PRESSURES ON COASTAL ENVIRONMENTS

ECOLOGICAL EFFECTS OF FISHING

This essay is a "pressure" topic, intended to document the ecological effects that fishing can have on living marine resources and their environment. Fishing provides many benefits to society, including food, employment, business opportunities, and recreation. It is extremely important that these benefits continue to be available in the future. However, like many human activities, fishing also can have deleterious ecological effects. Effective management of any living resource requires the maintenance of a dynamic balance between obtaining the benefits of exploitation and minimizing the impacts of exploitation. Understanding the deleterious ecological effects of fishing, and reducing them where feasible, can improve ecosystem health and productivity, potentially increasing fishery yields.

Approximately 27 million metric tons (30 million tons) of bycatch are discarded each year in the world's commercial fisheries, compared to a total of about 77 million metric tons (85 million tons) of landed catch. Much less information is available for recreational fisheries. In 159 distinct U.S. fisheries, bycatch discarding affects at least 149 species or species groups. Finfish, crustaceans and mollusks constitute a majority of these species or species groups, while protected species such as marine mammals, sea turtles and sea birds make up most of the remainder. Overfishing can lower the numbers of individuals of reproductive age, reducing population sustainability. Removing an abundant species from the fish community can alter food chains and the species composition of the community. "Ghost" fishing impacts are poorly known, but lost gear can continue to function, catching target, nontarget and protected species. In addition, mobile fishing gear, such as bottom trawls and scallop dredges, can remove or damage biota associated with the bottom and disrupt sedimentary structures, altering important habitat features.

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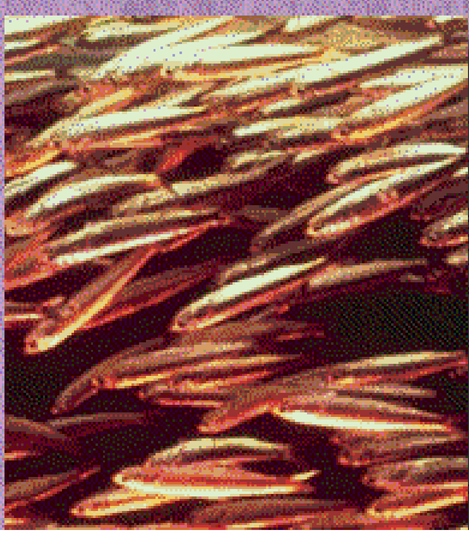

INTRODUCTION

Historically, marine fishery resources were assumed to be almost limitless, and fishing was thought to have little impact on fish stocks and marine ecosystems. However, during recent decades, concern about the condition of fisheries has increased. Since 1989 world harvests have apparently leveled off. Many fisheries experts and commercial and recreational fishermen now recognize that fishing can have profound effects on marine fish stocks and the ecosystems they inhabit. With this change in attitude has come increased Federal responsibility to build sustainable fisheries. The recently reauthorized Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. 1801 et seq.) provides many tools for the National Marine Fisheries Service (NMFS) to meet the Nation's stewardship responsibilities for fisheries. The Act now includes new requirements to reduce bycatch, halt overfishing, rebuild overfished stocks, and protect essential fish habitat.

This essay summarizes recent work on the biological and physical impacts of fishing. The information should be considered in the context that exploitation of marine fish and invertebrate resources provides many important benefits to society, including food, employment, business opportunities, and recreation. However, implementation of a sustainable-use policy requires knowledge of the impacts that exploitation can have on fishery resources and their environmental support system. Understanding the deleterious ecological effects of fishing, and reducing them where feasible, can improve ecosystem health and productivity, potentially increasing fishery yields. The biological impacts discussed here include bycatch (the unintended capture and subsequent discarding of nontarget species), ghost fishing (mortality caused by lost or abandoned gear), and alteration of populations and ecosystems. The physical impacts discussed here include effects of mobile fishing gear and small-boat propellers on bottom habitat. The information contained in this essay is primarily for the U.S. Exclusive Economic Zone (Figure 1), and for the continental shelf, where the water is generally less than 200 m (656 ft) deep. These issues have worldwide impacts, however, and considerable information also exists for European, Australian and Asian waters (Dayton et al., 1995).

The limited selectivity of fishing gear leads to bycatch, which is usually discarded for economic, legal or personal considerations. Bycatch discards include fish and invertebrates, as well as protected species, such as marine mammals, sea turtles and sea birds. Depending on the species, gear, handling techniques, and the health of individuals, some or all of the discarded animals die. A recent estimate of the worldwide marine bycatch discarding is approximately 27 million metric tons (30 million tons) per year, which is about one-third of the estimated 77 million metric tons (85 million tons) of catch that is retained per year (Alverson et al., 1994).

Although comprehensive data on the magnitude and biological significance of U.S. bycatch are not currently available, considerable information now exists, and better information is being prepared. The Magnuson-Stevens

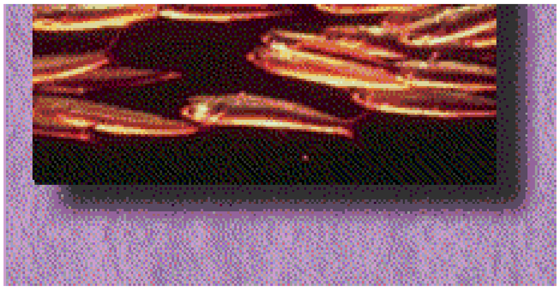

Photo 1. Many aspects of fishing affect fish populations and marine ecosystems.

Act's provisions requiring that bycatch and associated mortality be minimized have led to the development of a national bycatch plan (NMFS, on-line, 1998d). This document summarizes the available bycatch data, describes potential impacts and data gaps, and examines the causes of bycatch.

Lost fishing gear threatens marine life. Comprehensive data on ghost fishing impacts are not available, but entanglement in, and/or ingestion of, human-caused debris (including fishing gear and many other items) has been reported for over 250 marine species (Laist, 1996).

Fishing can have unintended effects on target species' populations and the ecosystems that they inhabit. Excess removal of larger, older and more fecund individuals from a population depletes spawning stocks, thus reducing a population's ability to replenish itself. Potential ecosystem impacts include changes in community structure and food chains. Removing a dominant species, for example, may allow competing or prey species to increase, or cause predator populations dependent on the harvested species to decline. Also, discarding of bycatch and processing waste may increase food availability for opportunistic scavengers, including other fish, crabs, and seabirds.

Physical impacts to the seafloor primarily come from mobile commercial fishing gear and, in shallow areas, boat propellers, anchors, and grounding. Mobile fishing gear, such as bottom trawls and dredges, which are towed along the bottom to capture groundfish, shrimp, and molluscan shellfish, can have deleterious effects on sea-floor habitat. Although mobile gear impacts have only begun to receive serious attention from U.S. scientists, some studies have already shown that a wide range in the type and degree of physical and biological damage can occur. The propellers of power boats, primarily used for recreation, can cause significant physical damage to shallow habitats, such as seagrass beds, while anchoring and grounding primarily damage coral reefs.

Photo 3. The large wooden object hanging over the side of the boat, called a door (see Figure 4), is pulled at an oblique angle in front of a trawl net to keep the net open. On bottom trawls, the door skids along the bottom, leaving a furrow several ft (about 1-2 m) wide and about 6 in (15 cm) deep.

Photo 2. Scallops are caught in dredges like this one.

(top)

NATIONAL PICTURE

The precise amount of fishing that occurs in U.S. waters is unknown. Approximately 150,000 vessels or permits are currently active for commercial fishing in federally managed waters (Appendix A), which extend from the state water boundaries, typically 3 nm from shore, to the U.S. Exclusive Economic Zone boundary, typically 200 nm from shore. In addition, there is a substantial number of state commercial-fishing permits for nearshore waters, and approximately 70 million trips are taken per year by marine recreational anglers (Table 1). Although more and better information is necessary for an accurate assessment of fishing's impacts on ecology, concern over this issue is growing across the nation.

Table 1. Number of recreational angler trips taken in marine waters per year by region[1].

Region	Number of Angler Trips
Hawaii[2]	708,000
Pacific Coast[3]	9,656,000
Gulf of Mexico[4]	20,868,000
South Atlantic	18,754,000
Mid Atlantic	15,576,000
North Atlantic	6,513,000

Source: NMFS, 1996a; NMFS, 1997a (on-line)

[1]Except where noted, data are estimates for 1995.
[2]Data are estimates for ca. 1980.
[3]Washington State data are for 1989; Alaska data are for 1993.
[4]Texas data are for May 1996 - May 1997 (L. Green, pers. comm.)

Bycatch

Much of the following information is taken from the NMFS bycatch plan, "Managing the Nation's Bycatch: Priorities, Programs, and Actions for the National Marine Fisheries Service" (NMFS, 1998d).

Fisheries affect many nontarget species. The United States has 159 distinct commercial fisheries, based on region, gear type and target species. Bycatch discarding of at least 149 species or species groups occurs in these fisheries; many of these species are bycatch in several different fisheries. Available data indicate that finfish, crustaceans and mollusks constitute the majority of the discarded species or species groups in terms of numbers, biomass and frequency of occurrence. Protected species, such as marine mammals, sea turtles and seabirds, make up the remainder.

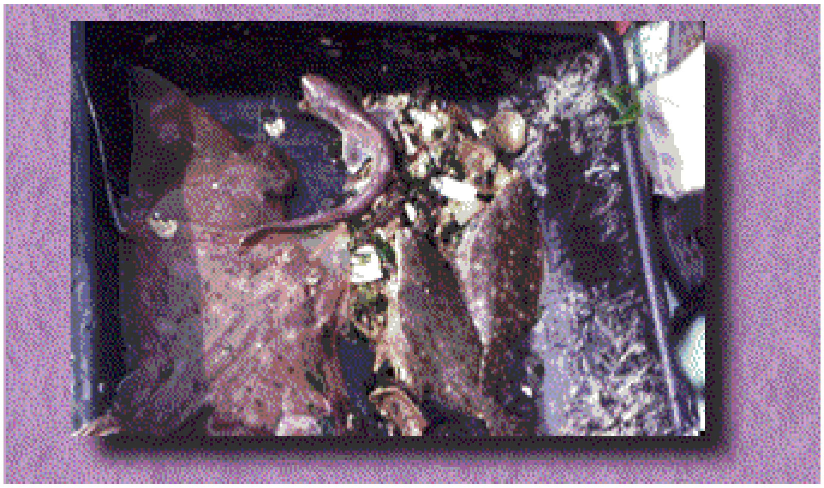

Photo 4. Groundfish fisheries target commercially valuable species such as flounder, but catches typically include less commercially desirable species such as skates and dogfish.

Although the quality of U.S. bycatch data varies considerably by region and fishery, available evidence strongly suggests that bycatch mortality is affecting the health of many fishery stocks (NMFS, 1998d). Discarding may be impacting about half of the stocks in the three regional fisheries: the Northeast, the Atlantic/Gulf of Mexico pelagic, and the Southeast (Table 2). This figure is zero for Alaska groundfish fisheries, which have been conservatively managed. A qualitative assessment of bycatch concerns showed that the population status of the affected stocks was the primary concern for Atlantic/Gulf of Mexico pelagic and Northeast fisheries, while socioeconomic issues affecting the fishing industry were the primary concerns for the Pacific pelagic and insular, Southeast, West Coast and Alaska fisheries (NMFS, 1998d). Population status and public concerns were the most important factors for protected species.

Table 2. Regional summaries of the health of stocks of discarded fish species or species groups.

Regional Fisheries	Percent of Stocks in which Discarding May Affect Stock Health[1]
Northeast	55%
Atlantic/Gulf of Mexico pelagic	40%
Southeast	63%
Pacific pelagic and insular	9%[2]
West Coast	20%
Alaska	0%

Source: *NMFS Bycatch Plan* (NMFS, 1998d).

[1]Discarded stocks that are overutilized and whose populations are near or below levels necessary to maintain maximum long-term potential yields.

[2]Information on the health of Pacific pelagic and insular fisheries stocks is very limited.

To develop strategies for reducing bycatch, it is important to understand why it occurs. NMFS used four categories to classify the reasons for bycatch discarding (NMFS, on-line, 1997a): (1) prohibition of protected species, such as marine mammals; (2) regulatory, such as undersized catch, quota limits or prohibited species; (3) discretionary, which may occur when no market exists for a species; and (4) catch-and-release, which occurs in recreational fisheries. Considering the occurrence of species and species groups in discarding (rather than biomass discarded, for which adequate data are not available), regulatory discarding was found to be the most important factor nationwide, as well as in most regions. Discretionary discarding was also significant in all regions. Discarding of protected species took place in all regions, but the importance of this factor was greatest for Pacific pelagic and insular, and Atlantic/Gulf of Mexico highly migratory, fisheries. Catch-and-release discarding was much less important than the other factors in all regions.

Both the U.S. Marine Mammal Protection Act and the Endangered Species Act protect marine mammals and other species at high risk of extinction, such as sea turtles, from human-caused impacts, including fishing. These species were once legal targets of commercial fisheries in U.S. waters, but their populations have been reduced so significantly that their retention is now prohibited, unless specifically authorized (e.g., for subsistence). Marine mammals are vulnerable to serious injury and mortality caused by fishing activities in all U.S. regions, and many populations are still recovering from historical commercial harvests (NMFS, 1996b). NMFS assesses marine mammal stocks, and identifies "strategic stocks," which suffer high rates of human-caused mortality or are at significant risk of extinction (Barlow et al., 1997; Hill et al., 1997; Waring et al, 1997; see Appendix B). Fishing-related mortality exceeds sustainable rates for no strategic stocks in Alaska, four strategic stocks in the Pacific, and nine strategic stocks in the Atlantic and Gulf of Mexico (Table 3). NMFS is establishing "Take Reduction Teams" to develop and implement strategies for reducing fishing-related mortality of strategic marine mammal stocks to sustainable levels. Five teams have been established as of the first quarter of 1998: Gulf of Maine Harbor Porpoise, Atlantic Offshore Cetacean, Pacific Offshore Cetacean, Atlantic Large Whale, and Mid-Atlantic Coastal Gill Net (NMFS, 1998a).

Photo 5. Animals that receive special protection under the law are sometimes caught in abandoned fishing gear.

Table 3. Numbers of marine mammal stocks, and strategic marine mammal stocks impacted by fishing, by region.

	Alaska	Pacific	Atlantic/Gulf of Mexico
Total stocks	33	55	57
Strategic stocks	10	13	21
Strategic stocks impacted[1] by fishing	0	4	9

[1] Strategic stocks for which fishing-related mortality exceeds sustainable levels.
Sources: NMFS Marine Mammal Stock Assessments for 1996 (Barlow et al., 1997; Hill et al., 1997; Waring et al., 1997)

Several fisheries affect protected sea turtles. The shrimp trawl fisheries of the South Atlantic and the Gulf of Mexico are now required to use turtle excluder devices in their nets to address this problem, but there is still debate about the efficacy of these requirements (see Case Study). Some sea turtle bycatch also occurs in the Hawaiian longline and mid-Atlantic summer flounder *(Paralichthys dentatus)* trawl fisheries.

Although seabird bycatch is a relatively new issue with few available data, there have been reports of seabird mortalities caused by commercial fishing in the Pacific, Alaska and Northeast regions (D. Forsel, pers. comm.; NMFS, 1998d). Of particular concern is the number of albatross (*Diomedea* spp.) caught in Alaskan hook-and-line and Western Pacific longline fisheries. Because these birds have low reproductive rates, excess mortality can have a particularly large impact on them (Bergin, 1997). Worldwide, recent serious population declines have been observed for six of the 14 albatross species. Mortality of common murres *(Uria aalge),* rhinoceros auklets *(Cerorhinca monocerata),* and the endangered marbled murrelet *(Brachyramphus marmoratus)* has been reported for some gill-net and purse-seine fisheries in the Columbia River and Puget Sound (Melvin et al., 1997; Wolf et al., 1996). Mortality of shearwaters, gulls and gannets has been reported in gill-net fisheries in the Northeast.

Photo 6. A pelican is entangled in discarded fishing line.

Some approaches for reducing seabird bycatch are now being developed. Baited hooks attract seabirds during the deployment of hook-and-line gears. New regulations of the North Pacific Fishery Management Council require that longlining vessels fly streamers or use other devices to scare away seabirds. Also, the use of heavier weights on longlines causes them to sink more rapidly, reducing the opportunity for seabirds to attack the bait. In Puget Sound, recent studies of the sockeye salmon *(Oncorhynchus nerka)* fishery have shown that increasing the visibility of the upper portions of gill nets and restricting fishing to daylight hours can reduce seabird mortality (Melvin et al., 1997).
(top)

Ghost Fishing

Modern fishing gear is typically constructed of long-lasting materials; pots are thought to last from two to 15 years or more, while gill nets may last for a decade. Many gear types can continue to function when lost at sea (Breen, 1990). Three gill nets lost in Puget Sound caught fish for at least three years and crabs for at least six years (High, 1985). Estimates of annual trap losses range from 2% to 30% for various fisheries (Carr and Harris, 1997; Chopin et al., 1996; Laist, 1996; O'Hara, 1992; Smolowitz, 1987), while annual gill-net losses are probably well over 1% (Natural Resources Consultants, 1990). In one survey off New England, 2,240 lost nets were estimated to occur in a 220 sq km (64 sq nm) region (Carr and Cooper, 1987), although many were not in a fishing configuration. Another survey near Kodiak, Alaska, revealed an estimated average of 42 lost crab pots per sq km (144 per sq nm) (Stevens, 1996).

