disturbance, but by the following year, recruitment of young-of-the-year trout into the reach exceeded that of the upstream reach and populations had recovered to predisturbance densities. Despite the general rapid recovery of the biota within the disturbed reaches, most populations showed broad temporal fluctuations in abundance, suggesting that ecosystem stability was diminished by the debris flow. Long-term monitoring of Quartz Creek may yield additional insight into the role of episodic disturbance in stream ecosystems.

Lassig, B.R. (1983)

The effects of a cyclonic storm on coral reef fish assemblages.

Environ. Biol. Fish. 9:55-63

ABSTRACT
Visual censusing techniques were used to monitor the fish assemblages on eight shallow water coral patch reefs at Lizard Island (northern Great Barrier Reef) over a 27 month period. Larval settlement was distinctly seasonal with peaks occurring in December or January. Cyclones are most prevalent at this time of year. Three cyclones passed close to Lizard Island during the study period. Fish assemblages were censused before and immediately after one cyclone that struck at the time of peak larval settlement. The cyclone had little effect on adults but caused high juvenile mortality and re-distribution of sub-adult individuals. Because settlement strongly influences the diversity and density of adults, cyclones have marked effects on the fish assemblages as a whole. The frequency of tropical storms in many coral reef areas and the depths to which their effects

penetrate suggest that physical disturbances may be an important determinant of coral reef fish assemblage structure.

Laubier, L. (1980)

The Amoco Cadiz Oil Spill: An Ecological Impact Study.

Ambio 9:268-276

ABSTRACT

On the night of March 16-17, 1978, the supertanker Amoco Cadiz ran aground, spilling into the sea almost 223,000 tons of oil with a volatile fraction of 30 to 40 percent. A program to assess the ecological impact of the spill was begun immediately, to run for three years. It includes: chemical monitoring of the water, the sediments and the marine organisms; study of ecological effects on flora and fauna, including acute mortality and reestablishment of heavily damaged communities; studies of microbial degradation of the oil. Major results of these studies have been presented at a special symposium and are reviewed here, The recovery of areas exposed to waves, currents and wind energy is almost complete, but there is still oil in areas more protected from the physical energy of the sea. The ecological impact was extremely complex; in addition to the direct loss in biomass (acute mortality) and the corresponding loss in production, there are sublethal long-term effects especially on reproduction.

Laughlin, R.B. Jr, Ng, J. and Guard, H.E. (1981)

Hormesis: A Response to Low Environmental Concentrations of Petroleum Hydrocarbons

Science 211:705-707

Abstract

Possible lasting harmful effects resulting from short-term exposures to pollutants were investigated using the zoeal larvae of the mud crab, exposed to water soluble fractions of jet fuel for either the first 5 days of the stage or for the duration of zoeal development, which is 11 to 14 days. The salinity of the water, concentration of the fuel, and length of exposure each affected the survival of the zoeae. Short-term exposure or continuous exposure to low concentrations of petroleum hydrocarbons caused no increase in mortality or changes in the development rate, and increased megalopal weight was characteristic of such groups. This phenomenon is termed hormesis and has seldom been reported as a generalized aspect of environmental stress etiology. These experiments suggest an organismic resilience to episodic oil-spill incidents. It is felt that

many marine organisms have compensatory physiological strategies that enable them to tolerate low concentrations of pollutants or short term exposures.

Lee, N.Y., Winters, K. and Nicol, J.A.C.

The biological effects of the water-soluble fraction of a No 2 fuel oil on the plankton shrimp, Lucifer faxoni

Univ. of Texas, Marine Science Inst., Port Aransas Marine Lab. Port Aransas, TX 78373

Environmental Pollution, 15(3):167-183.

ABSTRACT
Biological parameters used to assess toxicity were survival, respiration, feeding rate. and degree of activity. In the survival and feeding studiea, 2 experiments were carried out, one with freshly prepared water-soluble fraction (WSF) (Exp. 1), the other with WSF exposed to air for 48 hr (Exp. 2) before the animals were introduced. Based on survival data for 14-d exposure, critical levels of toxicities in Exp. 1 were about 0.2 ppm, while in Exp. 2 they were around 2 ppm. A similar trend was found in studies of feeding and degree of activity. Unexposed extracts (Exp. 1) were more toxic and the effect on feeding was immediate and irreversible; exposed WSF was less toxic and the effect on feeding was delayed and reversible. The chemical composition of fresh WSF and of WSF exposed to air from 6 hr to 5 d was determined. Alkyl benzenes, indans, and naphthalenes were rapidly lost from the exposed solution, with only negligible concentrations remaining after 24 hr. In contrast, certain nonhydrocarbon compounds (e.g., alkyl anilines, phenols. and indoles) were generally prosent even after 5 d at >50% of their initial concentration. The biological and chemical data appear to indicate that the higher toxicity of fresh WSF to L. jaroni was due to volatile aromatic hydrocarons. The toxicity of oil spills could be markedly less than some laboratory results suggest because there is reduced toxicity following weathering by evaporation. Respiration rates of L. jaroni during an 8-hr exposure to freshly prepared WSF rose with increasing concentrations <30% of WSF, then fell with further increases of concentration of WSF.

Lee, R. F. (1977)

Accumulation and Turnover of Petroleum Hydrocarbons in Marine Organisms

Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. (D.A. Wolfe, ed.), Pergammon Press pp. 60- 70

ABSTRACT

This review deals with the uptake, storage and discharge of petroleum hydrocarbons by marine organisms under laboratory and field conditions. Organisms collected from oil spill and chronically polluted areas were analyzed. Special attention was directed toward the ability of animals to depurate their hydrocarbons accumulated after exposure to oil. Organisms studied were: benthic algae; zooplankton; benthic crustaceans; benthic worms; bivalves; and fish. Bivalves received emphasis because of the extensive amount of laboratory and field studies on their accumulation of petroleum.

Lee, R.F., Dornseli, F.B., Gonsoulin, F., Tenore, K. and Hanson, R. (1981)

Fate and Effects of a Heavy Fuel Oil Spill on a Georgia Salt Marsh.

Mar. Environ. Res. 5:125-143

ABSTRACT

Addition of a heavy oil to a Spartina salt marsh in the autumn resulted in high concentrations of polycyclic aromatic hydrocarbons in sediment and benthic animals. The highest concentrations of phenanthrene, chrysene and fluoranthene in the sediment were 112, 105 and 75 ng/g sediment, respectively. These concentrations rapidly decreased during the 20 week period following the spill. The times for these hydrocarbons to decrease to 50% of their highest values, i.e. half-life, were approximately 100, 70 and 30 days in sediment, mussels and oysters, respectively. Benthic macrofauna species showed three responses to oil addition which included no change, an increase, or a decrease in the population. No changes were noted in populations of fiddler crabs (Uca pugnax), oysters (Crassostrea virginica), and mussels (Modiolus demissus). Mud snails (Nassarius obsoleta) increased in density after the spill due to immigration of adult snails from untreated areas to scavenge on animals killed by the oil. Many of the adult periwinkles (Littorina irrorata) were killed by the oil. In the spring, juvenile periwinkles recolonised to oiled areas as a result of larvae settling.

Lee, W.Y. and Nichol, J.A.C. (1980)

Study of the Recovery of a Marine Isopod (<u>Saphaeroma quadridentatum</u>) from Petroleum-Induced Sensitivity

Biological Monitoring of Marine Pollutants, Proceedings of a Symposium on Pollution and Physiology of Marine Organisms
Academic Press, New York pp. 467-482

ABSTRACT

Experiments were designed to determine (a) whether offspring of water soluble fractions of a No. 2 fuel oil (WSF)-exposed isopods become less resistant to WSF in terms of rates of development, reproduction, and survival, and (b) the number of generations it would take to recover from such exposure. Chronic exposure of juvenile isopods to low levels of WSF resulted in a less resistant F1 generation. Petroleum-induced susceptibility lasted for about 1 to 2 generations when progeny of exposed isopods were grown in WSF-free sea water. Based on the life cycle of <u>Saphoeroma auadridentatum</u> observed in the laboratory, treated isopods required only 1/2 to 1 year to recover in WSF-free sea water. This short time interval was related to published data on the rates of accumulation and depuration of petroleum compounds by marine invertebrates. The rapid loss of accumulated hydrocarbons in clean sea water was probably the main reason why petroleum-induced sensitivity did not persist over a long period of time. Isopods in this study recovered more rapidly than the fauna in an oil-spill site. Since recovery of isopods took place in WSF-free sea water, the estimated time interval should be considered only as the minimum time period for a population to recover following an oil spill. However, when applying laboratory results to a field study, the authors suggest that other factors such as the chemical characteristics of oil and its persistence in the environment must be also taken into account.

