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Constraints on Sustainable Marine Fisheries in the United States: A Look at the Record

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Abstract.—The factors that may either constrain or contribute to sustainable marine fisheries were examined by reviewing and analyzing the history and current status of several U.S. fisheries. Among major factors under consideration are inherent vulnerability (vulnerability in some species is high because of low intrinsic rates of increase and/or naturally infrequent recruitment); environmental degradation (fisheries may collapse because of anthropogenic habitat destruction); availability of data (information necessary to conduct accurate stock assessments may be inadequate for some species); quality of the scientific advice (inappropriate models or scientifically inaccurate assessments may be used); and effectiveness of management decisions (managers may disregard recommendations from scientific committees, and/or implement management measures that are risk-prone). Fisheries that are examined include the Atlantic Coast striped bass *Morone saxatilis* fishery, the New England groundfish fishery, the Atlantic shark fishery, the Atlantic and Gulf reef fish fisheries, and the Pacific rockfish fishery. Although many of the factors listed above contributed to declines in these fisheries, the root cause in all cases was harvesting at rates that were much higher than could be sustained by recruitment. Management was largely ineffective because management decisions were risk-prone and motivated by short-term economic considerations rather than long-term sustainability. Only after passage of legislation not only authorizing but specifying mandatory stock rebuilding, has most management been sufficiently precautionary to allow sustainability.

Introduction

Sustainability in its most fundamental sense means a resource may be used indefinitely (NRC 1998). A sustainable fishery is one that is managed to maintain yield indefinitely, a target that has proven to be elusive at best (Mace 1999). Globally, 30% of all fisheries may be overexploited or depleted, and another 40% are at least fully exploited (Pauly et al. 1998). Despite highly structured management systems, of the 305 stocks in the United States for which assessments are available, 72 are fully exploited, 92 are overfished, and 57 are not only overfished, but are continuing to be subjected to overfishing (NMFS 2001). The status of 600 other stocks remains unknown. How has such disastrous management been practiced in the face of modern fisheries science and a well-established management infrastructure?

Marine fisheries that extend beyond the boundaries of single states in the United States are generally managed by three entities. Interstate fishery management commissions are responsible for managing migratory stocks in state waters. Regional fishery management councils have regulatory jurisdiction over the U.S. exclusive economic zone (EEZ), which extends from the outer limit of state jurisdiction (usually 3 mi from shore) to 200 mi offshore, and which usually comprises the nation's continental shelf. In addition, the U.S. Secretary of Commerce through the National Marine

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Fisheries Service (NMFS) has jurisdiction over Atlantic tuna, billfishes, swordfish, and sharks and may elect to prepare a secretarial management plan in lieu of a plan developed by one of the councils to manage an EEZ resource. The National Marine Fisheries Service sits on the councils and approves or disapproves council plans. These are the organizations that have been "on watch" while many of our fisheries have failed. What happened?

Several factors may lead to overfishing or fishery collapse, including inherent vulnerability, environmental degradation, availability of data necessary for management, quality of scientific advice, and effectiveness of management decisions:

1. Inherent vulnerability: Many species may be particularly vulnerable to overfishing because of their inherent biological characteristics (Musick 1999a). Many naturally long-lived species have very low intrinsic increase rates (r) because of slow growth, late maturity, and low fecundity and are therefore vulnerable to overfishing (Musick 1999b). Others may have naturally infrequent and sporadic recruitment mitigated by environmental effects such as oceanographic regime shifts (Parker et al. 2000). Still others may have naturally skewed sex ratios or spawning behavior that make them particularly vulnerable (Coleman et al. 2000).
2. Environmental degradation: Fishery collapse may be caused by anthropogenic effects such as massive habitat alteration (Lichatowich 1999).
3. Availability of data necessary for management: Funding for fishery research is woefully inadequate, and fishery scientists may not have the resources to pursue fishery-independent surveys or even onshore fishery-dependent sampling that may be required to provide managers with dependable advice (Parker et al. 2000).
4. Quality of scientific advice: Life histories of marine fishes vary widely and population models suitable for some species may be unsuitable for others. Faulty scientific advice may be given because inappropriate models are used or calculation errors are made (Musick 1995).
5. Effectiveness of management decisions: Because of excess fishing capacity and overcapitalization, managers too often have ignored good management advice provided by scientists and pursued short-term economic goals in lieu of long-term sustainability. Management decisions may be risk prone rather than risk averse (Fordham 1996; NRC 1999).

In this chapter, we examine five case studies of U.S. fisheries, briefly detail the history and status of each, and analyze each in light of the biological vulnerability of the stocks, environmental effects, availability of data, quality of the science, and effectiveness of management decisions. The five case studies include Atlantic Coast striped bass *Morone saxatilis,* New England groundfish fishery, Atlantic shark fishery, south Atlantic and Gulf of Mexico reef fish fisheries, and the Pacific rockfish fishery. We have chosen these fisheries because we are somewhat familiar with most of them and sufficient records exist to pursue our analyses. We believe these case histories generally represent a cross section of well-studied U.S. marine fisheries.

Atlantic Coast Striped Bass

The striped bass is an important recreational and commercial species in estuarine and coastal fisheries along the East Coast of the United States. It is anadromous and long-lived (greater than 20 years, Murdy et al. 1997). The tributaries of Chesapeake Bay are the most important spawning and nursery areas for the species, followed by the Hudson River, Delaware River, and Albemarle Sound (Boreman and Austin 1985). Declines of this species began in the early 1970s and commercial landings dropped from 15 million pounds in 1973 to 3.5 million pounds in 1983 (Field 1997) (Figure 1). In 1979, Congress passed an amendment to the Anadromous Fish Conservation Act (FCA) to create an emergency striped bass study, which funded research into the decline and its economic consequences and which supported monitoring activities. These studies determined that uncontrolled and excessive fishing mortality caused the collapse of the Chesapeake Bay population (Field 1997; Richards and Rago 1999). A fishery management plan (FMP) for striped bass was prepared in 1981 by the Atlantic States Marine Fisheries Commission (ASMFC), which recommended different bay and coastal size limits, as well as spawning season closures. These measures were implemented at the discretion of the states, most of which complied

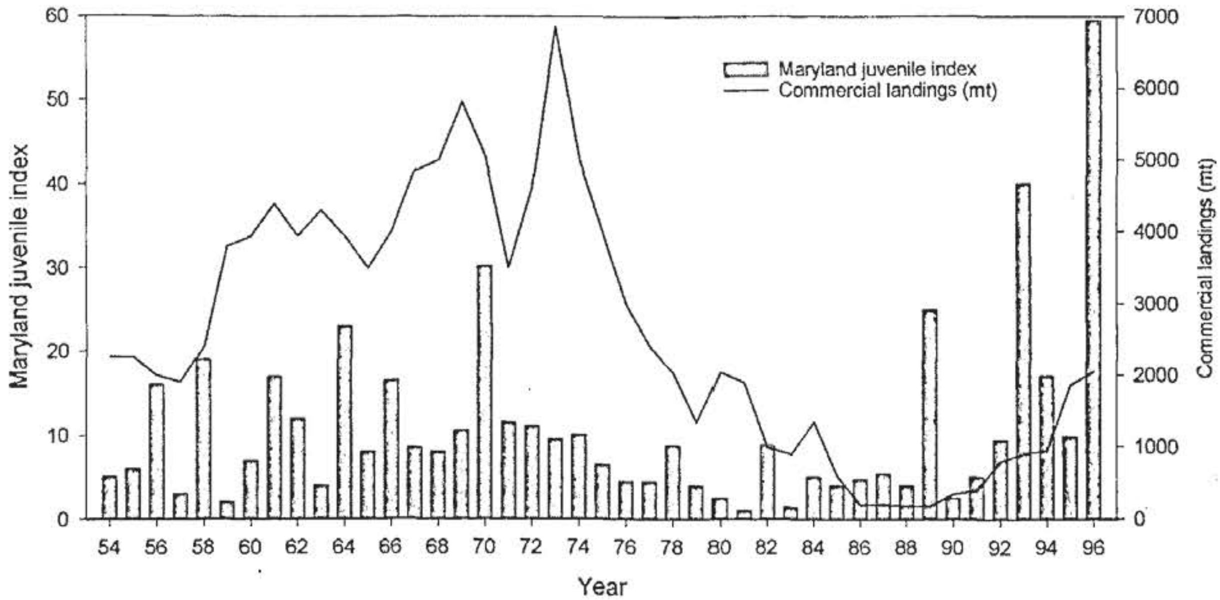

Figure 1. Indices of juvenile striped bass abundance for Maryland's waters of Chesapeake Bay and commercial landings (metric tons [mt] North Carolina through Maine) of striped bass, 1954–1996 (after Richards and Rago 1999).