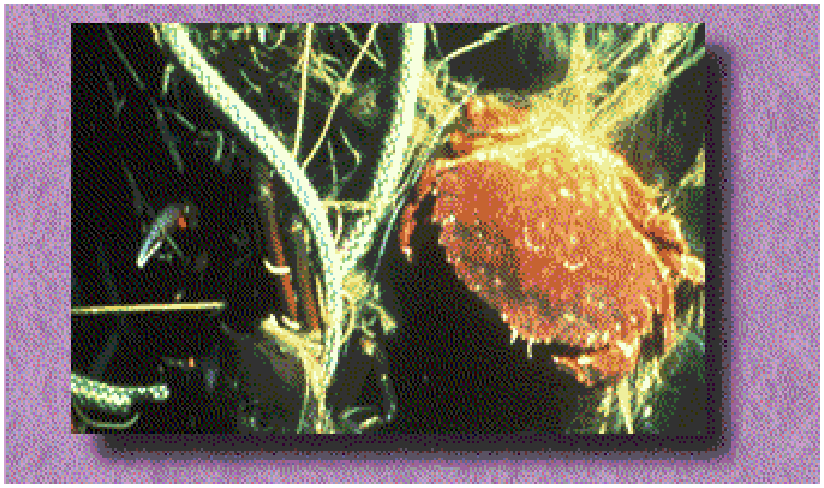

Photo 7. Nets continue to catch fish and crabs after they are lost at sea.

The species most likely to be affected by ghost fishing are those originally targeted by the lost gear. Ghost fishing mortality is included in NMFS's calculations of bycatch mortality and total fishing-related mortality. However, it is difficult to accurately estimate the impact of ghost fishing on fisheries, since most mortality goes undetected. Lost traps may have been responsible for catches equal to 7.2% of the Fraser River (British Columbia) Dungeness crab *(Cancer magister)* landings in 1984, 7.5% to 30% of the British Columbia sablefish *(Anoplopoma fimbria)* landings in 1977-1983, and 5% of American lobster *(Homarus americanus)* landings in New England (Laist, 1996).

Lost gear may also affect protected species. Rates of pinniped entanglement, primarily in lost fishing gear, have been reported at about 0.5% near the Pribilof Islands in the Bering Sea (Fowler et al., 1993; Laist, 1997) and 0.1% off California (Stewart and Yochem, 1987). Endangered Hawaiian monk seals *(Monachus schauinslandi)* can also become entangled in fishing debris; weaned pups are most susceptible (Henderson, 1990). Several whale species have been entangled in fishing gear off New York and New Jersey (Sadove and Morreale, 1990).

Several efforts are under way to reduce the impact of ghost fishing (Stevens, 1996). One approach is to incorporate degradable components in fishing gear such as traps and gill nets. When these components deteriorate, the lost gear ceases to function. Also, new techniques to recover lost gear are in development.
(top)

Population and Ecosystem Impacts of Fishing

Overharvest of an abundant species, or removal of too many reproductive individuals from a population, can have far-reaching ecological effects. Because recruitment in many fish stocks is episodic, replenishment can depend on a stable breeding population that carries over through poor years. Hence, heavy fishing of older age classes, combined with the ongoing harvest of individuals just reaching reproductive age, can significantly impede the recovery of depleted stocks. Bycatch discarding and ghost fishing can exacerbate these impacts. For example, commercial and recreational fishing have severely truncated the age distribution of the mid-Atlantic summer flounder stock (NMFS, 1995) (Figure 2), which reduces harvestable biomass, as well as the ability of the stock to recover from overfishing. Spawning stocks of Northeast cod *(Gadus morhua)* are near historically low levels, and reaching the recovery target for spawning biomass will require a considerable drop in fishing levels (NMFS, 1995). Heavy fishing-related mortality, combined with natural events that reduced recruitment, are thought to have caused the collapse of the Alaskan King crab fishery in the mid-1980s (Dayton et al., 1995).

Although heavy fishing and discarding can alter food chains and ecological communities, marine ecosystems are so complex that it is difficult to document cause-and-effect relationships between fishing and ecosystem changes (Alaska Sea Grant, 1993). For example, scientists are investigating the extent to which declines of Steller sea lion *(Eumetopias jubatus)* populations in the western and central Gulf of Alaska and the eastern Aleutian Islands can be attributed to natural environmental variation versus reduced prey availability caused by intense fishing on walleye pollock *(Theragra chalcogramma),* a major food source for this species (Loughlin and Merrick, 1989; Lowry et al., 1989). In the Gulf of Maine, the fishing-induced decline in nearshore cod has been implicated in reducing predation rates on benthic invertebrates (Witman and Sebens, 1992). Also in the Northeast, species dominance in the groundfish community has shifted from the cod family and flatfishes to spiny dogfish *(Squalus acanthias)* and skates (Figure 3) (Murawski, 1996). This change coincided with a heavy harvest of the cods and flatfishes. In addition, the Atlantic States Marine

Fisheries Commission is currently developing a fisheries management plan for the horseshoe crab (*Limulus polyphemus)* (Atlantic States Marine Fisheries Commission, on-line, 1998). Horseshoe crab eggs, which are deposited in the upper intertidal zone of beaches, are a major food source for migrating shorebirds during the spring. One reason for developing this plan is the increasing concern that heavy horseshoe crab harvest may be reducing egg availability for shorebirds on the beaches of Delaware Bay, which is a major stopover location during the spring migrations of many shorebird species.

The presence of large amounts of discarded processing waste and bycatch can alter food chains by artificially supporting opportunistic, mobile scavengers and predators. For example, the total catch of the Bering Sea/Aleutian Islands and Gulf of Alaska groundfish fisheries was 2.25 million metric tons (2.48 million tons) in 1994 (Queirolo et al., 1995). Of that total, 1.68 million metric tons (1.85 million tons), or 74%, was discarded as processing waste (1.34 million metric tons [1.48 million tons]) or bycatch (0.34 million metric tons [0.38 million tons]). Some of this material was discarded at sea and returned to the ecosystem, albeit in the form of dead tissue, rather than living fish. The rest was discarded on or near shore by land-based processing facilities, and removed from the marine ecosystem. The highest estimated percentage of discarded bycatch and processing waste in the diet of a groundfish species is 29% for Gulf of Alaska sablefish, but estimates for several other species in the Gulf of Alaska and the Aleutian Islands are considerably lower. Seabirds, such as gulls, are consumers on the surface, while fish and invertebrates, such as sculpins and crabs, are consumers on the bottom. The impacts of these food-chain alterations are poorly known. In addition, particularly in areas with slow currents, the decompostion of discarded material may lower dissolved oxygen concentrations in bottom waters (Jones, 1992; Dayton et al., 1995).

The national standards for fishery conservation and management in the reauthorized Magnuson-Stevens Act are intended to reduce overfishing and to rebuild overfished stocks. Meeting these standards should reduce some of the population and ecosystem impacts of fishing.
(top)

Physical Impacts of Mobile Fishing Gear

Fishermen often use mobile gear, such as bottom trawls and dredges (Figure 4), on the continental shelf of the United States. Towed along the sea floor, these gears have physical impacts on bottom habitat (de Groot, 1984; Eleuterius, 1987; Messieh et al., 1991; Riemann and Hoffmann, 1991; Jones, 1992; Dayton et al., 1995; Auster et al., 1996, Cahoon et al., 1995; Collie et al., 1997; Fonesca et al., 1984; Mayer et al., 1991; Peterson et al., 1987; Engel and Kvitek, 1998; Freese, 1998; Krieger, 1998). Plants and animals attached to or living on the bottom can be removed, killed, or injured. Sediments, rocks, and other substrates and structures on the bottom can be disturbed. Nutrient concentrations in near-bottom water can be increased, which may slightly increase phytoplankton productivity. Suspended solids concentrations can also be increased; these materials typically settle nearby, potentially impacting bottom-dwelling biota. Dissolved oxygen concentrations in near-bottom waters can decrease due to the exposure of previously covered anoxic subsurface sediments. In deeper waters, where natural physical events (e.g., storm waves) rarely affect the bottom, mobile gear may be the most common source of disturbance in fished areas (L. Watling, pers. comm.). Only a few studies of mobile gear impacts to bottom habitats have been completed in U.S. waters, but at least eight field studies are now investigating this problem in various areas.

Although national information on the physical impacts of mobile gear is not available, determining where bottom trawls and dredges are used most frequently can provide some insight as to where the greatest impacts may occur. The numbers of Federal permits for these gears are highest in the Northeast and Southeast regions (including the Gulf of Mexico) (Table 4), which reflects the large number of vessels engaging in ground fisheries and scalloping in the Northeast, and shrimp trawling in the Southeast. Since these fisheries have been active for many years, the physical impacts are probably widespread.

Table 4. Number of bottom trawl and dredge permits or vessels, and total catch for these gears, by region.

Region	Fisheries	Number of Vessels or Federal Permits	Total Catch[1]
Northeast	Groundfish, scallops	4,746	130,934 mt
Southeast (southeastern Atlantic and Gulf of Mexico)	Shrimp	Approx. 28,500 vessels[2]	444,829 mt, plus nearly 42 million pelagic and reef fishes in Federal waters[3]
West Coast	Groundfish, shrimp	260 (shrimp permits from other agencies)	255,100 mt
Alaska-Bering Sea and Aleutian Islands	Groundfish	312	626,039 mt, plus over 7.3 million salmon and crabs
Alaska-Gulf of Alaska	Groundfish, scallops	260	65,056 mt, plus nearly 94,000 salmon and crabs

Source: *NMFS Bycatch Plan* (NMFS, 1998d), except as noted.

1 Includes landed catch plus discards, if known.

2 Source: Federal Register 62(127): 35774.

3 Total bycatch estimates range from about 9 billion (NMFS, 1996b) to 46 billion (Nichols and Pellegrini, 1992) individuals.

Links between bottom habitat integrity and marine fish populations are not well understood. However, growing evidence suggests that an intact bottom structure is important to temperate fishes, especially during their early bottom-dwelling phases. Juvenile cod, for example, initially occupy a wide range of bottom types off southern Nova Scotia and on Georges Bank, a highly productive area off the Massachusetts coast (Tupper and Boutilier, 1995; Lough et al., 1989). Their survival is highest in structurally complex habitats, apparently because habitat complexity reduces the efficiency of predators. In addition, sedimentation and reduced oxygen concentrations associated with mobile gear may affect sensitive larval shellfish and filter feeders, such as clams, scallops and oysters (Jones, 1992). All of these factors also may have an impact on biodiversity.

Among the new provisions of the reauthorized Magnuson-Stevens Act are requirements for describing, identifying, conserving, and enhancing "Essential Fish Habitat" (EFH) in amended fishery management plans (Office of Habitat Conservation, on-line, 1997). The fishery management plan amendments, which must be completed by October 1998 and updated every five years thereafter, are required to include sections on minimizing the adverse impacts of human activities on EFH. Both fishing and non-fishing activities (e.g., pollution, habitat destruction) are to be covered. Options for managing the adverse impacts of fishing activities include gear restrictions (e.g., limiting or prohibiting the use of fishing gear known to impact a particular habitat type), time/area closures that will eliminate some or all fishing in sensitive areas or time periods, and harvest limits that will reduce impacts on species that provide habitat structure, such as seagrasses, kelp beds, and oyster reefs.

(top)

REGIONAL CONTRASTS

This section focuses on bycatch and physical impacts associated with mobile gear. Bycatch issues are compared between the Northeast and Gulf of Mexico. Physical impacts are compared in New England and Alaska. See Table 4 for numbers of permits and catch amounts by region.

Northeast and Gulf of Mexico Bycatch

The Northeast and Gulf of Mexico regions provide interesting contrasts in the types of fisheries and gears used (Appendix C), and the resulting biological impacts (NMFS, 1996b; 1998d). Northeast fisheries target a diverse array of finfishes and invertebrates, primarily using bottom trawls, but also using gill nets, longlines, dredges and traps. Because overfishing of traditional groundfish (cod family and flatfishes), mostly taken by bottom trawls and gill nets, has been severe, their populations are at very low levels (NMFS, 1995). The lobster trap fishery takes an estimated 85% to 90% of all legal-sized individuals in the Gulf of Maine every year (Cohen and Langton, 1992). Sea scallop *(Placopecten magellanicus)* stocks are heavily fished with dredges, and harvests are dependent on the year class entering the fishery. Gulf of Mexico fisheries target mainly shrimps, menhaden, reef fish, and king *(Scomberomorus regalis)* and Spanish *(Scomberomorus maculatus)* mackerel. The huge shrimp fishery (approximately 25,000 vessels) primarily uses bottom trawls in estuarine and nearshore areas. The landed weight of the menhaden *(Brevoortia tyrannus)*, caught by purse seines, is the largest of the Gulf fisheries. Reef fish are caught with a variety of gears, including traps, hook and line, and spears. Recreational catches of several groups, including coastal migratory pelagics, reef fish, and drum and croacker, are as large or larger than commercial catches (Appendix A). Several key species are overfished, including red drum *(Sciaenops ocellatus)*, red snapper *(Lutjanus campechanus)* and several groupers.

Photo 8. A small boat trawls for shrimp in a Louisiana bay.

In the Northeast, the reason for much of the discarding of bycatch is the co-occurence of many groundfish species (Brown et al., 1996; NMFS, 1995). Trawl catches typically contain several species, each of which may be subject to a specific regulatory regime (e.g., minimum size, net mesh size restrictions, trip limits, area closures) (NMFS, 1998d). The resulting array of regulations leads to considerable discarding of illegal fish, many of which are undersized. For example, the 1987 southern New England yellowtail flounder *(Pleuronectes ferrugineus)* year class was exceptionally large. Many of these fish were discarded as bycatch before they reached legal or marketable size, causing the loss of an estimated $15 million in potential future catch. In addition, in Atlantic Canada, a region adjacent to the northeastern United States, bycatch of juvenile cod has recently been implicated as a possible factor contributing to the collapse of cod stocks (Myers et al., 1997).

Two issues involving marine mammal bycatch in the Northeast have emerged in recent years. Bycatch of harbor porpoises *(Phocoena phocoeana)* in the gill-net fisheries of the Gulf of Maine, Bay of Fundy and southern New England exceeds sustainable rates, which has led to the establishment of four time-area closures in the Gulf of Maine (Figure 5). The purpose of these closures is to eliminate gill-net fishing in areas and during periods when harbor porpoise abundance is high (P. Fiorelli, pers. comm.). Initial experiments with "pingers" (acoustic devices that repel harbor porpoises) have been promising, but more research is needed (Avila, 1996; Barnaby, 1996). The endangered north Atlantic right whale *(Eubalaena glacialis)* uses New England waters for feeding and as nursery areas for calves. More than half of living north Atlantic right whales show signs of previous entanglement with fishing gear, and about 10% of known mortalities of this species resulted from such entanglement.

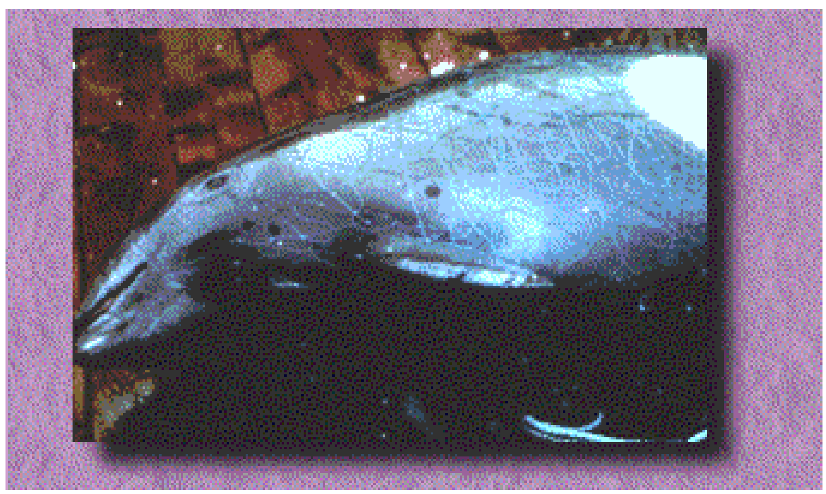

Photo 9. To offset the bycatch of harbor porpoises, areas in the Gulf of Maine are closed to gill-net fishing when large numbers of porpoises are present.