Leppakoski, E.J. and Lindstrom, L.S. (1978)

Recovery of Benthic Macrofauna from Chronic Pollution in the Sea Area off a Refinery Plant, Southwest Finland

J. Fish. Res. Board Can. 35:766-775

ABSTRACT

Quantitative field studies (density, wet biomass, Shannon diversity, species richness, evenness of distribution) on benthic sublittoral macrofauna were made in the.vicinity of an oil refinery in southwest Finland before and after the installation of a new wastewater treatment plant that reduced the amount of oil and liquid effluents by ca. 90-95%. The number of species and species diversity

increased during the 1st and 2nd yr after pollution abatement at the stations close to the former outflows. The amphipods Pontoporeia affinis, Corophium volutator, and C. lacustre, midge larvae of the Chironomus plumosus-group, the oligochaete Tubifex costatus, the polychaetes Harmothoe sarsi and Polydora redeki, and the bivalve Cardium sp. were the most successful recolonisers of the 23 taxa sampled. The strong lethal effect of oil-contamiated sediments upon Chironomus plumosus larvae decreased markedly in laboratory experiments (LTs were estimated at 7 d in 1973 and at 28 d in 1974; in 1975, 80-90%of the larvae survived for 28 d. Details of postabatement succession are discussed. The results demonstrate not only the recovery from chronic oil pollution but also the degree of ecological damage caused by previous continuous discharge of oil.

Levasseur, J., Durand, M-A. and Jory, M-L. (1981)

Biomorphologic and Floristic Aspects of the Reconstitution of a Phanerogamic Vegetal Cover, Altered by the Amoco Cadiz Oil Spill and the Following Clean-Up Operations. Special Study of the ile Grande Salt Marshes (Cotes du Nord) (in French).

Amoco Cadiz Fates and Effects of the Oil Spill. Proceedings of the International Symposium. pp. 455-473

ABSTRACT

Oiling and subsequent cleaning of coastal marshes of the ile Grande have drastically reduced vegetational cover. They have also caused profound modifications of habitat types and distribution. Current reestablishment of vegetation involves the two classical processes of (1) primary succession, where dykes have been raised or lower and middle areas of marshes have been bulldozed, (2) secondary succession elsewhere. It seems necessary to consider changes at the level of the site rather than the community and specifically as regards the population. The age and prior extension of certain clones have a decisive influence on the redistribution of species dominance actually under way since the first stage of succession implies reoccupation of the surface. In this respect, rhizomatous geophytes are currently favored. In the middle and upper marsh areas, contrary to what is seen in haute-slikke or bas-schorre, chances of vegetational reestablishment are correlated with degree of species and growth form diversities.

Levasseur, J.E. and Jory, M.L. (1982)

Natural recovery of salt-marsh vegetation destroyed by the Amoco Cadiz oil spill: Circumstances and tendencies. (in French)
Original Title: Retablissement naturel d'une vegetation de marais maritimes alteree par les hydrocarbures de l'Amoco Cadiz : Modalites et tendances

Ecological Study of the Amoco Cadiz Oil Spill: Report of the NOAA-CNEXO Joint Scientific Commission (E.R. Gundlach and M. Marchand, eds.) pp. 329-362

ABSTRACT

Recovery of lIe Grande salt-marsh vegetation (Spartina maritima, Salicorina nerennis, Halimione portulacoides, Pucinella maritima, and Juncus maritimus) partially destroyed by hydrocarbons has been significantly restored since 1980. Ways and timing of recovery are due to the relative dominance, in each point, of two processes, viz. in situ regeneration of perennial individuals and germination of seeds produced near or on the site. Colonisation is mainly due to annual species while germination of perennials is a rare event, except in shadey places with loose and clean substrate. However, it is impeded either in tide exposed points or in formerly heavily trampled places.

Linden, O (1975)

Acute Effects of Oil and Oil/Dispersant Mixture on Larvae of Baltic Herring

Ambio 4:130-133

ABSTRACT

The acute toxic effects of a crude oil, either alone or dispersed by two commonly used oil spill dispersants, were tested on newly hatched herring larvae. The results show that if the oil is dispersed with a dispersant, the toxicity increases 50 to 100 times compared to the oil without the dispersant. A natural oil dispersion without the dispersant loses much of its toxicology in 24 and 72 h. If, however, the oil is dispersed by a dispersant, the high toxicity remains almost unchanged in the same time.

Linden, O., Elmgren, R and Boehm, P. (1979)

The Tsesis Oil Spill: Its impact on the coastal ecosystem of the baltic Sea

Ambio 8:244-253

ABSTRACT

The Tsesis oil spill was relatively minor by international standards-roughly 1000 tons of medium grade fuel oil. However, severe effects were observed, at least locally, in the pelagic, littoral and benthic ecosystems and the speed of recovery varied greatly. The plankton communities were back to normal after about one month, but it took a year before the littoral communities showed considerable recovery and within that time the soft bottom community did not show even the beginning of a recovery.

Longwell, A. C. (1977)

A Genetic Look at Fish Eggs and Oil

Oceanus, Vol 20(4):46-58

ABSTRACT

The buoyant fish eggs sampled in the vicinity of Argo Merchant oil spill were observed. Oil droplets were seen of 94% of the cod eggs. Cytological and cytogentic assays of mortality and morbidity of cod and pollock eggs from the vicinity of the Argo Merchant oil spill were made. Speculation in the genetic effects of major oil spills on fish populations were made.

Mageau, C., Engelhardt, F.R., Gilfillan, E.S. and Boehm, P.D. (1987)

Effects of short-term exposure to dis[ersed oil in Arctic invertebrates

Arctic 40(Suppl. 1):162-171

ABSTRACT

A series of experimental studies was carrried out as part of the baffin Island [Canada] oil spill (BIOS) project to define the behavioural, physiological, and biochemical reactions of three arctic marine benthic invertebrate species exposed to chemically dispersed crude oil. Behavioural responses and patterns of hydrocarbon accumulation and release observed in the bivalves and the urchin during the 1981 field spill were similar to those observed during the laboratory simulations. Ostial closure, loss of responsiveness to mechanical stimuli and narcosis were characteristic of the bivalves. Exposed urchins displayed a functional loss of the tube foot and spine behaviour. Detailed hydrocarben analysis indicated different uptake dynamics among the species. The effects of dispersed oil were immediate and short lived and resulted in temporary

accumulation of hydrocarbons. Depuration of these stored hydrocarbons occurred during the experimental recovery period. In vivo biodegradation of hydrocarbons was indicated in the bivalves. Physiological, parameters measured in bivalves exposed to oil included elements of scope for growth, activity of aspartate aminotransferase and glucose-6-phosphate dehydrogenase. Dose-response relationships between physiological rates and hydrocarbon body burden were apparent.

Maki, A. W. (1991)

Exxon Valdes Oil Spill: Initial Environmental Impact Assessment.

Environmental Science and Technology 25:24-29

ABSTRACT

Exxon's response to the Exxon Valdez oil spill on Bligh Reef in Prince William Sound in Alaska was unprecedented in scale. The Exxon response included the employment of more than 11,000 people, utilization of essentially the entire world supply of containment booms and skimmers, and an expenditure of more than two billion dollars. Following the spill and cleanup, Exxon mobilized a massive environmental assessment program. Data from these studies indicate that wildlife and habitats are recovering from the impacts of the spill and that commercial catches of herring and salmon in Prince William Sound are at record high levels. Samplings of petroleum aromatic hydrocarbons concentrations in the waters clearly demonstrate that average levels have remained well below exposure levels known to cause acute and chronic effects to sensitive aquatic life. Field counts of plants, fish and mammals from throughout the spill area provide convincing data that wildlife species are surviving and reproducing, thus confirming that biological recovery is rapidly taking place. Ecosystem recovery from spill impacts is due to the combined efforts of the cleanup program as well as natural physical, chemical, and biological processes. From all indications this recovery process can be expected to continue.

Malins, D. C. (1982)

Alternations in the Cellular and Subcellular Structure of Marine Teleosts and Invertebrates Exposed to Petroleum in the Laboratory and Field: A Critical Review.