between 1981 and 1984 (Richards and Rago 1999). In 1984, Congress passed the Striped Bass Conservation Act, which allowed federal closure of striped bass fisheries in those states that did not comply with the ASMFC FMP (Field 1997). Subsequently, ASMFC implemented amendments to the FMP that set mandatory targets for reduced fishery mortality, and in 1985, Maryland and Delaware voluntarily placed a moratorium on striped bass harvest, as did Virginia in 1989 (Richards and Rago 1999). Between 1985 and 1988, the abundance of females on the spawning grounds doubled, and by 1995, female spawning stocks in upper Chesapeake Bay went from 3 to 10 year-classes (Richards and Rago 1999). The fishery was allowed to reopen in 1990 with rigorous catch reporting requirements, stringent size limits, and quotas in the recreational and commercial fisheries. In 1995, the Chesapeake Bay stock was declared recovered with expanded, but still tightly controlled, limits on the fisheries (Field 1997). In 1999, the stock abundance was estimated at 36.2 million fish (Beal 2000), a near record level of abundance.

Factors Affecting the Fishery

1. Inherent vulnerability: Although most female striped bass mature by age 6, they may reach 30 years of age (Merriman 1941). Despite very high fecundity, the species has infrequent recruitment with 6–8 year cycles for dominant year-classes (Boreman and Austin 1985). There is evidence that decadal shifts in the climatic regime can affect the success of recruitment in Chesapeake Bay fishes (Wood 2000). However, there is a question of whether gross overfishing in the 1970s caused or substantially contributed to successive year-class failures. Secor (2000a, 2000b) makes a convincing argument and provides evidence that a diversity of spawning year-classes leads to higher probability of successful recruitment because fish of different ages spawn at different times during the protracted spawning season and large, old females produce many more eggs than young females. This increases the probability that at least some of the new year-class will survive the usually negative stochastic environmental events that control recruitment. This phenomenon is probably widespread in highly fecund, long-lived fishes. Secor's (2000a, 2000b) demonstration that spawning populations composed of multiple year-classes may ameliorate environmental effects still points to overfishing as the basic source of the striped bass collapse.

2. Environmental degradation: Because striped bass are anadromous, they are more vulnerable to environmental destruction of spawning and nursery habitats than are marine fishes, and these habitats have undoubtedly been degraded during the last century. However, the stock collapse during the 1970s occurred at the same time that water quality was improving because of the passage of the Clean Water Act. That and the current robust condition of the stock argue that environmental degradation did not contribute in a major way to the stock collapse.
3. Availability of data needed for management: Striped bass have been recognized as an important resource for many years, and life history studies were carried out in the 1930s and 1940s (Merriman 1941). Recruitment surveys began as early as the 1950s and 1960s. Currently both fishery-dependent and fishery-independent monitoring efforts are as great or greater than in any other U.S. fishery (Richkus et al. 1992). The quantity and quality of the data available in the 1970s and 1980s contributed greatly to the effective management strategies that evolved.
4. Quality of scientific advice: Quality of the science in the fishery seems not to have been an issue; it was adequate.
5. Effectiveness of management decisions: The ASMFC moved to manage the fishery only after it collapsed with virtually no interstate management in the 1970s. Even after implementing the FMP in 1981, recovery was not apparent until the passage of the Striped Bass Conservation Act, which mandated compliance (Richards and Rago 1999) and allowed the ASMFC to implement more stringent regulations that previously would have been ignored by some of the states. Once given legal authority, the ASMFC performance has been exemplary, and the fishery is being managed sustainably.

New England Groundfish Fishery

The New England groundfish fishery is the oldest fishery in the United States with the longest history of management. The fishery harvests a mixture of species, the most important of which have been Atlantic cod *Gadus morhua,* haddock *Melanogrammus aeglefinus,* pollock *Pollachius virens,* and several flatfishes (Murawski et al. 1997). The abundance of cod was the principal impetus for European colonization of the New World. As early as 1653, the Massachusetts Bay Colony established a fishery management commission to promote the cod fishery (Kunzig 1995). By 1776, the New England cod fishery involved more than 500 vessels and 5,000 fishermen, and during the 19th century, the fishing industry became the most important maritime industry in New England (Albion 1972; Fordham 1996). The basic fishing gear used for many years was hand lines and bottom set lines with multiple hooks, but in 1905, the first steam-powered trawler fished New England waters (Fordham 1996). Trawling increased dramatically during the first half of the 20th century, and trawls quickly became the principal gear used to harvest New England groundfish. Then, in the 1960s, a large international fleet of distant-water factory trawlers began depleting one fish stock after another. In response, the International Commission for the Northwest Atlantic Fisheries (ICNAF) imposed catch quotas in 1973 (Fordham 1996; Murawski et al. 1997). Groundfish stocks began to recover under the ICNAF quota system when, in 1976, Congress passed the Magnuson Fishery Conservation and Management Act (FCMA). The purpose of the act was to establish a fishery conservation zone (FCZ, now called EEZ), which excludes all foreign fishing vessels without special permits in waters within 200 mi of the U.S. coast (Fordham 1996). The New England Fishery Management Council (NEFMC) assumed responsibility for management of the New England groundfish fishery in 1977. Between 1977 and 1982, management was based upon a quota system adopted from ICNAF. At the same time, domestic entry into the fishery was promoted by federal aid programs that created a boat building and fishery boom in New England (Fordham 1996). This resulted in rapid expansion of the fishing fleet, overcapitalization, and overcapacity that U.S. taxpayers are still paying for today (Figure 2). Annual quotas were allocated quarterly, but because total allowable catches (TAC) were often met or exceeded before the end of the year, fisheries were often closed for parts of quarters, or quota was "borrowed" from the next