In the Gulf of Mexico, shrimp trawl bycatch is the predominant finfish bycatch issue. Determining the ratio of bycatch discarding to landed weight in this fishery has been very controversial, but by most accounts, it is very high. Recent estimates include 10:1 (Alverson et al., 1994) and 2-4:1 (Graham, 1996). Some experts suggest that recently reported declines in the bycatch ratio are due to declines in the fish stocks caused by the high bycatch rates of the shrimp trawl fishery (R. Shipp, pers. comm.). As many as 115 fish species are caught as bycatch in the Gulf of Mexico shrimp trawl fishery (Bryan, et al. 1982). Most of this bycatch is too small to be marketed, and is discarded. One recent estimate of annual bycatch is more than 46 billion fish per year, including 36 billion Atlantic croaker *(Micropogonias undulatus)* , 5.5 billion seatrout *(Cynoscion* spp.), 1.8

billion longspine porgy *(Stenotomus caprinus)* , and 1.5 billion spot *(Leiostomus xanthurus)* (Nichols and Pellegrin 1992). These authors also estimated that about 41 million red snapper per year are caught as shrimp-trawl bycatch. Another recent estimate of annual shrimp-trawl bycatch is about 9 billion fish per year, including 7.5 billion croaker, 1 billion seatrout, and 500 million spot (NMFS, 1996b).

Much attention has focused on juvenile red snapper, since catches of this species have decreased as shrimping effort has increased (Figure 6). High recreational catches may also have contributed to this decline (Goodyear, 1995). Juvenile red snapper catch rates in shrimp trawls are relatively low (~6 fish per hour), but with the shrimp fleet expending 4-5 million hours of fishing effort per year, the cumulative impact on the red snapper population is large (NMFS, on-line, 1997b). Even if all directed commercial and recreational harvests of red snapper were prohibited, the species could not recover from its current low abundance unless juvenile mortality from shrimp trawling declines by at least 50%. As a result, in November 1996, the Gulf of Mexico Fishery Management Council voted to require the use of bycatch reduction devices in shrimp trawls to exclude nontarget finfish (R. Shipp, pers. comm.). Because of delays in implementing this policy, NMFS adopted a six-month interim rule requiring these devices in May 1998. The interim rule will expire in November 1998, so the situation is still evolving (R. Raulerson, pers. comm.).

(top)

Photo 10. An undisturbed scallop bed has a diverse and structurally complex community.

Physical Impacts of Mobile Fishing Gear in New England and Alaska

Fisheries in both New England and Alaska focus on groundfish, such as the cod and flatfish families. Bottom-trawling gear is used primarily in areas that are relatively clear of large obstructions. Some areas are heavily fished, suggesting that trawling impacts may be ubiquitous. For example, trawling and scallop dredging cumulatively cover the entire bottom of Georges Bank an average of about 3.5 times per year (Auster et al., 1996). However, some areas are fished much more frequently than others (Figure 7), so the impacts are concentrated in the most heavily fished areas.

Photo 11. After dredging, the structural complexity of the scallop bed has declined markedly.

Studies in both regions have shown that trawling can reduce habitat structure and complexity, principally by removing slow-moving or attached organisms and smoothing the sea floor. Reductions in habitat complexity may lead to increased predation on juveniles of harvested species (Valentine and Lough, 1991; Lough et al., 1989). In the Gulf of Maine, comparisons of unfished and heavily trawled areas showed that the direct removal of biological (e.g., sponges, anemones, shell aggregates) and sedimentary (e.g., sand waves, depressions) structures reduced habitat complexity (Auster et al., 1996). Similarly, an ongoing trawl impact study in the Gulf of Alaska (Freese, 1998) is examining the effects of trawling at sites in which trawling does not normally occur. The population densities of two of 32 species or species groups decreased significantly after trawling. Both of these groups, "large sponges" (*Mycale* sp., *Geodia* sp., and *Esperiopsis* sp.) and "morel sponges," attach to the bottom and provide shelter for other organisms, such as juvenile fish. In another study in the Gulf of Alaska, about half of the redtree coral (*Primnoa* spp.) in the path of a bottom trawl was removed or broken by a single pass (Krieger, 1998). The long-term impacts of repeated trawling, and recovery times from the physical effects of trawling, are still unknown.

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CASE STUDIES

Gulf of Mexico/South Atlantic Sea Turtles

The capture and drowning of sea turtles through shrimp trawling in the Gulf of Mexico and South Atlantic have been contentious issues since the 1970s. Although an individual fisherman may catch at most a few turtles in a year, the magnitude of this fishery makes the overall impact of these captures significant (National Research Council, 1990). Prior to the full implementation of turtle excluder device (TED) requirements for most shrimp fisheries, annual sea turtle mortality was an estimated 5,000 to 50,000 loggerheads *(Caretta caretta)* and 500 to 5,000 Kemp's ridleys *(Lepidochelys kempi)*. TEDs allow sea turtles to escape from shrimp nets through a "trap door." NMFS-certified TED designs permit the escape of 97% of captured sea turtles under test conditions, but their effectiveness is sometimes lower in the field.

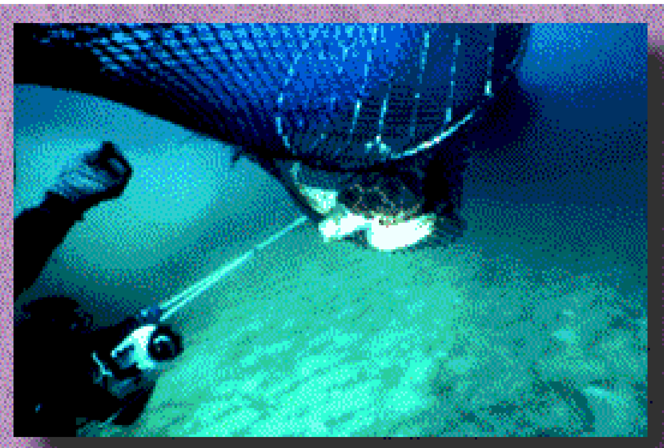

Photo 12. A diver observes a sea turtle escaping a shrimp trawl during a TED test.

Legal requirements for the use of TEDs are now in place for U.S. shrimp fisheries. NMFS introduced TEDs in a voluntary program in 1983, but lack of participation led to regulations requiring TEDs in 1987 (Risenhoover, 1990). The regulations were not fully implemented until 1989, in part because of claims that TEDs reduce shrimp catch (Graham, 1996). The legal requirements for foreign countries exporting wild-caught shrimp to the United States are not clearly defined. The U.S. Court of International Trade has ruled that nations exporting wild-caught shrimp to the United States must comply with sea turtle protection measures by May 1, 1996 (Duff, 1995). However, in March 1998, the World Trade Organization overturned this requirement. The United States is now appealing this decision, and may be required to change the law or subsidize the affected foreign shrimp fleets (M. Rogers, pers. comm.).

Debate continues about the efficacy of TED requirements in reducing sea turtle bycatch mortality. Since 1990, TEDs may have reduced annual loggerhead strandings (dead sea turtles washed up on beaches) in South Carolina waters by as much as 44%, and reported strandings have also declined in the northwestern Gulf of Mexico (Crowder et al., 1995). In addition, the population of the highly endangered Kemp's ridley is recovering in the Gulf of Mexico (Turtle Expert Working Group, 1996). Current population estimates for this species are approximately 1% of the estimates from the 1940s. However, the number of nests reached its lowest point in 1985, when 702 nests were found. By 1995, the number of nests had rebounded to 1,930. This turnaround has been attributed to the protection of nesting areas from predation and human exploitation, and to the use of TEDS in the Gulf of Mexico and South Atlantic shrimp fisheries.

However, the association between strandings and shrimping activity remains (Caillouet et al., 1996; Lutz and Musick, 1997). For example, nine sea turtles were stranded on the Texas coast during the four weeks prior to the 1994 shrimping season, but 99 were stranded during the four weeks following the season's opening (Matlock, 1995). Possible explanations for these mixed results include improper functioning of TEDs under field conditions, cumulative stress on the turtles as a result of repeated captures in heavily fished waters, violations of TED requirements by U.S. or foreign fishermen, and geographic boundaries for required TED use that do not accurately reflect sea turtle distributions. Because of these continuing problems, TED regulations and technology may continue to evolve (Collins, 1996).
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Alaska Halibut

Current regulations in Alaska prohibit fishermen from retaining bycatch of Pacific halibut *(Hippoglossus stenolepus)*, salmon, herring and crab (NMFS, 1998d). When fisheries exceed their bycatch limits for one of these species, they must close (Pereyra, 1996; Trumble, 1996). These regulations are intended to prevent overfishing and to sustain healthy stocks. This requirement, however, causes confusing and controversial shifts in catch allocation among fisheries and gear types. Overall bycatch rates in most Alaskan bottom-trawl fisheries are low, averaging only about 14% by weight (NMFS, 1998d; Alverson et al., 1994), but the huge volume of catches, approximately 2.3 million metric tons (2.5 million tons) per year, results in a substantial amount of discarding.

Discards of the aforementioned species are counted as part of their annual total allowable catches, so that any bycatch of these species (which must be discarded) reduces the amount of catch that can be retained in directed fisheries. Several Alaskan fisheries have closed prematurely because of their halibut bycatch. In 1994, the bycatch mortality of Pacific halibut equaled 19% of the total allowable catch and 29% of the commercial landings (Trumble, 1996). Because of bycatch closures, the overall 1995 groundfish harvest reached only about two-thirds of the total allowable catch. Excessive halibut bycatch also required fishermen to forgo approximately 16,000 metric tons (17,600 tons) of flatfish harvest in 1994 (Stone and Bublitz, 1996). Thus, in Alaska, Pacific halibut bycatch regulations help maintain healthy stocks, but they also decrease harvest and revenues for both directed fisheries and the other fisheries that cause halibut bycatch mortality.
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Propeller Scarring of Seagrasses in Florida

Photo 13. Several Alaskan fisheries may close before reaching their allowable catches because of halibut bycatch.

Seagrasses are vascular plants that occur in shallow estuarine and coastal waters. They are very important to the ecology of these areas, providing food and habitat for myriads of fish and invertebrates, as well as for endangered sea turtles, wading birds, and, especially in Florida, the endangered West Indian (Florida) manatee *(Trichechus manatus)* . They also improve water quality by stabilizing sediments and absorbing some pollutants. Seagrasses are vulnerable to physical disturbance, especially in shallow waters. Scarring occurs when the propeller of a power boat contacts a seagrass bed while under way, tearing roots, stems, and leaves, and leaving behind a barren furrow. Depending on the species of seagrass, recovery from propeller scarring requires 1-5 years.

The Florida Marine Research Institute of the Florida Department of Environmental Protection recently completed a study of propeller scarring of seagrass beds in the shallow marine waters of coastal Florida (Sargent et al., 1995). Aerial surveys were conducted during 1992 and 1993. Scarred areas were plotted on maps, and the amount of scarring quantified. Florida contains 2.7 million acres of seagrass beds, 174,000 acres (6.4%) of which were found to have significant propeller scarring. Approximately 900 scarred areas, covering 30,000 acres, were identified in the Florida Keys alone. The significance of this problem is magnified because seagrass beds are also threatened by other anthropogenic factors, including pollution, dredging and filling, and coastal development. In a related problem, injury from propellers and boat impacts is the largest known cause of manatee mortality in Florida, having caused more than 750 manatee deaths between 1974 and 1997 (Florida Marine Research Institute, on-line, 1998).

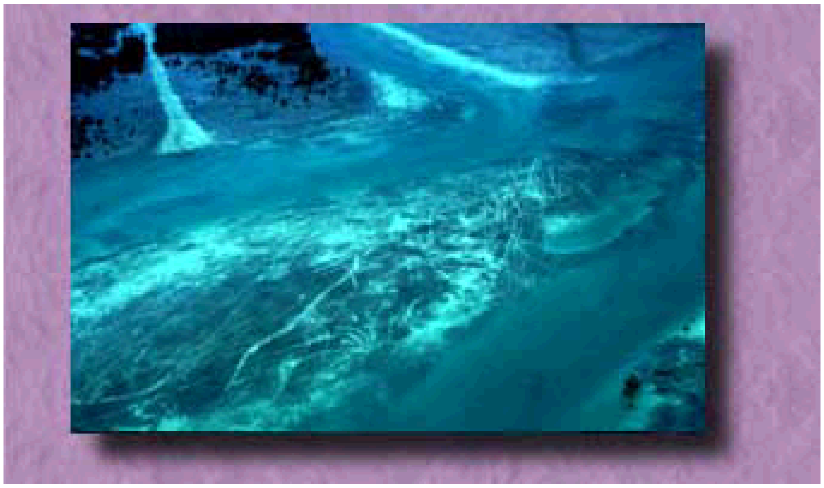

Photo 14. Aerial photograph of propeller-scarred seagrass bed near Windley Key, in the Florida Keys.

Both recreational and commercial boaters were found to be responsible for propeller scarring to some degree. However, approximately 95% of the boats registered in Florida are recreational. Recreational boaters, typically engaged in fishing and other water sports, often operate in shallower areas where seagrasses are most vulnerable. The most frequent causes of propeller scarring were attributed to misjudgments of water depth, navigational errors, and intentional shortcutting through shallow seagrass beds. Figure 8 is a map of the seagrass beds near Pine Island, in southwestern Florida's Lee County. Propeller scarring is extensive in this area. The authors discussed a scarred region near a marina. Apparently, boaters using this marina preferred to cut across a seagrass bed rather than use a marked channel that follows a longer route to the Intercoastal Waterway. Florida is now developing management strategies to reduce the occurrence of propeller scarring of seagrass beds, including boater education, channel marking, increased enforcement, and zoning that restricts or completely eliminates boating in sensitive areas.

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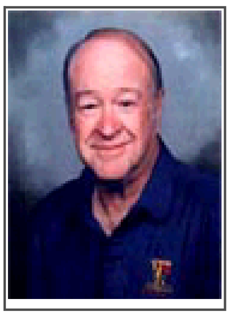
EXPERT INTERPRETATION

The five individuals below are experts in the topic of Ecological Effects of Fishing. Here they voice their opinions on two questions relevant to that topic. Their opinions do not necessarily reflect those of NOAA.

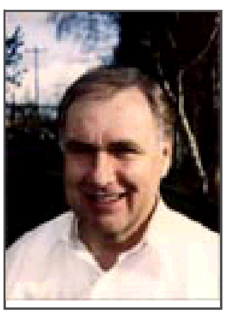
Question 1. What is your opinion on the relative importance of the ecological impacts of fishing discussed here (bycatch discarding, ghost fishing, population and ecosystem impacts, and the physical impacts of mobile gear on bottom habitat), compared with other factors that affect fish abundance, such as the amounts of retained catch and environmental variation?

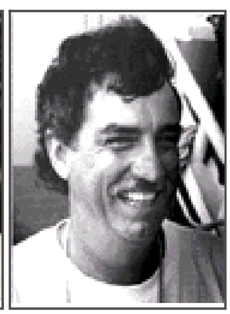
Question 2. Discuss the appropriate circumstances for technological solutions for reducing bycatch (e.g., bycatch reducing devices, acoustic deterences) versus behavioral solutions (e.g., changing fishing methods, effort reduction, time-area closures, establishing protected areas).

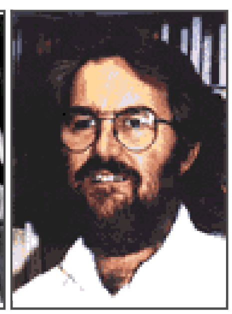
Experts


Lee Alverson


Paul Dayton


Walter Pereyra


Robert Shipp


Les Watling

Dayton L. (Lee) Alverson

Chairman of the Board, Natural Resource Consultants, Inc., Seattle, Washington

Dr. Alverson has authored more than 150 technical and scientific publications in the field of fisheries. His current research includes fishery management related to bycatch and unobserved mortality in global fisheries. He is lead author on a widely referenced United Nations publication titled "*A Global Assessment of Fisheries Bycatch and Discards* ". Dr. Alverson was director of the National Marine Fisheries Service Northwest and Alaska Fisheries Science Center for 10 years, and has served as the Assistant Administrator for Fisheries for the National Oceanic and Atmospheric Administration. He has also been the chief negotiator for the United States in the U.S./Canada salmon treaty process.

Question 1. What is your opinion on the relative importance of the ecological impacts of fishing discussed here (bycatch discarding, ghost fishing, population and ecosystem impacts, and the physical impacts of mobile gear on bottom habitat), compared with other factors that affect fish abundance, such as the amounts of retained catch and environmental variation?

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Direct effects of fishing have resulted in a significant number of world ocean resources being overfished and/or depleted. Recent *World Status of Fisheries* reports from the United Nations' Food and Agricultural Organization suggest that up to 45% of the global marine landings caught in 1994 were taken from stocks considered to be overfished, depressed, or some combination of these categories. Environmental variation works concurrently to moderate or accelerate population trends, and may play a dominant role in the overall size of some stocks.