Can J. Fish. Aquat. Sci. 39:877-889

ABSTRACT
Laboratory studies with individual petroleum components, model mixture of hydrocarbons, fractions of petroleum, and whole oil have demonstrated, mostly at high exposure concentrations, an association between petroleum and various cellular/subcellular alterations in marine organisms. Recent evidence, notably from studying the effect of the Amoco Cadiz oil spill, suggest that cellular/subcellular alterations also result from exposing marine organisms to petroleum in the field. In marine environments, however, it is still generally not possible to predict the type or degree of impact of petroleum or organisms because little information is available on the influence of myriad natural and man-induced environmental variables on its fate and effects.

Mankki, J. and Vauras, J. (1974)

Littoral Fish Populations after an Oil Tanker Disaster in the Finnish SW Archipelago

Ann Zool Fenn 11:120-126

ABSTRACT
Littoral fish populations of areas of the Baltic Sea affected by an oil spill from a tanker were examined 2 yr after the disaster occurred. The most frequent species were Phoxinus phoxinus (L.), Gasterosteus aculeatus (L.) and Pungitius pungitius (L.). The aim was to ascertain whether the oil, and the emulsifiers used to repel it, had long-term effects on these species. The fish were caught with a beach seine in June and JUky, 1971. Their age, growth, condition factor and regression coefficient of log length on log weight were studied in several populations. No statistically significant differences were found between populations of 3 oil-polluted areas and a control area. The effects of oil and emulsifiers on the fish and the situation after the disaster are discussed.

Merrell, T. R.

Fisheries Resources.

Environmental Studies in Port Valdez, Alaska: A Basis for Management. Lecture Notes on Coastal and Estuarine Studies Vol. 24, Springer-Verlag, New York, 1988. pp 203-224,

ABSTRACT

Pink, chum, and coho salmon and Pacific herring are the most important fisheries resources in Port Valdez from both commercial and recreational standpoints. Early life stages of these species are the most vulnerable to oil pollution: pink and chum salmon eggs in intertidal spawning streambeds, and fry during early marine life; coho salmon smolts during their seaward migration through Port Valdez; and Pacific herring eggs and larvae during their first few weeks of life before they have dispersed away from spawning sites. The new Solomon Gulch Hatchery is expected to reach full production of salmon by 1989, when more than 6 million pink, 324,000 chum, and 60,000 coho salmon will return each year as adults. Most of the pink and chum salmon will be caught by common property commercial net fisheries, and most of the coho salmon by sport fishermen. Unless a catastrophic oil spill occurs in Port Valdez, or concentrations of toxic components from the treated tanker ballast effluent become substantially higher in Port Valdez than at present, it is unlikely that oil pollution will have significant adverse impacts on hatchery or natural stocks of salmon, herring, or other fishery resources. The possibility of eventual subtle indirect effects of hydrocarbons on salmon and herring, and their habitat, cannot be ruled out. Hydrocarbon concentrations from the ballast effluent are gradually increasing in sediment and water and could eventually have harmful effects, such as altering migratory behavior of juvenile and adult salmon, or diminishing the abundance of prey species upon which salmon and herring are dependent during early sea life.

Michael, A.D., Van Raalte, C.R. and Brown, L.S. (1975)

Long-term effects of an oil spill West Falmouth, Massachusetts

1975 Conference on provention and control of oil pollution pp 573-582

ABSTRACT

A small spill of No. 2 fuel oil occurred near Wild Harbor, Massachusetts in September 1969. The benthic fauna of the Wild Harbor marsh, boat basin, and offshore area was sampled through the fourth and fifth years after the spill (1973, 1974). Sediment samples were analyzed for the presence of petroleum hydrocarbons. Gas chromatography produced evidence of hydrocarbons typical of weathered fuel oil in the sediments of the marsh, boat basin, and two offshore stations. The numbers of benthic species at the offshore stations and the marsh were slightly, but

significantly, lower than those found at control stations. Population densities were similar to control areas for the offshore stations but not in the case of the marsh. The boat basin was still heavily affected. Some stations were characterized by the presence of opportunistic species. The recovery process in terms of the total benthos has leveled off, but there was evidence for further recovery during the course of the study.

Michaelis, F.B. (1983)

Effect of Turoa oil spill on aquatic insects in the Mangawhero River system.

N. Z. Entomol. 7:447-455

ABSTRACT

Oil (17,000 I) was spilled from Turoa Skifield on Mt Ruapehu and entered the headwaters of the Mangawhero and Makotuku Rivers where it persisted for up to 5 months. Brown trout, rainbow trout, long-finned eels, and blue duck were not killed. However, in the upper reaches, aquatic insects were disturbed and killed by the oil spill within 2 weeks. The total numbers of aquatic insects were not significantly affected at the lower stations within Tongariro National Park over the following year. Mayflies were significantly reduced in numbers in the Mokotuku River following the oil spill and may be indicator species for oil pollution. Comparisons with overseas studies confirmed a recovery time of at least 6 months for the sensitive orders of aquatic insects following an oil spill of this magnitude.

Milner, A.M. and Bailey, R.G. (1989)

Salmonid colonization of new steams in Glacier Bay National Park, Alaska

Aquaculture and Fisheries Management 20:179-192

ABSTRACT

Following the rapid recession of a neoglacial ice sheet within the last 250 years, colonization of recently deglaciated streams by salmonid fishes was investigated in Glacier Bay National Park. south-eastern Alaska. The primary factors governing the establishment, species diversity composition and abundance of salmonids in Glacier Bay streams were water temperature, sediment loading and stream discharge. No salmonids were found in the turbid meltwater streams emerging from retreating ice. Coho, Oncorhynchus kisutch (Walbaum), and sockeye, Oncorhynchus nerka (Walbaum)

salmon and Dolly Varden, Salvelinus malma (Walbaum), charr were the first salmonids to colonize the youngest clearwater stream. Juvenile Dolly Varden were more abundant than juvenile coho salmon in the most recently formed clearwater stream because of the characteristic absence of pool habitat. Densities of juvenile coho salmon were six times greater in a stream with a series of lakes compared with a stream of similar age without lakes. Future advancement of salmonid stocks will probably depend upon the rate and extent of the development of riparian vegetation and inputs of large woody debris from the developing forest to provide further instream cover, habitat variation and channel stabilization.

Morrow, J.E. (1973)

Oil-induced Mortalities in Juvenile Coho and Sockeye Salmon

Journal of Marine Research 30:135-143

ABSTRACT

A laboratory study was undertaken to determine the effects of crude oil in concentrations that might occur from an oil spill on sockeye and coho salmon. Specimens aged 9 to 13 months had seawater of 3 percent salinity. Crude oil was introduced in concentrations from 500 to 3,500 ppm and the water temperature was set at 3, 8, or 13C. Stress behavior under the influence of oil was also investigated. Mortality rates of up to 100 percent were produced in 96 hrs. The majority of the 96-hour experimental mortality rates were significantly higher than the mortality rates of control animals. The mortality rates were directly related to the concentration of oil, but appeared to be inversely related to water temperature. Mortality apparently was caused by some component of crude oil that is soluble in water and is also volatile and/or easily oxidized. It was found that crude oil loses its toxicity to salmon after exposure to air, probably through the loss of volatile toxic components. Hence, conclusions based on bioassay work with oil of unknown history may be less valuable than those derived from studies wherein the handling history of the oil is known.

Nakatani, R.E. and Nevissi, A.E. (1991)

Effect of Prudhoe Bay Crude Oil on the Homing of Coho Salmon in Marine Waters
North American Journal of Fisheries Management 11:160-166

ABSTRACT

Resource managers and the fishing industry have expressed concern that a crude-oil spill occurring in the pathway of a salmon run may destroy the ability of the maturing salmon to reach the home stream. To address this concern, groups of mature 3-year-old and precocious 2-year-old coho salmon Oncorhynchus kisutch were tagged and exposed in seawater for 1 h to sublethal concentrations of Prudhoe Bay crude oil, dispersed oil, or seawater oil dispersant alone, and then were released in seawater about 5 km from their home stream. The results show that the coho salmon's homing success and speed of return to the home stream were not affected by any of the treatments. The longevity or holding tests, in which coho salmon were held in saltwater net pens after experimental treatments, showed that the larger 3- year-old coho salmon were more sensitive to the stress of confinement than the smaller 2-year-old fish.