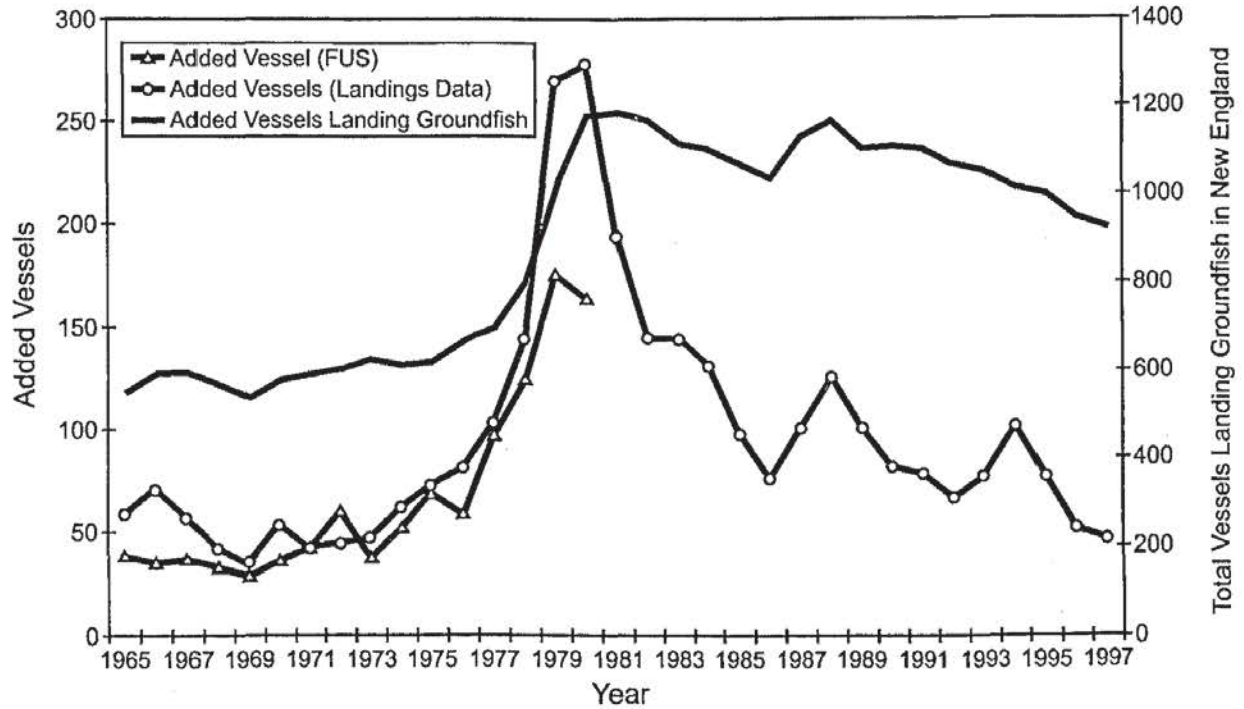

Figure 2. Additions to the New England fishing fleet and total number of vessels landing groundfish in Maine, Massachusetts, or Rhode Island, 1965–1997 (after NOAA 1998).

quarter of the year (Murawski et al. 1997). Fordham (1996) has noted "as in all 'open access' fisheries, the incentive was for fisherman to catch as much as they could, as fast as they could before someone else did."

The quota system became an anathema to the fishing industry, which was focused on short-term economic return rather than long-term sustainability. The NEFMC responded by abandoning the quota system in 1982 and adopting the "interim plan" originally intended as a temporary measure to conserve groundfish while a long-term comprehensive plan was being developed. The council also released a major policy statement that announced its intent to "provide an environment in which the multispecies fishery can operate and evolve with a minimum of regulatory intervention or restriction of fishing options" (Fordham 1996). Under the interim plan, quotas were replaced with suites of indirect measures such as mesh size restrictions and seasonal closed areas. Finally, in 1985, the Northeast Multispecies Fishery Management Plan was adopted. This plan established mesh size regulations by geographic area, minimum sizes of fishes landed, and seasonal area closures, all of which were ineffective in preventing overfishing (Figure 3).

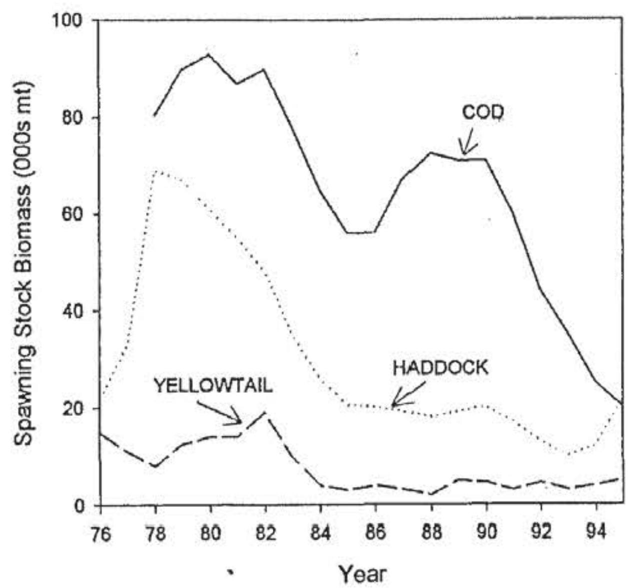

Figure 3. The decline of cod, haddock, and yellowtail flounder on Georges Bank from 1976 to 1994 (after National Marine Fisheries Service 1995).

The plan was amended seven times between 1985 and 1996. The first four amendments amounted to ineffective tinkering with minimum fish sizes and establishment of overfishing definitions, but Amendment 5, implemented in 1995 in response to a lawsuit filed by conservation groups, changed the structure of the plan by directing a 50% reduction in groundfish fishery effort (Murawski et al. 1997; NOAA 1999).

After passage of the FCA in 1996, the NEFMC approved Amendment 7 to achieve stock rebuilding now required by law and to establish target quotas, reduction in days at sea, expansion of closed areas, and other measures. Some stocks have begun to recover (NMFS 2001).

Factors Affecting the Fishery

1. Inherent vulnerability: Most stocks in the fishery are not inherently vulnerable to overfishing. Of particular exception are Atlantic halibut *Hippoglossus hippoglossus* and barndoor skate *Dipturus laevis,* both of which are long-lived and late maturing. The former was fished to near extirpation in U.S. waters by the early 20th century, and the latter has declined by more than 95% because it is taken and discarded as bycatch in the groundfish fishery. Both are on the American Fisheries Society list of marine fish stocks at risk of extinction in North America (Musick et al. 2000a, 2000b) Although regime shifts have been implicated in the decline of northern Atlantic cod *Gadus morhua* stocks off Newfoundland, Sinclair and Murawski (1997) concluded that "The major reason for the decline of the northwest Atlantic groundfish has been persistent recruitment overfishing. Although environmental variations likely have important effects on stock production, we found no environmental factor that could explain either the general decline in productivity observed since the 1950s, or the precipitous decline in the 1990s."
2. Environmental degradation: Most fish species in the New England groundfish fishery are not estuarine dependent (Bigelow and Schroeder 1953) and thus are not particularly vulnerable to coastal environmental degradation. Any anthropogenic habitat degradation affecting groundfish stocks has been caused by the fishery itself. Bottom trawls and scallop dredges have been documented to cause massive damage to hard bottom habitats in the Gulf of Maine and to result in reduction of habitat (both for juvenile and adult fish) and biodiversity (Auster et al. 1996; Auster and Langton 1999). The impact of these effects on groundfish populations is unclear.
3. Availability of data: Compared to most fisheries under management in the United States, this fishery has been data-rich. The NMFS Northeast Fisheries Science Center (NEFSC) has carried out fishery-independent survey cruises seasonally since 1963. These surveys provide stock trends, recruitment indices, estimates of stock size, age structures, and so on. In addition, there is a well-established port sampling system in New England to record the pertinent characteristics of the landings (Boreman et al. 1997).
4. Quality of scientific advice: Stock assessments are performed at NEFSC on a regular basis and involve scientists from NMFS and the states. Most assessments involve virtual population analysis (VPA) tuned with recruitment indices. These analyses are performed at stock assessment workshops (SAWs), the results of which are peer-reviewed by a stock assessment review committee (SARC). These reviews are rigorous and the quality of the science is excellent.
6. Effectiveness of management decisions: The NEFMC has perhaps the worst record in the United States for responsible management of its fisheries. It is difficult to imagine how the stocks could have been worse off with no management at all. Although the council inherited from ICNAF an effective quota system that was rebuilding stocks, they abandoned this management strategy in favor of ineffective regulations that allowed gross overfishing and stock collapse. Responsible management was not implemented until conservation groups sued the council, and the more stringent FCA mandating stock rebuilding was passed. Sinclair and Murawski (1997) have noted, "Had recruitment overfishing been prevented, catastrophic declines in these resources could have been averted."