Although discards contribute directly to fishing mortality in most fisheries, the added mortality from discards is usually significantly lower than that resulting from the landed catch. The exception may be in tropical shrimp fisheries, where the biomass of affected finfish and invertebrates may be substantially larger than the retained catch. Knowledge of the mortalities imposed through discarding is essential for effective management of the impacted ecological complex.

The physical ecological impacts of fishing are not well understood. Trawling and other forms of active fishing gear used on the seabed can result in significant disturbances and changes in the benthic community structure. The consequence of these changes in terms of sustainable fisheries is a matter of current investigation and controversy. In many of the world's heavily trawled areas, such as the eastern Bering Sea flatfish fishery, there is little evidence that the productivity of target stocks is decreased by changes in the benthic communities due to trawling.

Although ghost fishing may constitute a serious impact to some fisheries, I am more concerned over the gamut of unobserved fishing mortalities due to illegal fishing, mortalities associated with fish and invertebrates that pass through nets and drop-off lines, and mortalities to other marine life associated with the setting and hauling of fishing gear.
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Question 2. Discuss the appropriate circumstances for technological solutions for reducing bycatch (e.g., bycatch reducing devices, acoustic deterences) versus behavioral solutions (e.g., changing fishing methods, effort reduction, time-area closures, establishing protected areas).

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It is important to recognize that a number of options exist for solving bycatch discard problems and for reducing bycatch levels, although no single approach is likely to constitute a universal solution. The resolution of bycatch problems must be examined in terms of the methodology and gear types being deployed by region, the magnitude of the discards, the consequences to impacted populations, and the set of options available for bycatch reduction. Thus, the problem in one area may be largely resolved by a technological solution, and in another area, by time/area closures.

Technological solutions have proven effective in some fisheries (e.g., fish bycatch in the northern shrimp fishery, dolphin bycatch in the eastern tropical Pacific Ocean tuna fishery). However, technological solutions frequently require extensive time periods to be developed and tested, and are not always easily enforced. Time/area solutions can be effective at times, but may generate a new bycatch problem while solving another. From a management standpoint, bycatch solutions frequently require a combination of technological, operational and time/area approaches. In this regard, the fishing community itself possesses a wealth of technical and operational talent which, if given the appropriate incentives, can contribute significantly to bycatch reduction.

For the many stocks of the world that suffer from excess fishing, perhaps the quickest and most effective manner of addressing excessive bycatch is a reduction in the overall fishing effort–but only at a social and economic cost that society must be willing to bear.
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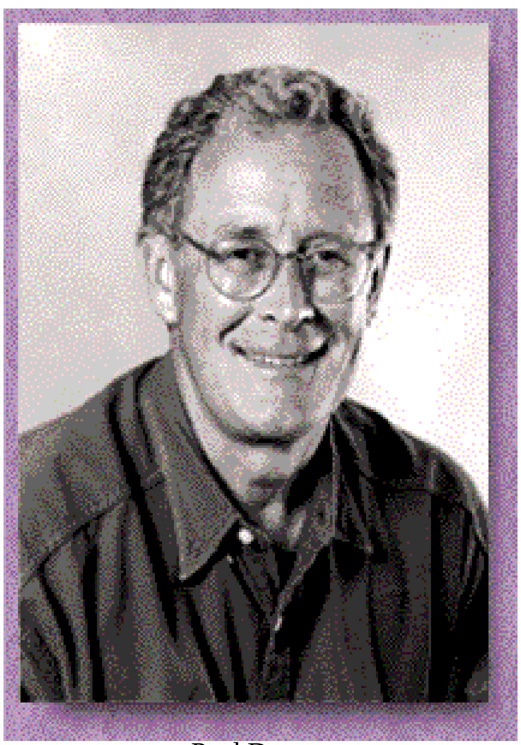
Paul Dayton

Professor of Marine Ecology, Scripps Institution of Oceanography, University of California, San Diego

Dr. Dayton's research has focused on rocky intertidal and temperate kelp forest communities as well as polar regions and the tropics. In recent years, he has been very concerned with the damage to coastal biological communities caused by fishing. He won a Mercer Award from the Ecological Society of America, has served on several National Academy of Science committees concerned with marine ecological issues, is a member of the Marine Mammal Commission, and received a scholar award for coastal wetlands research from the Pew Charitable Trusts.

Question 1. What is your opinion on the relative importance of the ecological impacts of fishing discussed here (bycatch discarding, ghost fishing, population and ecosystem impacts, and the physical impacts of mobile gear on bottom habitat), compared with other factors that affect fish abundance, such as the amounts of retained catch and environmental variation?

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Natural climate changes may have important but usually short-term effects on marine ecosystems. Other chronic impacts in coastal systems that reflect man's activities include eutrophication, usually from nonpoint source runoff, and habitat loss in bays and estuaries. By far, the largest impacts on marine ecosystems are from direct and indirect impacts of fishing.

Most important are the many indirect effects of fishing including incidental take, the loss to ghost fishing, and the destruction of many of the bottom habitats around the world. In addition, there are important alterations in seabird communities from dumping the bycatch and offal from fish processing. The consequences are highly variable, of course, but the most serious impacts are those that take the longest to recover from. The worst impacts are the extinctions of species. Not many marine species go extinct because of fishing, but white abalones, as well as some marine turtles and mammals, are very close. Other impacts from which recovery will be very slow include bottom habitats characterized by slow-growing sponges, bryozoans and corals. Recovery of these species will take many decades to centuries. Finally, all mammals, reptiles and marine birds have very low rates of reproduction and growth, as do all sharks and rays. These species also are extremely vulnerable to incidental take in fisheries because the recovery time is so slow.

It is important for management to focus on the recovery time of noncommercial species and habitats as well as commercial species. One consequence of the long history of such impacts is that we have lost the memory of the natural order. The changes have been slow to develop and are so profound that there are no baseline expectations about what really is natural.
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Question 2. Discuss the appropriate circumstances for technological solutions for reducing bycatch (e.g., bycatch reducing devices, acoustic deterences) versus behavioral solutions (e.g., changing fishing methods, effort reduction, time-area closures, establishing protected areas).

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Technological devices for reducing bycatch, while often very helpful, do not offer a quick fix to the problem. For example, careful choice of net size, deployment of hooks, use of acoustical devices or bycatch exclusion devices on trawls, or specialized fishing techniques, can result in important reduction of the bycatch of particular species. Unfortunately, they are rarely sufficient because the techniques still have some bycatch that is extremely serious for animals with low reproductive rates. For example, albatross are less likely to be hooked by long lines run through tubes, but the hooks still kill highly endangered turtles; acoustic pingers can reduce the bycatch of mammals but not of turtles, sharks, rays or even birds; specialized techniques, such as backing down a purse seine, can spare the lives of dolphins but not those of turtles, sharks or other fishes; turtle exclusion devices save turtles but not the sponges and other bottom organisms killed by the trawl itself. In almost all cases, technical fixes are partial fixes affecting a minority of the species impacted by the fishery. They do not replace more aggressive precautionary management designed to insure that representative habitats and populations persist into the future. The highest priority is that of protecting the species most vulnerable to bycatch.

Another useful management procedure is to establish meaningful sanctuaries or protected areas that serve many functions, such as preserving representative communities as well as brood stocks of many species. Unfortunately, while technology can help, in the long run there is no quick fix, and if our natural marine ecosystems are to persist, there must be the political will to implement these much more difficult solutions.
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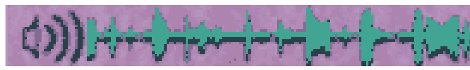
Walter Pereyra

President and Chief Executive Officer, ProFish International, Inc., Seattle, Washington; and Vice Chairman, North Pacific Fishery Management Council

Dr. Pereyra founded ProFish International, Inc., a partner in two factory trawlers and a combination trawl catcher boat, 15 years ago. For the past eight years, he has been a member of the North Pacific Fishery Management Council, which is responsible for managing the extensive North Pacific groundfish and crab resources. Prior to his involvement in the fishing industry, Dr. Pereyra was a groundfish scientist with the National Marine Fisheries Service, directing research in conservation engineering aimed at developing species-specific fishing gear.

Question 1. What is your opinion on the relative importance of the ecological impacts of fishing discussed here (bycatch discarding, ghost fishing, population and ecosystem impacts, and the physical impacts of mobile gear on bottom habitat), compared with other factors that affect fish abundance, such as the amounts of retained catch and environmental variation?

Click here for audio response

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The ecological impacts of fishing cannot be viewed in a vacuum separate from the other important factors affecting fish populations, such as environmental changes, predation, and the biological characteristics and health of the various species involved. For example, in the case of the Bering Sea king crab resource off Alaska, the population has been at low levels of abundance for a number of years despite drastic reductions in the directed fishery, strict controls on king crab bycatch, and trawling closures in areas of high abundance. Why hasn't the king crab population responded positively to these regulatory controls on removals? The answer probably lies in those factors over which we have no control. For example, the ocean environment has been noticeably warmer over the last decade, which in the past has been negative for king crab recruitment, while predator populations of cod, flatfish and possibly salmon have been in high abundance during this period.

In general, fishing impacts are greatest when populations are at low levels of abundance. The breeding population of short-tailed albatross is a case in point. This species has now decreased to such a low level that removal of only four individuals in two years by the North Pacific longline fisheries is considered sufficient to close those fisheries that might intercept this endangered species. At the other extreme, rock sole in the Bering Sea has increased some ninefold in 17 years, is at a very high level of abundance, and is harvested at only 22% of its acceptable biological yield–but with an observed discard rate of more than 50% of the catch.

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Question 2. Discuss the appropriate circumstances for technological solutions for reducing bycatch (e.g., bycatch reducing devices, acoustic deterences) versus behavioral solutions (e.g., changing fishing methods, effort reduction, time-area closures, establishing protected areas).

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The reduction of bycatch mortality associated with fishing activities requires the application of both technological and behavioral solutions. Such solutions will be most effective if they are instituted through the self-interests of the fishers themselves. Unfortunately, due to the open access nature of most fisheries, we are faced with applying command-and-control approaches to manage these fisheries. These methods do not create incentives for fishers to take individual initiative to reduce bycatch, but rather, must rely on the imperfect knowledge of the management system to bring about bycatch reduction through enforced compliance.

The perverse incentives created by our outdated management systems can best be overcome through the establishment of quasi-property rights to the

directed catch and associated bycatch, e.g., individual fishing quotas (IFQs). Once a fisher has a "share interest" in the target and nontarget resource, it will be in his self-interest to modify his fishing gear and methods, and/or time and area of fishing, to minimize bycatch impacts. The apparent reason for lower bycatch and discard rates in fisheries where catch quotas are allocated to individual fishers or communities of fishers is the economic incentive that quasi-ownership of the resource has on the behavior of the fishers. That is,. they will fish at a slower pace, avoid areas of high bycatch or the incidental capture of small fish, and use fishing gear that is less likely to retain unwanted species or catch. Moreover, because of the intrinsic value associated with individual quota shares, there is an incentive to minimize discards. Thus, societal gains in bycatch reduction can be expected when fisheries are managed under an IFQ format where the fishers operate in their own self-interests, rather than in response to some type of forced command-and-control regulatory regime.
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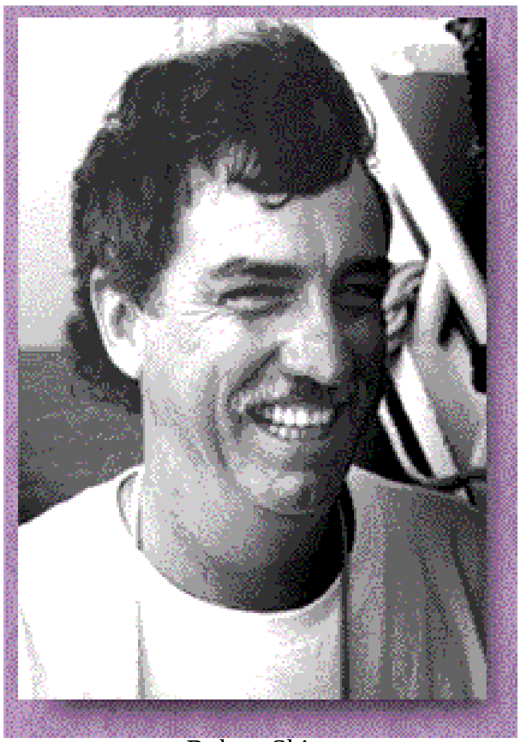
Robert Shipp

Chairman, Department of Marine Sciences, University of South Alabama

Dr. Shipp has taught at the University of South Alabama since 1972. He was associate director of the Dauphin Island Sea Lab for 10 years, and has edited *Northeast Gulf Science* since 1978. Dr. Shipp was appointed to the Gulf of Mexico Fishery Management Council in 1991, and served as its chairman for two years. His popular, semi-technical *Guide to Fishes of the Gulf of Mexico* is used by the U.S. Coast Guard and the National Marine Fisheries Service for field identification of fishes.

Question 1. What is your opinion on the relative importance of the ecological impacts of fishing discussed here (bycatch discarding, ghost fishing, population and ecosystem impacts, and the physical impacts of mobile gear on bottom habitat), compared with other factors that affect fish abundance, such as the amounts of retained catch and environmental variation?

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I will start with the last part of the question. I have very little concern about environmental variation, other than that it is often suggested as an untestable explanation, and used to disguise other problems. Regarding other factors, destruction of nursery areas and bycatch of large numbers of recruits would likely be major culprits. Certainly, overharvest can be extremely detrimental to long-lived species (e.g., bluefin tuna, Gulf red snapper), but for many annual or short-lived species (e.g., penaeid shrimp, blue crabs) overharvest is of lesser concern.

One must consider impacts on species groups, considering the life cycle and habitat for each. Surely shrimp bycatch is an extremely hurtful activity, and besides the mortality on nontarget species, trawls can be devastating to bottom communities. Thus, multiple species and their habitats are negatively impacted. However, longline bycatch and similar mortality related to target fishing by hook and line may be relatively minor.
(top)

Question 2. Discuss the appropriate circumstances for technological solutions for reducing bycatch (e.g., bycatch reducing devices, acoustic deterences) versus behavioral solutions (e.g., changing fishing methods, effort reduction, time-area closures, establishing protected areas).

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Technological answers are becoming an absolute necessity to minimize damage caused by traditional fishing methods. However, these are going to be slow in coming, strongly resisted by fishers, and difficult to enforce.

However, I don't think the term "versus" is appropriate here in discussing fishing impacts. Rather, technological advances should be considered in concert with behavioral changes.

Among the latter, that is, "behavioral changes," there is a poor track record for most methods, such as effort reduction and time-area closures. However, establishment of reserves or sanctuaries offers a minor panacea for many problems in fisheries. These provide refuge for large assemblages of species, as well as an insurance policy against failed management, either due to poor judgment, poor data, or neglect.
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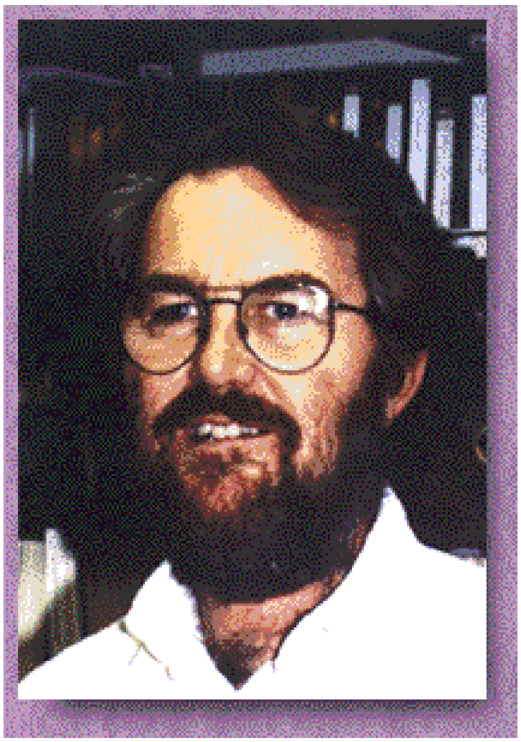
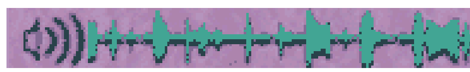


Les Watling

Professor of Oceanography, School of Marine Sciences, Darling Marine Center, University of Maine

Dr. Watling is a biological oceanographer interested in benthic environments, their inhabitants, and the way they are impacted by fishing gear. He also specializes in the taxonomy of small crustaceans, especially cumaceans and amphipods, for which he has developed theories about their phylogeny and biogeography. He has published more than 70 scientific papers and has edited four symposium volumes.

Question 1. What is your opinion on the relative importance of the ecological impacts of fishing discussed here (bycatch discarding, ghost fishing, population and ecosystem impacts, and the physical impacts of mobile gear on bottom habitat), compared with other factors that affect fish abundance, such as the amounts of retained catch and environmental variation?