Naslund, I. (1989)

Effects of habitat improvement on the brown trout, Salmo trutta L., population of a northern Swedish stream

Aquaculture and Fisheries Management 20:463-474

ABSTRACT

Effects of four types of habitat improvement structures have been evaluated in Laktabacken Creek, a steep and infertile brown trout, Salmo trutta L., stream in Northern Sweden. Boulder dams proved to be the most efficient structure, increasing brown trout densities by up to three times and standing crop by up to five times their original values. Log deflectors gave similar effects on standing crop while boulder groupings and boulder deflectors seemed to be inefficient. Older/larger fish were primarily favoured. No increase in growth or enhanced condition has been registered. Obviously, profitable stream positions for older fish were lacking in Laktabacken Creek. An increase in the amount of cover and an increase in the winter survival might be secondary effects of alterations.

Neff, J.M., Sharp, M.S. and McCulloch, W.L. (1981)

Impact of the Esso Bayway Oil Spill on Salt Marsh Macro Fauna

Proceedings of the 1981 Oil Spill Conference (Prevention, Behavior, Control, Cleanup) pp 413-418

ABSTRACT

On January 28,1979, approximately 6,000 barrels of light Arabian crude oil was spilled into the lower Neches River near Port Neches, Texas. Much of the oil became stranded in the adjacent brackish-freshwater marsh, which is considered to be an important nursery area for postlarval penaeid shrimp. The purpose of this investigation was to assess the long-term impact of the spill on the macrofauna of the marsh. Petroleum hydrocarbon concentrations in marsh sediments were high (up to 7,000 mg/kg dry wt) at all but one unoiled reference station. Due to unusually high rainfall, salinity in the marsh was very low until September 1979, when it rose to 6 to 12 parts per thousand. Macrocrustacean and fish populations were very similar at both oiled and reference stations in terms of species composition, number of species, and number of animals. Species diversity indices were similar at oiled and reference stations. Postlarval penaeid shrimp Penaeus setiferus did not enter the marsh until September when the salinity rose. They were equally abundant at oiled and reference stations. We conclude from this 9-month study that the spilled oil had little or no significant effect on the aquatic macrofauna, including penaeid shrimp, of the Neches River marshes. Environmental factors, salinity, and temperature, had a much greater effect on the marsh populations and obscured any effects that might be attributed to oil.

Nellbring, S., Hansson, S., Aneer, G. and Westin, L. (1980)

Impact of Oil on Local Fish Fauna

The Tsesis Oil Spill. Report of the First Year Scientific Study pp 193-201

ABSTRACT

From earlier echo sounding surveys it is known that pelagic fish (herring, Clunea harenaus membras, L. and sprat, Sprattus sprattus L.) are very abundant in the spill area during late autumn and winter. It is also known that herring spawn in the archipelago in the spring. The analysis of herring did not indicate any contamination by oil. The low frequency of spawning by herring in the affected area may indicate effects of oil pollution. It may, however, also be due to the differences that undoubtedly exist between the polluted and reference areas as regards exposure and sediment type distribution on the fairly shallow bottoms, where herring spawn was found. On comparison, it is clear that the hatching of herring eggs was less successful in samples from the oil affected area. Significant differences also between samples from within the polluted area may, however, indicate that factors other than oil pollution may

have influenced hatching rate. One such factor was the fungal infection of the roe. In the spring after the oil spill, hardly any adult Gammarids were present in the polluted area. It is therefore possible that their absence led to increased fungal attack on fish roe.

Nelson-Smith, A. (1968)

Biological consequences of oil pollution and shore cleansing

Biological Effects Of Oil Pollution On Littoral Communities: Supplement To Volume 2 of Field Studies, Field Studies Council, London pp.73-80

ABSTRACT:
The effects of oil spills in different areas were investigated to provide interesting comparisons. Oil spilled into a small cove yielded extensive shore pollution and mortalities. No emulsifiers were used and in less than a year the animal populations were again normal, gastropod molluscs appeared to be most seriously affected. Marine algae populations were also reduced. Misuse of emulsifiers embedded the oil more firmly and resulted in increased mortalities. Emulsifiers enable the oil to wet the surfaces of shore organisms and to penetrate their systems and also to spread the oil to previously unreached areas. Time of year of oil spill and mobility of organisms regulate the rate at which the members of the shore community are able to recover from oil pollution.

Nelson-Smith, A. (1980)

Biological consequences of oil-spills in arctic waters

The Arctic Ocean: the Hydrographic Environment and the Fate of Pollutants (L. Rey and B. Stonehouse, eds.) Macmillan, pp. 275-293

ABSTRACT:
This is a review of the biological effects of oil spills and blowouts in Arctic waters and on Arctic shorelines, as well as the implications of cleanup techniques.

Netboy, A. (1989)

The long road back.

Atl. Salm. J. 38:16-17

ABSTRACT:

The author provides an historical account of the decline and restoration of the Atlantic salmon (Salmo salar) to the rivers of New England. Much has been spent and much accomplished by the restoration projects but the ultimate success or failure of these efforts remains in doubt.

Nounou, P. (1980)

The Oil Spill Age--Fate and Effects of Oil in the Marine Environment

Ambio 9:297-302

ABSTRACT

This paper presents a summary of the fate and effects of oil pollution in the marine environment and prospects for the future. Although large spills from wrecked ships or blown wells are more spectacular, 90% of oil in the ocean comes from rivers, coastal refineries, deballasting by tankers, offshore exploration, and natural seepage. Within a few days after a discharge, oil spreads on the surface, the volatile components evaporate, and the oil disperses according to properties of the oil and the energy in the environment. Emulsif ication and tar lump formation can occur. Oil may then degrade chemically or biologically or persist in sediment. Literature on effects of petroleum on marine organisms is not very consistent because researchers use different techniques and different oils. Lethal concentrations vary with species and age of the organism, eggs being very sensitive. Sublethal effects are many. Direct coating and ingestion of oil affect immobile species, such as barnacles and algae, as well as sea birds. Edible fish and shellfish can be contaminated. Bioaccumulation of carcinogens in food chains is widespread, as are disturbances in ecosystems. The greatest damage occurs near the shore, but deep-sea contamination of breeding grounds or migration routes can severely damage some species.

Olla, B.L., Pearson, W.H., Miller, S.E. and Blaylock, J.W. (1981)

Detection of the Water-Soluble Fraction of Crude Oil by the Blue Crab, Callinectes sapidus.

Mar. Environ. Res. 5:3-11

ABSTRACT

The ability of the blue crab, Callinectes sapidus, to detect petroleum hydrocarbons was measured with behavioral techniques. When presented with a water-soluble fraction of Prudhoe Bay crude oil, blue crabs abruptly changed antennule orientation, began rhythmic beating of the maxillipedal flagellae, and increased antennular flicking rate. The threshold concentration at which 50% of the crabs detected the water-soluble fraction was 2 x 10^{-6} mg/litre. The blue crab apparently can readily detect petroleum hydrocarbons at concentrations found in chronically polluted areas as well as oil spill situations.

Olla, B. L., Bejda, A. J. and Pearson, W. H. (1983)

Effects of oiled sediment on the burrowing behavior of the hard clam, Mercenaria mercenaria.

Mar. Environ. Res. 9:183-193

ABSTRACT

The burrowing behavior of juvenile hard clams, Mercenaria mercenaria, in oil-contaminated sediment was examined in a series of laboratory experiments. At oil concentrations within the range that might occur after an oil spill, depth and rate of burrowing were altered. The depth to which clams in oiled sediment burrowed after 96 h was significantly shallower than the depth in the controls, while the time taken to burrow beneath the surface was longer in oil-contaminated sediment. Alterations in burrowing were indicative of avoidance behavior rather than oil-induced debilitation. The results suggest that such alterations may increase the vulnerability of this species to predation.

Olmsted, L.L. and Cloutman, D.C. (1974)

Repopulation After a Fish Kill in Mud Creek, Washington County, Arkansas Following Pesticide Pollution

Trans. Amer. Fish. Soc. 103:79-87.

ABSTRACT

Repopulation after a fish kill caused by pesticide pollution in Mud Creek, Washington County, Arkansas is reported. Twenty nine species of fishes were eliminated from the study area as a result of the poison. Repopulation began almost immediately after the pesticide dissipated, and was accomplished primarily by immature individuals. Chronology and rate of repopulation of each species are

reported, and factors influencing the rate of repopulation and population structure are discussed.