Atlantic and Gulf of Mexico Reef Fish Fisheries

The U.S. reef fish fisheries off the South Atlantic States and in the Gulf of Mexico both harvest mostly the same species, and the histories of the fisheries are similar and thus will be discussed together here. Commercial and recreational harvest of reef fish is primarily by hook and line, although other methods such as trapping, long-lining, and trawling have also contributed to the catch. This fishery is pursued mostly over hard bottom habitats from North Carolina to Texas. The nucleus of the fishery is the snapper–grouper complex comprised of two diverse families (Lutjanidae and Serranidae), many species of which are long-lived (Coleman et al. 2000). The South Atlantic Fishery Management Council (SAFMC) manages 73 species of reef fishes in the Atlantic, and the Gulf of Mexico Fishery Management Council (GMFMC) manages 55 species of reef fishes in the Gulf. The recent history of the U.S. reef fisheries has been one of unmitigated disaster, despite evidence that the stocks were particularly vulnerable to overfishing as early as 1972 (Huntsman et al. 1992, 1994, 1999) and implementation of the FMPs in the Atlantic in 1983 and in the Gulf of Mexico in 1984. At least 14 of 22 reef fishes for which stock information is available off the southeastern United States are overfished (Coleman et al. 2000). The American Fisheries Society has recognized six species of Atlantic groupers to be *vulnerable* to extinction, one species to be *threatened,* and four species to be *endangered* (Musick et al. 2000b).

Factors Affecting the Fishery

1. Inherent vulnerability: The most vulnerable species in both recreational and commercial fisheries are the larger, long-lived species, which grow slowly (have low von Bertalanffy k coefficients), mature at moderate ages, live to be greater than 15 years of age, and have low natural mortality (*m*) (Huntsman et al. 1999; Coleman et al. 2000). These characteristics make them extremely vulnerable to overfishing (Musick 1999a). In addition, many species aggregate at specific sites and times for spawning, and most have high site fidelity even during nonspawning periods. Many spawning aggregations have been extirpated by fishing and, once gone, have not been replenished from other areas (Koenig et al. 1996; Sadovy and Eklund 1999). Most of the overfished species are protogynous hermaphrodites, maturing first as females then becoming males later in life. Thus, the older, larger individuals are all males, which are always much fewer in number than females because of natural mortality and the resulting demographic structure of populations. Because fisheries usually crop off the largest, oldest individuals in populations first, sex ratios in protogynous species become skewed even more heavily in favor of females and may result in an insufficient number of males for the population to achieve its full reproductive potential. Such a situation may have caused the sudden stock collapse of the red porgy *Pagrus pagrus* as early as 1982 (Huntsman and Schaaf 1994; Huntsman et al. 1995; Coleman et al. 2000) (Figure 4). An insufficient number of males is also becoming apparent for other species such as gag *Mycteroperca microlepis* (Figure 5). In addition, cropping off larger, older females may severely deplete reproductive potential of populations (Harris and McGovern 1997). The number of eggs produced by an older female may be two orders of magnitude greater than that of younger females (Coleman et al. 2000). Because of different spawning times among

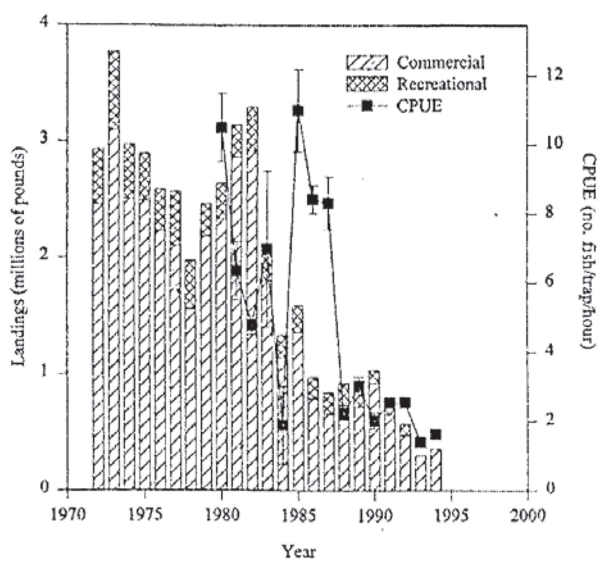

Figure 4. Commercial and recreational landings of red porgy since 1972. Recreational landings are from headboat surveys conducted by the Beaufort Laboratory of the National Marine Fisheries Service (70%), and the Marine Recreational Fisheries Statistics Survey (30%). Catch per unit effort (CPUE) = MARMAP trap catch per unit of effort (after Harris and McGovern 1997).

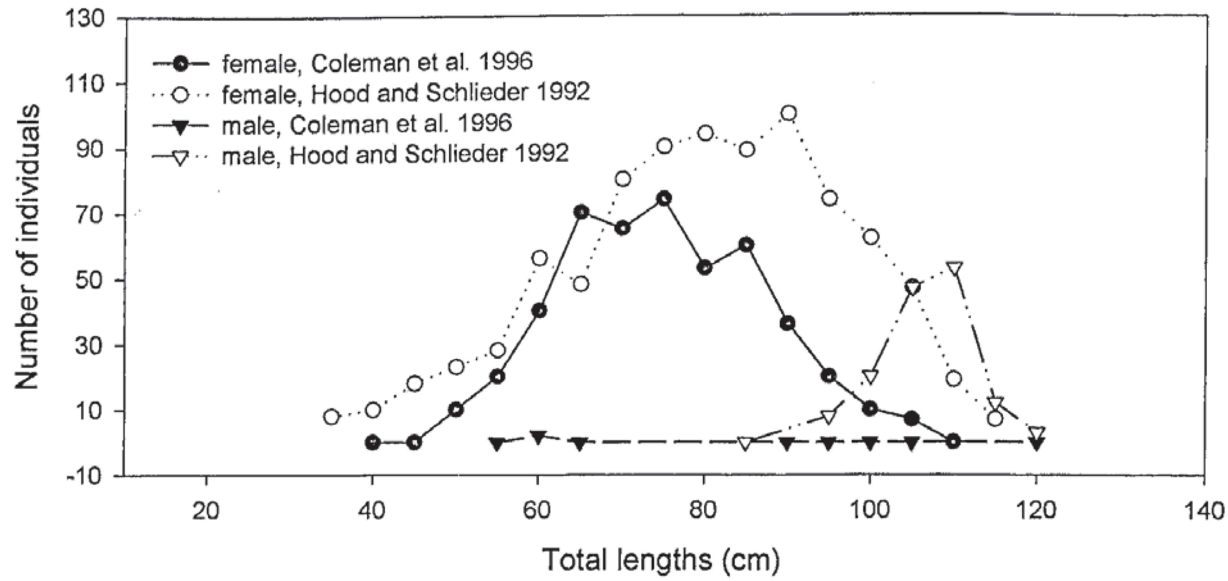

Figure 5. Sex-by-size-frequency distributions for gag: data from recent study (closed symbols) (N_{female} = 464, N_{male} = 9) and historical data from 1977 to 1980 (open symbols) (N_{female} = 818, N_{male} = 134). Males are represented by triangles, females by circles (after Hood and Schlieder 1992; Coleman et al. 1996).

different age-classes, the effect of truncating the age and size structure on the probability of recruitment is unknown, but it may be as important in reef fishes as it is in striped bass (Secor 2000a) and Pacific rockfishes (Parker et al. 2000). It is clear that reef fishes possess a multiplicity of inherent characteristics that make them prone to overfishing.