 Click here for audio response

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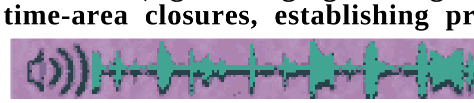
To most people, the act of fishing is a simple process of gathering, some say harvesting, of fish from the wild. Few people think of the consequences of that simple act. The removal of fish, which are most often predators, may have effects on the ecosystem that we have hardly thought about, such as the rapid increase in numbers of prey species.

The method of taking fish also has important consequences. When gill nets are lost, they continue to "fish" for years, perhaps decades, resulting in an unending string of useless deaths. On the sea bottom, the problem is even more severe. Most bottom-dwelling fish are caught using trawls or dredges. These devices, in order to work correctly, must scrape the ocean floor, with the result that many species of no commercial importance are removed and killed.

Approximately half of the world's continental shelves are impacted by mobile fishing gear each year. Since this problem has only recently come to light, we do not yet know what it means to the functioning of shelf ecosystems. Because there are many inconspicuous invertebrates living on the sea bottom, and their living structures are usually damaged or destroyed by trawls and dredges, the continued use of mobile fishing gear has most likely contributed to an overall reduction in biodiversity in the sea. For the most part, we will never know, since most of the areas currently being fished were not studied before trawling and dredging began.
(top)

Question 2. Discuss the appropriate circumstances for technological solutions for reducing bycatch (e.g., bycatch reducing devices, acoustic deterences) versus behavioral solutions (e.g., changing fishing methods, effort reduction, time-area closures, establishing protected areas).

 Click here for audio response

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There is no easy solution to the reduction of bycatch associated with mobile fishing gear. Of course, there are environments in which such gear can be used with little or no damage. Those environments include places where natural physical disturbance levels are often high, such as shallow, sandy marine bottoms where storm waves occasionally resuspend the bottom sediments. Most other areas, however, do not see very high levels of natural disturbance. In fact, all parts of the ocean bottom deeper than 70 meters are unlikely to experience any natural physical disturbance (although there are a few deep-sea environments where sediment slumping or benthic storms occur). Therefore, in order to lessen the chance of reducing habitat complexity as a result of trawling or dredging, those gear types should not be used in areas where natural disturbance levels are low.

Fishermen need to reconsider going back to low-impact methods of fishing. Most structurally complex bottoms were fished initially using fixed gear, such as longlines. Providing they are deployed such that they sink rapidly, long lines have relatively minor impacts on the bottom habitat. There are not likely to be any technological fixes that will allow a trawl or dredge to pass over the bottom in such a manner that it catches fish or shrimp but leaves other species and their dwellings intact. In fact, technology has taken us the other way, exemplified best by the development of the rock-hopper, which allowed previously unfishable environments to be fished.
(top)

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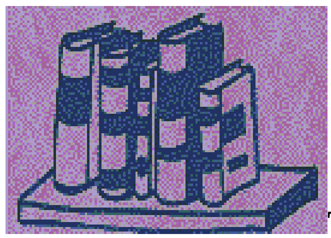

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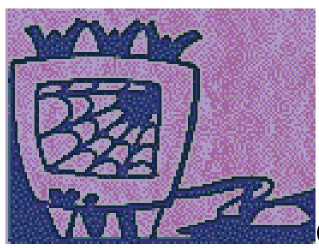

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http://www.imma.org/download.html (select Technical Reports from the Downloadable Documents list)

Presents a thorough literature review of the effects of incidental catches on more than 10 species of fur seals, true seals, sea lions and walrus. Includes information on the numbers of animals taken, location of the fisheries, and types of gear used. Also included is a complete list of references cited in the text.

Woodley, T.H. 1993. Technical report no. 93-02: Potential Effects of Driftnet Fisheries for Albacore Tuna *(Thunnus alalunga)* on Populations of Striped *(Stenella coeruleoalba)* and Common *(Delphinus delphis)* Dolphins from the Northeast Atlantic. International Marine Mammal Association, Inc.

http://www.imma.org/download.html (select Technical Reports from the Downloadable Documents list)

Provides an analysis of the potential impact of incidental mortalities in driftnet fisheries on the populations of striped and common dolphins. Uses demographic models to predict the maximum sustainable incidental mortalities before populations begin to decline. Also included is a complete list of references cited in the text.

Bycatch

Corey, T. and E. Williams. 1995. Bycatch: Whose issue is it anyway? Rhode Island Sea Grant, Nor'Easter.

http://seagrant.gso.uri.edu/region/noreaster/Bycatch_SS95.html

This in-depth article explores the bycatch issue from many different perspectives. Excerpts interviews of prominent officials in government, academia, commercial fisheries and conservation organizations. Discusses issues such as what bycatch really is and when it becomes a problem. Examines criticisms of government rules and regulations and problems with technological solutions. Also discusses how cooperative efforts can be used to solve problems.

Australia Department of Primary Industries and Energy. Bycatch: The Non-Target Catch of Fishing.

http://www.dpie.gov.au/resources.energy/fisheries/fishfacts/ff4.html

Provides concise statements on what bycatch is, the fate of bycatch, what constitutes a bycatch problem, how amounts and types of bycatch vary depending on the fishery, and methods of reducing bycatch. Links to a page at the same site that uses detailed diagrams to describe the major types of fishing gear in use by commercial fisheries. Includes a list of references in print for further information.

Northeast Fisheries Science Center, Woods Hole Laboratory. Yellowtail Flounder.

http://www.wh.whoi.edu/library/sos94/spsyn/fldrs/yellotail.html

Provides a synopsis of the yellowtail flounder fisheries of Georges Bank, southern New England, Cape Cod and the Mid-Atlantic. Includes landings data and discusses the contribution of bycatch to the decline of the fishery.

International Pacific Halibut Commission. 1993. Halibut Bycatch Survival/Sorting Experiment.

http://www.iphc.washington.edu/pages/currentresearch/vesselsurveys/bycatch/cruise.htm

Describes the results of an experiment to determine the effectiveness of improved methods of reducing bycatch mortalities in bottom trawls. The experiment involved sorting and discarding halibut from the groundfish catch more rapidly than is now current practice and estimating the savings in halibut discard mortality rates.

International Marine Mammal Association, Inc. Pinniped Bycatch.

http://www.imma.org/unfao.html

Provides the estimated annual bycatch of sea lions, fur seals, true seals and walrus, and information on fisheries and fishing gear, for all major geographic areas where these marine mammals are found.

Institute for Fisheries Resources/Seabird Bycatch Project. Marbled Murrelet Information Page.

http://www.pond.net/~fish1ifr/bycatch3.htm

Describes the status of the marbled murrelet and the contributions of net fishing bycatch to the bird's population decline. This is one of the primary seabird bycatch concerns in the Pacific Northwest.

Institute for Fisheries Resources/Seabird Bycatch Project. Albatross Information Page.

http://www.pond.net/~fish1ifr/bycatch4.htm

Provides links to background information on albatross species and the effects of bycatch on the birds. Links include pages on albatross bycatch bibliography, an article on the decline of the albatross, and proposed regulations and management measures.

Australia Department of Primary Industries and Energy. Seabirds and Fishing.

http://www.dpie.gov.au/resources.energy/fisheries/fishfacts/ff10.html

Describes the problem of seabird bycatch and how birds are incidentally taken, including the types of fisheries and methods that are most responsible. Examines possible solutions and their effectiveness, including deterrent practices and modifications to fishing methods and gear. Contains a section on the albatross, highlighting the bird's vulnerability to incidental catch, population declines, and methods being employed to reduce mortalities.

National Marine Fisheries Service. Sea Turtles.

http://kingfish.ssp.nmfs.gov/tmcintyr/turtles/turtle.html

Provides in-depth information on the green, Kemp's ridley, leatherback, loggerhead and olive Ridley sea turtles. Includes information on each species' biology, ecology, distribution and human impacts (e.g., bycatch and the effects of discarded fishing equipment). Discusses turtle excluder devices and their effectiveness at reducing bycatch. Provides synopses of National Marine Fisheries Service recovery plans for each species.

Inforrain. 1997. A Comparison of Bycatch in Pelagic and Bottom Trawl Pollock Fisheries.

http://www.inforain.org/maps/ak/bycatch.html

This site contains maps and statistics on the bycatch of king and Tanner crab, king salmon and Pacific halibut in the pollock pelagic and bottom trawl fisheries off Alaska. Also accessible through this site is a growing network of information at the bioregional, watershed, community and business scales. The area covered is the coastal temperate rainforest of North America, extending from San Francisco, California, to Kodiak Island, Alaska. The site is being developed by Interrain Pacific, a nonprofit organization promoting conservation-based developed through enhanced understanding of social and ecological patterns of change.

Alaska Seagrant. 1996.

http://www.uaf.alaska.edu/seagrant/Pubs_Videos/pubs/AK-SG-97-02toc.htm

This site provides the Proceedings of the Symposium on the Consequences and Management of Fisheries Bycatch entitled "Fisheries Bycatch: Consequences and Management". The publication provides case studies of the characteristics, consequences and mitigation of bycatch.

Legislation Relating to Bycatch

National Marine Fisheries Service. Magnuson-Stevens Fishery Conservation and Management Act, as amended through October 11, 1996.

http://www.nmfs.gov/sfa/magact/

Provides the complete text of the Magnuson-Stevens Fishery Conservation and Management Act. See Section 303(a)(11) for information on bycatch provisions required to be included in fishery management plans. See Section 405 for provisions on incidental harvest research.

National Marine Fisheries Service. The Marine Mammal Protection Act of 1972, as amended, through 1994.

http://kingfish.ssp.nmfs.gov/tmcintyr/mmpatext/mmpacont.html

Provides the complete text of the Marine Mammal Protection Act. See Section 118 (16 USC 1387), Taking of marine mammals incidental to commercial fishing operations; Section [ ] (16 USC 1385), Dolphin protection; and Subchapter IV, Global moratorium to prohibit certain tuna harvesting practices.

National Marine Fisheries Service. Endangered Species Act of 1973.

http://kingfish.ssp.nmfs.gov/tmcintyr/esahome.html

Describes National Marine Fisheries Service responsibilities under the Endangered Species Act, including those related to the incidental catch of endangered species. Also provides a link to the full text of the Act.

Benthic Disturbances

Van Dolah, R.F., P. Hinde, and N. Nicholson. Effects on Roller Trawling on a Hard Bottom Sponge and Coral Community. Skidaway Institute of Oceanography.

http://www.skio.peachnet.edu/noaa/trawls.html

Describes the results of an experiment to determine the extent of damage to hard bottom sponge and coral assemblages caused by trawling. Also examines recovery rates of damaged areas and provides a complete list of references cited in the text.

Legislation Relating to Benthic Disturbance

National Marine Fisheries Service. Magnuson-Stevens Fishery Conservation and Management Act, as amended, through October 11, 1996.

http://www.nmfs.gov/sfa/magact/

Provides the complete text of the Magnuson-Stevens Fishery Conservation and Management Act. See Section 303(a)(7) for information on requirements of fishery management plans to minimize the adverse effects of fishing on habitats.

Protected Resources

National Marine Fisheries Service. National Marine Mammal Laboratory. Seattle, WA.

http://nmml01.afsc.noaa.gov/

The laboratory conducts research on marine mammals off the coasts of Oregon, Washington and Alaska. This work includes stock assessments, life history determinations, and status and trends analyses that support U.S. and international efforts to develop effective management strategies.

National Marine Fisheries Service. Office of Protected Resources. Silver Spring, MD.

http://www.nmfs.gov/tmcintyr/prot_res.html

Coordinates marine species protection, conservation and restoration for the National Marine Fisheries Service, under the Endangered Species Act of 1973 and the Marine Mammal Protection Act of 1972. Within the office, specialists in marine resources and ecology, fishery biology, and veterinary medicine coordinate and manage programs in the following areas: biodiversity assessment and conservation, endangered species protection, marine mammal protection, research and public display permits, marine mammal health, and response to marine mammal stranding.

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APPENDICES

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Appendix A

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Characterstics of U.S. fisheries

Fishery Unit[1]	Major species[1]	Number of Vessels or Federal Permits[2]	Recent Average Total Yield (mt)[1,3]	Importance of Commercial and Recreational Fisheries[1,4]	Comments[1]
Northeast Demersal	cod family (6 species), flatfish (7 species), spiny dogfish, skates, goosefish, scup	6,642	185,535	mostly commercial; recreational significant	Substantial Canadian catch included in total yield.
Northeast Pelagic	Atlantic herring, Atlantic mackerel, squids, bluefish	1,024	165,800	mostly commercial; recreational significant	Substantial Canadian catch included in total yield.
Atlantic Anadromous	striped bass, American shad, alewife/blueback	unknown[5]	4,836	roughly equal	
Northeast Invertebrate	American lobster, sea scallop, surf clam, ocean quahog	10,855	99,500[6]	nearly all commercial	Substantial Canadian sea scallop catch included in total yield.
Atlantic Highly Migratory Pelagics	tunas (>6 species), billfish (3 species)	300	246,955	mostly commercial; recreational significant	Total U.S. catch is only about 14,600 mt; some species have substantial bycatch from longline fisheries.
Atlantic Sharks	large coastal (20 species), small coastal (6 species), pelagic (10 species)	389	9,324	mostly commercial; recreational significant	Some species have substantial bycatch from shrimp trawl and longline fisheries; slow reproductive rates make sharks vulnerable to overfishing.
Atlantic/Gulf of Mexico Coastal Migratory Pelagics	dolphin, king mackerel, Spanish mackerel, cobia	2,036	17,884[7]	roughly equal	Substantial Mexican catch in addition to U.S. total.
Atlantic/Gulf of Mexico/Caribbean Reeffish	over 100 species, including snappers, groupers, amberjacks	4,650	31,225	roughly equal	Red snapper has substantial bycatch from shrimp trawl fishery.
Southeast Drum & Croaker	seatrouts, black and red drums, Atlantic croaker, spot	39973	16,785	roughly equal	Most harvest from state waters; substantial bycatch from shrimp trawl fishery.
Southeast Menhaden	Atlantic and gulf menhaden	61	890,000	all commercial	About 5% of catch sold for bait.
Southeast/ Caribbean Invertebrate	shrimps (6 species), spiny lobster, stone crab, queen conch	25,000[8]	112,483	mostly commercial	Shrimp trawl fishery bycatch is a major issue that is increasingly regulated.
Pacific Coast Salmon	chinook, coho, pink, sockeye, chum	2,956	22,957	mostly commercial; recreational significant	Substantial Native American catch included in total yield; land-use practices affect reproduction.

Alaska Salmon	sockeye, pink, coho, chum, chinook	70,224	364,800	mostly commercial	Minor recreational and subsistence fisheries exist; substantial hatchery enhancement of wild stocks.
Pacific Coast and Alaska Pelagic	Pacific herring, chub and jack mackerel, Pacific sardine	2,050	116,800	mostly commercial	
Pacific Coast Groundfish	Pacific whiting, rockfishes (many species), flatfishes (>5 species), sablefish, lingcod	1,490	357,386	mostly commercial; recreational significant	Substantial Canadian Pacific whiting catch included in total yield.
Western Pacific Invertebrate	spiny and slipper lobsters, corals	5-15	143	all commercial	No coral fishery has occurred since 1988.
Western Pacific Bottomfish and Armorhead	snappers, groupers, jacks, emperors	1,000	388	mostly commercial	Much of armorhead distribution outside of U.S. waters
Pacific Highly Migratory Pelagic	tunas (4 species), billfish (6 species), dolphin, pelagic sharks	110-160[9]	2,077,232	mostly commercial; recreational significant	U.S. landings 240,438 mt.
Alaska Halibut	Pacific halibut	4,630[1]	36,500	mostly commercial; recreational significant	Substantial Canadian catch included in total yield.
Bering Sea/ Aleutian Groundfish	walleye pollock, Pacific cod, flatfishes (>5 species), atka mackerel	863	1,902,402	all commercial	Russia catches a substantial additional portion of the Eastern Bering Sea stock of walleye pollock.
Gulf of Alaska Groundfish	walleye pollock, Pacific cod, flatfishes (>5 species), atka mackerel, rockfish (many species)	2,456	249,582	all commercial	
Alaska Crab	snow, tanner, king crabs	350-400[1]	125,744	all commercial	Most of catch is snow crab.
Alaska Shrimp	northern pink shrimp, 4 other species	364	1,500	all commercial	
Alaska Snail	snails	4	71	all commercial	
Northeast Nearshore	blue crab, sea urchins, hardshell clam, blue mussel, tautaog, oyster	unknown[5]	75,230[10]	both are important, depending on species	
Southeast Nearshore	blue crab, mullet, oyster, bluefish	unknown[5]	90,830[10]	both are important, depending on species	
Pacific Coast Nearshore	market squid, shrimps and prawns, sea urchins, dungeness crab, clams	unknown[5]	113,245[10]	both are important, depending on species	
Alaska Nearshore	dungeness crab, scallops, clams, sea urchins	unknown[5]	3,210[10,11]	both are important, depending on species	Some subsistence fishing occurs.