Orth, R.J. (1977)

Effect of nutrient enrichment on growth of the eelgrass Zostera marina in the Chesapeake Bay, Virginia, USA

Marine Biology 44:187-194

ABSTRACT

Experimental addition of two commercial fertilizers to beds of eelgrass (Zostera marina) in Chesapeake Bay off Church Neck. Delmarva Peninsula, Virginia, greatly increased the length, biomass, and total number of turions over controls at both shallow and deep stations during a two to three months period. Results suggest: (1) Z. marina beds in Chesapeake Bay are nutrient-limited, (2) growth form of Z. marina may be related to sediments nutrient supply, and (3) Z. marina may competitively exclude Ruppia maritima by light-shading. Fertilizers used were: (1) 5% ammonium nitrate, 10% phosphoric anhydride, 10% potassium oxide; and (2) 10% ammonium nitrate, 5% phosphoric anhydride, 10% potassium oxide. The area is characterized by extensive intertidal sand flat populated by patchy widgeon grass(R. maritima) and grading into a mixed subtidal seagrass bed of Z. marina and R. maritima, and then into a monospecific bed of Z. marina indeeper portion. Two stations were established, Station A in 0.3 m of water, and Station B in 0.6 m of water (mean low water). No significant difference was found betwen the two fertilizers for any of the parameters monitored. There were significantly more turions in both fertilized plots and controls in the shallow area than in the deeper area, but turions in deep plots were significantly longer than those in shallow plots.

Oudot, J., Fusey, P., Van Praet, M., Feral, J.P.and Gaill, F. (1981)

Hydrocarbon Weathering in Seashore Invertebrates and Sediments over a Two-Year Period Following the Amoco Cadiz Oil Spill: Influence of Microbial Metabolism.

Environ. Pollut. Ser. A. 26:93-110

ABSTRACT

The weathering of aliphatic and aromatic hydrocarbons from the Amoco cadiz oil was monitored from May 1978 to Jan. 1980 in selected seashore invertebrates and sediments of the polluted area in Brittany, using high temperature high

resolution gasliquid chromatography. The major part of the oil was relatively rapidly eliminated but some petroleum constituents, such as logchain n-alkanes, triterpanes and alkylated phenanthrenes and dibenzothiophenes, appeared to persist for a time. In high energy sites (Roscoff beach), depuration was generally quite complete between 12 and 18 months after the wreck, whereas, in sheltered muddy sediments and associated organisms of Aber Benoit and Aber Wrach, the presence of neosynthesized very long-chain alkanes up to nC56 was shown. These compounds are believed to result from bacterial metabolism and were still clearly visible 22 months after the accident. Microbial degradation was the main weathering factor and bacterial counts in the Aber Benoit muds showed that almost all the bacteria present were adapted to hydrocarbon utilization.

Peckol, P., Levings, S.C. and Garrity, S.D. (1990)

Kelp response following the World Prodigy oil spill.

Mar. Pollut. Bull. 21:473-476

ABSTRACT

Associated with the June 1989 grounding of the tanker World Prodigy on Brenton Reef, Rhode Island, approximately 922 t of No. 2 fuel oil were released into surrounding coastal waters. The authors investigated effects of oiling on the subtidal kelps, Laminaria saccharina and L. diaitata. Kelp condition, growth rates with depth, and pigment acclimation were compared with prespill measurements of kelp performance at the same site in 1984-1987. There was no evidence that kelps were detrimentally affected by oiling; we observed no necrotic or bleached tissue on any kelps in an oiled cove. Growth rates of both species were within the range of our previous years' data and pigment acclimation was similar for all years. Lowest growth rates occurred in 1985 during a severe brown tide. This study and other data suggest that Narragansett Bay was spared potential disaster because little fuel oil mixed into the water column and contacted subtidal organisms.

Peters, R. J. (1989)

A Comparison of Two Methods for Determining Avoidance of Water Soluble Petroleum Hydrocarbons By Salmonids

Masters Thesis, University of Washington Seattle.1989

ABSTRACT

Two methods commonly used to determine salmonid avoidance of pollutants were evaluated. These two methods differed with regard to the number of fish tested per experimental trial. Method one was a multiple fish design in which sixteen to twenty fish were tested simultaneously. The second method was a single fish design, in which a single fish was tested per experimental trial. The pollutant used in this study was a mixture of hydrocarbons used to simulate the water soluble fraction (WSF) of Prudhoe Bay Crude oil. This synthetic water soluble fraction (sWSF) contained percentages of alkanes (38.8 %), cycloalkanes (6.9 %), and aromatics (54.2 %), which were found in equilibrium concentrations of the water soluble fraction of Prudhoe Bay crude oil in fresh water at 25C. Juvenile chum salmon were tested in seawater using a two-choice Y-maze test chamber. The species and substrate were chosen since limited avoidance data is available regarding these variables. No significant avoidance responses were obtained when tested with ANOVA. Slight differences were displayed in testing power. Since these tests were conducted at different times it is difficult to conclude if the power was test related or time related. The multiple fish design required less time to complete than the single fish design. The multiple fish design also more closely simulated the natural environment. The materials required for each design varied slightly. The multiple fish design required more fish; holding facilities, and food, while the single fish design required more sample bottles and analytical supplies. The ambiguity of the results prevent the researcher from concluding which method provides the best results, with the least cost and effort. Sensitivity seems to favor the single fish method. While time requirements favor the multiple fish design. The materials required are approximately the same. Thus each method has both itls advantages and disadvantages.

Phinney, D. E. (1975)

Repopulation of an Eradicated Stream Section by Brook Trout

Trans. Amer. Fish Soc. 104:685-687

ABSTRACT

The rate of reropu]ation of a stream section treated with rotenone was studied by electrofishing. Brook trout from the unaffected areas upstream had completely repopulated the area after one year. The primary repopulation was by young-of-the-year trout.

Platts, W.S. and Nelson, R.L. (1988)

Fluctuations in trout populations and their implications for land-use evaluation.

N. AM. J. FISH. MANAGE. 8:333-345

ABSTRACT

The authors describe the magnitude of fluctuations in trout populations in several widely separated streams in the intermountain region of the western US, and consider their potential effect on land-management planning. Trout populations included native and exotic species, self-reproducing and hatchery-maintained populations, and assemblages that ranged from monospecific to diverse. Annual fluctuations in population statistics were generally large, and were related to geographic setting and trout species. Except in cases of irregular occurrence, populations of brook trout Salvelinus fontinalis, particularly in Rocky Mountain study areas, were numerically the most stable; those of allopatric cutthroat trout Salmo clarki in the Great Basin were the least stable numerically. Total salmonid community tended to fluctuate less than individual populations, except when fry of anadromous chinook salmon Oncorhynchus tshawytscha were present. Inherent trout population fluctuations must be considered within the framework of land-use planning if fishery goals are to be achieved. Habitat-based models to evaluate the effects of land uses and habitat enhancement efforts frequently fail to incorporate these fluctuations. Such models often have little utility in predicting sizes or biomass of salmonid populations in the intermountain west.

Renaud-Mornant, J. and Gourbault, N. (1980)

Survival of Meiofauna After the Amoco Cadiz Oil Spill (Morlaix Channel and Roscoff Beach, Brittany, France) (in French).
Original Title: (Survire de la Meiofaune Apres l'Echonement del Amoco Cadiz (Chenal de Morlaix, Greve de Roscoff)

Bull. Mus. Natl. Hist. Nat. (France)(4e Ser., Zool. Biol. Ecol. Anim.). 2:759-772

ABSTRACT

The effects of hydrocarbon contamination on subtidal and intertidal meiofauna were studied a few days after the spill (March 1978) and surveyed one month and seven months later. Apparently no drastic reduction in species had occurred, but reduced densitites were observed after one month. Turbellaria and particularly Harvacticoidea seemed to have been more affected than other taxonomical groups.

Recovery within seven months seemed related to both hydrodynamism and sediment porosity allowing a proper restoration of living conditions. Resistance to hydrocarbon toxicity may be due to the ability of faunal taxa to withstand large trophic temporary fluctuations. High reproduction rates, protection of brood and adaptability to unstable habitats, might have been important recovery factors.

Riaux-Gobin, C. (1985)

Long-term changes in microphytobenthos in a Brittany estuary after the Amoco Cadiz oil spill.

Mar. Ecol. (Prog. Ser.). 24:51-56

ABSTRACT

After the Amoco Cadiz oil spill (Mar. 1978), a 4 yr survey of the microphytobenthos (cell numbers and chlorphyll a content) was carried out on a mud flat polluted by petroleum hydrocarbons. There was an obvious peak of microphytic biomass 7 mo after the spill, a decrease during 1979-1980, and a slow increase again in 1981. Moreover an annual pattern in biomass variations, involving early spring and autumn maxima, was noticed for 1979-80-81, whereas this seasonal cycle did not appear in 1978. During the unexpected increase in chlorophyll a content in autumn and winter 1978, a bloom of Euglenophyta and small epipelic diatoms was observed. Results suggest that the hydrocarbons affected the long-term trend of the biocenosis.

