SHIFTING GEARS

Addressing the Collateral Impacts of Fishing Methods in U.S. Waters










Lance E. Morgan
Ratana Chuenpagdee

PEW SCIENCE SERIES

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Public debate and policy decisions regarding management of natural resources should be guided by good science. Too often, they are not. In some cases, the problem is a lack of data. In others, it is the tendency to sacrifice the dictates of good science to the exigencies of politics. In many instances, however, the problem is not the absence of scientific information or an unwillingness to pay attention to it. Rather, it is that the available scientific data is frequently unintelligible to decision makers as well as those who shape public opinion.

The goal of this series of publications is to bridge the gap that so often exists between scientists working to illuminate the causes and consequences of specific environmental problems, and those individuals who are faced with making decisions about how to address these problems. Each of the series' reports is designed to accomplish two objectives: first, to communicate the results of sound scientific research on problems that are or will soon be at the forefront of environmental decision making and debate; and second, to do so in a way that is readily comprehensible to policymakers, resource managers, the media and the public.

The intent of the series is not to simplify the scientific endeavor. Rather, it is to make the fruits of that endeavor more accessible to those people and institutions charged with making decisions that will affect the future health and, in some cases, very survival of those natural systems upon which human society depends.

Joshua Reichert
Director
Environment Division
Pew Charitable Trusts

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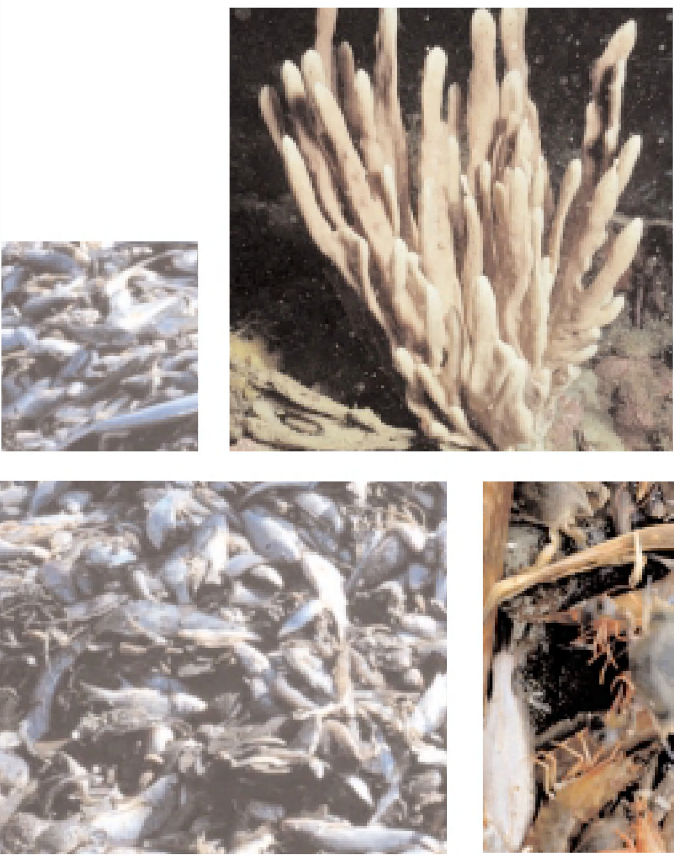

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A Note on Terminology

We avoid using the term “harvest” to refer to capture fisheries in the United States, adopting the view that in order to harvest a resource, one must first plant and care for the organism. Inaccurate use of this term, though commonplace, suggests that fisheries can be managed like cattle or crops, a view that does not adequately account for the enormous complexities in fisheries management.

We have adopted the term “fishers” as a gender-neutral term for people in fishing occupations in general.

EXECUTIVE SUMMARY

How We Fish Matters

With global reports of declining fisheries catches, and with the disintegration of many local fishing communities here in the United States, there is much debate about how best to manage our fisheries. Traditionally, fisheries have been managed on a "numbers" basis, species-by-species. In what is referred to as "single-species management," the focus is on how many fish can be removed before we cause deleterious effects to future stocks. What is all too often lost in this assessment is the impact of how we fish—what gear we use, how it is deployed, and its consequences for the health and sustainability of our marine species and ecosystems.

While specific problems, such as the collapse of New England groundfish fisheries, are widely covered by the media, the ongoing harm to non-target species and damage to marine ecosystems caused by fishing is largely overlooked. Currently, almost one-quarter of global fisheries catches are discarded at sea, dead or dying, each year. Scientists estimate that 2.3 billion pounds of sea life were discarded in 2000 in the United States alone. In addition, many uncommon, threatened, or endangered species, such as sharks, sea turtles, seabirds, and marine mammals, are killed in fishing operations. There is growing concern that fishing gears that contact the seafloor damage the very habitats that marine life depend on for their survival.

These collateral impacts of fishing gears—whether the incidental take of an endangered seabird or the destruction of a deep-sea coral reef—alter marine food webs and damage habitats, reducing the ability of marine ecosystems to sustain fisheries.

Fishers, scientists, and managers acknowledge that these problems exist, but the complexity of assessing ecological impacts associated with different gears—how we fish—has long been a stumbling block to the serious consideration of gear impacts in fisheries management decisions.

Severity Ranking of Collateral Impacts

By synthesizing existing information and using expert knowledge, *Shifting Gears* documents and ranks the collateral impacts of various fishing gear classes. This ranking will help fishers, conservationists, scientists, managers, and policymakers in addressing the urgent need to reduce the impacts of fishing.

Although previous studies document the impacts associated with specific fishing gears, *Shifting Gears* is the first to integrate information on bycatch and habitat damage for all major commercial fishing gears, gauge the severity of these collateral impacts, and compare and rank the overall ecological damage of these gears.

While there has been clear documentation of collateral impacts in some fisheries, until now no scientific method has addressed what types of impacts are considered most harmful. It is difficult for any one sector of science or society to determine the answers to such questions as which is more ecologically damaging, a gear that kills endangered sea turtles or one that destroys a portion of a deep-sea coral forest. Social science methods can help us answer such questions by integrating the knowledge-

• *At least forty seabird species, including albatrosses and petrels in Alaska, are killed by pelagic longlines, with mortality rates high enough to cause population declines in at least half of these species. Streamer line usage is reducing this number.*

able viewpoints and values of fisheries and marine professionals to fill gaps in current ecological assessments. These answers, in turn, provide enhanced understanding of collateral impacts, which is needed for ecosystem-based management. Ecosystem-based management focuses on maintaining the health and viability of the ecosystems on which fish depend for their survival, rather than simply calculating, species-by-species, the number of fish that can be removed.

The innovative "damage schedule" approach used in this study combines existing information with the knowledgeable judgments of those involved in fisheries issues to produce a ranking of the impacts of commercial fishing gears. Using data compiled from over 170 sources, an expert panel of fishers, managers, and scientists reviewed impacts of ten commercial fishing gears widely used in the United States. The results of this workshop were summarized and incorporated into an anonymous survey that was distributed to fishery management council members (including fishers), scientists who served on the National Research Council's Ocean Studies Board or its study panels, and fishery specialists of conservation organizations. These professionals were asked to consider the suite of collateral impacts of various gear classes in paired comparisons, each time choosing which set of impacts they considered to be ecologically most severe.

Contrary to general expectations, the results of this survey show remarkable consensus among the different groups: there was consistent agreement about which fishing gears are the most and least damaging to marine resources. The respondents rated the ecological impacts from bottom trawls, bottom gillnets, dredges, and midwater (drift) gillnets relatively "high," impacts from longlines, pots and traps relatively "moderate," and the impacts from hook and line, purse seines, and midwater trawls relatively "low." In addition, these marine professionals consistently judged habitat impacts to be of greater ecological importance than bycatch impacts.

Toward Ecosystem-based Management

Taking gear impacts into account is an important first step in the move toward ecosystem-based management. Shifting effort from the gears deemed to have high impacts to those with low impacts is one way to improve fisheries management. Other methods for mitigating gear impacts include closing areas to certain types of fishing and developing new, less harmful fishing technologies or gear deployment practices. This report can serve as the basis for future policies to reduce the impact of fisheries on marine life and their habitats.

The time has come for fishery managers and conservation organizations to add fishing selectively, avoiding habitat damage, and protecting marine biodiversity as important components in maintaining ocean ecosystems and healthy fisheries. The results of this report demonstrate that people with diverse interests and experiences agree on the relative severity of ecological damage caused by different fishing gears. This consensus ranking demonstrates that common ground exists for better management of the collateral impacts of fishing gears.

Changing Perspectives

Humanity's collective view of the ocean, our understanding of human influence on it, and the way we value marine life have changed dramatically over the past century. In the late nineteenth century, the sea seemed so bountiful that eminent British biologist Thomas Huxley (1883) declared, "I believe that…all the great sea-fisheries are inexhaustible…nothing we can do seriously affects the number of fish." But at the close of the twentieth century, scientists had provided unmistakable evidence that the sea is in trouble (Norse 1993; Butman and Carlton 1995). The health of estuaries, coastal waters, and oceans has become an increasing global concern, and it is now clear that the largest threat to the sea's biological diversity and productivity is fishing (Jackson et al. 2001; Pauly et al. 2002; Dayton et al. 2002).

Humans have hunted marine animals for a very long time, but the sea's opacity made fishing very inefficient. Our earlier, limited technology allowed many fish to escape and others to remain undiscovered. But twentieth-century innovations—larger boats, steel hulls, and powerful engines; improved fishing gears; and weather forecasting, navigation, and fish-finding technologies—have "made the seas transparent" (Koslow et al. 2000; Roberts 2002). These innovations, coupled with an inexhaustible demand for seafood, place almost all marine populations and habitats at risk.

Usually, the collapse of fisheries is attributed to overfishing, the taking of more individuals than the remaining population can replace. Fishery managers traditionally have paid less attention to the incidental, or collateral, impacts of fishing on nontarget species (those not actively sought by fishers) and on the habitat of both target and nontarget species. These collateral impacts, which are the focus of this report (see Box 1 for definitions of these terms), receive less attention for several reasons: few nonfishers observe fishing operations; very few people, including fishers and fishery managers, ever visit the seafloor; and as human beings we tend to underestimate the adverse environmental effects of our actions, in part because of the short history of our individual experiences (i.e., shifting baselines; Pauly 1995, Dayton et al. 1998). This lack of awareness has greatly slowed actions to curtail bycatch and habitat damage caused by fishing.

Box 1 Definitions

Collateral impact:
Unintentional or incidental damage to sea life or seafloor habitat caused by fishing activities directed toward other types of sea life. Collateral impact includes bycatch and habitat damage.

Bycatch:
The incidental catching and discarding of species alive, injured, or dead, while fishing. Three classes of bycatch are as follows:

1. **Economic bycatch**—species discarded because they are of little or no economic value (e.g., in poor condition or nonmarketable);
2. **Regulatory bycatch**—marketable species discarded because of management regulations (e.g., size limits, allocations, seasons);
3. **Collateral mortality**—species killed in encounters with fishing gears that are not brought on board the vessel.

Habitat damage:
Damage to living seafloor structures (e.g., corals, sponges, seagrasses) as well as alteration to the geologic structures (e.g., boulders, cobbles, gravel, sand, mud) that serve as nursery areas, refuges, and homes for fishes and organisms living on or near the seafloor.

There have been efforts to address the collateral impacts of fishing, but they have been insufficient to deal with the magnitude of these problems. Examples include the effort, led by the United States in the 1980s, to ban High Seas drift nets over a certain length—because of high mortality to marine mammals, seabirds, and sea turtles—and restrictions on dynamite fishing and cyanide fishing on coral reefs in areas of the Indo-West Pacific. These methods are banned not because they can result in overfishing but because of the collateral impacts they cause. Restricting these methods was undoubtedly easier for Americans because the restrictions had no substantial effect on U.S. fisheries. However, U.S. fisheries cause significant bycatch and habitat damage that need to be addressed comprehensively. This report details the results of a study that asked, "Which classes of commercial fishing gear used in the United States produce the most severe collateral impacts?"

This question must be answered because the United States faces major challenges in managing its fisheries. Federal fishery management derives from the Magnuson-Stevens Fishery Conservation and Management Act (FCMA) (Box 2). The 2002 report of the National Marine Fisheries Service (NMFS), National Ocean and Atmospheric Administration, U.S. Department of Commerce, on the status of U.S. fish stocks revealed that 93 of 304 fully assessed stocks either were overfished or were experiencing overfishing (another 655, or 68 percent, of U.S.-managed stocks were not assessed). News stories about overfishing have become routine across the country, including the well-publicized troubles of New England groundfish (e.g., Atlantic cod, haddock, yellowtail flounder) and West Coast rockfishes (e.g., bocaccio, canary rockfish, yelloweye rockfish). The collapse of fish populations represents a serious social and economic, as well as ecological, problem for coastal communities. At the same time, the United States is witnessing population declines in many sea turtle, marine mammal, and seabird species that we do not harm deliberately. These parallel declines are very likely linked to the ways we fish.

A growing number of scientists (e.g., Dayton et al. 1995; Pitcher and Pauly 1998; Pitcher et al. 1999; NRC 1999; Dayton et al. 2002) recommends refocusing attention from

Box 2 The Magnuson-Stevens Fishery Conservation and Management Act

Passed in 1976, the Magnuson-Stevens Fishery Conservation and Management Act (FCMA) established control of U.S. fishing resources out to 200 nautical miles from the U.S. coastline. The stated purposes of this law include developing and conserving fishery resources in U.S. waters, but it also was designed to Americanize these resources by removing foreign fishing fleets. In addition, the Act established regional fishery management councils to advise the National Marine Fisheries Service regarding fishery regulations within eight specified fishery management regions.

In 1996, in response to findings that had accumulated over two decades, the FCMA was substantially revised by the Sustainable Fisheries Act. The amended law required the regional fishery management councils and NMFS to improve the sustainability of fisheries by stopping overfishing, "rebuilding" stocks, reducing bycatch, and identifying and protecting essential fish habitat.

Each of the eight regional fishery management councils has seven to twenty-one voting members representing a combination of state and tribal management officials, the regional director of NMFS, and individuals who are knowledgeable of fishery resources, nominated by state governors and appointed by the secretary of the U.S. Department of Commerce. The main function of the councils is to prepare fishery management plans and subsequent amendments to be submitted to the Secretary of Commerce for approval and implementation. These fishery management plans must take into consideration social, economic, biological, and environmental factors associated with fisheries, while minimizing bycatch to the extent practicable and designating essential fish habitat and methods to reduce damage to it. Thus, these conservation mandates of the FCMA provide the foundation for the implementation of ecosystem-based management.

single-species management (which evaluates fish stocks one by one) to the protection and rebuilding of ecosystems, including species and their habitats. Considering the bigger picture and managing fisheries with a broader range of considerations is called ecosystem-based management.

Ecosystem-based management is needed because the way people think about fish, and the tools used to "manage" them, no longer adequately reflect what marine scientists know about fish. The prevailing management paradigm focuses on avoiding overfishing by asking, "How many tons of a stock can be fished without diminishing future catch?" This approach deals with fish populations one by one, as if each fish population and fishery existed in isolation. But scientists have known the flaws inherent in this approach for decades (Larkin 1977; May et al. 1979). Fishing gears are seldom selective. It affects a wide range of species—those targeted, their young, and other commercial and noncommercial species—as well as the geologic and biological components of seafloor habitats (Figure 1). Altering food webs by removing predators, prey, competitors, and alternative hosts of parasites, or affecting habitats by removing structure-forming species on the seafloor, can result in unintended changes in populations and marine ecosystems (Estes et al. 1998; Pauly et al. 1998; Tegner and Dayton 2000). Fishery management principally based on stock assessment cannot possibly predict these cascading effects. And fisheries cannot be managed sustainably unless fishery management deals successfully with the collateral impacts of fishing gears.