Western Pacific Nearshore	jacks, surgeonfishes, squirrelfishes, various invertebrates	unknown[5]	1,520[10]	both are important, depending on species	Subsistence fishing is substantial in many areas.

[1]Source: Our Living Oceans '95 (NMFS, 1996b)

[2]Number of vessels engaged in the fishery, or number of Federal commercial fishing permits. Source is NMFS Draft Bycatch Plan (NMFS, on-line, 1997a) unless otherwise noted.

[3]Total yield is for U.S. fisheries unless otherwise noted.

[4]Additional data sources : NMFS, on-line, 1998b,c

[5]Not a federal fishery.

[6]Data for bivalves is for shucked meats.

[7]Data are for U.S. catch only.

[8]Data Source: Federal Register 62(127):35774

[9]Our Living Oceans 95 (NMFS, 1996b) states that 500-2,000 vessels participate in the Pacific albacore fishery

[10]Generally commercial catch only; bycatch estimates are missing or incomplete.

[11]Excludes nearshore catches of salmon and Pacific halibut.

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Appendix B

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Estimates for annual marine mammal mortality from fishing, Potential Biological Removal[1] values, and strategic status[2] of stocks.

Alaska Region | Pacific Region | Atlantic/Gulf of Mexico Regions

Alaska Region

Species	Stock	Fishing Mortality	PBR
Pinnipeds			
Bearded seal	Alaska	2	N/A
Harbor seal	Southeast Alaska[3,4]	36	2114
Harbor seal	Gulf of Alaska[3]	36	673
Harbor seal	Bering Sea[3]	31	379
Northern fur seal	**Eastern North Pacific[3]**	**18**	**1713**
Ribbon seal	Alaska	1	N/A
Ringed seal	Alaska	1	N/A
Spotted seal	Alaska[3]	2	N/A
Steller sea lion	**Eastern U.S.[3]**	**15**	**1672**
Steller sea lion	**Western U.S.[3]**	**35**	**383**
Small Cetaceans			
Beluga whale	Beaufort Sea[3]	0	649
Beluga whale	Eastern Chukchi Sea[3]	0	74
Beluga whale	Eastern Bering Sea[3,4]	0	129
Beluga whale	Bristol Bay[3,4]	1	26
Beluga whale	**Cook Inlet[3,4]**	**0**	**15**
Dall's porpoise	Alaska	42	1537
Harbor porpoise	Southeast Alaska[4]	4	82
Harbor porpoise	Gulf of Alaska	25	71
Harbor porpoise	Bering Sea	2	86

Killer whale	Eastern North Pacific Northern Resident	1.4	7.6
Killer whale	Eastern North Pacific Transient	1.4	3.1
Pacific white-sided dolphin	North Pacific	4	4867
Large Cetaceans			
Baird's beaked whale	Alaska	0	N/A
Bowhead whale	**Western Arctic[3]**	**0**	**77**
Cuvier's beaked whale	Alaska	0	N/A
Fin whale	**Northeast Pacific**	**0**	**N/A**
Gray whale	Eastern North Pacific[3]	4	432
Humpback whale	**Western North Pacific**	**0**	**N/A**
Humpback whale	**Central North Pacific**	**0.8**	**2.8**
Minke whale	Alaska	0	N/A
Northern right whale	**North Pacific**	**0**	**N/A**
Sperm whale	**North Pacific**	**0**	**N/A**
Stejneger's beaked whale	Alaska	0	N/A

Alaska Region | Pacific Region | Atlantic/Gulf of Mexico Regions

Pacific Region

Species	Stock	Fishing Mortality	PBR
Pinnipeds			
California sea lion	United States	915	6680
Guadalupe fur seal	**Mexico to California**	**0**	**104**
Harbor seal	California	234	1678
Harbor seal	Oregon/Washington Coast	15	1540
Harbor seal	Washington Inland Waters	36	921
Hawaiian monk seal	**Hawaii**	**N/A**	**4.8**
Northern elephant seal	California Breeding	145	2142
Northern fur seal	San Miguel Island	0	216
Small Cetaceans			
Bottlenose dolphin	California Coastal	0	1.3
Bottlenose dolphin	California/Oregon/Washington Offshore	4.4	15
Bottlenose dolphin	Hawaii	N/A	N/A

Common dolphin, long-beaked	California	14	53
Common dolphin, short-beaked	California/Oregon/Washington	272	3097
Dall's porpoise	California/Oregon/Washington	22	330
False killer whale	Hawaii	N/A	N/A
Harbor porpoise	Central California	14	33
Harbor porpoise	Northern California	0	76
Harbor porpoise	Oregon/Washington Coast	13	212
Harbor porpoise	Inland Washington	15	21
Killer whale	California/Oregon/Washington	1.2	3.5
Killer whale	Southern Resident Stock	0	1.9
Killer whale	Hawaii	N/A	N/A
Northern right whale dolphin	California/Oregon/Washington	47	151
Pacific white-sided dolphin	California/Oregon/Washington	22	796
Pantropical spotted dolphin	Hawaii	N/A	N/A
Pygmy killer whale	Hawaii	N/A	N/A
Risso's dolphin	California/Oregon/Washington	37	224
Risso's dolphin	Hawaii	N/A	N/A
Rough-toothed dolphin	Hawaii	N/A	N/A
Spinner dolphin	Hawaii	6.8	N/A
Striped dolphin	California/Oregon/Washington	1.2	154
Striped dolphin	Hawaii	N/A	N/A
Large Cetaceans			
Baird's beaked whale	California/Oregon/Washington	1.2	2
Blainville's beaked whale	Hawaii	N/A	N/A
Blue whale	**California/Mexico**	**0.2**	**1.5**
Blue whale	**Hawaii**	**N/A**	**N/A**
Bryde's whale	Eastern Tropical Pacific[5]	0	0.2
Bryde's whale	Hawaii	N/A	N/A
Cuvier's beaked whale	California/Oregon/Washington	28	61
Cuvier's beaked whale	Hawaii	N/A	N/A
Dwarf sperm whale	California/Oregon/Washington	0	N/A
Dwarf sperm whale	Hawaii	N/A	N/A
Fin whale	**California/Oregon/Washington**	**0**	**1.5**

Fin whale	**Hawaii**	**N/A**	**N/A**
Humpback whale	**California/Oregon/Washington**	**1.2**	**0.5**
Melon-headed whale	Hawaii	N/A	N/A
Mesoplodont beaked whale	**California/Oregon/Washington[6]**	**9.2-13**	**11**
Minke whale	**California/Oregon/Washington**	**1.2**	**1**
Pilot whale, short-finned	**California/Oregon/Washington**	**13**	**5.9**
Pilot whale, short-finned	Hawaii	N/A	N/A
Pygmy sperm whale	California/Oregon/Washington	2.8	19
Pygmy sperm whale	Hawaii	N/A	N/A
Sei whale	**Eastern North Pacific**	**0**	**N/A**
Sperm whale	**California/Oregon/Washington**	**4.5**	**1.8**
Sperm whale	**Hawaii**	**N/A**	**N/A**

Alaska Region | Pacific Region | Atlantic/Gulf of Mexico Regions

Atlantic/Gulf of Mexico Regions

Species	Stock	Fishing Mortality	PBR
Pinnipeds			
Gray seal	Northwestern North Atlantic	4.5	122
Harbor seal	Western North Atlantic	476	1729
Harp seal	Northwestern North Atlantic	0	N/A
Hooded seal	Northwestern North Atlantic	0	N/A
Small Cetaceans			
Atlantic spotted dolphin	**Western North Atlantic**	**22**	**16**
Atlantic spotted dolphin	Northern Gulf of Mexico	1.5	23
Atlantic white-sided dolphin	Western North Atlantic	181	192
Bottlenose dolphin	West North Atlantic Offshore	82	88
Bottlenose dolphin	**Western North Atlantic Coastal**	**29**	**25**
Bottlenose dolphin	Gulf of Mexico Outer Shelf[7]	2.8	432
Bottlenose dolphin	Gulf of Mexico Shelf/Slope[7]	2.8	45
Bottlenose dolphin	Western Gulf of Mexico Coastal	13	29
Bottlenose dolphin	Northern Gulf of Mexico	10	35
Bottlenose dolphin	Eastern Gulf of Mexico Coastal	8	90

Bottlenose dolphin	**Gulf of Mexico Sound/Bay/Estuary[8]**	**30**	**39.7**
Clymene dolphin	Northern Gulf of Mexico	0	41
Common dolphin	**Western North Atlantic**	**234**	**155**
False killer whale	Northern Gulf of Mexico	0	2.4
Fraser's dolphin	Northern Gulf of Mexico	0	0.7
Harbor porpoise	**Gulf of Maine/Bay of Fundy**	**1834**	**483**
Killer whale	Western North Atlantic	0	N/A
Killer whale	Northern Gulf of Mexico	0	2
Pantropical spotted dolphin	**Western North Atlantic**	**22**	**16**
Pantropical spotted dolphin	Northern Gulf of Mexico	1.5	265
Pygmy killer whale	Western North Atlantic	0	0.1
Pygmy killer whale	Northern Gulf of Mexico	0	2.8
Risso's dolphin	Western North Atlantic	68	111
Risso's dolphin	Northern Gulf of Mexico	19	22
Rough-toothed dolphin	Northern Gulf of Mexico	0	6.6
Spinner dolphin	Western North Atlantic	1	N/A
Spinner dolphin	Northern Gulf of Mexico	0	45
Striped dolphin	Western North Atlantic	47	164
Striped dolphin	Northern Gulf of Mexico	0	34
White-beaked dolphin	Western North Atlantic	0	N/A
Large Cetaceans			
Blainville's beaked whale	Northern Gulf of Mexico	0	N/A
Blue whale	**Western North Atlantic**	**0**	**N/A**
Bryde's whale	Northern Gulf of Mexico	0	0.2
Cuvier's beaked whale	**Western North Atlantic[9]**	**9.7**	**8.9**
Cuvier's beaked whale	Northern Gulf of Mexico	0	0.2
Dwarf sperm whale	**Western North Atlantic**	**0.2**	**N/A**
Dwarf sperm whale	**Northern Gulf of Mexico**	**0**	**N/A**
Fin whale	**Western North Atlantic**	**0**	**3.4**
Gervais' beaked whale	Northern Gulf of Mexico	0	N/A
Humpback whale	**Western North Atlantic**	**4.1**	**9.7**
Melon-headed whale	Northern Gulf of Mexico	0	29

Mesoplodont beaked whale	**Western North Atlantic[9]**	**9.7**	**8.9**
Minke whale	Canadian East Coast	2.5	21
North Atlantic right whale	**Western North Atlantic**	**1.1**	**0.4**
Northern bottlenose whale	Western North Atlantic	0	N/A
Pilot whale, long-finned	Western North Atlantic[10,11]	42	50
Pilot whale, short-finned	**Western North Atlantic[10]**	**42**	**3.7**
Pilot whale, short-finned	**Northern Gulf of Mexico**	**0.3**	**1.9**
Pygmy sperm whale	**Western North Atlantic**	**N/A**	**N/A**
Pygmy sperm whale	**Northern Gulf of Mexico**	**0**	**N/A**
Sei whale	**Western North Atlantic**	**0**	**N/A**
Sperm whale	**Western North Atlantic**	**0.2**	**3.2**
Sperm whale	**Northern Gulf of Mexico**	**0**	**0.8**

Alaska Region | Pacific Region | Atlantic/Gulf of Mexico Regions

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strategic stock

Sources: NMFS marine mammal stock assessment reports for 1996 (Barlow et al., 1997; Hill et al., 1997; Waring et al., 1997).

[1]Potential Biological Removal (PBR) is an index mandated by the U.S. Marine Mammal Protection Act, which is an estimate of a sustainable annual level of human-caused marine mammal mortality.

[2]Strategic stocks are defined by NMFS as marine mammal stocks for which human-caused mortality (primarily caused by fishing and subsistence hunting) exceeds the PBR, or that are listed as threatened or endangered under the U.S. Endangered Species Act, or will be so listed in the near future.

[3]Subsistence mortality also occurs for this stock.

[4]Little data are available for this stock.

[5]Only 0.2 percent of this stock occurs in U.S. waters.

[6]PBR includes 2.2 Blainville's beaked whales.

[7]Mortality estimates include both outer continental shelf, and continental shelf-edge and slope stocks.

[8]Estimates combine data for 33 estuarine stocks.

[9]Estimates include both Cuvier's beaked and Mesoplodont beaked whales.

[10]Mortality estimates include both long-finned and short-finned species.

[11]Mortality estimates incomplete; status may be revised.

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Appendix C

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Comparison of Northeast and Gulf of Mexico fisheries

Northeast

Fishery	Major Species	Average Retained Landings (mt)	Principal Gears
Groundfish	cod family flounders small elasmobranchs goosefish scup	186,000	bottom trawls gill nets
Pelagics	Atlantic herring Atlantic mackerel squid	166,000	bottom trawls mid-water trawls gill nets seines
Anadromous	river herrings American shad striped bass Atlantic salmon sturgeons	4,800	haul seines trawls pound nets gill nets hook and line
Invertebrates	American lobster red shrimp sea scallop surf clam ocean quahog	99,500	traps dredges
Highly migratory pelagics[1]	swordfish tunas billfish sharks	247,000	longlines hook and line

Gulf of Mexico

Fishery	Major Species	Average Retained Landings (mt)	Principal Gears

Coastal migratory pelagics	dolphin king mackerel Spanish mackerel cobia	7,900	gill nets hook and line troll lines
Reef fishes	snappers (15 species) groupers (14 species) porgies (6 species) others (24 species)	23,000	traps hook and line longlines spears trammel nets
Drum and croaker	Atlantic croaker red drum black drum kingfishes seatrouts	13,300	hook and line gill nets trammel nets pound nets purse seine haul seine
Menhaden	Gulf menhaden	560,000	purse seine
Invertebrates	shrimps (6 species) spiny lobster, stone crab	99,000	trawl (shrimp) trap (spiny lobster, stone crab)

Sources: NMFS, 1996b; NMFS, on-line, 1998b,c.

[1]Includes entire U.S. Atlantic seaboard.

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GLOSSARY

age class: the portion of a fish population in a specific age group, often broken out as year classes.

benthic: occurring at or near the bottom of a water body.

biomass: the weight or volume of living organisms at a given location and time.

bottom trawl: fishing net towed along the bottom to catch fish or invertebrates living on or near the bottom.

bycatch: for the purposes of this report, unintentional capture or mortality of nontarget living marine resources, which may be retained or discarded (NMFS definition includes discard and ghost fishing mortality, but excludes retained incidental catch).

bycatch reduction device: component of fishing gear intended to lower the amount of non-target catch (e.g., Nordmore Grate used to exclude finfish from shrimp trawls).

cetacean: whales (large cetaceans) and dolphins (small cetaceans).

community structure: organization of the group of species occurring in an area and interacting through ecological relationships such as food webs and competition.

crustacean: predominantly aquatic invertebrates with jointed limbs and an external skeleton, such as crabs, lobsters and shrimps.

dredge: fishing gear dragged along the bottom to dig up shellfish such as clams, oysters and scallops.

ecosystem: a community of species and their environment, which function and interact as a unit.

eutrophication: an increase in the rate of supply of organic matter to an ecosystem, usually involving overenrichment by nutrients.