Roesijadi, G., Anderson, J.W. and Blaylock, J.W. (1978)

Uptake of hydrocarbons from marine sediments contaminated with Prudhoe Bay crude oil: Influence of feeding type of test species and availability of polycyclic aromatic hydrocarbons.

J. Fish. Res. Board Canada 35:608-614

ABSTRACT:

Selected benthic animals were exposed to marine sediments contaminated with Prudhoe Bay crude oil, and uptake of hydrocarbons was monitored under various experimental schemes. When uptake of aliphatic and diaromatic hydrocarbons by two deposit feeders, Macoma inquinata and Phascolosoma agassizii, was compared with that of a suspension feeders, Protothaca staminea, it was found that the deposit feeders generally accumulated hydrocarbons to a greater extent than the suspension feeder. However,

other factors, such as the intrinsic capabilities of species to accumulate hydrocarbons, also played an important role in the extent of contamination. Hydrocarbon concentrations in the bivalve species (M. inquinata and P. staminea) increased during the 60-day exposure period; whereas concentrations in the sipunculid Phascolosoma agassizii appeared to have reached an equilibrium relatively early in the exposure. Experiments on uptake of 14C-phenanthrene, -chrysene, -dimethylbenz(a)anthracene, and -benzo(a)pyrene by M. inquinata indicated that compounds directly associated with sediment were less available for uptake than those released from sediment to surrounding seawater. Additionally, the heavier molecular weight aromatic compounds tended to be more concentrated in tissue and retained for longer periods of time than the lighter compounds.

Sanders, H.L., Grassle, J.F., Hampson, G.R., Mose, L S., Garner-Price, S. and Jones, C.C. (1980)

Antaomy of an Oilspill: Long-term Effects from the Grounding of the Barge Florida off West Falmouth, Massachusetts

J. Marine Res. 38:265-380

ABSTRACT

To determine carefully the effects on the marine estuarine benthos of number 2 oil spilled by the barge Florida off West Falmouth, Massachusetts, the authors sampled along an onshore-offshore gradient of pollution. Analysis of hydrocarbons established that pollution was greater and more persistent in the intertidal and subtidal zones of Wild Harbor River, less severe in degree and duration at stations farthest from shore. Plant, crustaceans, fish and birds suffered both high mortality immediately after the spill, and physiological and behavioral abnormalities directly related to high concentrations of the fuel oil. Five years after the spill its effects on the biota were still detectable, and partly degraded no. 2 fuel oil was still present in the sediments in Wild Harbor River and estuary.

Sanders, H.L. (1978)

Florida Oil Spill Impact on the Buzzards Bay Benthic Fauna: West Falmouth

J. Fish. Res. Board Can. 35:717-730.

Abstract
No matter what criterion is used to measure the effects of the Florida oil spill, the densities and species composition and the array of statistical methods demonstrate that the same hierarchical pattern emerges. Densities and species composition remain stable over time at the minimally oiled and unoiled stations, but display considerable fluctuations and marked changes at the more heavily oiled stations. With simple presence or absence data, highest fidelity is present at the marginally oiled stations, lower fidelity at the intermediately oiled stations, and lowest fidelity at the severely oiled stations. The discrepancy index measures mean yearly differences in fauna composition at each of the stations. Very large and large differences are documented for the severely and intermediately oiled stations but only small differenees are found for the marginally oiled stations. The coefficient of variation is a measure of faunal variability throughout the entire sampling period for each of the stations. Faunal variation remains very high at the severely and intermediately oiled stations but low at the marginally oiled sites. Cluster analysis reveals profound temporal changes in the fauna from samples collected at the severely and intermediately oiled stations but demonstrates a much more homoreneotts pattern with only small seasonal changes from samples obtained at the marginally oiled stations.

Seneca, E.D. and Broome, S.W. (1982)

Restoration of marsh vegetation impacted by the Amoco Cadiz oil spill and subsequent cleanup operations at lIe Grande, France.

Ecological Study of the Amoco Cadiz Oil Spill: Report of the NOAA-CNEXO Joint Scientific Commission (E.R. Gundlach and M. Marchand, eds.) pp.363-420

ABSTRACT
The authors developed a proposal for restoring marsh at the Ile Grande site adapting techniques and procedures developed for Spartina alterniflora, in North Carolina to restoration of a part of the Ile Grande marsh using vegetation indigenous to that region. Although there was considerable variation in response to fertilizer materials and rates, both nitrogen and phosphorus were required for good transplant growth on the disturbed sites tested. Slow release fertilizer materials produced better growth than did the conventional, more soluble fertilizer materials. Higher survival and better growth were obtained with Halimione portulacoides and Puccinellia maritima transplants than with those of the other three species tested, Juncus maritima, Spartina maritima, and Triglochin maritimus. Above ground

growth of the best experimental plantings of Puccinellia spread radially at the rate of about 10 cm annually. At this rate of spread, these experimental plantings would achieve complete substrate cover in about 3 years after planting.

Shaw, D.G., Paul, A.J. And Smith, E.R. (1977)

Responses of the clam Macoma baltica to Prudhoe Bay crude oil

1977 Oil Spill Conference American Petroleum Institute Publ. 4284, pp.493-494.

ABSTRACT

The responses of the bivalve mollusk to crude oil were studied under laboratory conditions designed to simulate the stranding of oil on intertidal sediments in which this animal resides. The relationship of dry tissue weight to shell length, an indirect indicator of general health and fitness, was not significantly altered by exposure to oil at a level which did result in significant mortalities. This suggests that death is caused by a metabolically specific mode of poisoning rather than by a general weakening of the animal. In a 2nd experiment, animals were subjected to 2 temporarily separated oiling events. Neither in mortalities nor in GC analysis of tissues for hydrocarbons were cumulative effects observed. A tendency to burrow to the sediment surface in the presence of oil increases with decreasing depth of available sediment. This behavior may be used as a convenient indicator of oil pollution.

Straughan, D. (1971)

Oil Pollution and Wildlife and Fisheries in the Santa Barbara Channel

Transactions of the 36th North American Wildlife and Natural Resources Conference pp. 219-229. .

ABSTRACT

The known biological effects of the Santa Barbara (California) oil spill of January 28, 1969 are reviewed. Areas of ignorance are noted, and difficulties obtaining reliable baseline data commented upon. The total loss of birds attributed to the spill was 3,686 by May 31, 1969. Loons and grebes were the most abundant dead birds, while cormorants and pelicans were the second most abundant populations of marine mammals were apparently not seriously affected. Similarly, no significant effect on fish was observed. Although a decrease in commercial landings was

caused by a decrease in local fishing effort during and immediately after the spill. No flavor taint was found in fish or invertebrates.

Straughan, D.

Oil Pollution and Fisheries in the Santa Barbara Channel

Biological and Oceanographical Survey of the Santa Barbara Channel Oil Spill, 1969-1970, vol 1, Biology and Bacteriology, pp. 245-254.

ABSTRACT

Despite reports of smaller yields of fish caught by commercial and party boat fisherman after the January 1969 Santa Barbara oil spill, Post-spill surveys made by the California Department of Fish and Game indicate few variations from earlier surveys. Fish sampled appeared healthy and well fed; species diversity was maintained. Lower yields were attributed to a reduction of fishing boats entering the area, because fisherman either feared that fish would be contaminated or were unwilling to take extra time to clean oil from boats and gear.

Teal, J.M. and Howarth, R.W. (1984)

Oil Spill Studies: A Review of Ecological Effects

Environmental Management 8:27-44

ABSTRACT

We reviewed seven particularly well known and/or studied oil spills that have occurred since the National Academy of Sciences 1975 report, Petroleum in the Marine Environment or that occurred prior to that report but about which significant new information has since been acquired. The spills studied were from the barge Florida, and tankers Arrow, Argo Merchant, Amoco Cadiz, and Tsesis and blowouts from the Bravo and Ixtoc 1 platforms.

These best studies held only limited insight into effects because they lack controls and have a high degree of natural variability. The Tsesis, Florida, and Amoco Cadiz cases are exceptional since they occurred in areas of ongoing research programs and had nearby areas suitable for controls. Oil spills have produced measurable effects on ecosystems that have not been readily predictable from laboratory studies on isolated organisms. However, ecosystem-level interactions are poorly understood even without the complications resulting from effects of

pollution. These generalizations emerge: oil regularly reaches sediments after a spill; oil in anoxic sediments is persistent; oil regularly contaminates zooplankton and benthic invertebrates: fish are also contaminated, but to a lesser extent; oil contamination decreases the abundance and diversity of benthic communities.