2. Environmental degradation: Reef fishes in nearshore habitats have been impacted most by human activities (Coleman et al. 2000). Pollution and physical alteration has affected juvenile habitat. Seagrass beds and mangroves have been severely impaired due to coastal development. Harvesting and siltation are destroying oyster reefs, an important nursery habitat for several reef fish species. Because offshore reef habitats are susceptible to destruction by trawl and dredge gear (Dayton et al. 1995), the SAFMC in 1988 prohibited use of trawl gear in the reef fish fishery from Hatteras to Cape Canaveral (SAFMC FMP Amendment I). A significant source of indirect anthropogenic mortality has been juvenile bycatch in the shrimp trawl fishery, particularly for red snapper *Lutjanus campechanus*.
3. Availability of data needed for management: Reef fish stock information is available for only 22 of 73 species in the Atlantic and 5 of 55 in the Gulf. Analysis of recruitment from planktonic to benthic habitats has been hindered by a lack of ability to identify the larvae of 40 of 73 species in the SAFMC FMP (Coleman et al. 2000). However, fishery-independent surveys have not been available in the southern Atlantic to provide recruitment indices that can be used to tune VPAs (Coleman et al. 2000). Virtual Population Analyses without such tuning have led to spurious conclusions about the state of reef fish stocks (Huntsman et al. 1999). Some of the largest species that occupy the apex position in food webs are inherently sparse. Others have become rare because of overfishing. It is difficult if not impossible to collect the quantitative information necessary to perform statistically reliable population assessments on such species (Huntsman et al. 1999). However, that should not preclude precautionary management.
4. Quality of scientific advice: Information needed to manage reef fishes accumulated at a rapid rate after Moe's (1969) first ever aging of a grouper (NMFS 1991). Much information has accrued on life history parameters and stock status (Huntsman et al. 1999; Coleman et al. 2000). The quality of the information, particularly over

the last decade, has been quite good and available for consideration by managers (Plan Development Team 1990; Goodyear and Schirripa 1991; Bohnsack and Ault 1996). Nevertheless, the lack of reliable information on the status of numerous species still represents an impediment to developing reliable scientific advice.

5. Effectiveness of management decisions: Management of the reef fish fisheries in the Atlantic and Gulf of Mexico has been largely ineffective with the exception of wreckfish *Polyprion americanus,* which has been managed with an individual transferable quota (ITQ) system initiated virtually when the fishery began (Sedberry et al. 1999). Goliath grouper (formerly called jewfish) *Epinephelus itajara,* severely reduced by overfishing and prohibited from harvest in the EEZ by both councils and in inshore fisheries by the state of Florida in 1990, appears to be recovering (A. M. Eklund, NMFS Southeast Fisheries Science Center, personal communication; NMFS 2001). This species occurs in shallow water where it has high survival after capture and release. Reef fishes are taken in mixed species fisheries (but less so when in spawning aggregations), and high survival after capture and release is necessary for management regulations, such as species-specific bag limits and size limits, trip limits, or quotas, to be effective. Both councils have passed several regulatory amendments to their FMPs establishing bag and size limits, as well as prohibiting retention of some species. Unfortunately, much of the fishery is pursued offshore in deeper water where most fish brought to the boat are moribund. Thus, these regulations are largely ineffective. Worse, these dead releases or discards have not been counted against total mortality estimates and quotas for the species (Coleman et al. 1999, 2000; Huntsman et al. 1999). Information has been widely available on the mortality in deep water grouper fisheries, yet the councils passed regulations which they knew, or should have known, would be largely ineffective or even destructive. Huntsman et al. (1999) have called this action "dereliction of sworn responsibility," harsh words, but probably more accurate than not. One solution to this problem is the establishment of Marine Protected Areas (MPAs) (Murray et al. 1999). A scientific panel proposed the use of MPAs to SAFMC in 1990 (Plan Development Team 1990; NMFS 1991) and after further study again in 1996. To date, neither council has acted on these recommendations in a meaningful way.

Spawning potential ratio (SPR) is an index of the biomass of the present spawning stock relative to the biomass of the virgin stock (before fishing) (Gabriel et al. 1989). Both councils have used SPR as a threshold to define overfishing in managing various species under their stewardship; the SAFMC has used SPR = 0.3 where the GMFMC used SPR = 0.2, a less precautionary value. In reality, most SPR values realized for species managed by the SAFMC since 1986 have been about 0.15 (Huntsman et al. 1996). Mace (1994) has suggested that SPR values less than 0.3 may be risk prone, and in fact, she recommended using 0.4 for stocks where the stock–recruitment relationship was unknown. Coleman et al. (2000) have shown that SPR, as presently used (based on female biomass), is completely inappropriate for protogynous hermaphrodites like many of the reef fishes, for which the much smaller male spawning biomass is more important. They showed that SPR values based on female biomass could indicate that the stock is healthy; yet because of the loss of males, stock collapse can occur. Thus, the councils have been using inappropriate overfishing thresholds for management. This situation may have occurred because of scientific ignorance and incorrect advice when originally implemented, but the problem has been made obvious now for several years with no apparent response from the councils (Huntsman et al. 1999; Coleman et al. 2000). Most reef fish management decisions made by these councils have not been precautionary.

Atlantic Shark Fishery

In the 1940s, an Atlantic longline fishery developed for sharks, particularly for shark livers that were used to produce vitamin A (Springer and French 1944). This fishery was abandoned after a decade because of the development of synthetic vitamin A. Sharks were taken in relatively small numbers as unwanted bycatch in recreational and commercial fisheries until the 1970s when the motion picture *Jaws* provided the impetus for the rapid expansion of a directed recreational shark fishery (Hoff and Musick 1990). Shark fishing tournaments proliferated along the coast from New York to Texas. Hundreds of tons of sharks were landed, most ending up in landfills, and by the 1980s, the stocks of large coastal species had declined by approximately 50% (Casey and Hoey 1985; Hueter 1991; Musick et al. 2000c) (Figure 6). Then, the infrastructure developed to deliver shark fins from U.S. East Coast ports to processors in Hong Kong, Singapore, and Taiwan. Shark fins are the principal ingredient in shark fin soup, an epicurean item of high value in some Asian (particularly Chinese) cultures. During the same period, the U.S. longline fishery for swordfish came under tight regulation by NMFS. As the price of shark fins soared from less than $1 per pound wet weight to $20 per pound and more, the Atlantic longline fleet turned to sharks (Branstetter 1999). Most of the catch was finned, and the carcasses were thrown overboard. The meat was of relatively low value and took up substantially more storage area in the hold than high value fins. NMFS proceeded to develop a market for shark meat (a successful effort) and to encourage the development of the "underutilized" shark resource, disregarding warnings that shark fisheries are vulnerable to collapse and must be managed from the outset (Colvocoresses and Musick 1980). The Mid-Atlantic Fishery Management Council (MAFMC) became concerned about the shark decline in 1986 and convened a blue ribbon panel of shark experts to review the problem and identify data needs. The council requested funding from the Secretary of Commerce to pursue the data collection necessary to prepare an FMP (Hoff and Musick 1990). At the same time, the American Elasmobranch Society passed a resolution requesting the MAFMC and NMFS to prepare an FMP for Atlantic sharks because of documented declines and the well-known vulnerability of sharks to overharvesting. The NMFS responded by initiating the direct preparation of an FMP under the auspices of the Secretary of Commerce (a secretarial plan) in place of the proposed MAFMC plan. Preparation of the NMFS plan proceeded mostly through the Southeast Fishery Science Center (SEFSC). Meanwhile, the commercial fishery continued unabated while landings in the recreational fishery plummeted (Branstetter 1999). The commercial landings reached their peak in 1989,