Federal fisheries: fisheries within the U.S. Exclusive Economic Zone (i.e., within 200 nm of shore) for which the National Marine Fisheries Service has direct responsibility; these are distinct from estuarine and nearshore fisheries within the 0-3 nm territorial sea, which are state responsibilities.

finfish: bony and cartilaginous fish, as opposed to shellfish, such as clams and lobsters.

fishery: the act, process, and industry of catching fish, crustaceans, mollusks, or other aquatic organisms. Fisheries are often targeted at particular species or species groups, and are conducted using specific gears, such as trawls and gill nets. A fishery can be for commercial, recreational, subsistence, or aesthetic purposes.

food chain: the succession of organisms in a community through which food energy is passed from prey to predator.

ghost fishing: capture of living marine resources by lost fishing gear; a component included in estimates of bycatch and total fishing-related mortality.

gill net: stationary net suspended vertically in the water, designed to intercept and capture swimming fish by their gills.

longline: fishing gear consisting of a long, heavy fishing line (up to several km in length) upon which baited hooks and short leaders are attached at regular intervals, deployed at various depths, and designed to attract and hook fish passing by.

marine mammals: warm-blooded marine or estuarine vertebrates with live-born young nourished by mammary glands; primarily pinnipeds (seals and sea lions) and cetaceans (whales and porpoises).

metric ton: unit of weight commonly used in fishery catch statistics, equal to 2,205 pounds.

mollusks: shelled invertebrates such as clams and snails; also includes squids and octopuses.

pelagic: related to species living up in the water column and often in open waters, such as mackerels and tunas.

pinniped: marine mammals such as seals, sea lions and walruses that use flippers for locomotion

population: a group of organisms of one species that occurs within some defined area and is to some extent isolated from other groups of the same species.

potential biological removal (PBR): an index mandated by the U.S. Marine Mammal Protection Act, which is an estimate of a sustainable annual level of human-caused marine mammal mortality.

pots/traps: baited, cagelike fishing gear that the target species enters but cannot exit, such as a lobster or crab pot.

protected species: species that are protected by law, including the Endangered Species Act, which covers all species at risk of extinction, including sea turtles and some marine mammals and seabirds; the Marine Mammal Protection Act, which is intended to keep marine mammal populations at sustainable levels; and the Migratory Bird Treaty Act, which covers all migratory birds, including several species also covered under the Endangered Species Act.

purse seine: long net that is used to encircle a school of fish. Fish are captured when the bottom of the net is pulled together and gathered.

recruitment: the number or weight of catchable fish added to a stock each year by growth and migration.

seabirds: birds that feed and/or spend most of their time in estuaries, coastal areas, or on the ocean, such as gulls, gannets, puffins, murres and albatrosses.

sea turtles: large, highly migratory turtles that nest on marine beaches and spend the rest of their lives at sea, primarily in warm waters. Six species occur in U.S. waters: loggerhead, green, Kemp's Ridley, olive

Ridley, leatherback and hawksbill. All are listed as threatened or endangered under the Endangered Species Act.

selectivity: ability of a type of gear to catch a certain size or kind of fish, compared with its ability to catch other sizes or kinds.

sessile: related to stationary invertebrates, such as clams, oysters and barnacles.

stock: a discrete population of a species, such as Gulf of Maine cod.

strategic stock: marine mammal stock for which human-caused mortality (primarily caused by fishing and subsistence hunting) exceeds the PBR; that is listed as threatened or endangered under the Endangered Species Act; or that will be so listed in the near future.

target species: the species or species group sought in a particular type of fishing, such as shrimp in the shrimp fishery; may correspond to a particular size range or sex.

turtle excluder device (TED): required component of trawl nets in fisheries likely to encounter sea turtles (e.g., Gulf of Mexico and Southeast shrimp fisheries); typically consists of a grating to keep turtles from entering the cod end of the net and a trap door through which the turtle can escape.

year class: the portion of a population hatched or born in the same year.
(top)

CREDITS

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(top)

Photo Credits

Many of the photos were gathered from NOAA archives or were generously provided from the personal collections of NOAA staff members.

Others were contributed from outside of NOAA, and we gratefully thank the following institutions:

Photo 2. Chesapeake Bay Foundation
Photo 4. Chesapeake Bay Foundation
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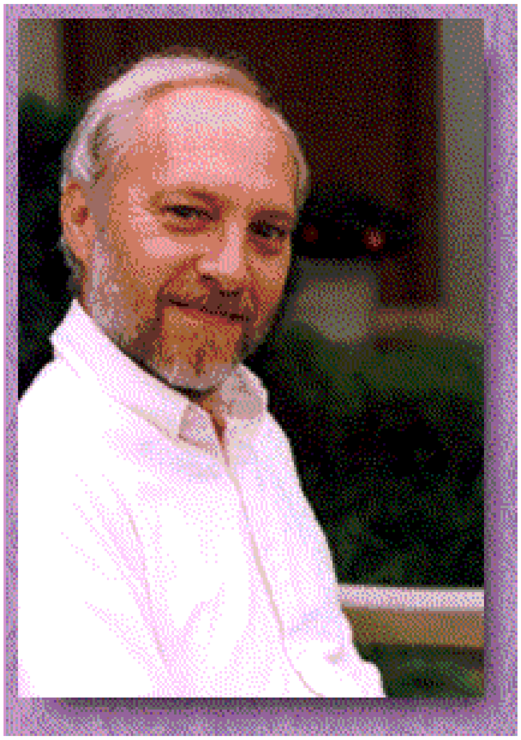
About the Authors



Stephen K. Brown is a biological oceanographer with the National Marine Fisheries Service, Office of Science and Technology in Silver Spring, Maryland. He did most of his work on this essay while working for NOAA's Strategic Environmental Assessments Division, also in Silver Spring, Maryland. He obtained his PhD in estuarine ecology from Rutgers University, and has held postdoctoral positions at the Hopkins Marine Station of Stanford University and at the University of Washington School of Fisheries. His research interests involve analyzing, modeling, and mapping the distributions and habitat affinities of fish and invertebrates. The underlying purpose of his work is to apply scientific information from an array of relevant disciplines to support management and conservation of estuarine, coastal and marine systems.

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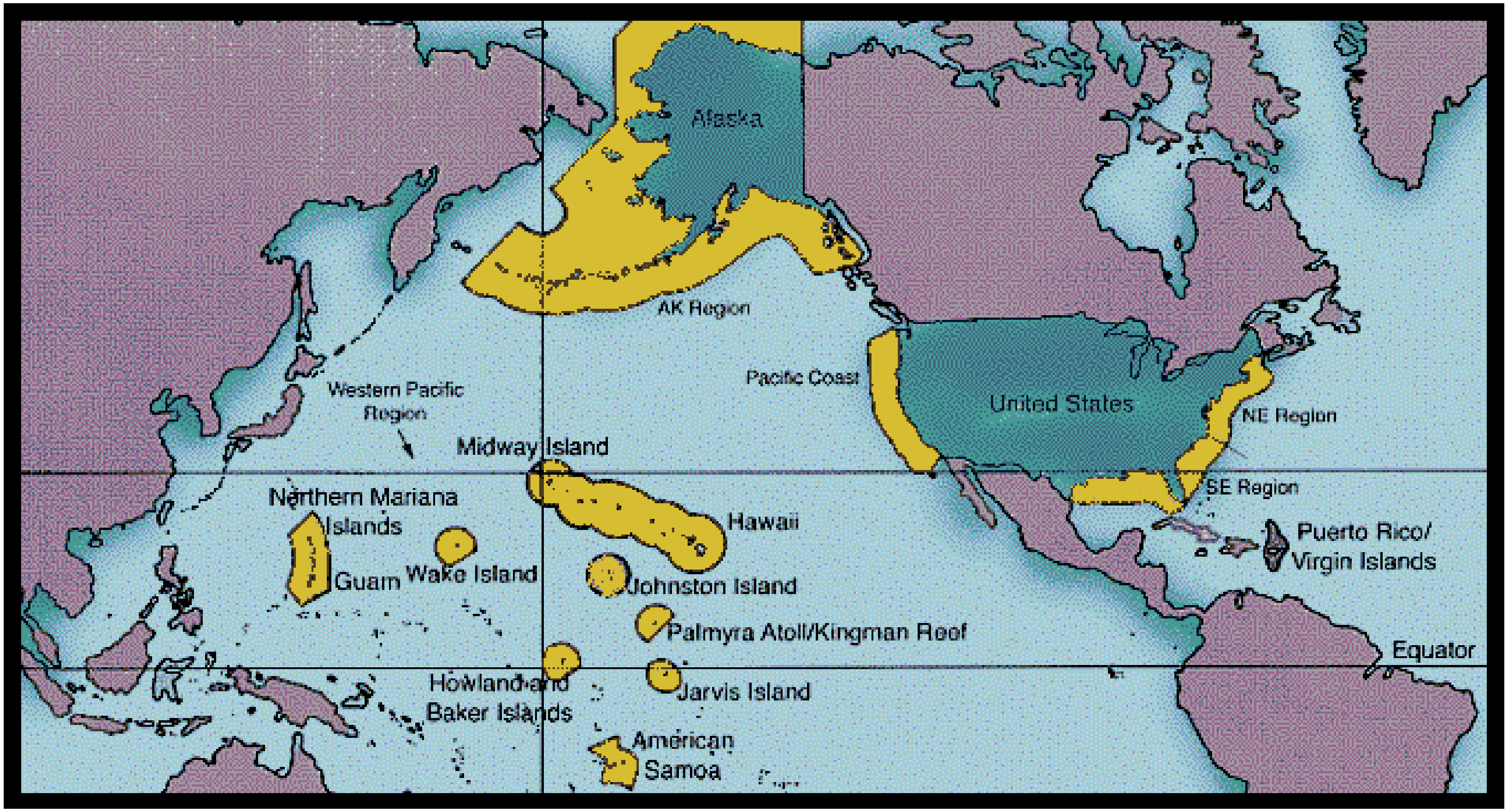

Figure 1. U.S. Exclusive Economic Zone and major fishery management regions.

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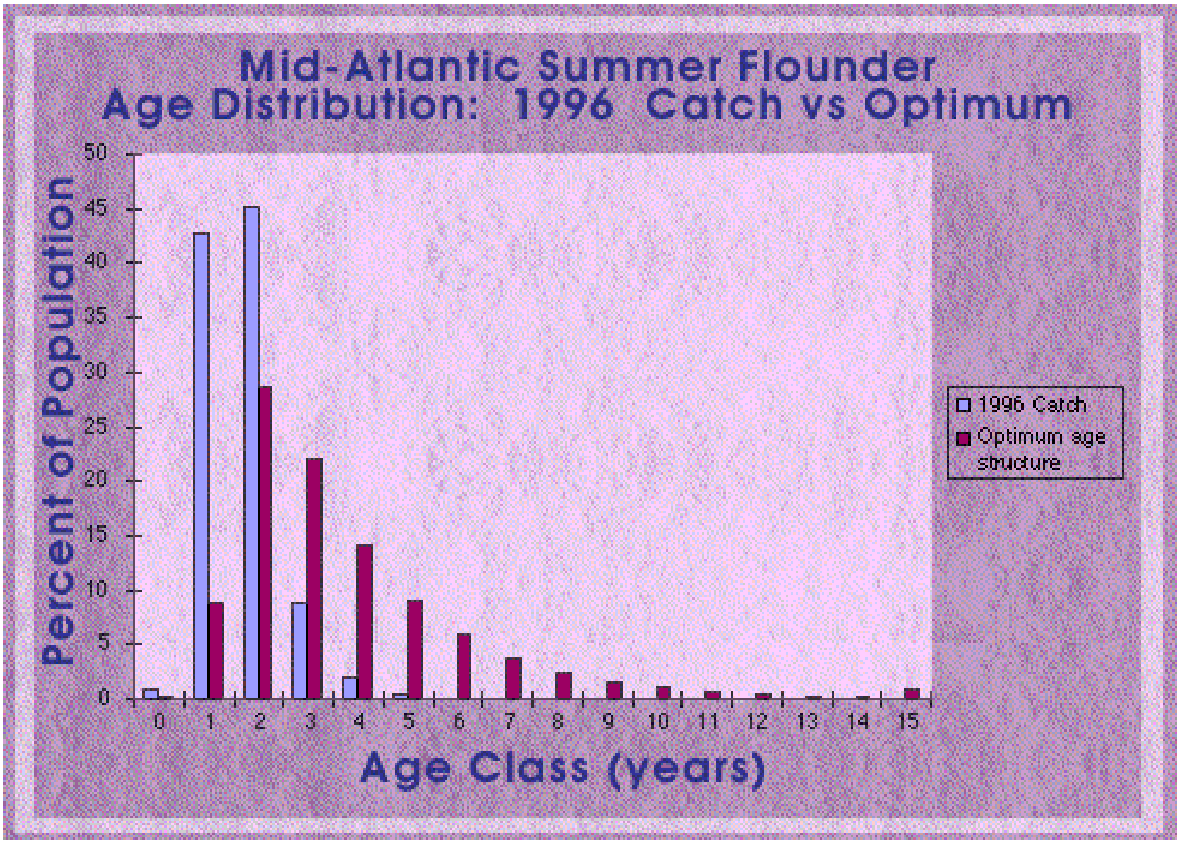

Figure 2. Comparison of mid-Atlantic summer flounder age distribution in 1996 to the optimum age distribution for maximum sustainable yield.

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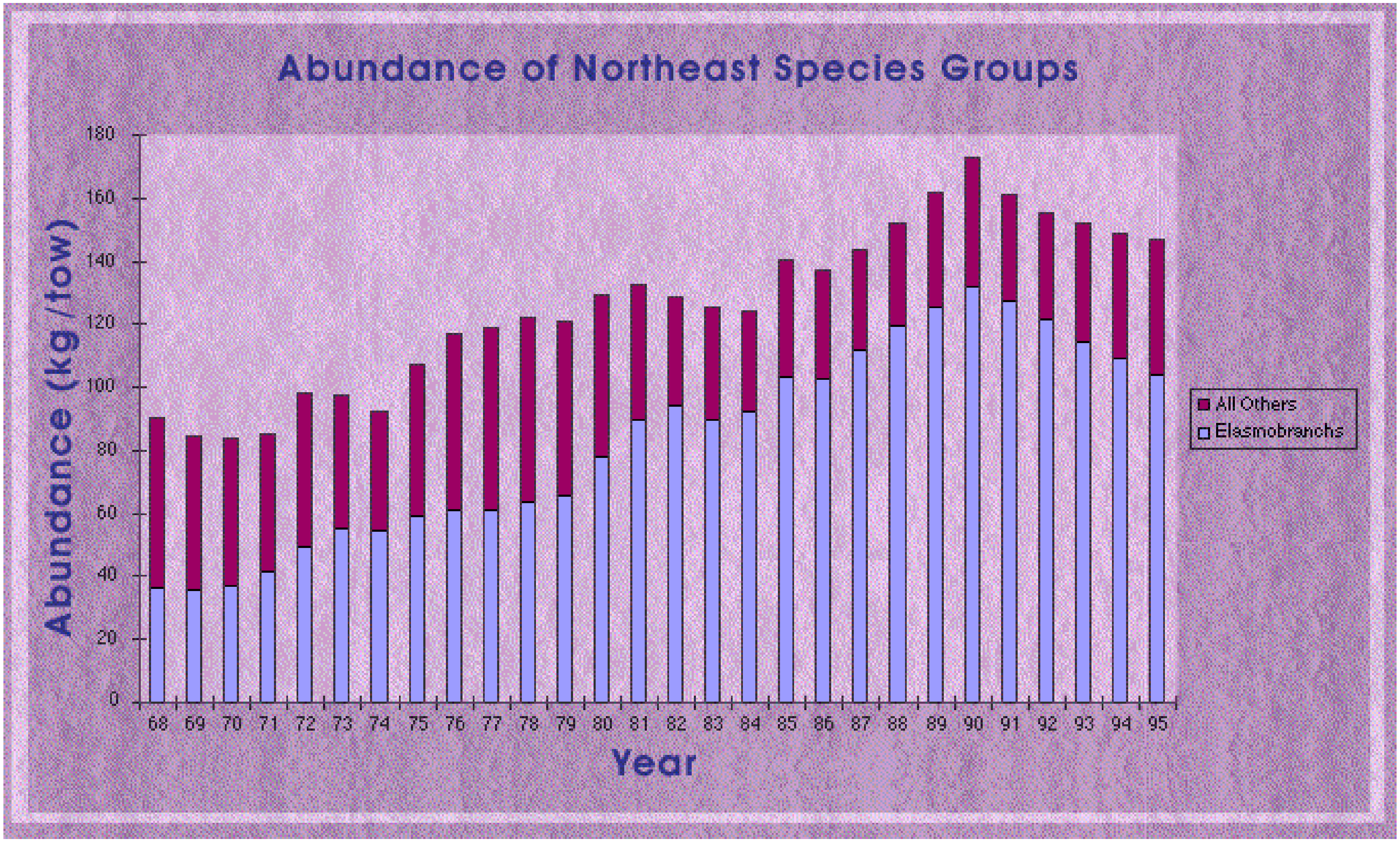

Figure 3. Relative abundance of small elasmobranchs (spiny dogfish and skates) and other species (primarily cods and flatfish) in the Northeast, 1968-1995.