Ecosystem-based management is both fascinating and challenging for several reasons. For one, ecosystem-based management involves many more considerations than single-species management. Moreover, our knowledge is not

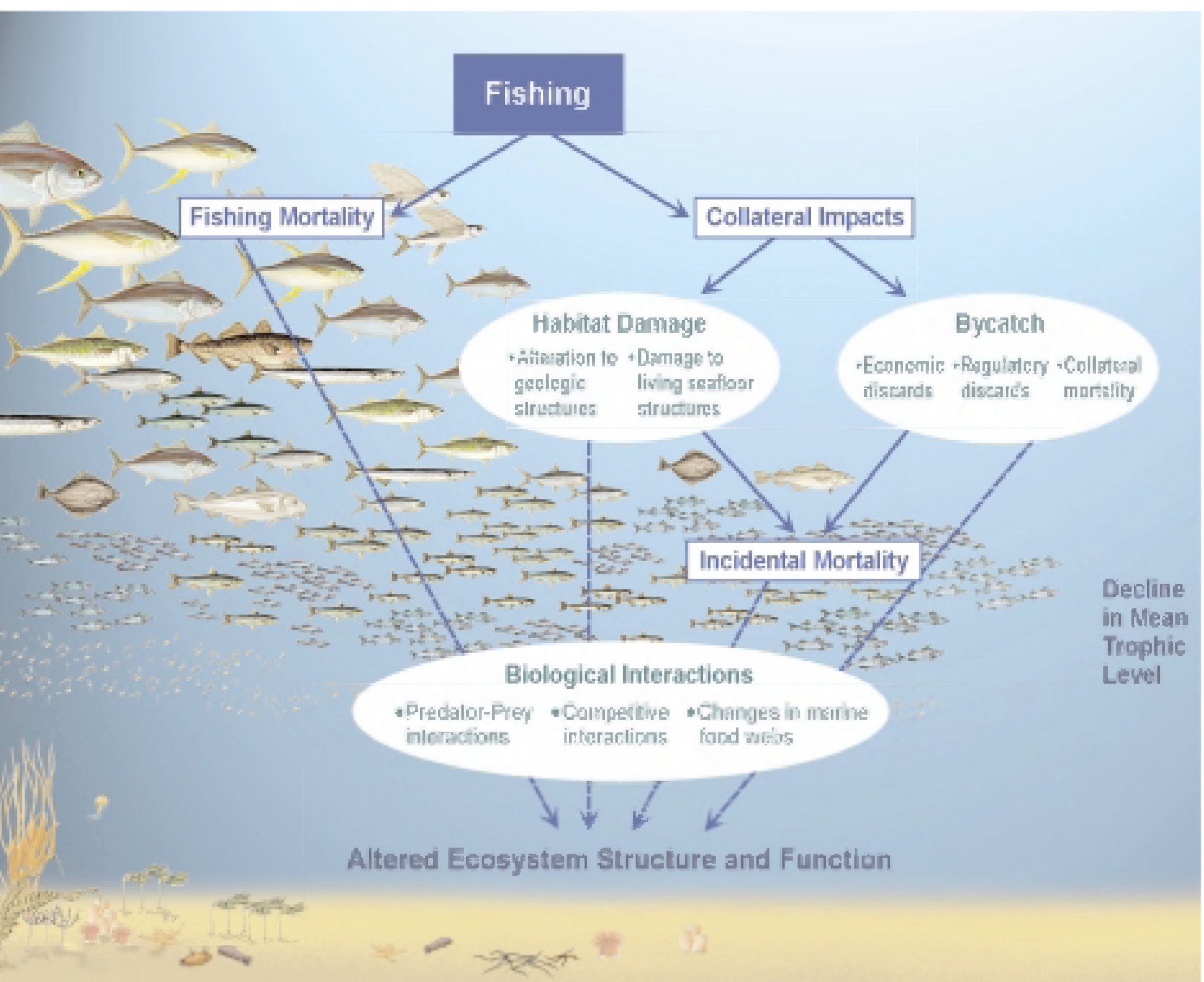


Figure 1

Ecological Impacts of Fishing

Fishing reduces the abundance of target and non-target fish populations. Other non-target species can be injured or killed as bycatch. The physical impact of fishing gear on the seafloor harms habitats for important commercial species and other marine life. Together these impacts can lead to habitat damage, reduced biodiversity, changes in food webs, and reduced ecosystem function.

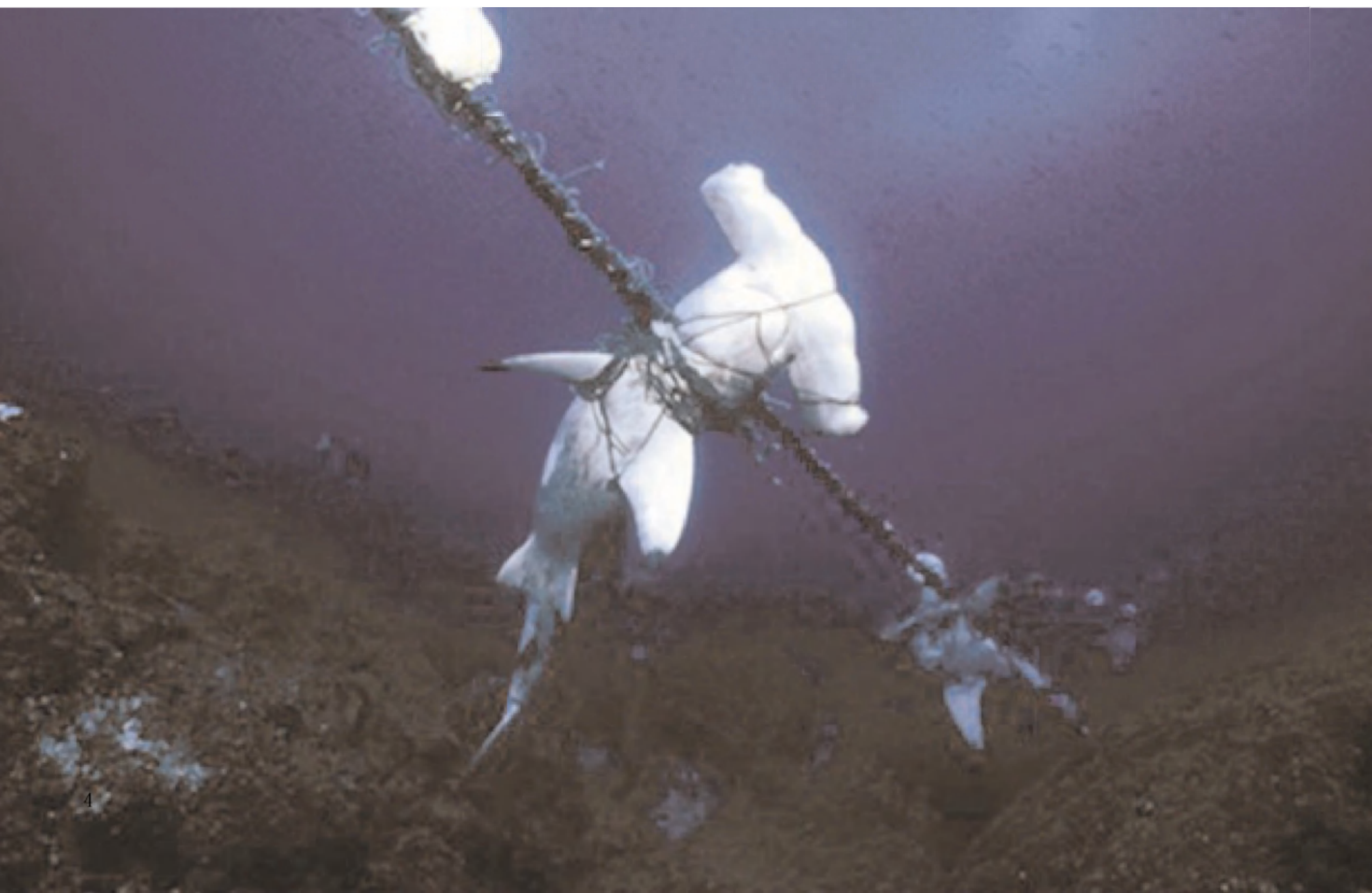
Adapted from Pauly et al 1998, and Dayton et al 2002.

complete: scientists have not yet identified and described all the species and processes that drive marine ecosystem dynamics. Another challenge is that "nature is variable, uncertain, unpredictable, and capricious" (Pimm 2001). In other words, it gives managers moving targets. But the complexity and variability of marine ecosystems is no excuse for failing to make the transition from single-species management to ecosystem-based management. The continuing collapse of so many fisheries and the ongoing problems of bycatch and habitat damage, which affect marine ecosystems more broadly, illustrate that single-species management has not worked.

Ecosystem-based management aims to sustain—and, where needed, restore—fisheries and ecosystems, but it has yet to be implemented to any meaningful degree in the United States. An essential first step is for us to understand the way different classes of fishing gears affect species that are not their intended targets, as well as the gears' effects on the composition, structure, and functioning of marine ecosystems. Therefore, how we fish must be a central consideration in marine ecosystem-based management.

A key stumbling block in assessing these collateral impacts has been an absence of ways to compare classes of fishing gears. It is not inherently difficult to assess fisheries in terms of tons or dollars. But ecological assessments are more challenging. For instance, what would a thoughtful fishery manager consider more harmful: a gear class that kills large numbers of juvenile fishes before they are marketable, one that kills many uncommon seabirds, one that lays flat whole forests of coral, or one that disturbs large areas of nursery habitat for young fishes? Such comparisons

• *Bycatch of sharks and finfish, species that associate with the targeted fish schools, occurs throughout U.S. waters.*



are crucial because different gears target the same species in the same places, and fishery managers need information and tools to address their comparative ecological effects. Many studies have summarized aspects of bycatch or habitat alteration (Alverson 1998; Auster and Langton 1999; Hall 1999; Johnson 2002; NRC 2002), but this report uniquely considers these collateral impacts together in evaluating the overall ecological effects of different classes of commercial fishing gears.

Ideally, managers base their decisions on the best available information, taking into account underlying assumptions and acceptable levels of uncertainty. In fishery management, uncertainty regarding gear-specific habitat damage and bycatch can be high, if data are available at all, which makes decision making difficult. As desirable as it is to maintain and expand data acquisition efforts and scientific understanding, we need means of interpreting and using existing information. This is especially true where knowledge exists but has not been formalized or standardized in the scientific literature.

Bycatch and habitat damage reduce the value of marine ecosystems through direct economic losses to fisheries, and harm ecosystem integrity. The extent of these losses can be determined in different ways: by quantification of lost monetary value due to changes in productivity or removal of species with monetary value, or by nonmonetary measures of social well-being related to the resource (e.g., enjoyment of the act of fishing). Because we are still in our scientific infancy in determining the effects of fishing on ecosystems (Hall 1999) and it is exceedingly difficult—if not impossible—to place a monetary value on marine ecosystems, this report uses a nonmonetary valuation approach, the "damage schedule," to assess the consequences of fishing in terms of bycatch and habitat damage.

Similar methods have been applied to environmental issues such as siting of potentially noxious facilities (Opaluch et al. 1993); comparison of the value of private goods (e.g., concert tickets, clothing, travel certificates) with that of public goods (parking capacity, wildlife refuges, clean air) (Peterson and Brown 1998); and assessment of the health of the eastern Bering Sea ecosystem (Chuenpagdee and Vasconcellos 2000). This report employs the damage schedule to incorporate individuals' scientific knowledge and subjective judgments regarding habitat damage and bycatch associated with different classes of fishing gears. This method is a simple and straightforward way to rank the adverse ecological effects of gears used in U.S. commercial fisheries, providing a management tool for decision makers and others interested in marine ecosystem-based management.

Application of the damage schedule in this report involved three steps. First, we reviewed the literature and compiled information for commercial fisheries, fishing gears, and their impacts on bycatch and habitats. Next, we conducted a workshop of fishers, fisheries specialists, scientists, and managers, who used this information to rate the level of bycatch and habitat damage for each fishing gear. We then used the gear ratings from this expert workshop to design a questionnaire that we used to survey a broad range of marine professionals to elicit their judgments about the relative severity of bycatch and habitat damage caused by those classes of fishing gears. The results of the survey provide a ranking of the different impacts of the fishing gears on bycatch and habitat, and serve as the basis for the management implications and policy recommendations found at the end of this report.

• *Despite regulations, old nets and cod ends are dumped at sea, entangling marine mammals and damaging sensitive seafloor organisms.*

Bycatch

Every year, fisheries in the United States discard vast numbers of invertebrates, fish, sea turtles, sea birds, and marine mammals that were caught unintentionally (Alverson 1998). Using Alverson's estimate that roughly 25 percent of catch is discarded, Dayton and colleagues (2002) estimated that in 2000, U.S. fisheries discarded 2.3 billion pounds (1.05 million metric tons) of sea life. In some fisheries, such as the Gulf of Mexico shrimp fishery, it is estimated that there is nearly 10 lbs. of bycatch for every pound of shrimp landed (Alverson et al. 1994; Nance and Scott-Denton 1997).

One of the most vexing issues is the scarcity of valid bycatch estimates. Many estimates are based on fishers' logbooks, but it is doubtful that they always report bycatch accurately. More often, bycatch is estimated from reports by onboard observers. Unfortunately observer coverage, not including fisheries with very large vessels, is limited (e.g., less than 1 percent observer coverage in the case of the Gulf of Mexico shrimp fishery). The low rate of observer coverage means that the only way to get overall bycatch estimates is to extrapolate from small samples to an entire fleet. These estimates also assume that fishers fish the same way whether or not observers are on board and that species are uniformly distributed—neither of which is necessarily valid.

Bycatch occurs because fishing gear does not discriminate between the target species and those that live in close association with it. Many factors influence the severity of bycatch, including the species' pattern of distribution (e.g., patchiness or concentration in one area, seasonality), predictability of behavior, and associations with other species, as well as the degree to which fishers can control deployment of the gear (Hall 1996). With the possible exception of

- *Bycatch of fishes and invertebrates can outweigh target species (shrimp) by five, ten, or twenty or more times.*

harpooning, spearfishing, and hand-picking, all classes of fishing gears result in some level of unintended catch.

Bycatch creates problems for both fishers and managers. Bycatch of species protected under the Marine Mammal Protection Act of 1972 or the Endangered Species Act of 1973 can cause fisheries to be closed. In addition, regulatory bycatch—discards that occur because management regimes limit the types of fish a particular fisher can land—leads to discarding of marketable species. For example, current regulations in Alaska prohibit fishers not licensed to fish for Pacific halibut, salmon, herring, or certain crab species from retaining these species. When a fishery exceeds its bycatch limit for one of these species, it is closed for the season (Pereyra 1996; Trumble 1996). In 1994, the bycatch mortality of Pacific halibut in Alaska equaled 19 percent of the total allowable catch and 29 percent of commercial landings (Trumble 1996). Because of regulatory bycatch closures, the overall 1995 groundfish catch reached only about two-thirds of the total allowable catch. Excessive halibut bycatch also required fishers to forgo approximately 17,600 tons (16,000 metric tons) of other flatfishes (e.g., sole) catch in 1994 (Stone and Bublitz 1996).

It is clear that bycatch significantly impacts individual species. In the United States in 2001, the federal government proposed listing the smalltooth sawfish as endangered under the Endangered Species Act solely because of bycatch mortality (Federal Register 2001). Other species imperiled as a result of bycatch include the barndoor skate in the North Atlantic Ocean and the leatherback sea turtle in the Pacific. Impacts to many other species, especially non-target species, are not known, and even more problematic is the assessment of the ecosystem-wide consequences of bycatch.

Habitat Damage

Perhaps more significant but even less understood than bycatch is the adverse effect of commercial fishing gears on benthic (seafloor) habitats. The seafloor is, quite literally, a largely uncharted frontier for science, yet it is crucial to the biological productivity of the ocean. Only in recent years has science begun to comprehend the importance of the seafloor as fish habitat and the ecological implications of its disturbance by humans.