Thomas. M.L. (1982)

Communities and Ecosystems

Oil and Dispersants in Canadian Seas: Research Appraisal and Recommendations, EPS 3-EC-82-27 Environmental Protection Service, Ottawa (Ontario). pp 125-134.

ABSTRACT

Research involving the effects of oil on marine communities and ecosystem is fairly recent. The magnitude and persistence of ecological effects on shoreline ecosystems depends on the amount of oil retained in the habitat. Disappearance rates vary with type of oil, climate, and weather conditions. Planktonic ecosystems vary in their response to oil depending on the species present and the type and concentration of the oil. Circumstantial evidence suggests that fish species composition and diversity of the stock may change in an oil spill area. Benthic communities show increases in opportunistic species in oiled sites and take several years to return to normal. Shoreline ecosystems are often devastated by oiling. In general, shore algae are quite resistent to oil pollution, while severe oil pollution causes either extensive mortality or narcosis to shore animals. Disappearance of grasses in salt marshes may cause accelerated erosion and habitat degradation. The use of dispersants for cleanup of oil on shorelines or in very sheltered or shallow bodies of water generally results in more extensive ecological disturbance than the oil alone.

Thomas, M.L.H. (1978)

Comparison of Oiled and Unoiled Intertidal Communities in Chedabucto Bay, Nova Scotia

J. Fish. Res. Board Can. 35:707-716.

Abstract

During 1976, detailed surveys of four oiled and four unoiled control stations. each subdivided into seven standardized intertidal levels, were carried out in Chedabucto Bay. Seventy-one species were found, 14 unique to control and 9 to oiled locations. Species diversity was

uniformly higher at control than oiled stations. No differences in horizontal zonation of major species were apparent. Analysis of abundance and biomass data for the eight stations and seven tidal levels showred a significant overall diffcrence between oiled and control situations. However, no particular station or tidal level was significantly different from any other. Ten species accounted for most of the variance between oiled and control stations. Six of these were more important at controls and four more important at oiled stations. The flora were particularly affected at oiled stations and species dominant on both sedimentary and rocky shores at all but the lowest tidal levels have been reduced. Length and weight data for the clam, Mya arenaria showed signifcantly lower values at oiled stations, but that for the periwinkle Littorina littorea showed the opposite. The length-weight relationship for both of these species showed a significantly lower increase in weight per unit of length at oiled than at control stations. Oiled stations showed significantly greater concentrations of oil in biota and sediments than unoiled, where concentrations were essentially at background levels.

Tribble, G.W., Bell, L.J.and Moyer, J.T. (1982)

Subtidal effects of a large typhoon on Miyake-jima, Japan.

Publ. Seto Mar. Biol. Lab., Kyoto Univ. 27:1-10

ABSTRACT

On October 19, 1979, a large typhoon passed within 160 km of the Japanese Island of Miyake-jima. The typhoon generated surf in excess of 7m. A well known bay was surveyed after the storm, revealing significant effects in both the substrate and algal coverage. Disruption was most severe in the 5-10 m depth range; a shallower site was less affected. This may be a result of both large waves breaking farther offshore and the acclimation of shallow areas to typhoons as a result of previous storms of lower magnitude. Decreases in the abundance of 18 species of tropical reef fishes did not follow a depth dependent pattern and were thought to result from both mortality and displacement. It is hypothesized that strong differences in the level of reduction between species resulted from differential mortality due to spatial and behavioral differences between species.

Turnpenny, A.W.H. and Williams, R.

Factors affecting the recovery of fish populations in an industrial river

Environ. Pollution (Ser A.) 26:39-58

ABSTRACT

The River Ebbw Fawr, an industrial river of southeast Wales, was investigated over a three-year period to follow the re-establishment of fish populations as a result of pollution control measures at coal washeries and a steelworks on the river. These measures were effective in reducing levels of toxic materials and restoring dissolved oxygen levels and pH values acceptable for fish. Five freshwater fish species became established in parts of the river during the study period (1974-77). The brown trout Salmo trutta L. was the first to enter, followed by eel Anguilla anguilla L., stoneloach Noemacheilus barbatulus L., stickleback Gasterosteus aculeatus L. and bullhead Cottus gobio L., respectively. The flounder Plathicthys flesus L.,a euryhaline species, penetrated the river beyond the upper tidal limit. The minnow Phoxinus phoxinus L., a resident of other parts of the Ebbw system, did not recolonise during the study. Calculated toxicities and the results of fish caging tests indicated that water quality was satisfactory for fish populations throughout the river with the possible exception (a short reach immediately below the steelworks. The absence of fish from some upstream reaches with good water quality was due to the limited numbers of fish available for recolonisation and their restricted movements. Good growth and condition factors amongst the recolonising brown trout stock suggest that a sport fishery could be developed on the river, though constraints on.

Vandermeulen, J. H. (1977)

The Chedabucto Bay Spill - Arrow, 1970: The self-cleaning processes and the biological recovery.

Oceanus 20(4):31-39

ABSTRACT

A study was made of the biological damage and recovery of Chedabucto Bay following the wreck of the Florida. The Bunker C petroleum hydrocarbons still resident on or in the shoreline sediments are measured. Also measured are the rates of hydrocarbon movement between water column and sediment, the degradation rates and the tissue oil load and physiological responses of oiled organisms.

Walsh, W.J. (1983)

Stability of a coral reef fish community following a catastrophic storm.

Coral Reefs 2:49-63

ABSTRACT

In January 1980, a severe 3 day storm struck the normally protected leeward coral reefs of Kona, Hawaii. Waves generated by the storm, were in excess of 6 m and caused extensive reef destruction and shoreline alteration. Shallow nearshore areas were denuded of most bottom cover and marine life. Damage to corals was extensive with broken colonies of the coral Porites compressa occurring down to depths of 27 m. Pronounced algal blooms occurred in a clearly defined sequence subsequent to the storm. Fish mortality directly attributable to the storm was slight and the few dead fishes noted were either surge zone or tide pool species. After the storm the shallow reef flat was devoid of resident fishes while deeper areas contained many fishes which had moved from shallower water. This habitat shift substantially reduced the immediate impact of the storm on the fish community. Recolonization of evacuated areas by fishes began shortly after the storm and within 16 months many areas had regained their prestorm appearances.

Webb, J.W., Tanner, G.T. and Koerth, B.H. (1981)

Oil Spill Effects on Smooth Cordgrass in Galveston Bay, Texas.

Contrib. Mar. Sci. Univ. Texas 24:107-114

ABSTRACT

Observations of the effects of number 6 fuel oil spilled into coastal waters and washed into Spartina alterniflora mashes were made near Galveston, Texas. Aboveground biomass of some fringing marshes was completely removed in November as part of a clean up operation. However, regrowth the following spring occurred with no noticeable effects on the plants. Oil also entered a larger marsh area, partly covering some plants and completely covering others. The oil killed the aboveground portion of a plant only when oil covered most of the plant. Plants, regardless of the extent of oil coverage, produced new growth in the following spring that appeared to be similar to other S. alterniflora communities of the area.

Williams, U.P. and Kiceniuk, J.W. (1987)

Feeding Reduction and Recovery in Cunner _Tautoaolabrus adspersus_ Following Exposure to Crude Oil

Bull. Environ. Contam. and Toxic. 38:1044-1048

ABSTRACT

Cunners (_Tautoaolabrus adsnersus_) are found throughout the year in inshore Newfoundland waters in depths of less than 10 m. This species is a bottom dweller and is commonly found around rocks, wharves, ledges and other areas where shelter is readily available. This species' inshore habitat and non-migratory habit make it potentially susceptible to a pollutant such as oil. This study was initiated to determine the time course of the onset of feeding reduction and recovery under environmentally realistic conditions experienced during an oil spill. Productivity of a fish stock is an important consideration and is the product of the number of individuals in that stock as well as their growth rates. Growth rate in fish is largely determined by food intake and any factor which affects this will be detrimental to the overall productivity of that stock. Exposure of fish to relatively high concentrations of oil can result in a number of diverse and deleterious biological changes, one result of which is a depression of feeding. This study shows that a concentration in the 150-250 microgram/L range for 4-5 weeks is required for the onset of feeding depression and recovery can occur in as few as 2-3 weeks. A particular population of cunners would have to be exposed to relatively high concentrations of oil for a prolonged period of time while they are actively feeding, before there would be an effect on the productivity of that population.