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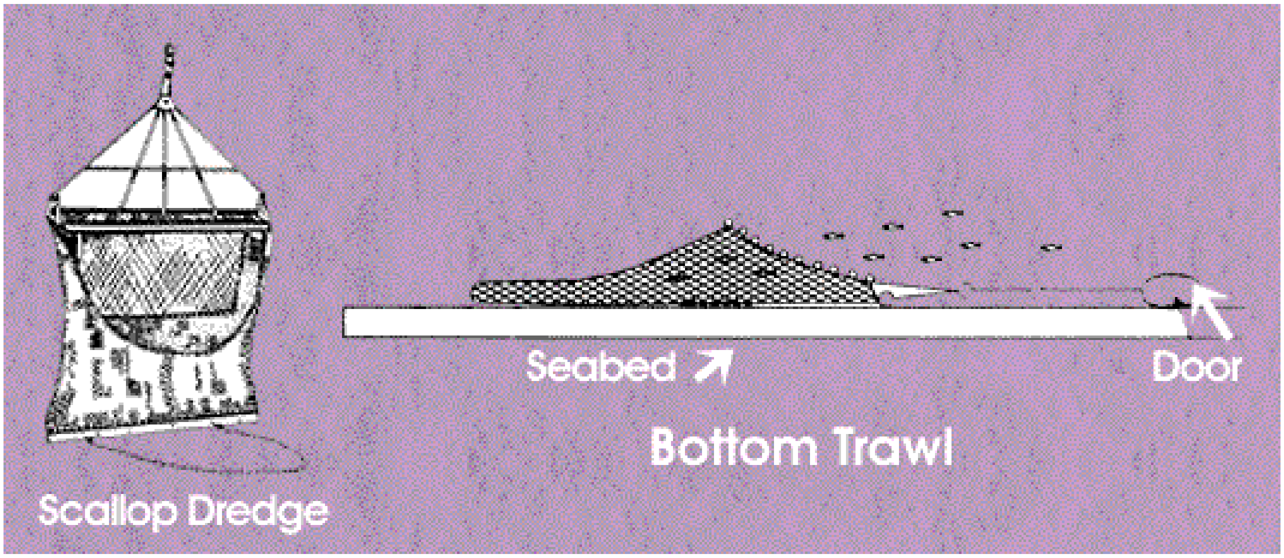

Figure 4. Bottom trawls and scallop dredges are examples of mobile fishing gear that are towed on the sea floor.

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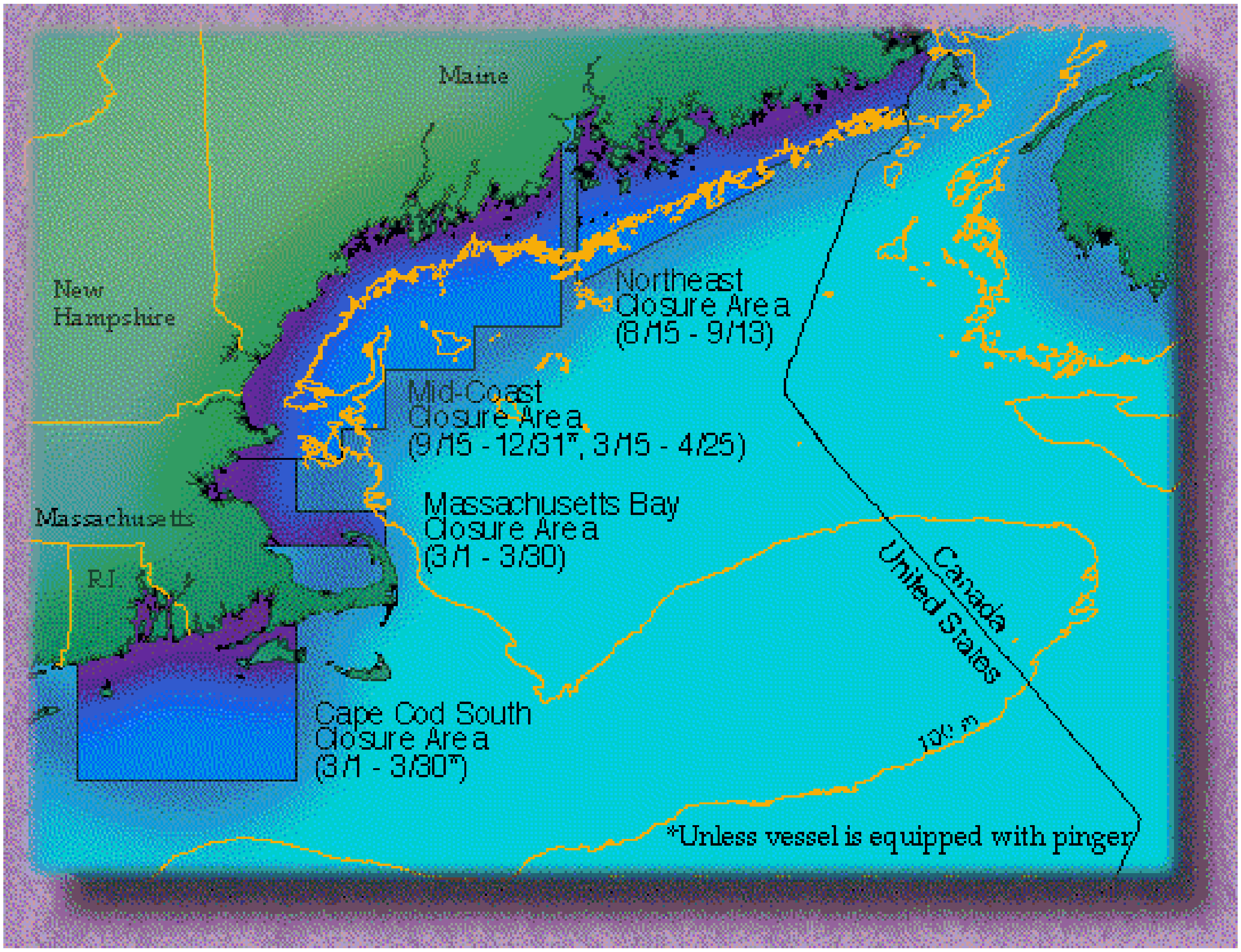

Figure 5. Time-area closures for reducing harbor porpoise bycatch in Gulf of Maine and southern New England gill-net fisheries.

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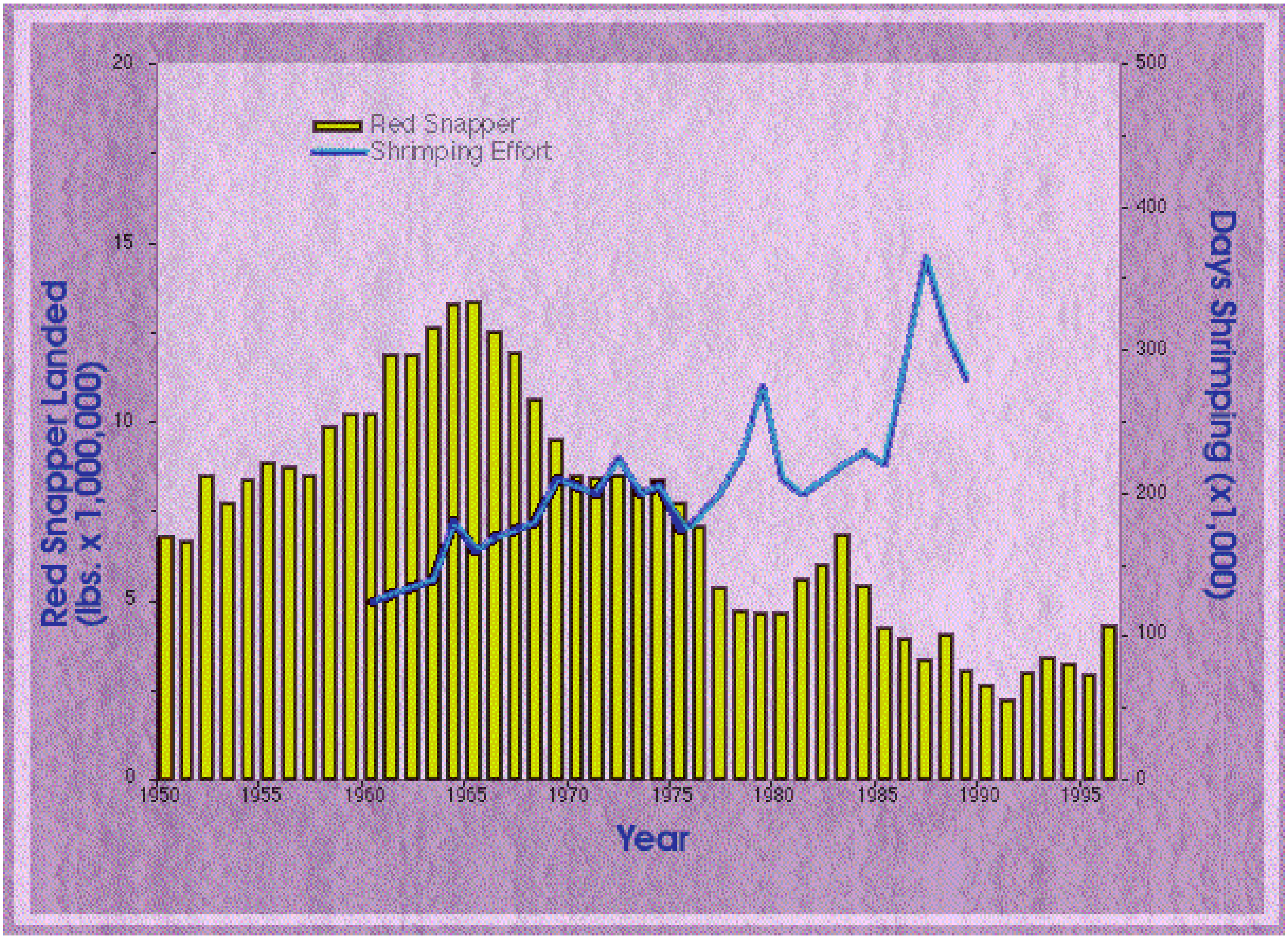

Figure 6. Red snapper landings and shrimping effort over time. Sources: NMFS, 1997b (on-line); Nance, 1992.

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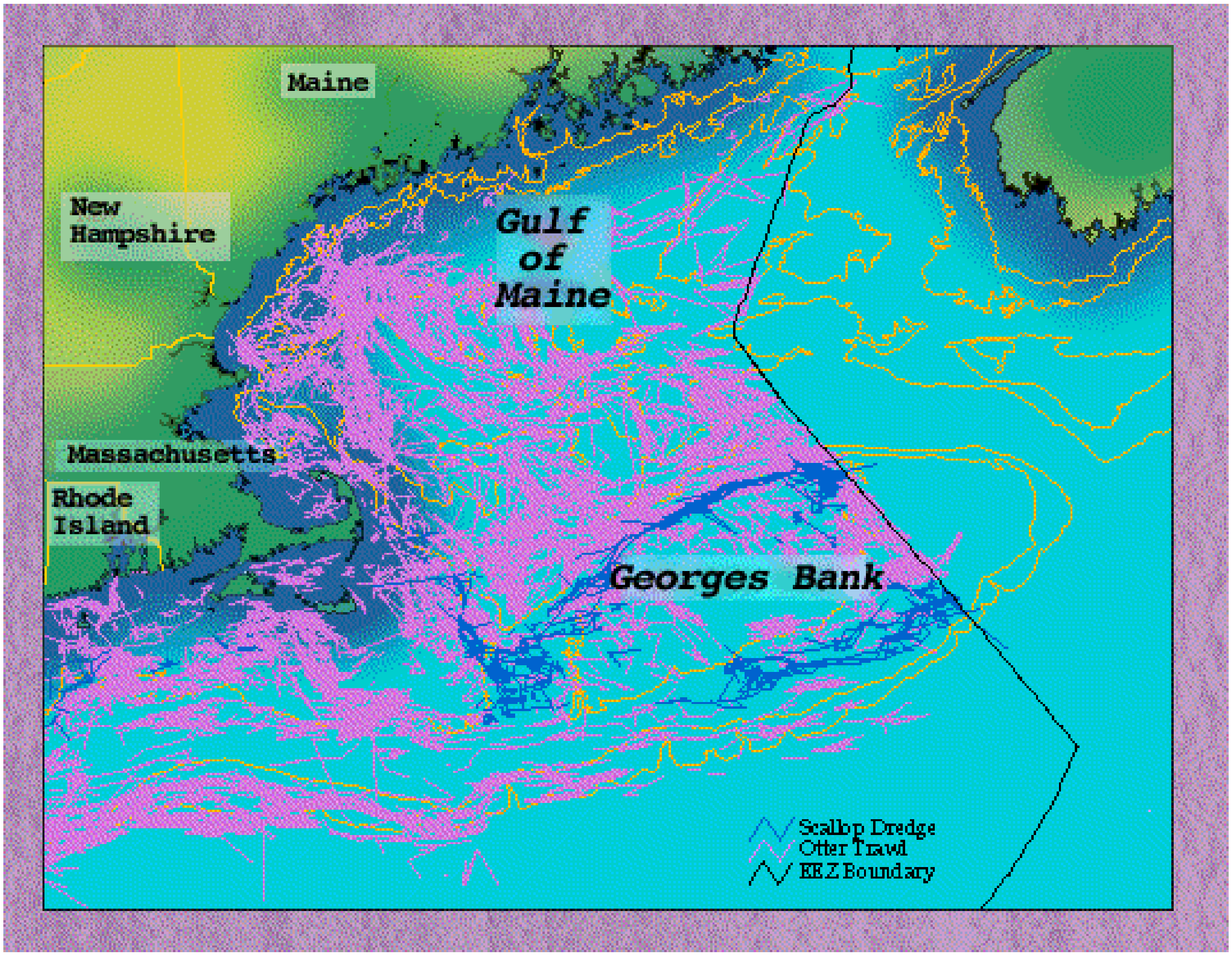

Figure 7. Trawl and dredge tracks reported by onboard observers in the Northeast (January 1989 - April 1994), equal to considerably less than 5% of the total number of commercial trawl and dredge tows made during this period.

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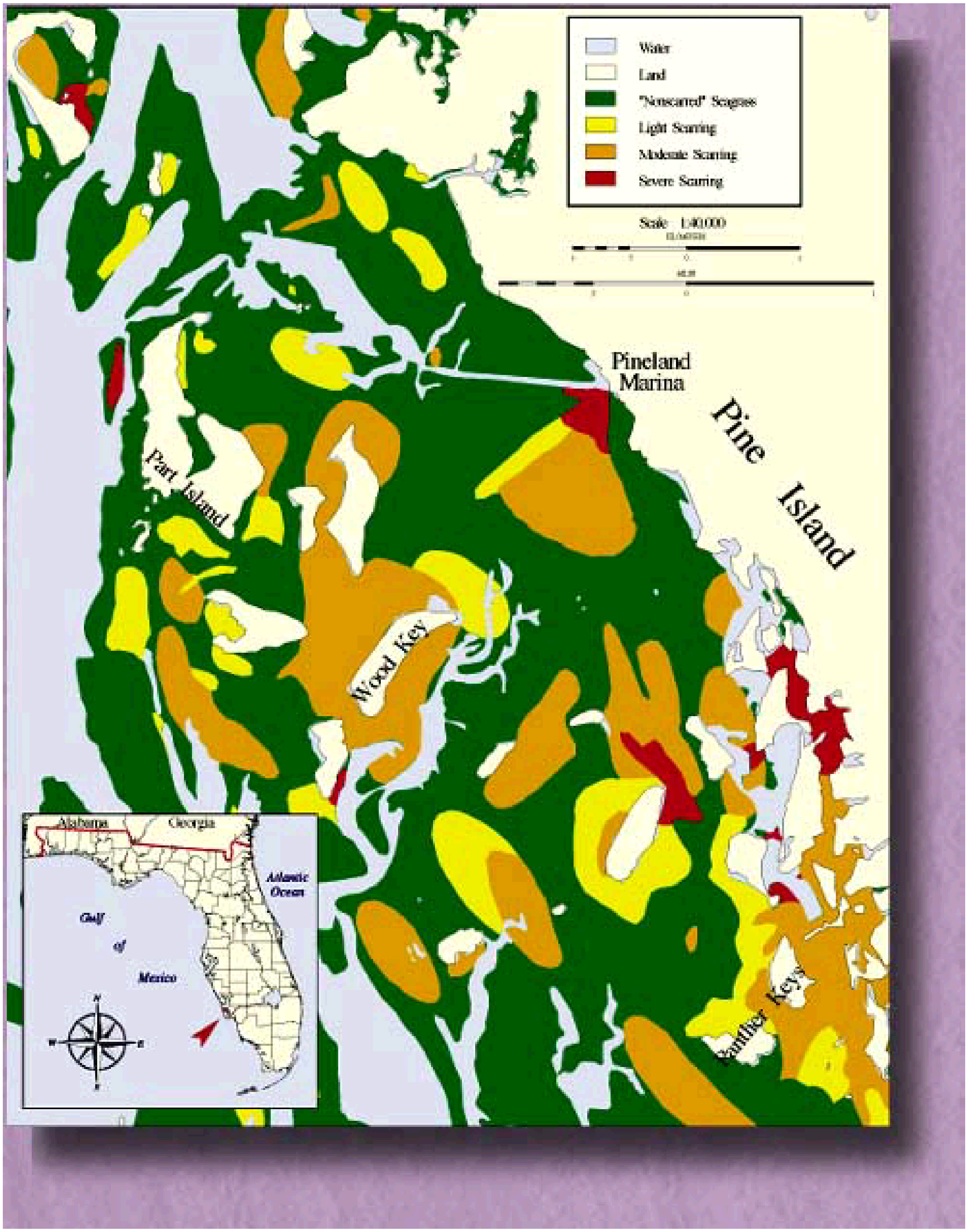

Figure 8. Map of propeller scarring in seagrass beds near Pine Island in Lee County, Florida.
Source: Sargent et al., 1995