Fishing gears that contact the seafloor disturbs geologic and biological structures. These gears plane off structures on soft areas of the ocean bottom, displace boulders, and harm bottom-dwelling organisms by crushing them, burying them, or exposing them to predators. The habitat damage caused by a particular gear depends on its footprint—that is, whether the gear is towed across the bottom and causes linear disturbances or contacts the bottom only at restricted points. Type of habitat, duration of contact, and type, width, weight, and number of units employed all determine the extent of adverse effects. The benthic animals most sensitive to fishing gears are those that are erect and fragile, long-lived and slow-growing, or living in waters where severe natural disturbances are less common, particularly below a depth of 350 feet (100 meters).

• *Bottom trawls cause damage to seafloor habitats including scarring of sandy-bottom seafloors.*

Efforts to understand the role of the seafloor are complicated by the fact that many places were substantially altered before scientific study began (Watling and Norse 1998; Thrush et al. 2001). The lack of a historical baseline makes it much more difficult to determine the significance of what we see today. To paraphrase Dayton and colleagues (1998), no matter how well one understands present populations, any current program will fail to discern the ghosts of missing animals.

Physical and Biological Habitat Impacts

The photo on this page shows the seafloor, undisturbed, rich with life. On the next page is a photo of the same location after a dredge has left its footprint.

What scientists do know is that seafloor communities support an extraordinary diversity of life and much of the sea's productivity. Of the more than 235,000 animal species known to live in the ocean, more than 98 percent are found in or on the ocean floor (Thurman and Burton 2001). Many major marine species groups are exclusively or almost exclusively benthic as adults. These include sponges, corals, annelid worms, clams, oysters, sea slugs, shrimps, lobsters, crabs, sea stars, rockfishes, and other perch-like fishes. Not surprisingly, the importance of the seafloor is reflected in statistics for commercial landings in the United States. In the year 2000, of 380 marine fisheries listed in NMFS' fishery landings database (on the Internet at http://www.st.nmfs.gov/), 283 species (worth $2,800 million) lived primarily in association with the seafloor, whereas only 85 species (worth $630 million) lived primarily in the water column. Twelve other species (worth $189 million) moved between the two habitats.

Another factor that can amplify habitat damage, bycatch, or both is the loss of fishing gear, which can lead to ghost-fishing. This occurs when lost gear continues to disturb the seafloor or catch organisms even though fishers are no longer able to recover the catch. Because lost pelagic and midwater gear gradually gets heavier from encrusting organisms and dying animals, it eventually sinks, and can damage the seafloor. Lost gear adds to the collateral impacts caused when it was in use.

Fishing in the United States

This report categorizes fishing gear according to ten classes commonly used in commercial capture fisheries in the United States. The ten gear classes considered are: dredges, bottom gillnets, midwater and drift gillnets, hook and line, bottom longlines, pelagic longlines, pots and traps, purse seine, bottom trawls, and midwater trawls. The report does not address the different types of handfishing (harpooning, spearfishing, and diver collecting),[1] nor does it include an assessment of the country's substantial recreational fisheries, although the latter also adversely affect marine populations and ecosystems (Dayton et al. 2002). Neither did we consider destructive fishing methods not used in the United States, such as chemical or dynamite fishing, nor international fisheries such as the Eastern Tropical Pacific tuna fishery. The ten classes of fishing gear addressed in this report are used in differing degrees in all eight fishery management council (FMC) regions, and the same gear may target different species in different regions (Figure 2).

In general, fishing gears can be broadly classified according to whether they target species associated with the seafloor (benthic) or those living in the water column (pelagic). Different fishing gears are used to target different species across diverse habitats. Each FMC has regional differences in habitats and species which dictate in part how gears are modified and used, although many aspects of an individual gear's usage are common to all target species and habitats. Following on page 12 is a description of the ten major gear classifications used in this study (Figure 3).

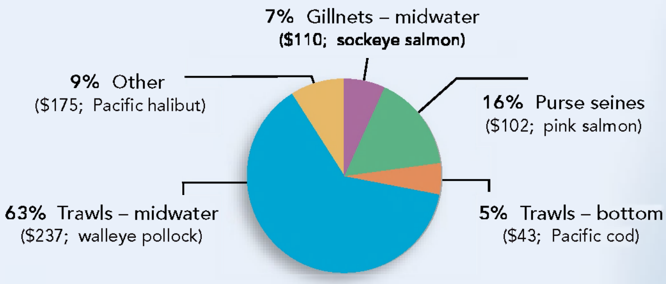
1 This gear class was initially included in our study, but removed from the list of gears evaluated due to insufficient information on impacts associated with their use, and because suspected impacts are considered negligible.

Figure 2

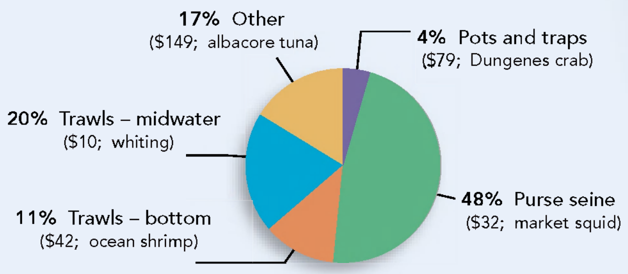
Landings by Gear Class in 2001 by Fishery Management Council Region

Regional breakdown of commercial fish landings in thousand metric tons (MT) and value (millions of dollars). For each FMC region, the pie chart shows percentage landings by weight, total dollar value for gear class in millions, and highest value species for each gear class.

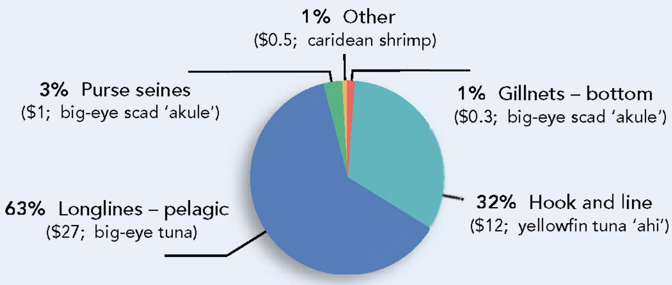
North Pacific – 1,530 MT ($666)

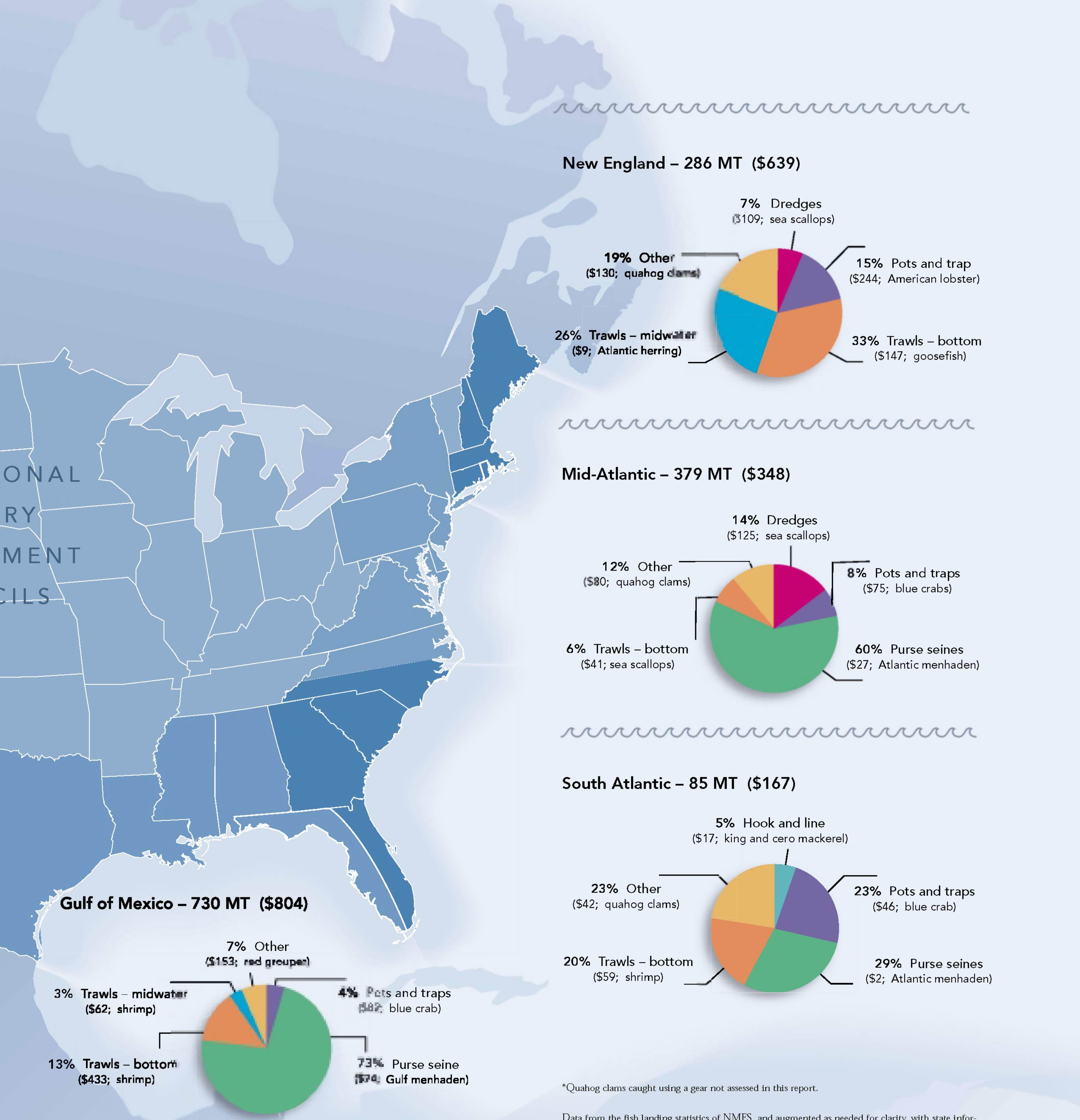


Pacific – 389 MT ($312)



Western Pacific – 9 MT ($40)





*Quahog clams caught using a gear not assessed in this report.

Data from the fish landing statistics of NMFS, and augmented as needed for clarity, with state information. The PACFIN database for the Pacific FMC. The Akfin database for Alaska. Data for Western Pacific FMC is available for Hawaii only, from Hawaii Division of Aquatic Resources statistics. No data is available for the Caribbean FMC.

Figure 3 Descriptions of Fishing Gears

1 Dredges

(Including Scallop Dredges and Hydraulic Clam Dredges)

Dredges are used to catch benthic species such as clams, scallops, oysters, blue crabs, sea urchins, sea cucumbers, and goosefish. They are towed behind a vessel, sometimes in pairs. Dredges are defined by the width of the frame. Most dredges are thirteen or fifteen feet (approximately four to four and one-half meters) wide and can weigh as much as 2,400 pounds, or 1,000 kilograms. The dredge most commonly used in the United States is the New Bedford style dredge, which consists of a large metal frame with a metal bag to hold the collected organisms. The frame and cutting bar ride along the surface of the seafloor, occasionally digging into the bottom, while the bag drags along behind, in contact with the seafloor. The front of the frame is outfitted with a tickler chain, which triggers organisms such as scallops to propel from the seafloor so they are more easily captured. Rock chains are used on rocky areas of seafloor to prevent large boulders from entering the bag.

Gillnets

A gillnet is a curtain-like panel of netting that is suspended vertically in the water by floats along the top of the net and weighted along the bottom (lead line). Because the monofilament line used to make the net is transparent, organisms are unable to see the net, and they swim into it and become entangled, often by their gill cover (operculum). Two main types of gillnets are in use: bottom gillnets and midwater gillnets.

2 Bottom Gillnets

(Including Anchored or Set Gillnets)

Bottom gillnets are used to catch benthic species such as sharks, goosefish, cod, pollock, and flounder. These nets are either weighted and/or anchored to maintain contact with the seafloor. An individual gillnet can be 350 feet (100 meters) long. Often, ten to twenty nets are tied together in a line.

3 Midwater Gillnets

(Including Drift Nets)

Midwater gillnets are most commonly used to catch pelagic (water-column) fish species such as sharks, herring, mackerel, salmon, and swordfish. Midwater gillnets are marked at the ends with buoys, but the nets are not anchored to the seafloor. Midwater gillnets can be as much as 1,200 feet (360 meters) long and 12–50 feet (3.5–13 meters) deep. Many net panels can be tied together.

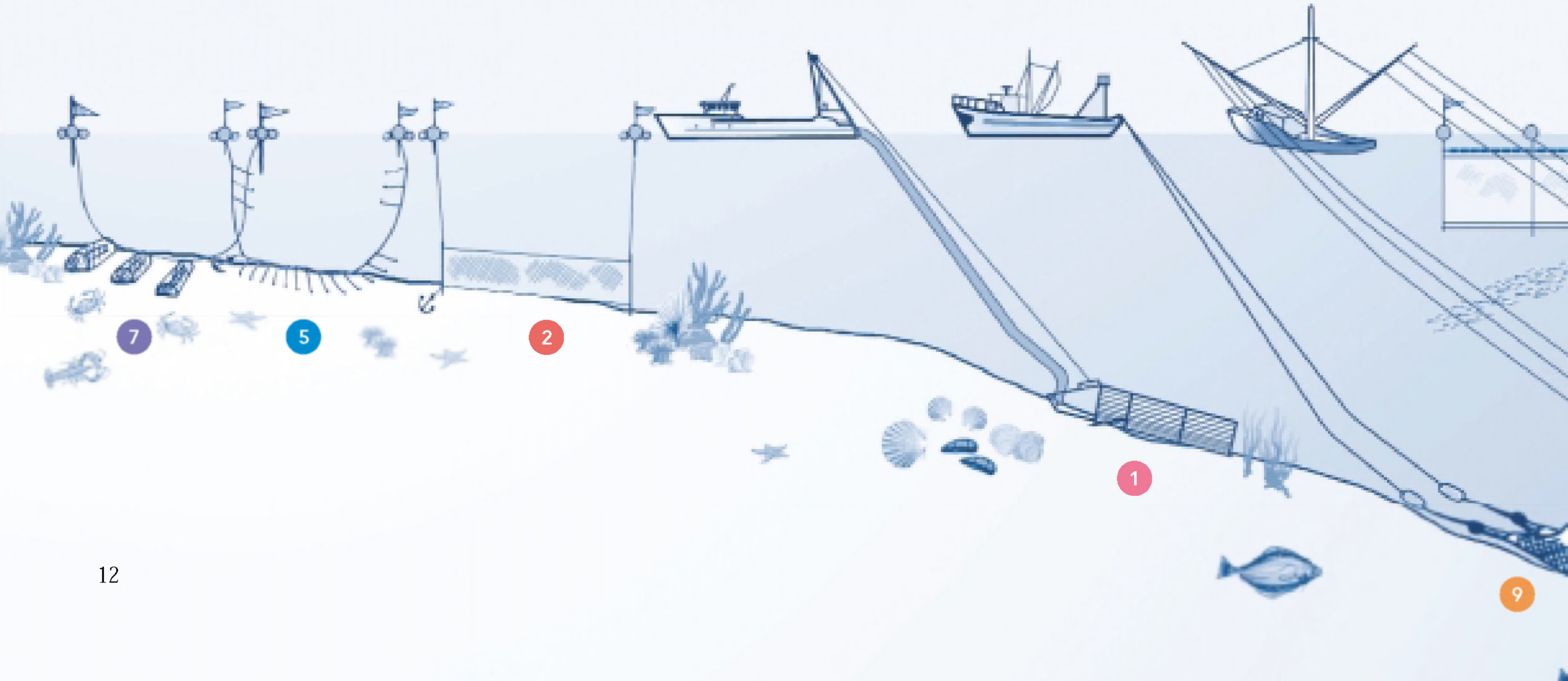
4 Hook and Line

(Including Trolling, Bandit Rigs, Handlines, and Jigging)

Hook-and-line fishing is used to catch both pelagic species, such as salmon, tunas, and swordfish, and benthic species, such as sablefish, snappers, groupers, halibut, rockfishes, and cod. In hook-and-line fishing, individual lines with baited hooks or lures are deployed from a vessel, much as most recreational fishing is done. Hook sizes, sinkers, and the weight and composition of lines vary, depending on target species and rig. In most hook-and-line fisheries, monofilament or steel line is used. Hook-and-line fishing includes the use of rod and reel or power-assisted reel (bandit rig), handline fishing (no reel used), trolling, and jig fishing, in which several hooks are deployed from the base line in a cascade. Jigging is also used to catch schooling organisms such as flying squid.