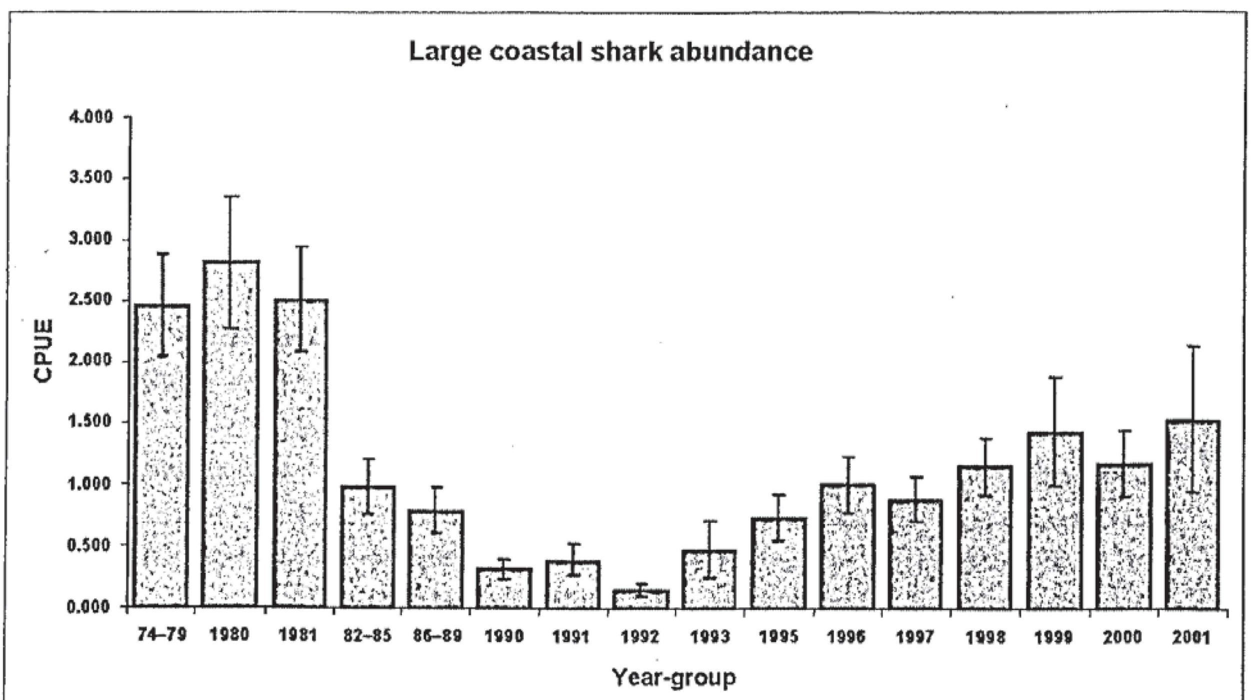

Figure 6. Trends in abundance of large coastal sharks in the Atlantic shark fishery. Catch per unit effort (CPUE) is sharks/100 hook hours (see Musick et al. 1993).

the same year a NMFS draft management plan was widely circulated for review. Unfortunately, the secretarial shark FMP was not implemented until 1993, 7 years after the need for an FMP was recognized, even though some states had passed regulations banning finning and restricting trip limits as early as 1990 (Camhi 1998). When finally implemented, the NMFS shark FMP outlawed finning, and established landings quotas in the commercial fishery and creel limits in the recreational fishery. Subsequent stock assessments by scientists both from within and without NMFS showed that the original regulations were insufficient to allow stock rebuilding, and more stringent regulations were required (NMFS 1994, 1996). These new regulations were implemented in spite of the initiation of a lawsuit by members of the commercial shark fishing industry. The shark FMP was melded together with other highly migratory species into a fishery management plan for Atlantic tuna, swordfish, and sharks after passage of the Sustainable Fisheries Act (SFA) in 1996 with the final plan implemented in 1999 (NMFS 1999). That plan grouped large coastal sharks into two groups based on morphology (ridgeback versus nonridgeback) and life history characteristics. It mandated a minimum size limit for ridgebacks, further reduced the quota on nonridgebacks, and placed several additional species under full protection. These new regulations were suspended pending litigation brought by the commercial fishing industry. Following a settlement between NMFS and the industry, the list of prohibited species was reinstated to protect shark species particularly vulnerable because of very low rebound potentials. However, size limits and quota reductions were put on hold until the completion of a new assessment in 2002.

Factors Affecting the Fishery

1. Inherent vulnerability: Most sharks grow slowly, mature at an advanced age, have low fecundity and are long-lived (Musick et al. 2000c). These attributes make them particularly prone to overharvesting and stock collapse (Hoenig and Gruber 1990; Hoff and Musick 1990).
2. Environmental degradation: Most sharks are stenohaline and thus are restricted to marine or high salinity estuarine waters (Camhi et al. 1998). Although shark populations may have been marginally impacted by estuarine and coastal environmental degradation, the principal cause of stock collapse has been gross overharvesting by both recreational and commercial fisheries.
3. Availability of data necessary for management: Although the fishery-dependent data necessary for detailed stock assessments were not available in the 1980s or even the early 1990s, sufficient information was available from previous fishery failures to highlight the extreme vulnerability of sharks and the need for precautionary management (Holden 1973; Colvocoresses and Musick 1980; Anderson 1985; Hoenig and Gruber 1990; Hoff and Musick 1990). In addition, some long-term fishery-independent data were available (Musick et al. 1993); yet, management was not implemented by NMFS until 1993 after some of the stocks had declined by 75–90% (Musick et al. 1993). Recent assessments have been based on improved fishery-dependent and -independent data, but observer coverage needs to be expanded.
4. Quality of scientific advice: The stock assessment in the 1993 FMP was based on a maximum likelihood production model inappropriate for long-lived, late-maturing animals such as sharks (Ricker 1958). Consequently, the intrinsic rate of increase (*r*) calculated from the model was two to three times higher than could be achieved by the stocks (Musick 1995). This led to an overly optimistic estimate of recovery time of 2 years. Subsequent analyses incorporating more appropriate models and utilizing much better catch data, as well as more accurate stock demographic parameters, have led to stock recovery estimates of a decade or longer (NMFS 1996, 1998).
5. Effectiveness of management decisions: NMFS was slow to react to shark management problems that required rapid resolution during the 1980s. By the time the NMFS plan was implemented in 1993, stocks had collapsed and a major rebuilding effort was required. Even after implementation of the plan and criticism from the scientific community that quotas were at least two to three times greater than

could lead to stock recovery, NMFS neglected to implement more stringent regulations until after the SFA of 1996. Recent NMFS management decisions have been precautionary for the most part, even if hampered by litigation. State regulation of shark fisheries has lagged far behind regulation in the EEZ, and the ASMFC and GMFMC have yet to implement FMPs to complement the federal FMP. Thus, fishing activities in state waters continue to reduce the effectiveness of regulation in the EEZ (Camhi 1998).

Pacific Rockfish Fishery

The Pacific rockfish complex comprises more than 60 species in the genus *Sebastes* and three species in the genus *Sebastolobus*. Rockfishes are an extremely successful group and occupy virtually every coastal marine habitat from Mexico to the Aleutian Islands (Parker et al. 2000). Rockfishes comprise the core of the U.S. Pacific Coast bottom fish fishery from Washington to California and are managed by the Pacific Fishery Management Council (PFMC). Harvest of rockfishes began in the mid-1800 s off California, but not until the 1940s on the northwest coast (Lenarz 1987). Foreign fishing fleets harvested 20,000 metric tons a year of Pacific ocean perch *Sebastes alutus* until excluded from the EEZ by passage of the Magnuson-Stevens Fishery Conservation and Management Act in 1976 (Ianelli and Zimmerman 1998). Rockfish harvest today is primarily by otter trawl (≈90%), with hook and line used inshore and in areas of rough bottom (PacFIN 1999). Recreational catches have declined from 8,000 metric tons in the early 1980s to nearly 2,000 metric tons and have been focused on nearshore species (Parker et al. 2000). Recreational harvest of inshore rockfishes has been much greater than commercial harvest, but a rapidly developing live fish commercial harvest particularly off California and Oregon is cause for concern among many scientists (Love and Johnson 1998; Bloeser 1999). Total harvest of rockfishes in the Washington–California management area was 22,000–50,000 metric tons in the 1990s and steadily decreased during the decade (PFMC 1999). Many species of rockfish have declined dramatically over the last 15–20 years (Parker et al. 2000) (Figure 7). The American Fisheries Society has recognized several stocks of rockfish to be vulnerable to extinction. At least seven species have declined in abundance by 75–98% from Washington to California, and an additional six stocks are considered to be at risk in Puget Sound (Musick et al. 2000b). Of the 10 stocks of rockfish assessed by the PFMC, 5 are considered at or near the target biomass, 1 is below, and 4 are overfished (less than 25% of original spawning stock biomass) (Parker et al. 2000).