Williams, U.P., Kiceniuk, J.W., Ryder, J.E. and Botta, J.R. (1988)

Effects of an Oilspill on American lobster (_Homarus americanus_) from Placentia Bay, Newfoundland.

Can. Tech. Rep. Fish. Aquat. Sci. 1650:13 pp.

ABSTRACT

In March 1988 an accidental spill of crude oil occurred at the wharf of the Come by Chance oil refinery, Placentia Bay, Newfoundland. Studies of selected parameters were undertaken to determine the possible short and long term effects on the local lobster fishery. Elevated levels of PAH were not detected in any of the sediments from the Bay. The results indicate that lobster were not contaminated as a result of the oil spill. Based on the results of analyses of

sediments for PAHs, future contamination, as a result of the spill at the oil refinery wharf, is not anticipated.

Winfrey, M.R. and Ward, D.M. (1981)

Effect of the Amoco Cadiz Oil Spill on Predominant Anaerobic Microbial Processes in Intertidal Sediments.

Amoco Cadiz: Fates and Effects of the Oil Spill. Proceedings of the International Symposium pp. 257-267

Abstract
Sediment porewater chemistry, sulfate reduction and methane production were examined in intertidal beach, marsh and estuary sediments along the Brittany coast in order to assess the impact of oiling from the Amoco Cadiz oil spill. Sediment cores (20-25 cm) were collected from a heavily oiled site and an unoiled site from each sediment type. Results and the comparison of electron flow through sulfate reduction and methane production demonstrate the dominance of sulfate reduction as a terminal process. Variations in methanogenesls and sulfate reduction between oiled and control sites were minimal. However, at the oiled site at Ile Grande, conversion of 2-^{14}C acetate to super$^{14}CH_4$, increased conversion of super$^{14}CO_2$ to super$^{14}CH_4$ during early incubations, and lower rates of sulfate reduction suggest the possible alteration of normal anaerobic processes.

Winfrey, M.R., Beck, E., Boehm, P. and Ward, D.M. (1982)

Impact of crude oil on sulphate reduction and methane production in sediments impacted by the Amoco Cadiz oil spill.

Mar. Environ. Res. 7:175-194

ABSTRACT
The activities of methane-producing and Sulfate-reducing bacteria in intertidal sediments along the Brittany coast of France were examined in order to determine the effect of the Amoco Cadiz oil spill on sediment microbial processes. Porewater chemistry, methane production, sulphate rate and 2-^{14}C-acetate metabolism did not vary significantly between beach, estuary, and marsh sites, oiled or unoiled, after the Amoco Cadiz spill. The oxidation of 2-^{14}Cacetate to super$^{14}CO_2$, was significantly decreased when mousse, crude oil, benzene or toluene was added to sediments from

the unoiled site. Inhibition seemed to be proportional to the extent of weathering.

Wolfe, D.A., Clark, R.C.Jr., Foster, C.A., Hawkes, J.W., and Macleod, W.D.Jr. (1981)

Hydrocarbon Accumulation and Histopathology in Bivalve Molluscs Transplanted to the Baie de Morlaix and the Rade de Brest.

Amoco Cadiz : Fates and Effects of the Oil Spill. Proceedings of the International Symposium. pp. 599-616

ABSTRACT

Experimental populations of cockles (<u>Cerastoderma edule</u>) and mussels (<u>Mytilus edulis</u>), obtained from Presqu'ile Quiberon, were held in cages at a depth of one meter in the Baie de Morlaix, a site known to have been heavily oiled by the Amoco Cadiz, and the Rade de Brest, a site known to be minimally exposed, from April 27 to May 22, 1978. Organisms were sampled 3 or 4 times over a 25-day period for histological examination and analysis of hydrocarbons. Subsurface seawater samples were taken and analyzed for hydrocarbons by uv/GC. Body burdens of hydrocarbons increased in both molluscan species at both sites, up to 5-fold increases within 5 days after transplantation, and these concentrations were maintained throughout the sampling period. There were clear histological and chemical differences detected between mussels held in Baie de Morlaix and the Rade de Brest, associated with the occurrence of dibenzothiophene and polynuclear aromatic hydrocarbons in the tissues.

Woodley, J.D., Chomesky, E.A., Clifford, P.A., Jackson, J.B.C., Kaufman,L.S., Knowlton, N., Lang, J.C., Pearson, M.P., Porter, J.W., Rooney, M.C., Rylaarsdam, K.W., Tunnicliffe, V.J., Wahle, C.M., Wulff, J.L., Curtis, A.S.G., Dallmeyer, M.D., Jupp, B.P., Koehl, M.A.R., Neigel, J. and Sides, E.M. (1981)

Hurricane Allen's Impact on Jamaican Coral Reefs

Science 214:749-754

ABSTRACT

Coral reefs of north Jamaica, normally sheltered, were severely dam aged by Hurricane Allen, the strongest Caribbean hurricane of this century. Immediate studies were made at Discovery Bay, where reef populations were already known in some detail. Data are presented to show how damage

varied with the position and orientation of the substratum and with the shape, size, and mechanical properties of exposed organisms. Data collected over succeeding weeks showed striking differences in the ability of organisms to heal and survive.

Workman, D.L. (1981)

Recovery of Rainbow Trout and Brown Trout Populations Following Chemical Poisoning in Sixteenmile Creek, Montana.

N. Am. J. Fish. Manage. 1:144-150

ABSTRACT
Chemical poisoning from toxaphene-base cattle dip resulted in the decimation of the rainbow trout (Salmo gairdneri) and brown trout (Salmo trutta) populations in the lower 35.6 km of Sixteenmile Creek, Montana. Immigration from untreated areas was the most important factor in initiating the recovery of yearling and 2-year-old trout populations. Repopulation of older trout depended upon recrutiment from new year classes. After 4 years and three spawning periods, trout carrying capacity of the habitat was attained and the age structures reestablished. Habitat quality had a measurable effect on the carrying capacity of each study section.

Zieman, J.C., Orth, R., Phillips, R.C., Thayer, G. and Thorhaug, A. (1981)

Effects of Oil on Seagrass Ecosystems

Restoration of Habitats Impacted by Oil Spills, (J.R. Cairns, Jr. and A.L. Buikema, Jr., eds.) Butterworth, Boston pp. 37-64.

ABSTRACT
A review of seagrass ecology is given to faciliate a discussion of the effects of oil spills on one of the most productive ecosystems known. Physically, seagrasses prevent erosion and stabilize the effects of tidal actions and provide habitat for numerous epiphytic organisms. Biologically, seagrasses perform an essential cycling of nutrients by absoring P through the roots and leaves and returning both N and P to water column from sediments via the plant. Seagrass ecosystems can be damaged by oil through direct suffocation or fouling of organisms or destruction of food market value of seagrass fisheries by tainting of flavor. Studies in the literature of major oil spills indicate that the greatest damage to aquatic organisms seems to be from aromatic hydrocarbon fractions

of oil. The effects of oil dispersants on seagrass communities are not known. Inert absorbents present little hazard to seagrass systems if properly used. The normal recovery of seagrass systems from oiling depends on the extent of damage to sediments. Efforts of restoring oil-damaged seagrass systems by transplanting plugs or shoots have met with variable success. It is suggested that research be carried out on the toxicity levels of the major hydrocarbon substances on the major seagrass species in laboratory and fiels tests.

Zitko, V., Burridge, L.E., Woodside, M. and Akagi, H. (1984)

Low contamination of fish by hydrocarbons from the uniake G-72 (Shell Oil, Vinland) wellsite blowout in February 1984.

Can. Tech. Rep. Fish. Aquat. Sci., no. 1305.

ABSTRACT

Cod (Gadus morhus) and haddock (Melanogrammus aeglefinus) fillet and liver were analyzed for hydrocarbons by spectrofluorometry and by gas chromatography-mass spectrometry. Fluorescence emission, di-, tri-, and tetramethyl benzenes, naphthalene and its methyl- and dimethyl homologues were used to detect contamination by gas condensate. Increased fluorescence and dimethylbenzenes were detected in the livers. It appears that fish were exposed to the gas condensate but the exposure was very low and did not affect the fish. The condensate was readily accumulated by juvenile Atlantic salmon in the laboratory. The excretion half-life was of the order of days. The potential of gas well blowouts to contaminate fish is higher than anticipated previously.