Longlines

A longline consists of a long stationary line (usually constructed from thick monofilament or steel) to which shorter lines with baited hooks (as many as 12,000 per line) are attached. They are typically left in place for periods ranging from several hours to a couple of days. Configuration of the lines, including the addition of floats or weights, can be tailored to different target species and habitats.



5 Bottom Longlines

Bottom longlines are used to catch benthic species such as cod (Pacific and Atlantic), rockfishes, Pacific halibut, sablefish, and groupers. Weights are added to the lines to allow them to rest on or slightly above the seafloor. The lines are marked with buoys on the sea surface.

6 Pelagic Longlines

Pelagic longlines are used to catch large pelagic species such as tunas and swordfish. They are free-floating, supported by large floats, and can be many miles long. They can be set at depths as great as 1,200 feet (360 meters).

7 Pots and Traps

Pots and traps are used to catch whelks, prawns, crabs, lobster, and fishes such as Pacific cod and Atlantic black sea bass. Frames are commonly made from wood, aluminum, steel, or vinyl-covered wire and wrapped with nylon mesh or twine. Baited pots are left in place for up to several days. Many pots can be connected by a common line (e.g., trot line or set line), and they can be set on the floor at a variety of depths, from very shallow to hundreds of meters.

8 Purse Seines

Purse seines are primarily used to catch schooling pelagic species such as squid, salmon, menhaden, sardine, and herring. This gear operates with two boats per net. The main boat remains stationary while a much smaller boat encircles the fish with a long net that has floats on top. Once the net is in place, the purse line is pulled to close the bottom of the net and capture the fish, which are then hauled aboard the larger vessel.

Trawls

Trawls are a class of mobile fishing gear in which a large, bag-like net is towed behind a vessel. The cone-shaped net is wide at the mouth and narrows to create a "cod end." The net is held open by a solid beam, or by the force of water pressure against the doors, often made of wood or steel, that move upright through the water. Each door can weigh many thousands of pounds (as much as 6,000 kilograms). The net is attached to the doors by a weighted bridle that connects to a foot rope on the bottom and a buoyed head rope to hold the net mouth open. In a beam trawl, a wooden or metal beam, rather than doors, holds the mouth of the net open. Use of beam trawls is minimal in the United States.

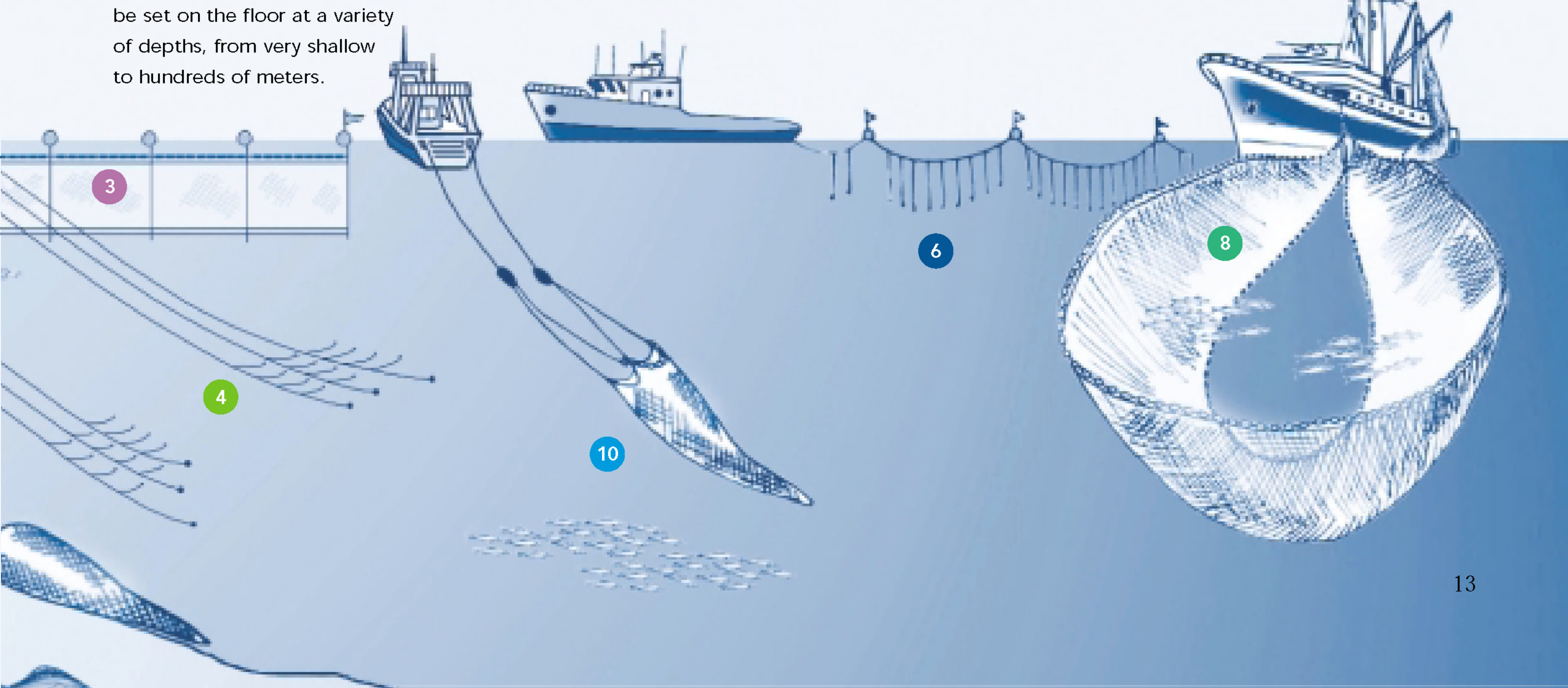
9 Bottom Trawls

(Including Otter Trawls, Shrimp Trawls, and Beam Trawls)
Bottom trawls are used throughout most of the United States to catch benthic species such as shrimp, sole, cod, flounder, and rockfishes. Most bottom trawls are variations of the otter trawl. Typically, doors are designed to come into contact with the seafloor; however, newer designs skid across the seafloor with less contact. The groundline, which keeps the net in close contact with the seafloor, can be a weighted chain or cable, sometimes modified with large, heavy discs and rollers designed to ride over obstructions and keep the net belly from snagging and tearing on the seafloor.

The spread of trawl nets can be as much as 200 feet (55 meters) wide and 40 feet (12 meters) high. Trawls are used from shallow depths of 50 feet (15 meters) inshore to extreme depths of 6,000 feet (2 km) on the continental slope.

10 Midwater Trawls

Midwater trawls are used mostly to catch pelagic and bentho-pelagic schooling species, such as pollock, hake, herring and Atlantic mackerel. The most common midwater trawls are similar to bottom trawls but with lighter rigging, and larger net mouths, up to 330 feet (100 meters). Despite their name, midwater trawls can be used close to the bottom and contact the seafloor.



Assessing Bycatch and Habitat Damage

The assessment of bycatch and habitat damage involved three steps.

Step 1: Literature Review and Data Compilation

The first step in this project was to review the literature documenting the ecological effects of the ten specified classes of fishing gear. The literature review focused on the largest fisheries, by landings and values, based on fishery statistics kept by NMFS. We reviewed over 170 documents for relevant bycatch and habitat information. Our review of the literature indicated that scientific knowledge of adverse effects vary considerably among gear classes. For example, bottom trawls and dredges are relatively well studied in comparison with other gears.

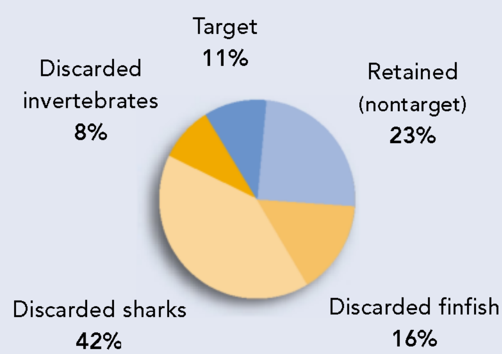
We compiled the bycatch and habitat impact information for the major fisheries where these gears operate. The data were then standardized for reporting units—for instance, using tonnage or the number of individuals. This compilation was provided to the expert workshop participants (see Box 3 for an example) and is summarized in Table 1.

Step 2: Expert Workshop—Rating of Fishing Gear Impacts

At a one-day workshop held in Seattle, Washington, on March 23, 2002, we convened a group of thirteen fishery experts to rate bycatch and habitat damage for each of the ten classes of fishing gear. These experts were selected because of their familiarity with different fishing gear classes and their knowledge of bycatch and habitat damage caused by these gears. They also represent a range of scientific disciplines, technical expertise, and geographic regions. The participants included two natural

Box 3 Bycatch in the California Drift Gillnet Fishery for Swordfish

The drift gillnet fishery for swordfish and sharks, using mesh nets with a stretched diameter greater than fourteen inches, has existed off the West Coast of the United States since 1977. Annually since 1980, with the exception of a few years, either the California Department of Fish and Game or NMFS has fielded an observer program to record the fishery's catch, bycatch, and adverse effects on protected species. Data available at the time of the expert review described in this report included observed bycatch from 1990 to 1998 (Rasmussen and Holts 2001; see pie chart) and estimated mortality of marine mammals, seabirds, and sea turtles (Julian and Beeson 1998). Observer coverage in this fishery ranges from about 13 to 18 percent, and information regarding bycatch of nontarget fish is collected in terms of number of individuals rather than weight. Estimated annual mortality of marine mammals from 1992 to 1994 was 492.5; observed mortalities were marine mammals – 219, sea turtles –19, and seabirds –6 (Julian and Beeson 1998).



BY INDIVIDUALS: SUM 101,639
1990–1998 (14% Observer Coverage)

Species Observed in Bycatch:

Marine Mammals • common dolphin • northern elephant seal • Dall's porpoise • northern right whale dolphin • Risso's dolphin • short-finned pilot whale • Pacific white-sided dolphin • **Finfish** • blue marlin • black marlin • sailfish • bay pipefish • blacksmith • bullet mackerel • California barracuda • California needlefish • common mola • jack mackerel • louvar • mobula • northern anchovy • oarfish • opah • Pacific bonito • Pacific hake • Pacific herring • Pacific mackerel • Pacific pomfret • Pacific sardine • remora • white seabass • yellowtail • **Sharks and Rays** • Pacific angel shark • prickly shark • salmon shark • six-gill shark • seven-gill shark • smooth hammerhead shark • soupfin shark • spiny dogfish shark • bat ray • big skate • manta • Pacific electric ray • pelagic stingray • round stingray • basking shark • white shark • megamouth shark • **Seabirds and Sea Turtles** • leatherback sea turtles • loggerhead sea turtles • unrecorded seabird species

Table 1. Overview of Bycatch and Habitat Damage by Gear Class

Note: See Appendix 1 for referenced literature.

1 Dredges

Habitat Damage

Dredging reduces habitat complexity, leading to long-term effects including decreased species richness and biomass and increased presence of weedy species. Dredging damages organisms, reduces biomass and smothers submerged aquatic vegetation (SAV) and algae. On sand, mud, and silt bottoms, dredging smooths bedforms, resuspends sediments reducing the number of species living there as a result of burial or smothering, and reduces nutrients and microbial activity. Dredging of gravel, hard-bottom, and living habitats reduces species living in the interstices of the gravel and rocks, species attached to the seafloor, and habitat complexity. On oyster reefs dredging reduces reef height and decreases oyster resistance to low-oxygen. Dredging also damages shellfish found in and on top of soft bottoms.

Bycatch

Dredges catch or damage organisms not targeted, especially sponges, bivalves, aquatic vegetation, and bottom fishes. These organisms often are uprooted from the seafloor and then crushed by the weight of the bag and are unlikely to survive if captured and discarded. Bag ring size can be regulated to reduce the number of unwanted organisms retained in the bag.

Ghost-Fishing

No effects are expected, given that dredging gear is rarely lost, and if it is, it stops fishing.

Examples of Threats

- Dredging for sea scallops and clams in New England causes significant bycatch of small crabs and other bottom-dwelling organisms, such as flounder.
- Dredges catch endangered barndoor skates in the offshore Atlantic sea scallop fishery.
- Dredges cause severe habitat damage, especially in areas of hard bottom and gravel. An example is seen off Swan Island in New England, where the coverage of living organisms attached to the seafloor has been greatly reduced.

2 Gillnets – Bottom (Anchored or Set)

Habitat Damage

In strong ocean currents or when being hauled out of the water, bottom gillnets may become tangled and snagged on rocks and living organisms, such as corals and aquatic plants, breaking or uprooting structures and organisms. Damage is higher with mechanical hauling gear.

Bycatch

Gillnets are a nonselective type of gear, often catching a wide range of nontarget species. By extending vertically into the water column, bottom gillnets cause bycatch of marine mammals, seabirds, sea turtles, sharks, and finfishes. Occasionally, benthic species such as crabs become entangled. In states where gillnets are legal, regulations limit soak times and net mesh size to reduce bycatch of nontarget and juvenile target species.

Ghost-Fishing

Gillnets often are intentionally placed near shipwrecks to take advantage of the fishes' attraction to these structures, resulting in the wrecks becoming covered with nets which continue to catch fish that cannot be recovered. The rate of continuous fishing by lost gillnets (ghost-fishing) depends on maintenance of a vertical profile, visibility to fish (older nets become more visible as a result of encrustation by algae, etc.), and abundance of fish in the area where the gillnet is lost. Lost nets can become tangled on seafloor structures such as coral heads and rocky outcroppings, damaging the seafloor and entangling organisms.

Examples of Threats

- In New England, gillnets cause bycatch of harbor porpoises, bottlenose and white-sided dolphins, pilot whales, harbor seals, gray seals, and harp seals.
- Shark bycatch occurs in gillnets throughout U.S. waters.
- Thousands of seabirds, such as common murres, as well as harbor porpoises, sea otters, and other marine mammals, are caught in halibut fisheries off California.
- Endangered and threatened sea turtles, such as green, loggerhead, and Kemp's ridley turtles, commonly are caught in southern gillnet fisheries, such as the Mid-Atlantic FMC monkfish fishery.
- In the southeastern and western Pacific Ocean and the Caribbean Sea, bottom gillnets may snag on corals and sponges, causing them to break.

3 Gillnets – Midwater and Drift

Habitat Damage
Because midwater gillnets rarely come into contact with the seafloor, their effects on habitat are minimal.

Bycatch
Gillnets are a nonselective type of gear, often catching a wide range of nontarget species. By maintaining a vertical profile in the water column, drift gillnets cause bycatch of marine mammals, seabirds, sea turtles, sharks, and finfishes. In states where gill nets are legal, regulations limit soak times and net mesh size to reduce bycatch of nontarget and juvenile target species.

Ghost-Fishing
The rate of continuous fishing by lost gillnets (ghost-fishing) depends on maintenance of a vertical profile, visibility to fish (older nets become more visible as a result of encrustation by algae, etc.), and abundance of fish in the area where the gill net is lost. Lost nets can become tangled on seafloor structures such as coral heads and rocky outcroppings damaging the seafloor and entangling organisms.

Examples of Threats
- In Alaska and Puget Sound, Washington, marbled murrelets and common murres are entangled and killed in salmon fisheries.
- High bycatch of sharks in midwater and drift gillnets occurs in swordfish fisheries.
- Threatened and endangered sea turtles, such as green, olive ridley, and leatherback turtles, are caught in fisheries along the coast of California and in the South Atlantic FMC region.
- Marine mammals are frequently taken as bycatch in midwater and drift gillnets, including approximately 2,000 harbor porpoises taken in New England and Mid-Atlantic FMC fisheries.
- Bycatch of juvenile swordfish and other billfishes occurs in Atlantic tuna and shark fisheries.