Factors Affecting the Fishery

1. Inherent vulnerability: Pacific rockfishes are among the longest-lived fishes with many exceeding 50 years and some species exceeding 150 years of age (Archibald et al. 1981; Leaman and Beamish 1984; Love et al. 1990; Cailliet et al. 2001). The age at maturity is usually 5–7, but may reach 20 years for some species (Wyllie Echeverria 1987; Barss 1989; Love et al. 1990). Rockfish have delayed maturity, long reproductive life span, and extreme iteroparity—all adaptations to a low probability of successful reproduction in any given year (Giesel 1976; Leaman and Beamish 1984). These life history traits make them extremely vulnerable to overfishing (Musick 1999b). The *Sebastes* rockfishes have primitive viviparity, and the *Sebastolobus* spp. are oviparous (Parker et al. 2000). Both genera have high fecundity with variable and sporadic recruitment, depending on oceanographic conditions. The last two decades have seen poor recruitment in many species (Parker et al. 2000). However, as with striped bass (Secor 2000a, 2000b), within each species, rockfish of different ages may spawn during different times of the spawning season, and truncation of the population's age structure reduces the probability of successful recruitment (Eldridge et al. 1991; Nichol and Pikitch 1994; Berkeley and Markle 1999). The gross overfishing that has occurred on Pacific rockfish stocks has severely truncated age distributions and exacerbated any oceanographic effects associated with larval survival. The probability of successful recruitment increases with the number of age-classes present in such species (Secor 2000a, 2000b).

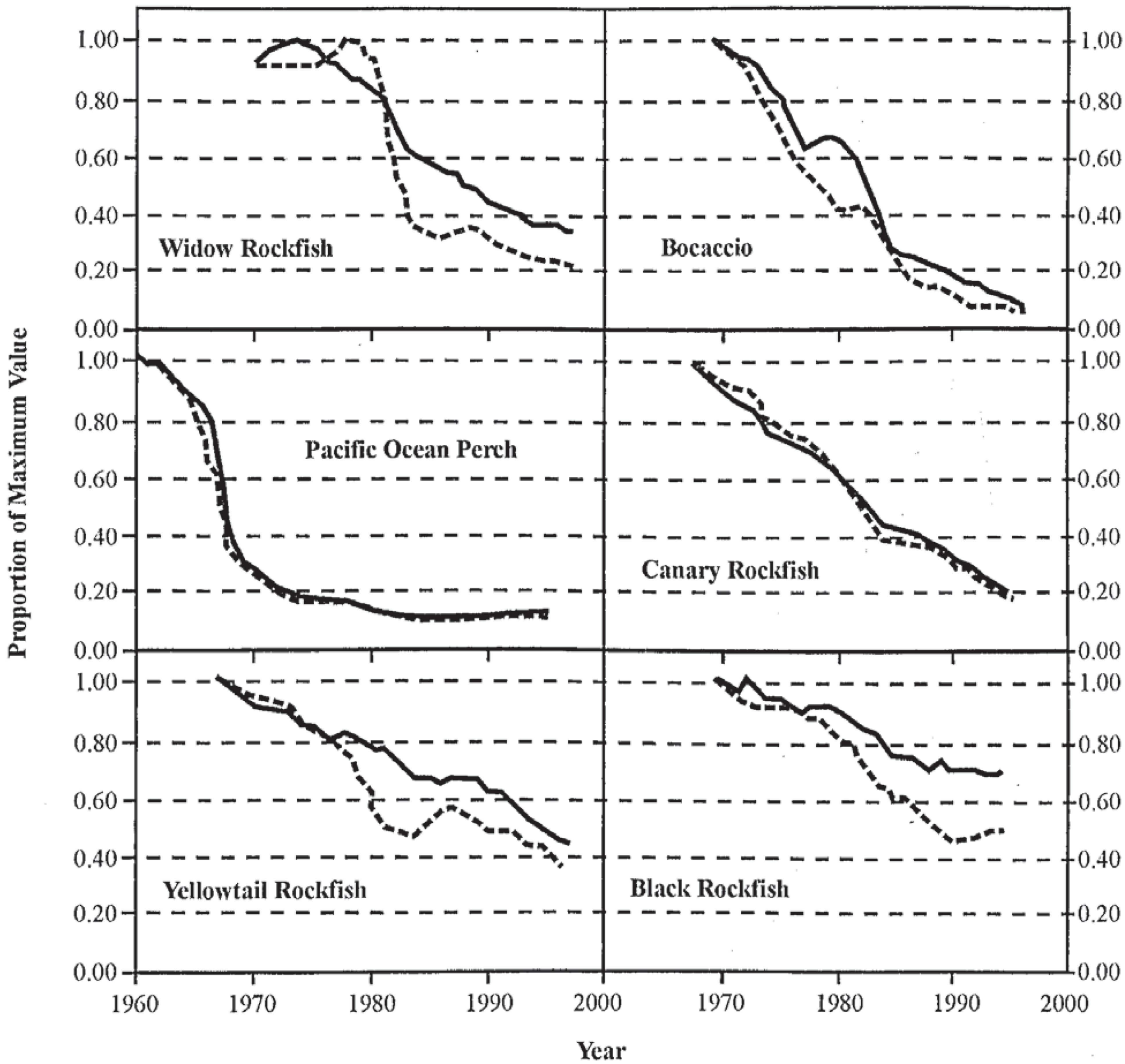

Figure 7. Trends in exploitable biomass (solid lines) and spawning output (dashed lines) for six West Coast rockfish stocks (after Ralston 1998).

2. Environmental degradation: Anthropogenic environmental effects are not obvious but might have contributed in some way to the decline of rockfishes. Trawl fisheries themselves are known to cause extensive habitat alteration, particularly on the hard bottom most rockfishes prefer (Dayton 1998). Friedlander et al. (1999) reported that a typical trawl fishery off northern California covered the seabed from 1.5 to 3 times a year, a level of disturbance sufficient to maintain a vastly altered community. Another anthropogenic impact may be associated with kelp forests. Jackson et al. (2001) have documented the historical fluctuations in kelp forest extent associated with human harvesting of sea otters that prey on sea urchins, which in turn are the principle grazers on kelp. Kelp forests from Washington to California are now relatively healthy because sea otters are protected and the urchins themselves became the target of a directed fishery in the 1970s and 1980s (Jackson et al. 2001). Thus, kelp forest decline cannot be blamed for recent declines in inshore rockfishes. Other potential anthropogenic effects are probably only local in extent.