4 Hook and Line

Habitat Damage
Hooks are often suspended in the water column and usually do not touch the seafloor. If they are set on or near the seafloor, damage can occur from entanglement, breakage, or minor degradation of seafloor organisms such as invertebrates (corals, sponges, or gorgonians), and lines and sinkers may cause abrasions.

Bycatch
Bycatch of finfish and sharks occurs when either undersized individuals or nontarget species are caught and discarded. As individual lines are retrieved, unwanted catch can be quickly returned to the water, increasing chances of survival; however, damage from hooking and handling and stress caused by capture decrease chances of survival.

Ghost-Fishing
Lost lines may affect habitat by entangling and damaging structures. Lines may also entangle and kill a variety of marine life.

Examples of Threats
- Lost gear can become tangled on seafloor structures such as coral heads and rocky outcroppings, damaging the seafloor and entangling organisms.

5 Longlines – Bottom

Habitat Damage
Damage to habitat caused by bottom longlines is limited because the gear is small in weight and area. However, hauling the lines from the bottom may cause the hooks to snag, and the lines may cause abrasions or entangle rocks, coral, or structural organisms such as sponges or gorgonians. When lines are hauled mechanically, this damage is magnified.

Bycatch
Bycatch of seabirds is a significant consequence of bottom longline fisheries. Deployment of longlines attracts seabirds, which dive for the baited hooks as the lines are released from the vessel. Seabirds may ingest these baited hooks and subsequently drown. Sharks and marine mammals are also caught when they mistake the bait for prey. When hooks are hauled in individually, nontarget catch may be released, but damage due to hooks, handling, and stress of capture decreases survival. Mechanical hauling and line-strippers prevent live release.

Ghost-Fishing
Unknown bycatch impact; lost gear continues to fish until bait is lost. Lost gear may entangle benthic species such as corals and gorgonians, resulting in damage or death.

Examples of Threats
- Bycatch of seabirds in Alaska groundfish longline fisheries resulted in thousands to tens of thousands of birds killed per year, prior to the incorporation of streamer lines, a bycatch reduction device.
- Bottom longlines may damage corals, such as gorgonian corals in Alaska, when hooks snag during hauling.

6 Longlines – Pelagic

Habitat Damage
Because pelagic longlines rarely come into contact with the seafloor, their effect on habitats is minimal.

Bycatch
Bycatch of seabirds, sea turtles, sharks, and billfishes is a significant consequence of pelagic longline fisheries. Deployment of longlines attracts seabirds, which dive for the baited hooks as the lines are released from the vessel. Seabirds may ingest these baited hooks and subsequently drown. Sharks, billfishes, sea turtles, and marine mammals are also caught when they mistake the bait for prey. When hooks are hauled in individually, nontarget catch may be released, but damage due to hooks, handling, and stress of capture decreases survival. Mechanical hauling and line-strippers prevent live release.

Ghost-Fishing
Unknown bycatch impact, but lost gear continues to fish until bait is lost. Lost gear may entangle benthic species such as corals and gorgonians, resulting in damage or death.

Examples of Threats
- Blue, whitetip, and thresher sharks, and other deep-ocean species often are caught on longlines set to catch tunas and swordfish.
- At least forty seabird species, including albatrosses and petrels in Alaska, are killed by pelagic longlines, with mortality rates high enough to cause population declines in at least half of these species. Streamer line usage is reducing this number.
- Critically endangered leatherbacks and other endangered and threatened sea turtles are common bycatch in pelagic longline fisheries for swordfish and tunas in both the Pacific and Atlantic fisheries.
- Bycatch of marine mammals occurs in most Atlantic pelagic longline fisheries, including that for big-eye tuna, in which more than 150 pilot whales are estimated to die every year.
- Bycatch of marlin and other billfishes occurs in Atlantic tuna and swordfish fisheries.

7 Pots and Traps

Habitat Damage
Setting and hauling traps on SAV or living substrates may cause damage and reduce available shelter and food. Trotline (setline) traps tend to cause more damage during hauling than single pots. Pots are not always or necessarily stationary on the seafloor, and bouncing occurs in the presence of large swells or strong tides. Although each trap has a small footprint, large numbers of traps may have a considerable cumulative effect. Reduction in biomass or cover of SAV and algae has been documented.

Bycatch
Nontarget bottom-dwelling species may be affected when they are attracted to the bait. However, because organisms entering the trap are enclosed and not entangled, they can be easily and quickly discarded when the pot is retrieved. Deeper dwelling organisms are more likely to die when brought to the surface due to changes in pressure that can damage internal organs. Marine mammals do become entangled in the marker lines connecting the pots to the buoy.

Ghost-Fishing
The effects of ghost-fishing by lost pots and traps can be very significant. The level of impact depends on several factors, including number of lost pots, rate of loss, density of pots in an area, bottom habitat and location of the lost pots, change in number of animals caught by ghost pots over time, degradation rates of pots, season of loss, catchability of unbaited pots (as well as the rebaiting of pots by dead and dying animals), rates of ingress and egress by organisms, and mortality of animals in lost pots. Mortality in pots depends on adverse environmental conditions (e.g., low oxygen), predation, injury by other animals in the pot, starvation, and disease. Delayed mortality may also occur after escape from pots.

Examples of Threats
- Shellfishes and crabs may be caught in lost gear.
- Buoy lines of lobster pots in New England entangle marine mammals, such as the critically endangered Atlantic right whale.
- In the Caribbean, pots and traps are set on living organisms or substrates 40 percent of the time and may crush or damage these organisms.

8 Purse Seines

Habitat Damage

Purse seines used for salmon in Alaska contact the seafloor and may harm submerged aquatic vegetation. In the Gulf of Mexico menhaden fishery, there is frequent seafloor contact, resulting in sediment resuspension that may bury certain invertebrates. These impacts are largely unknown. Effects on other habitats are expected to be minimal.

Bycatch

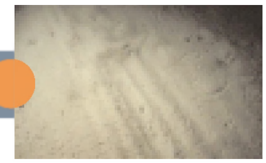
Bycatch of sharks and finfishes, species that associate with the targeted fish schools, occurs throughout U.S. waters.

Ghost-Fishing

No effects are expected, given that this type of gear is very rarely lost.

Examples of Threats

- Shark bycatch in the Gulf of Mexico menhaden fishery is equal to one-third of the target catch for sharks in this region.



9 Trawls – Bottom

Habitat Damage

Trawling reduces habitat complexity, species richness and biomass, and increases the presence of weedy species by altering the species composition (e.g., long-lived and fragile species are less likely to withstand trawling). It reduces the biomass of SAV through loss of rhizomes and smothering, reduces coverage of organisms attached to the seafloor, smooths bedforms, and compresses sediments in sand and mud habitats. Bottom trawling also resuspends sediment (turbidity), lowers the nutritive quality of sediment, and reduces primary and microbial production. Turbidity impedes the normal functioning of benthic organisms' feeding and respiratory structures, resulting in hypoxia or anoxia. Turbidity may also increase primary and microbial production in certain situations. On hard-bottom and living habitats, trawling reduces the size and/or density of invertebrates such as sponges and coral colonies. Trawling displaces boulders and damages seafloor structures, reducing feeding and sheltering sites for marine life.

Bycatch

Bycatch varies seasonally, temporally, and by target species. Bottom trawls catch nontarget species, including fishes, marine mammals, turtles, seabirds, and invertebrates, as the net sweeps across the ocean floor. Because such large quantities of ocean life are brought on board at once, the unwanted organisms are often returned to the ocean dead, having failed to recover from being crushed in the net, or unable to recover from being out of the water for the length of time it took to sort the catch.

Ghost-Fishing

Despite regulations, old nets and cod ends are dumped at sea. Lost trawl gear has low ghost-fishing potential unless the net is suspended by floats. Buoyant trawl web masses attract pelagic fishes and invertebrates, which in turn attract and entangle sea turtles and seals.

Examples of Threats

- Bottom trawls continue to drown sea turtles, especially leatherbacks and adult loggerheads, in the Gulf of Mexico and South Atlantic FMC region shrimp trawl fisheries, despite regulations requiring the use of turtle excluder devices (TEDs).
- Shrimp trawls catch substantial numbers of shark pups and juveniles in shallow waters.
- For every pound of shrimp caught in the Gulf of Mexico trawls, as much as 10 pounds of fishes and invertebrates are discarded, often dead or dying.
- Groundfish bottom trawls in New England catch significant numbers of endangered barndoor skates.
- Bottom trawls cause damage to bottom habitats and have long-lasting effects on the organisms growing on gravel habitats in New England and in areas with deep-sea corals and sponges in the north Pacific.

10 Trawls – Midwater

Habitat Damage

This gear is not configured to come into contact with the bottom. Seafloor contact that does occur is poorly studied.

Bycatch

Because midwater trawls target very large schools of fish, bycatch percentage is low, however the number of individuals in the bycatch is high.

Ghost-Fishing

Despite regulations, old nets and cod ends are dumped at sea. Lost trawl gear has low ghost-fishing potential unless the net is suspended by floats. Buoyant trawl web masses attract pelagic fishes and invertebrates, which in turn attract and entangle sea turtles and seals.

Examples of Threats

- Habitat damage occurs when trawls contact the seafloor, as in the Bering Sea pollock fishery.
- Because of its enormous scale, the Bering Sea pollock fishery has the largest total bycatch of any fishery, although the overall rate relative to targeted catch is small.

scientists, one social scientist, five fishers, four government officials, and one fishery specialist from a conservation organization (see Appendix 2 for details).

Workshop participants reviewed and categorized habitat impacts into two types: (1) effects on non-living physical structures (e.g., boulders, cobbles, gravel, mud, or sand seafloor), and (2) effects on seafloor organisms (e.g., kelp, seagrasses, sponges, sea anemones, corals, etc.), and bycatch into five additional groups: (1) shellfish and crabs, (2) finfish, (3) sharks, (4) marine mammals, and (5) seabirds and sea turtles. Next, the workshop participants rated the effects of each gear class, relative to that of the others, for each bycatch group and habitat type. They did this based on the results of the literature review provided to them in advance of the workshop, their expert judgment, and discussions with other experts at the workshop. The consensus ratings of bycatch and habitat impacts resulting from the workshop are displayed in Box 4, and were used to develop the impact scenarios in step 3.

Step 3: Survey Ranking of Bycatch and Habitat Damage

In this step we designed a questionnaire and surveyed individuals representative of the broad spectrum of fishing and fishery management to elicit their judgments concerning the severity of bycatch and habitat impacts. The questionnaire design followed the established method of paired comparisons, detailed in Box 5. (See also Chuenpagdee et al. 2001b).

For the questionnaire we used a set of impact scenarios resulting from the expert workshop participants' ratings of bycatch and habitat impacts for the ten fishing gears (Box 4). Because of the similarity of their impacts, we used one scenario to represent impacts from midwater trawl, purse seine, and hook and line.

We iteratively pre-tested and revised the draft questionnaire to improve comprehension, ease of completion, and clarity of instructions. As seen in Box 5, two impact scenarios were presented at a time and individuals were asked to select the scenario they considered to be more ecologically severe. Note that each impact scenario was presented without reference to the gear causing adverse effects, to reduce biased judgments. This is similar to the use of blindfolds in food tests, in which respondents are asked to indicate which beverage they prefer without knowing the brand names.

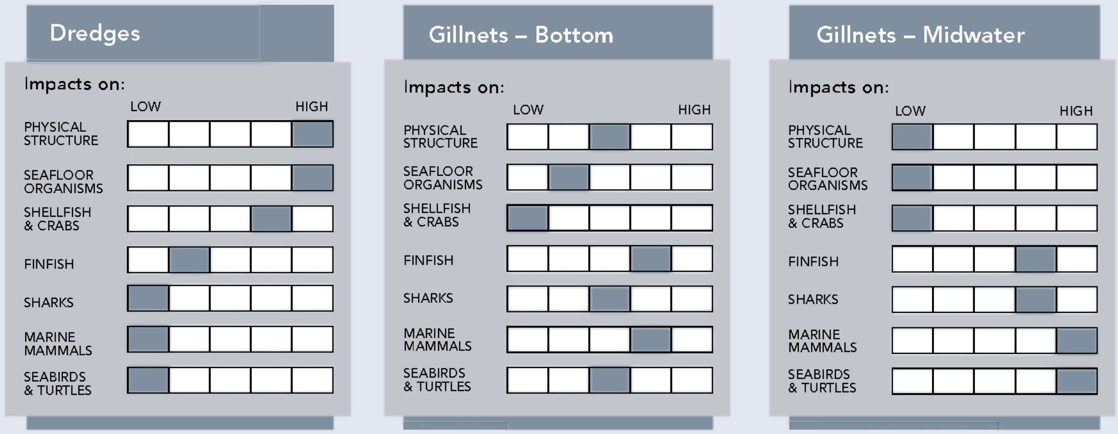
The survey package included the questionnaire, an introductory letter stating the purpose of the survey and emphasizing the confidentiality and anonymity of the respondents' answers, instructions for completing the questionnaire, clear definitions of how specific terminology was used in the study, and a set of demographic questions regarding respondents' gender, age, education, occupation, and the like. In addition, respondents were asked to indicate whether habitat damage or bycatch were more influential in their decisions.

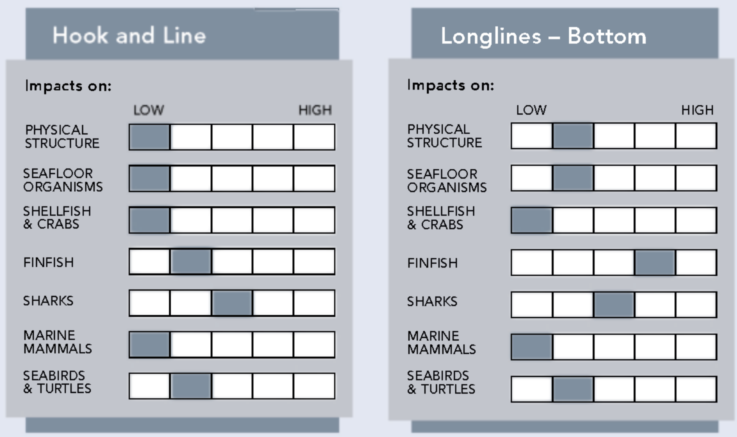
We identified three groups of potential survey respondents: (1) voting members of the eight regional fishery management councils, (2) scientists and experts who served on the National Research Council's Ocean Studies Board, or its study panels and (3) fishery specialists of marine-related conservation organizations. The first group represented those with responsibility and expertise in marine fishery management and those with experience in either commercial or recreational fishing. The second group represented those whose main role it is to provide scientific advice to policy makers on marine-related issues. The third group represented marine scientists and fishery specialists from environmental organizations. For each of these three groups we compiled a list of potential respondents and then randomly selected questionnaire recipients.

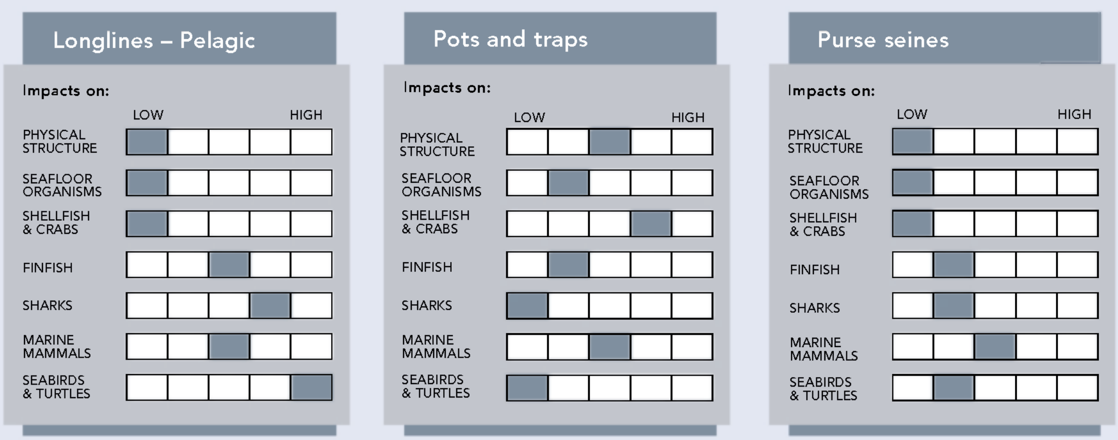
• *Threatened and endangered sea turtles, such as green, olive ridley, and leatherback turtles, are caught in fisheries along the coast of California, and in the South Atlantic and Gulf of Mexico FMC regions.*

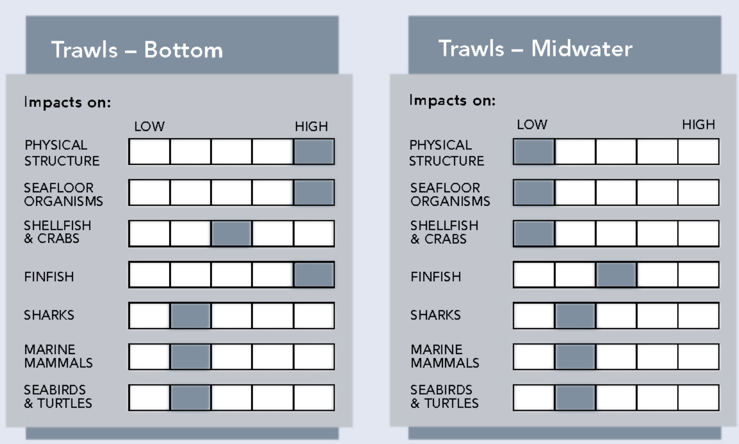
Box 4

Impact Rating of Ten Fishing Gear Classes as Agreed by Thirteen Expert Workshop Participants









Box 5 Paired Comparison Method

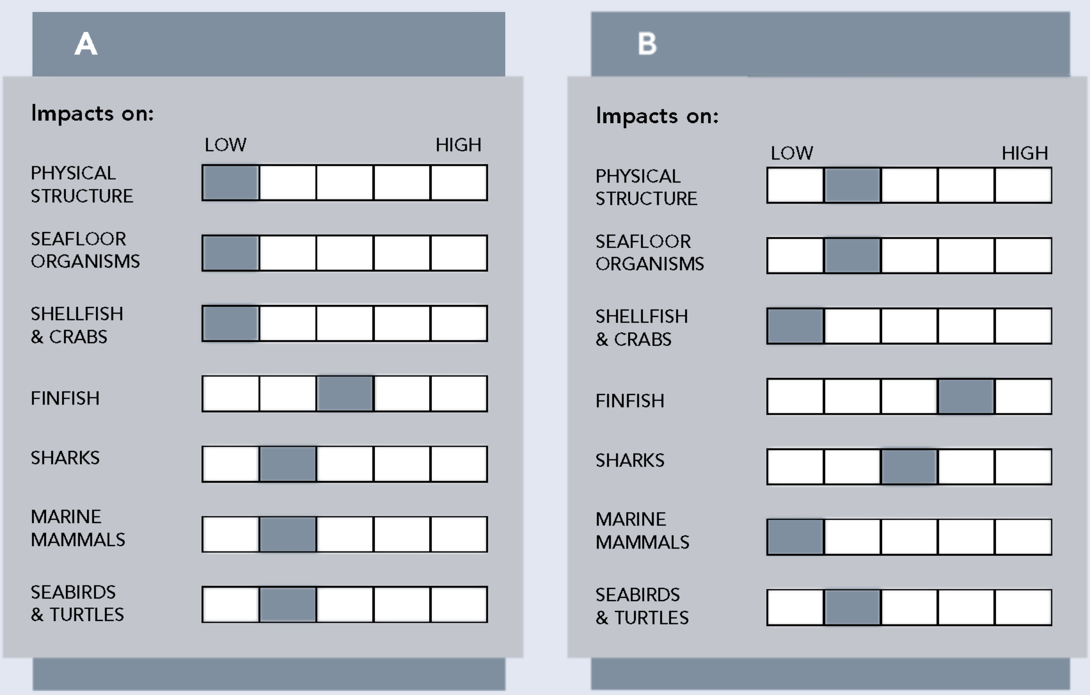
The method of paired comparisons often is used to elicit subjective judgments when several complex objects or attributes are being compared, as in taste testing or personnel evaluation (David 1988). The presentation of choices as binary options (two choices at a time) not only simplifies decision making for respondents but also follows the natural thought process people use to make decisions on a daily basis (Opaluch et al. 1993).

The basic model for the paired comparison method involves all possible pair combinations for the objects. For example, in the case of three objects, x, y, and z, there are three possible paired comparisons: (x, y), (x, z), and (y, z). When pairs are presented to a sample of respondents, it is assumed that each object has the same possibility of being selected because all are paired an equal number of times (in this example, two times). The paired comparison method results in an interval ranking, which is more informative than an ordinal ranking (obtained from direct ranking of the objects), as the distance between each object is meaningful. Applications of the paired comparison method to marine environmental issues are discussed in Chuenpagdee and colleagues (2001a, b) (damage to coastal resources in Thailand) and in Chuenpagdee and colleagues (2002) (importance of marine resources in Mexico).

Application of the paired comparison method in this study resulted in a one-dimensional scaling, in which all attributes presented (e.g., bycatch or habitat damage) were equally weighted and only the final choice mattered (whether impact scenario A was more or less severe than impact scenario B).

An example of a pair of impacts presented in the questionnaire is shown below.

An example of paired comparison from the questionnaire:



In your opinion, which of these sets of impacts, A or B, do you consider **ECOLOGICALLY MORE SEVERE?**
(please circle A or B)

Results of Paired Comparison Survey

A total of 70 respondents, including 24 each from the fishery management council and conservation organization groups, and 22 from the Ocean Studies Board group, completed and returned the survey, for an overall response rate of 53 percent. Twenty-nine percent of the respondents were female. The majority of respondents (about 60 percent) were between the ages of thirty-five and fifty-four, and 65 percent of all respondents had postgraduate degrees. Forty percent of respondents identified themselves as biologists or scientists, 17 percent as managers, 16 percent as university professors, 13 percent as fishers or workers in fisheries-related businesses, 7 percent as consultants or attorneys, and the other 7 percent as other occupations. More than half of the respondents (58 percent) indicated that they had experience onboard a commercial fishing vessel. Except for the Caribbean and North Pacific Fishery Management Council regions, the distribution of respondents, based on their geographic area of specialization and responsibility, was fairly even (Table 2). We classified 36 percent of respondents as "national"; that is, their expertise and knowledge were not specific to a particular region.

• *A factor that can amplify habitat damage, bycatch, or both is the loss of fishing gear, which can lead to ghost-fishing.*

Analysis of the paired comparison responses provided an aggregated score of relative severity for the gear impact scenarios, normalized to a scale of 0–100, with 100 being most severe. Table 3 shows these scores by respondent group, along with the ranking assigned to these scores (1–8, with 1 the most severe impact and 8 the least severe). Statistical analysis showed no significant difference among the three groups of respondents, suggesting strong agreement in the ranking of impact scenarios among the fishery managers (including fishers), scientists, and program staff of conservation organizations (Table 4). This finding allowed aggregation of responses from all respondents, resulting in severity ranking (damage schedule) of ecological impacts for the fishing gears considered in this study (Figure 4). The ranking shown in Figure 4 is a powerful tool for comparing disparate elements because it is familiar, simple, and straightforward (Gormley and Weiner 1999).

Survey results showed that respondents considered ecological impacts caused by bottom gears more severe than those caused by pelagic gears, suggesting that habitat damage weighed heavily in their decisions. This result is consistent with respondents' answers to the survey question asking whether bycatch or habitat damage was more influential in their decisions. Fifty-three percent of respondents indicated that habitat damage was the most important criterion, 37 percent stated that they used both criteria equally, and only 10 percent considered bycatch most important.

Until now, there has been no thorough comparative study of bycatch and habitat damage caused by major commercial fishing gears that would allow managers to make consistent and rational decisions to reduce adverse effects of fishing operations. The surprisingly strong consensus in impact ranking among those who responded provides a scientifically sound foundation for formulating potentially agreeable policies and can complement other fishery management tools.

This study also demonstrates the usefulness of the damage schedule approach in assimilating large amounts of data of disparate types into a simplified, standardized form that allows for comparison. The knowledge of the fishing community, scientific expertise, individual judgment, and conservation concerns were successfully integrated in this study, the outcome of which should serve to inform decision makers of the relative severity of damage caused by commercial fishing gears.

As demonstrated in this study, the significant level of agreement among the three groups suggests that well-informed people hold similar views concerning the adverse effects of fishing on ecosystems (Box 6). No less striking is the fact that respondents were generally more concerned with habitat damage than with bycatch. This finding has a strong policy implication for marine ecosystem management, as discussed later in this report.

Table 2. Number of Respondents by Occupation and Geographic Area of Specialization

Region	Fisheries related	Fisheries managers	Professor	Biologist/ Scientist	Consultant/ Attorney	Other	Total
New England	1	1	–	1	1	1	5
Mid-Atlantic	1	3	–	1	1	–	6
South Atlantic	2	2	–	1	1	1	7
Caribbean	1	–	–	1	–	–	2
Gulf of Mexico	1	–	–	3	–	1	5
Western Pacific	3	1	–	2	2	–	8
Pacific	–	5	–	4	–	–	9
North Pacific	–	–	2	1	–	–	3
National	–	–	9	14	–	2	25
TOTAL	**9**	**12**	**11**	**28**	**5**	**5**	**70**
% TOTAL	**13**	**17**	**16**	**40**	**7**	**7**	**100**

Note: The region designated "national" includes respondents whose expertise and knowledge are not specific to a particular region.

Table 3 Relative Impact Scores and Corresponding Rankings Based on Three Respondent Groups

	Fishery Management Council		NRC – Ocean Studies		Conservation Organizations	
GEAR CLASS	SCORE	RANK	SCORE	RANK	SCORE	RANK
Dredges	63	3	69	3	68	3
Gillnets – bottom	74	2	72	2	72	2
Gillnets – midwater	55	4	66	4	67	4
Longlines – bottom	36	6	29	7	24	7
Longlines – pelagic	29	7	41	5	36	5
Pots and traps	42	5	37	6	36	5
Trawls – bottom	90	1	89	1	95	1
Trawls – midwater	6	8	6	8	2	8
No. of respondents	24		22		24	

Note: Rank 1 was assigned to the highest normalized score and rank 8 to the lowest score. One impact scenario was used to represent midwater trawls, purse seines, and hook and line gear classes.

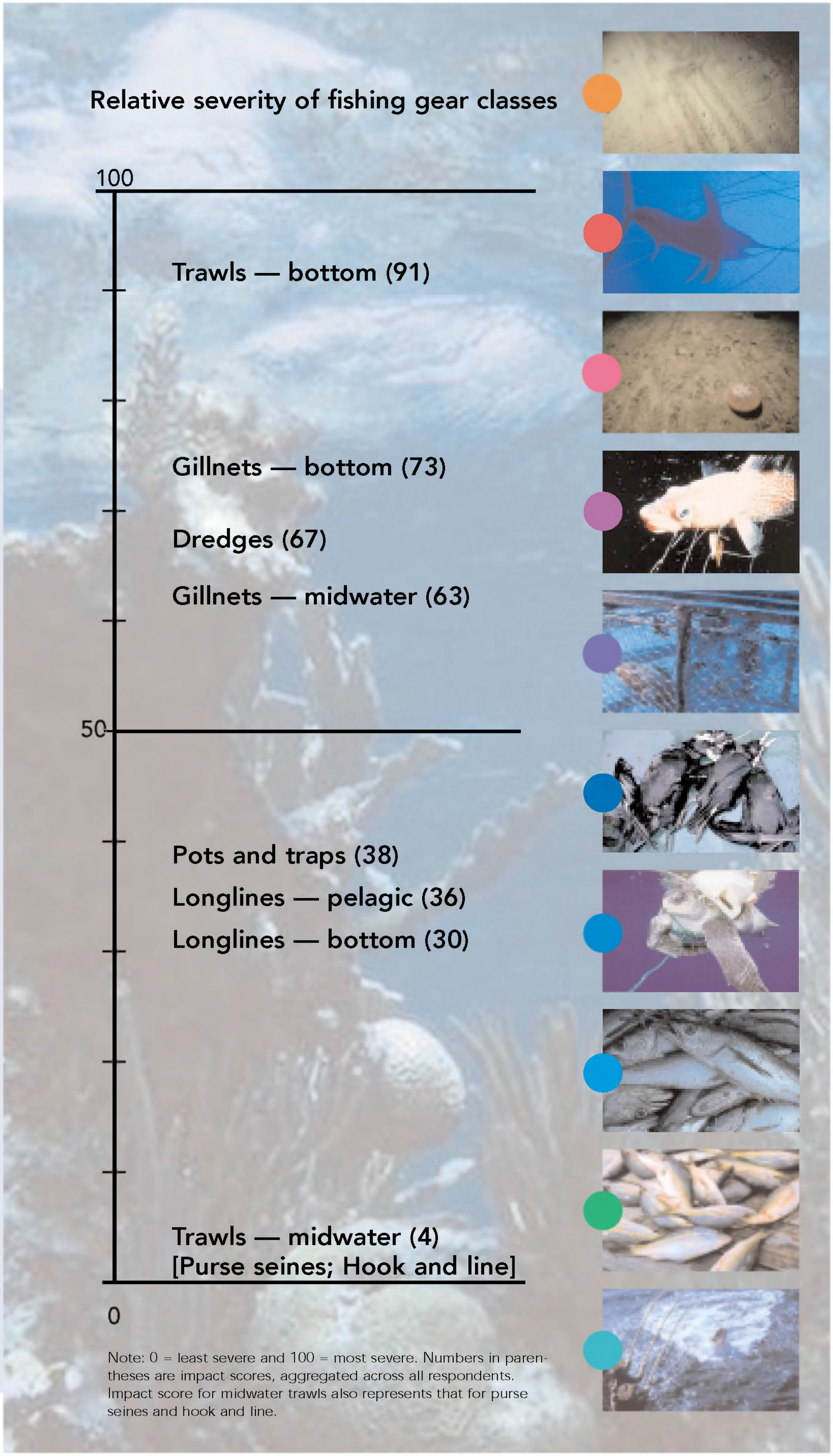
• *In New England, gillnets cause bycatch of harbor porpoises, bottlenose and white-sided dolphins, pilot whales, harbor seals, gray seals, and harp seals.*

Table 4 Kendall's Tau Rank Correlation Coefficients

	Fishery Management Council	NRC – Ocean Studies	Conservation Organizations
Fishery Management Council	1.000	–	–
NRC – Ocean Studies	0.817	1.000	–
Conservation Organizations	0.873	0.971	1.000
Average coefficient	0.887		

Note: All correlations are significant at alpha level 0.01.

Figure 4 ▶
Severity Ranking (Damage Schedule) of Ecological Impacts for All Fishing Gears, Based on All Respondents



Box 6
Important Results of This Study

- Experts strongly agreed about the levels of bycatch and habitat damage caused by the various fishing methods.
- Survey respondents, including fishers, managers, scientists, and conservationists, strongly agreed on the relative severity of damage caused by given fishing gear classes, based on impact scenarios involving bycatch and habitat damage.
- Survey respondents considered habitat damage to be of greater ecological importance than bycatch .

Formulating Policies Using the Severity Ranking of Collateral Impacts

To help fishery managers formulate policies to reduce bycatch and habitat damage, we have sorted the fishing gear classes that are the subject of this report into three categories according to their impact scores: high-impact, medium-impact, and low-impact (Figure 5). Gears in the high-impact category include bottom trawls, gillnets (midwater and bottom), and dredges. Gears categorized as medium-impact include longlines (pelagic and bottom), and pots and traps. In this ranking exercise, hook and line, purse seines, and midwater trawls fell into the low-impact category. This result has a straightforward message—high-impact gears need immediate management attention; medium-impact gears also should be reviewed carefully, but with less urgency; and low-impact gears merit somewhat lower priority.

Characterization of fishing gear classes and ranking of the bycatch and habitat damage they cause is a useful management tool, provided the rankings reflect fishery-specific practices. Box 7 illustrates an example of how fishery-specific information of ecological impacts can be evaluated using the severity ranking. Of course, measures of collateral impacts from various fishing gears may vary, not only with the kind of gear, but the scale of its use. Even a gear type that has relatively low bycatch or habitat impact per ton of target catch—such as midwater trawls—will have a very large cumulative impact on ecosystems, if fishing effort is very large, such as with the Bering Sea pollock fishery.

The severity ranking can be used as a pre-

Figure 5 Experts' Impact Rating, Survey Severity Ranking, and Policy Implications

GEAR CLASS	HABITAT IMPACTS: Physical	HABITAT IMPACTS: Biological	BYCATCH: Shellfish & crabs	BYCATCH: Finfish	BYCATCH: Sharks	BYCATCH: Marine mammals	BYCATCH: Sea birds & turtles	MANAGEMENT CATEGORY (Policy responses)
Trawls – bottom	5	5	3	5	2	2	2	HIGH IMPACT (Very Stringent)
Gillnets – bottom	3	2	1	4	3	4	3	HIGH IMPACT (Very Stringent)
Dredges	5	5	4	2	1	1	1	HIGH IMPACT (Very Stringent)
Gillnets – midwater	1	1	1	4	4	5	5	HIGH IMPACT (Very Stringent)
Pots and traps	3	2	4	2	1	3	1	MEDIUM IMPACT (Moderately Stringent)
Longlines – pelagic	1	1	1	3	4	3	5	MEDIUM IMPACT (Moderately Stringent)
Longlines – bottom	2	2	1	4	3	1	2	MEDIUM IMPACT (Moderately Stringent)
Trawls – midwater	1	1	1	3	2	2	2	LOW IMPACT (Least Stringent)
Purse seines	1	1	1	2	2	3	2	LOW IMPACT (Least Stringent)
Hook and line	1	1	1	2	3	1	2	LOW IMPACT (Least Stringent)

KEY: 5 VERY HIGH IMPACT 4 HIGH IMPACT 3 MEDIUM IMPACT 2 LOW IMPACT 1 VERY LOW IMPACT cautionary tool in marine ecosystem management, particularly when there is considerable uncertainty about how some gear classes affect habitats and species. On the basis of this scale, rigorous policies, including prohibition of certain gears in some areas, should be applied where collateral impacts are considered high. For some gear classes, the rankings are sufficiently clear that managers should proceed without delay with measures to reduce their adverse effects. It is important to remember that fishing involves killing fish, so use of all classes of fishing gears—even those classified as low-impact—require certain precautionary measures and judicious restraint. For example, most observers would agree that harpoons are associated with negligible bycatch and habitat damage, but history clearly documents their efficiency at killing whales. The Atlantic gray whale is now extinct and others are near extinction.

Policy Recommendations

With this scientifically sound comparison of fishing gears ranked by their associated bycatch and habitat damage, fishery managers, policy makers, and fishers can move on to the next step: minimizing and eliminating the impacts of fishing gears. Five possible policy options should be considered for ecosystem-based management, based on the rankings of bycatch and habitat damage:

1. "Shifting gears," or substituting less ecologically damaging gears for the more damaging gear types;
2. Changing fishing practices using appropriate incentives;
3. Promoting innovations in fishing gear and technology;
4. Establishing area-based restrictions; and
5. Supporting future studies, including assessment of social and economic effects of policy actions on fishing communities.

Box 7 Application of the Severity Ranking to Three Hypothetical Fisheries

The severity ranking developed in the *Shifting Gears* report is a useful management tool for assigning specific fisheries to high, medium or low collateral impact categories. For any fishery for which ecological impacts can be assessed, the relative severity of these impacts can be compared against the severity rankings in Figure 5. Here we demonstrate this point by using information on fishing gear impacts analyzed in this report and applying it to three hypothetical fisheries.

An intertidal clam dredge fishery might have very high impacts on physical habitat, with low bycatch of invertebrates and fishes, and no other bycatch (Collie et al. 2000; Peterson et al. 1987). A hypothetical midwater trawl fishery might cause significant seafloor disturbance (Loverich 2001), and may result in bycatch of species including finfishes, sharks, commercially important benthic crabs and occasional marine mammals (AMCC 2000). Finally a hypothetical troll (hook and line) fishery might have low finfish and shark bycatch, but no other bycatch or habitat damage (A. Coan, NMFS pers. comm.).

Given this information, the appropriate level of impacts for each fishery would look like:

Hypothetical fishery	HABITAT IMPACTS		BYCATCH				
	Physical	Biological	Shellfish & crabs	Finfish	Sharks	Marine mammals	Sea birds & turtles
Intertidal clam dredges	5	5	5	2	1	1	1
Midwater trawls	3	3	3	4	2	2	2
Troll (or hook and line)	1	1	1	2	2	1	1

Comparing these impact levels with those in Figure 5 suggests that the appropriate categories for these gears are high-impact for hypothetical intertidal clamming, medium-impact for the hypothetical midwater trawling and low impact for the hypothetical troll fishery.

Shifting Gears

Shifting gears is a solution that can be accomplished either by switching to fishing gears that cause fewer collateral impacts or by eliminating the use of gears that cannot meet reasonable ecological performance standards. Shifting gears is not a trivial task. It requires extensive commitment from fishery management councils as well as consultation and cooperation with the fishing community and public. One important step would be for managers and the industry to establish a gear accreditation system based on the severity of the gear's adverse effects. Such a system could be used to limit high-impact gear to certain habitats or areas least sensitive to ecological damage. These efforts will undoubtedly have social, economic, and political dimensions. In some cases, the adverse effects of certain classes of gears are so great compared with those of others that the course of action should be obvious (Box 8). In other cases, shifting gears might require financial assistance for fishers.

Other means of shifting gears include reassignment of fishing quotas or catch allocations, incentive programs, and the creation of fishery-specific performance standards.

Changing Fishing Practices

Fishing practices are complex, and they change in response to dynamic biological, economic, and social pressures, so it is not always easy for managers to track the latest methods. This understanding is important, however, because in some cases managers and fishers can significantly reduce collateral impacts by modifying existing practices. Fishers call on their experience and knowledge in making choices that influence their gear's interaction with the environment. These decisions, including configuration of the gear and where and when it is deployed, can result in markedly different levels of bycatch or habitat damage. Such behavioral changes have resulted in welcome decreases in bycatch in a number of fisheries. One of the

Box 8 Shifting Gears: From Trawls to Traps in the Spot Prawn Fishery

In February 2003, the California State Fish and Game Commission unanimously voted to end the spot prawn trawl fishery. A recent study of the spot prawn fishery in California revealed dramatic differences in bycatch between two types of gear: bottom trawls and traps (Reilly and Geibel 2002). California had failed to restrict the size of bottom trawl gear in the spot prawn trawl fishery despite high rockfish bycatch. Data collected by observers show that in northern California, the weight ratio of total bottom trawl bycatch, including invertebrates, to spot prawn catch was 8.8 to 1.0, whereas in the trap fishery it was 1.0 to 1.0, a nearly ninefold difference. In southern California, the weight ratio of total trawl bycatch, including invertebrates, to spot prawn catch was 20.6 to 1.0, and that of the trap fishery was 2.0 to 1.0.

Of particular importance in this region is the different gears' bycatch of rockfishes, whose populations have been severely reduced by commercial fishing and sportfishing. NMFS has determined that seven rockfish species in California waters are overfished and in need of rebuilding. Bycatch statistics for northern California in the same report show that the weight ratio of rockfish bycatch to spot prawn catch was 2.1 to 1.0 in the trawl fishery and 0.04 to 1.00 in the trap fishery, a fifty-two-fold difference. In southern California, the same ratios were 1.5 to 1.0 for trawls and 0.07 to 1.00 for traps, a twenty-one-fold difference.

This indicates that by shifting from bottom trawl to trap gear in the spot prawn fishery, fishers can reduce rockfish bycatch by an order of magnitude or more. To rebuild rockfish stocks, prohibiting the directed take of rockfish is essential but not sufficient. Rockfish recovery efforts must also address the rockfish's mortality as bycatch, and the homogenization of its complex habitat by trawls. The National Research Council (NRC 2002) found that low-mobility, long-lived species such as rockfish are more vulnerable to acute and chronic physical disturbance than are short-lived species, and that bottom trawls alter the composition and productivity of fish communities that depend on structurally complex seafloor habitats for food and refuge. Hence, reducing the use of bottom trawls for spot prawns will also reduce damage to the benthic habitat on which rockfish rely.

best-known examples is the back-down method currently employed by fishers in the Eastern Tropical Pacific yellowfin tuna purse seine fishery (Hall 1996). In this case, boat captains developed a technique to force a portion of the net below the water's surface; this allows dolphins to escape over the top of the net while tuna are retained. Adoption of the back-down method, in addition to net modifications, has reduced dolphin deaths in this fishery.

There are many other ways in which conscientious fishers can reduce bycatch and habitat damage. In some cases, skilled fishers can distinguish among species remotely using electronic fish finders and can avoid target schools associated with large numbers of species that would become bycatch. Or fishers can simply avoid areas where their experience tells them fishing would be likely to cause unacceptable damage to the seafloor.

Unfortunately, some economic and social situations create strong disincentives for conscientious behavior to reduce collateral impacts. Therefore, onboard observer programs or other measures to record spatial and temporal patterns of fishing and associated bycatch and habitat damage (e.g., vessel monitoring systems, gear-tracking tools, video recordings, landing reviews), if effectively implemented and monitored, can lead fishers to use gears with greater care. Undoubtedly, this works best when the fishing industry and fishery managers cooperate to set performance standards, to establish incentives that encourage self-policing among fishers, and to certify or otherwise reward fishers for low bycatch or decreased habitat damage. Joint government–fishing industry programs can provide welcome financial incentives for fishers to improve their performance and improve real-time communication about transitory situations involving bycatch risk.

• *Seafloor, undisturbed by fishing, near Swan's Island, Gulf of Maine.*

Promoting Gear Innovations

To minimize the adverse ecological effects of fishing gears, fishery managers and the fishing industry should promote modifications that enhance selectivity and reduce habitat damage. These can come from government research programs, from fishers, or from cooperative research programs between the two groups.

Modifications can range from minor adjustments to gear, such as changes in mesh size or shape, to larger modifications, such as insertion of turtle excluder devices (TEDs) into shrimp trawls. Use of streamer lines on longline boats has reduced bycatch of albatrosses and other seabirds (Box 9). Other examples include the use of raised footrope trawls to reduce bycatch in small-mesh whiting trawl fisheries in Massachusetts (Glass 2000) and the use of circle hooks instead of J-hooks in longline fisheries (Bolten et al. 2002) and hook-and-line fisheries. Circle hooks enable fishers to release sea turtles (and other species) with a better chance of post-release survival, since circle hooks do not cause as much damage as J-hooks. Unfortunately, circle hooks alone are insufficient to address sea turtle bycatch in longline fisheries. Separator trawls used in the Pacific cod fishery have been shown to reduce halibut bycatch by 40 percent while reducing the cod catch by only 6 percent (Glass 2000). Similarly, hose cages and large fish excluders in Gulf of Mexico menhaden fisheries help prevent nontarget finfishes and sharks from entering the boat's hold, although survival of large fish passing through the exclusion devices is currently less than 28 percent (Rester and Condrey 1999).

Incentive programs to enhance gear configuration, reduce gear loss and damage from ghost-fishing, and promote gear recycling programs also can result in reducing the adverse effects of fishing gears.

Box 9 Gear Innovations: "Bird-scaring Lines" in Longline Fisheries

Bycatch of seabirds occurs in many longline fisheries. Seabirds often go after the bait as it is released from the vessel, taking not only the bait but also the hook, and subsequently drowning. Birds can also become entangled in the lines, with the same result. Bycatch of seabirds is a twofold problem for fishers and fishery managers: (1) it has ecological consequences for seabird populations and is, in some cases, the main source of mortality to endangered seabirds such as the black-footed albatross (Gilman 2001), and (2) seabirds feeding on longline bait decrease the catch rate of target species. Therefore, sharply reducing bycatch is in the interest of both the birds and the fishers.

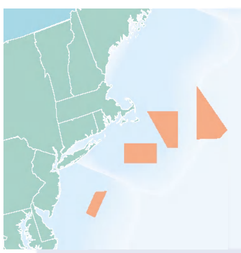
Attempts to mitigate seabird bycatch have taken the form of regulations that restricted longline fishers to certain areas or allowed them to fish only at night. Both can cause economic hardship by closing important fishing areas or decreasing the time in which catches can occur. However, bird-scaring lines developed by the Japanese have become the mainstay of effective reduction in seabird bycatch (American Bird Conservancy 2001).

Bird-scaring lines, sometimes called tori lines or streamers, can be the most cost-effective solution to seabird bycatch. Two long main lines, often made of steel or polyester, are positioned on either side of the longline and extend at an angle behind the boat, with floats attached to the ends. Approximately twelve brightly colored streamer lines are attached to the main lines, and the bright colors and flapping lines scare seabirds away from the baited hooks. These lines have been shown to reduce seabird mortality by as much as 92 percent in Alaska's sablefish longline fishery (American Bird Conservancy 2001), and they also have shown good results in Norwegian groundfish longline fisheries. Moreover, target catch increased by 32 percent in Norwegian groundfish fisheries as a result of retention of bait otherwise taken by seabirds (Lokkeborg 2001). In addition to being effective, bird-scaring lines are inexpensive, costing only $260 per pair. To encourage initial use of the lines, the U.S. Fish and Wildlife Service created a program to give the lines away for free in Alaska, at a cost to the agency of $850,000, in 2000 and 2001.

Establishing Area-Based Restrictions

Area-based restrictions such as fishing closures offer a clear advantage: they immediately and unambiguously end harm from destructive fishing. Many states have regulations restricting or banning particular classes of gears, either throughout state waters or in particular places or fisheries, as a way of reducing collateral impact. In federal waters, particular gear types are restricted or banned in many places or, in a very few cases, entire regions. For example, in the Pacific FMC, pelagic longlining recently was banned, and in the North Pacific FMC extensive areas have some sort of gear restriction in place. Similiarly, bottom trawls are banned throughout the 1.5 million square miles (3.9 million square kilometers) of the Western Pacific FMC region because of their damage to seafloor habitat and high level of bycatch. However, over 100,000 sq. miles (255,000 sq. kilometers, roughly an area the size of the state of Oregon) of the U.S. EEZ are trawled more than once each year (NRC 2002).

To use area-based restrictions most effectively, managers must judiciously determine which habitats are most in need of protection and which classes of fishing gears pose the greatest threat to benthic ecosystems. As this report demonstrates, bottom trawling has by far the greatest collateral impacts. Thus, closing areas to bottom trawls—from small areas to entire fishery management council regions—would protect structurally complex, biologically diverse habitats such as coral forests, coral reefs, kelp beds, sponge reefs, and seagrass beds and the species that depend on them (NRC 2002, Box 10).



Box 10 Effects of Closed Areas on the Sea Scallop Fishery on Georges Bank.

Following introduction of the otter trawl in the early twentieth century, overfishing of certain groundfishes, such as cod, various flatfishes, and skates, became a major issue in the northwestern Atlantic waters of the United States. After employing traditional management for many years, in December 1994 the New England Fishery Management Council closed three areas of Georges Bank, totaling some 6,600 square miles (17,000 square kilometers), to any type of gear able to capture groundfish.

Although the areas were closed primarily to manage depleted groundfishes, fishing for the Atlantic sea scallop also was banned. From the time the closures began until July 1998, the biomass of fishable sea scallops within the closed areas increased fourteenfold (Murawski et al. 2000). From 1999 until January 2001, areas within the Georges Bank closure system were opened to the scallop fishery. Many fishers stated that in 20 to 30 years of fishing, they had never witnessed catches of this size. To manage fishing effort during these short-term openings, managers implemented several restrictive measures, such as decreased days at sea, a limit of seven crew members per vessel, and increased dredge ring and mesh size, to control bycatch of groundfish.

In addition, comparative benthic surveys of both undisturbed and disturbed fishing areas that were begun in 1994, prior to the area closures, revealed a number of differences in benthic invertebrate communities. The number of organisms, biomass, species richness, and species diversity all increased in the undisturbed areas (Collie et al. 1997). Only species evenness, as expected, was found to be higher in disturbed areas. In the undisturbed areas, complex habitats formed by hydroids, bryozoans, and worm tubes provided protection for other species such as brittle stars, shrimps, and small fishes. Disturbed areas, on the other hand, were dominated by large mollusks and scavengers such as crabs and echinoderms. Collie and colleagues (1997) hypothesized that given five to ten years of nondisturbance and recovery, the closed areas of Georges Bank would be comparable to the undisturbed locations they had sampled.

In these sensitive habitats, recovery from a single pass of a trawl or dredge can take years, decades, or even centuries. Other areas, such as seamounts, have such high levels of endemism (presence of species that occur nowhere else) that trawling might eradicate species before we know of their existence (Koslow et al. 2001). As we continue to explore the deep sea, we undoubtedly will discover more about the nature and resilience of seafloor habitats.

Under the FCMA, fishery management councils can use the designations of essential fish habitat (EFH) and habitat areas of particular concern (HAPC) as spatial management tools, although these designations in themselves do not restrict fishing. Councils, however, have the authority to close areas to fishing. Designation of HAPCs can be made if one or more of the following criteria are met: important ecological function of the habitat, sensitivity of the habitat to anthropogenic (human-caused) environmental degradation or development activities, and rarity of the habitat type.

Further habitat mapping will provide managers with better tools; however, the level of resources and the time that would be needed to map the vast seafloor suggests that a wise precautionary approach is to restrict the more harmful fishing gear classes now. Since few seafloor habitats appear resilient to the damage caused by mobile fishing gear, zoning—creating a mosaic of places where different uses or combinations of uses are given precedence—can limit negative effects of fishing by restricting the most damaging gear to the least sensitive areas.

Area-based gear restrictions also are useful in reducing bycatch. Just as distributions of target species often can be predicted, so can those of bycatch species. This knowledge can be used to limit mortality of non-target species. For many species, scientists or fishers already know which feeding grounds or areas are important for such functions as migration and breeding. For example, sea turtles are found in higher abundance near known nesting beaches, so the risk of bycatch can be predicted to be higher at known times of nesting. It makes sense to take special care to protect waters near nesting beaches.

Knowledge of the spatial and temporal distributions of common or sensitive bycatch species has been used successfully to reduce bycatch in Alaska. For example, the Chinook Salmon Savings Areas and the Red King Crab Savings Area are closed to trawling in the month of August and year-round, respectively, to reduce excessive bycatch of chinook salmon in groundfish trawl fisheries and to protect the red king crab population (North Pacific Fishery Management Council 2002). Clearly managers need to carefully consider the use of area-based restrictions to mitigate both bycatch and habitat damage.

Supporting Future Studies

Policy makers and fishery managers should support increased funding for further studies of the effects of fishing gears on bycatch and habitat. For example, NMFS needs funding from the United States Congress to evaluate the effects of fishing gears on the diverse seafloor habitats, including essential fish habitat as mandated by the Magnuson-Stevens Fishery Conservation and Management Act in 1996. Seven years after this requirement was imposed, most councils have only just started to perform these assessments. Policy makers and fishery managers also should promote research to modify existing fishing gears and practices and to seek innovative, environmentally benign alternatives to damaging gears.

Congress should fund studies of social and economic effects on the industry and society during the transition from harmful fishing methods to those causing less damage to marine biological diversity and fisheries, as well as exploration of community-based approaches to management for ease of implementation of other policy recommendations.

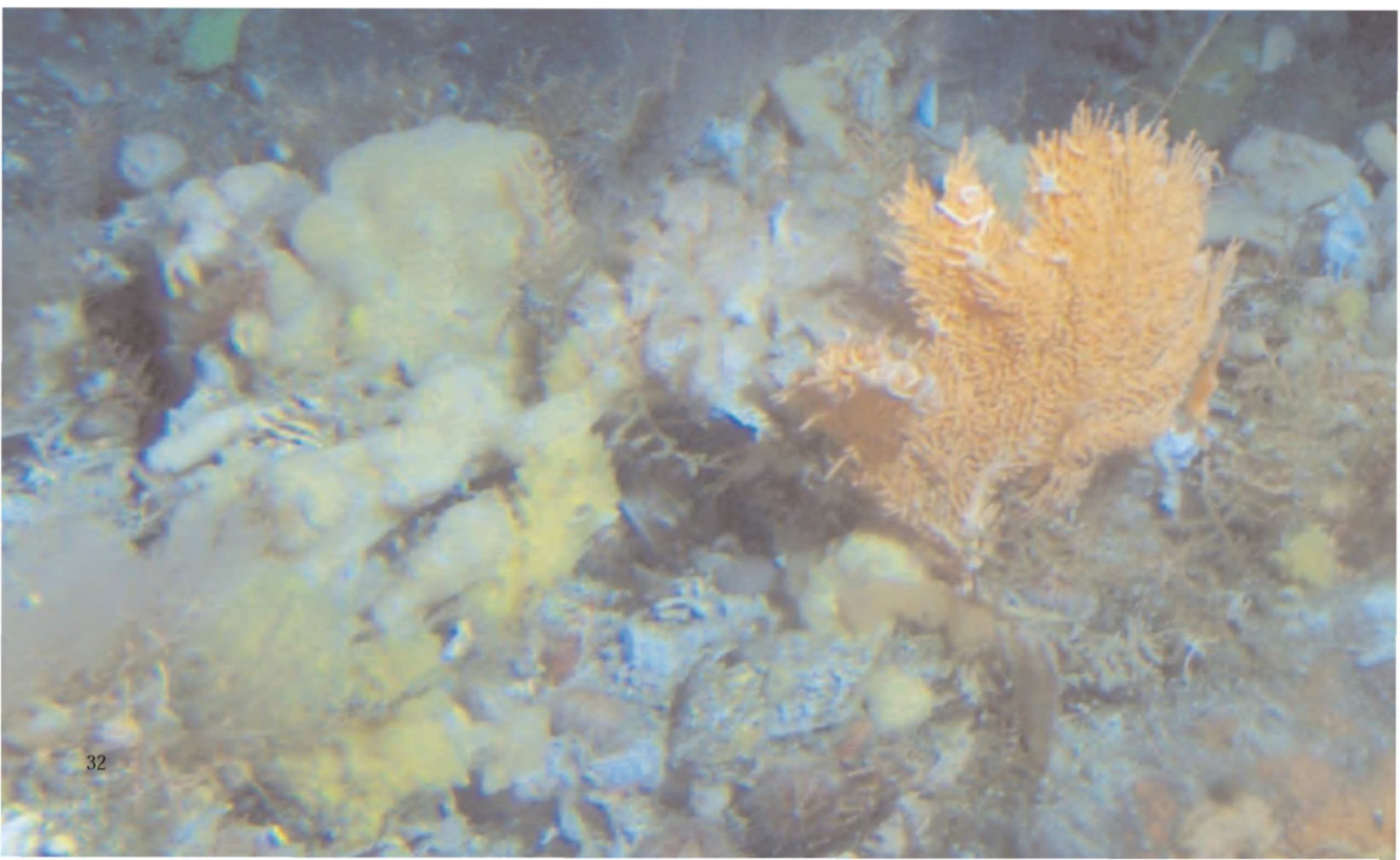
• *Marine mammals are frequently taken as bycatch in midwater and drift gillnets.*

Conclusion

A wealth of information and several recent scientific reviews (Watling and Norse 1998; Auster and Langton 1999; Dayton et al. 2002; NRC 2002; Pauly et al. 2002) have clearly demonstrated the harm that fishing does to marine ecosystems. Despite this, fishery management in the United States still focuses on maximizing levels of single-species catch rather than on protecting the intact ecosystems that support fish production. This report takes a first step toward addressing these problems by ranking the adverse effects of different classeses of fishing gears commonly in use in the United States.

The clear consensus demonstrated in this study should be welcome to fishers, decision makers, policy advisors, and conservation advocates because it provides a basis from which to move forward in addressing these complicated issues and suggests avenues for precautionary management. Suggestions for improving the state of marine ecosystems include shifting gears—retiring and phasing out fishing gear classes that cause the worst damage, allocating catch to less damaging gears, changing behaviors, improving the technology, increasing incentives and funding efforts to limit bycatch and habitat damage, establishing fishing closures, and increasing funding for government agencies to carry out their conservation mandates.

Shifting Gears suggests not only moving toward the use of less ecologically damaging fishing gears, but also shifting our thinking from single-species management to protection, recovery, and sustainable use of entire ecosystems.



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APPENDIX 1

Bycatch and Habitat Damage by Gear Class, as Summarized in Table 1

Gear Class	Federal Fishery Management Council Region	Target Species	Bycatch References: Fish	Bycatch References: Mammals	Bycatch References: Seabirds	Bycatch References: Turtles	Habitat References (Physical and Biological)	Ghost-Fishing References
DREDGES	Gulf of Mexico	sponge*					66; 154; 7; 55; 113; 125; 19; 20; 159; 165; 6; 104; 101; 9; 10; 108; 34; 35; 36; 75; 65; 102; 33; 95; 109; 94; 96; 119; 93; 67; 120; 126,5	
	Mid-Atlantic	hydraulic clam dredge*						
	New England, Mid-Atlantic	quahog, surf clam	110					
	South Atlantic, Mid-Atlantic, New England	scallop	46; 122					
	Pacific	geoduck, Manila clam*						
	North Pacific	scallop	11					
GILLNETS Bottom Gillnets	South Atlantic	flounder, sea trout, croaker, mullet	158; 18				68; 124; 167; 115; 29; 28; 166; 51; 151; 148	30; 38; 42
	Mid-Atlantic	multispecies (e.g., flounder)		128; 136		62		
	New England, Mid-Atlantic	spiny dogfish*						
	New England	monkfish*				161		
	New England	multispecies		136; 164				
	Pacific	California halibut, angel shark		86; 57	86; 57	86		
	Pacific, North Pacific	salmon*			105; 170			
	North Pacific	herring*						
	Western Pacific	Hawaii deep reef fish*						
GILLNETS Drift Nets, Midwater Gillnets	South Atlantic	shark	26; 25; 27	26; 25; 164		26; 25; 27	68; 124; 167; 115; 29; 28; 166; 51; 151	30; 38; 42
	South Atlantic, Mid-Atlantic	shad		136	58; 134; 135			
	South Atlantic, Mid-Atlantic	weakfish*						
	South Atlantic, Mid-Atlantic	bluefish*						
	Pacific	California swordfish, shark drift gillnet	133; 127; 18	86	86	86		
	Pacific	halibut		57				
	Pacific	Washington/Puget Sound non-treaty sockeye			169; 105; 170			
	North Pacific	salmon		2				
HOOK AND LINE	Gulf of Mexico, South Atlantic	snapper, grouper	144	144			10; 141	
	Gulf of Mexico, Mid-Atlantic, South Atlantic, New England	wreckfish		145		145		
	Pacific	albacore	32					
	North Pacific	cod, rockfish	8					
	Pacific	rockfish*						
	Pacific, North Pacific	salmon*						
	Western Pacific	Hawaii finfish*						
LONGLINES Bottom Longlines	Gulf of Mexico, South Atlantic	Florida grouper	144	144			116; 168	
	Gulf of Mexico, South Atlantic	shark	18	18	18	18		
	New England, Mid-Atlantic, South Atlantic	tilefish	111					
	New England	Cape Cod groundfish*						
	North Pacific	All (e.g., rockfish, sole)	8; 106	2	98; 150; 37			

Note: Numbers correspond to references listed after this table. Asterisks (*) indicate species with insufficient information.

	FEDERAL FISHERY MANAGEMENT COUNCIL REGION	TARGET SPECIES	BYCATCH REFERENCES				HABITAT REFERENCES (Physical and Biological)	GHOST-FISHING REFERENCES
			Fish	Mammals	Seabirds	Turtles		
LONGLINES Pelagic Longlines	East Coast, Gulf of Mexico, Caribbean	swordfish and/or tuna	18	39; 40	85; 78; 39; 37	40	39; 40; 85; 41; 116	
	Gulf of Mexico, Mid-Atlantic, South Atlantic, New England	highly migratory species (HMS) (shark, billfish, tuna)	39; 18		37			
	Western Pacific	Hawaii HMS (shark, billfish, tuna)	127; 18		171; 37	41		
POTS AND TRAPS	Caribbean	reef fish	144				61; 80; 3; 10; 71; 151; 49; 155	152; 71; 30; 77; 13; 14; 129; 76
	Gulf of Mexico, South Atlantic	Florida spiny lobster	103					
	Gulf of Mexico, South Atlantic, Mid-Atlantic	blue crab	45	164		45		
	Mid-Atlantic, New England	American lobster		164				
	Pacific	Dungeness crab*						
	North Pacific	multispecies (e.g., Dungeness crab, king crab)	8; 121	2	98			
PURSE SEINES	Gulf of Mexico, South Atlantic, Mid-Atlantic, New England	menhaden	91; 107	91; 43			142; 10; 151	
	New England	herring	153	153				
	Pacific	tuna		73		73		
	Pacific	small pelagics*						
	Pacific	squid*						
	North Pacific	salmon*						
	North Pacific	herring*						
TRAWLS Bottom Trawls	Gulf of Mexico	shrimp	117; 18; 1; 69;	164		72; 83; 50	31; 165; 21; 22; 23; 24; 146; 9; 10; 81; 82; 74; 54; 92; 149; 48; 137; 138; 156; 79; 55; 7; 47; 130; 140; 70; 4; 79; 151; 123; 6; 143; 132; 75; 114; 98; 89; 97; 15; 16; 112; 157; 160; 12; 162; 163; 159; 87; 59; 99; 119; 147; 17; 131; 63; 88; 60; 139; 84; 64; 120; 5	30; 44
	South Atlantic	blue crab	100					
	South Atlantic	shrimp				72; 83		
	Mid-Atlantic, South Atlantic	summer flounder*						
	Gulf of Mexico, South Atlantic, Mid-Atlantic, New England	multispecies (e.g., flounder, shrimp)	90; 122	164				
	Pacific	groundfish*						
	Pacific	shrimp*						
	North Pacific	multispecies (e.g., cod, flounder)	53	2	98			
TRAWLS Midwater Trawls	Gulf of Mexico, South Atlantic, Mid-Atlantic, New England	squid, mackerel, butterfish		164			119; 116	30; 44
	Mid-Atlantic	mackerel*						
	New England	herring	153	153; 52				
	Pacific	hake (whiting)	118	56				
	Pacific	rockfish*						
	North Pacific	pollock	53					
	North Pacific	Pacific ocean perch*						

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APPENDIX 2

"Shifting Gears" Expert Workshop Participants

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Kodiak, Alaska
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Gulf States Marine Fisheries Commission
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New Bern, North Carolina
Dredge gear

Dave Wallace
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Cambridge, Maryland
Dredge gear

John Pappalardo
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Cape Cod Commercial Hook Fishermen's Association
North Chatham, Massachusetts
Hook-and-line gear

Les Watling
Invertebrate biologist, benthic oceanographer
University of Maine
Walpole, Maine

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Commercial fisher
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Trawl gear

About the Authors

Dr. Lance E. Morgan is Chief Scientist at Marine Conservation Biology Institute and an affiliate assistant professor at the School of Marine Affairs, University of Washington. He has expertise in marine ecology and fisheries conservation. He has authored reports on organisms as diverse as red sea urchins, rockfish, fur seals, and sea lions. Dr. Morgan is currently conducting research on deep-sea corals in the Northeast Pacific Ocean.

Dr. Ratana Chuenpagdee is Assistant Professor at the Virginia Institute of Marine Science, College of William and Mary. She has expertise in fisheries biology, resource management and environmental studies. Dr. Chuenpagdee developed the "damage schedule" approach for environmental damage assessment. She is currently conducting research on assessing stakeholders preferences for ecosystem management options for the Chesapeake Bay.

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