3. Availability of data needed for management: Although the general life history of rockfish is known, few species have been studied in detail. Information is lacking about stock status and basic biological parameters necessary for assessment even for species that are exploited. Only limited information is available for maximum age, natural mortality, fecundity and age at maturity for a limited number of species (Love et al. 1990). Such essential information as stock identification, spawning behavior, total removals, and migration patterns are unknown or are based on limited data (Parker et al. 2000). Only 10 of the 54 species of rockfish managed by PFMC have had full stock assessments and 1 of 12 nearshore species taken by the commercial live-fish and recreational fisheries have been assessed. Accurate assessment of bycatch has been a major obstacle in rockfish management (Parker et al. 2000). Rockfish discards in the fishery have been estimated at 15–30% of the catch (PFMC 1997). Actual levels are unknown because there has been limited observer coverage. Mortality of discarded rockfish approaches 100% (Parker et al. 2000). Harvest composition is unknown.
4. Quality of scientific advice: Given the relatively meager resources available to collect information, some excellent science relative to the vulnerability of rockfishes to overharvesting has been published and available (Parker et al. 2000). At the same time, the scientific advice given to the PFMC focused on recruitment failure as an entirely environmentally mitigated phenomenon and ignored the interactive effect on stock juvenation wrought by gross overfishing on recruitment (Weber 2002). Unfortunately, such advice destined both scientists and managers to wait at the station for a recruitment train that never arrived.
5. Effectiveness of management decisions: The PFMC has been responsible for rockfish management in the EEZ since 1976 with the passage of the Magnuson Act. Management has been slow to adapt to new information (Leaman 1991; Ralston 1998); nevertheless, the PFMC has tried to follow the scientific advice even in the face of regional socio-economic pressure (Weber 2002). Fish populations have shown little response to the management measures implemented to date because scientists and managers have failed to appreciate the reproductive constraints inherent in rockfishes that restricts their ability to respond to intense overharvesting (Parker et al. 2000). Not until the SFA of 1996, which required rebuilding plans for stocks identified as overfished and which mandated reduction in fishing mortality and established deadlines for attaining biomass rebuilding targets, did the PFMC begin to take the draconian measures needed to rebuild rockfish stocks. Rebuilding plans have been implemented or soon will be implemented for four depleted species with others to follow. Even so, litigation recently initiated by several nongovernmental organizations (NGOs) against PFMC management regulations approved by NMFS resulted in a finding that catch limits for two severely depleted groundfish species, bocaccio *Sebastes paucispinis* and the lingcod *Ophiodon elongatus* (a hexagrammid), were too high and were not precautionary (Schmidt 2001). The standard management measure for rockfish in this fishery has been to establish the fishing mortality target at $F_{35\%}$, the rate that reduces the spawning potential per recruit to 35% of the unfished condition (Clark 1993). This target has been called into question given the observed population declines and the particular life history constraints of each species (Ralston 1998, 2002; Clark 2002).

Francis (2002) recently observed, ". . . what we are seeing are the long-term effects of short-term policy. In the early 1980s the PFMC wanted to stretch out the rockfish fishery so that landings could take place year around, and since West Coast groundfish were managed by annual quota, the council imposed modest landing or trip limits on the fleet. Now, 15 years later with drastically lower quotas, many stocks declared overfished and managed according to federal rebuilding plans, much more harvest capacity than is needed, and the same system of trip limits, only now prohibitively restrictive."

Many rockfish species may be captured together in mixed species fisheries in deeper water where discard or release mortality is very high, if not

100% (Parker et al. 2000). The implementation of size or bag limits, or even full protection for species at risk will not work in this situation. The establishment of large marine protected areas has been proposed as a solution to the problem, as well as an aid to reestablishing the age structure of overfished populations and restoring ecosystem biodiversity (Leaman 1998; Yoklavich 1998; Parker et al. 2000). Other management measures necessary for stock recovery are species-specific management and data collection; further reduction in fishing mortality including directed catch, bycatch and discards; establishment of at-sea observer programs; establishment of adequate fishery-independent surveys; and reduction in fishery capacity (Parker et al. 2000).

Discussion

Many of the overfished stocks examined in this report are particularly vulnerable because of natural biological constraints. Striped bass, most larger reef fishes, and rockfishes are long-lived because they require extensive iteroparity to offset sporadic and infrequent recruitment resulting from stochastic environmental conditions. Large sharks are also slow-growing, late-maturing, and long-lived, and have very low fecundity. Thus, low intrinsic rates of increase in sharks allow only modest levels of fishing mortality. These factors have been known for at least two decades but have largely been ignored by some fishery biologists and most managers until very recently.

Unlike freshwater and anadromous fish stocks, most marine fish stocks have only been marginally impacted by anthropogenic environmental degradation so far. Estuarine-dependent species are obviously particularly vulnerable. Of the stocks reviewed here, environmental degradation was only of minor consideration in these declines. Of concern, however, are the impacts to benthic habitats caused by fishing activities (Auster et al. 1996).

Availability of data required to support management decisions varied widely in the fisheries studied but was found to be particularly wanting in the rockfish, reef fish, and shark fisheries. Even so, during the last decade, sufficient scientific information has been available to show the need for precautionary management. Clearly more resources are needed for fishery-independent surveys and stock assessments. Federal fisheries research and management budgets have been woefully underfunded for decades (Weber 2002).

The regulatory role of NMFS in the fisheries management system appears to have been largely passive until the last decade, even though the agency had oversight over the various fishery management councils. With the passage of the 1996 SFA, the agency has been more proactive in insuring that FMPs provide the basis for sustainability. The SFA provides NMFS with some protection from the direct political intervention that has plagued the agency in the past, and the rise of NGOs with particular interest in fishery conservation has helped to balance the partisan voice of the commercial fishing industry in recent years (Weber 2002).

The quality of scientific advice has depended in large part on the data available. Given the data limitations in some fisheries, the quality of advice from both NMFS and state fisheries scientists has ranged from marginal to very good and has improved during the last decade.

In all of the fisheries studied, access was unrestricted and entry into the fisheries proceeded unchecked. This resulted in overcapitalization and overcapacity of fleets (with the possible exception of the inshore striped bass fishery). The response of the management agencies was to do virtually nothing until the stocks were in decline. Even then, most regulations implemented were superficial and risk prone, motivated by short-term economic considerations rather than long-term sustainability. Only after passage of the Striped Bass Conservation Act in 1984 did the ASMFC have the authority to impose responsible regulation on their member states. Also, only after passage of the 1996 SFA, which set mandatory requirements for recovery of overfished stocks, did the councils implement significant risk-averse regulations in the fisheries studied here unless forced to do so by litigation. Likewise, NMFS largely failed in its mandated oversight of the councils to ensure responsible fishery management until implementation of the SFA.

The problem with the councils is endemic. Membership on the councils is largely dominated by the commercial fishing industry, which in effect is charged with regulating itself (Grimes 2001). Thus, responsible restrictive regulations suggested by the council's staff and other scientific advisors have often been ignored. "Given the tendency of most fishermen to oppose any and all regulations aimed at limiting their activities, it would seem difficult to imagine their reaching anything resembling a consensus with agency staff" (Grimes 2001).

We concur with Grimes' (2001) conclusions concerning the council system: "Substantially affected interests should have their voting membership on the Councils greatly reduced if not eliminated entirely, and in attempt to mitigate for lost representation, such interests should also have their nonvoting membership increased. Fisheries management is a difficult process that should be based largely on science and technology determining what must be done to promote the long-term health and viability of the nation's fishery resources. This would be more efficiently accomplished by experienced, technically competent, and objective personnel that are more insulated from desires of special interests who seek to exploit the resource. Admittedly, affected persons are useful in helping to make allocation decisions, and their participation as nonvoting members would still allow them to contribute to such decisions without providing them the opportunity to determine quotas and other decisions that are more science or technology based. The management process sometimes requires that difficult decisions be made, and, in order to make the best decisions under complicated and politically tense circumstances, decision makers need to be as objective as possible. Although some may argue that agencies are not as objective as they are given credit for being, it is difficult to imagine an agency being less objective than a group of regulated persons who represent only a portion of the population, many of whom make their living through the exploitation of a resource that they are entrusted with regulating. It seems to be a shirking of regulatory responsibility to allow regulated interests to have such significant input, if not effective control of the regulatory process."

Recommendations

1. Of highest priority is to strengthen the Magnuson-Stevens Fisheries Conservation Act to more closely mandate sustainable management based on the precautionary principle (i.e., no wiggle room for the managers). Of particular importance is the mandated implementation of conservative overfishing definitions.
2. Mandated representation on management advisory committees and the councils should include advocates for the resource in addition to representatives of commercial and recreational fisheries, or the role of those with vested interests should be strictly advisory.
3. The interstate marine fisheries commissions should be given the authority to ensure FMP compliance among their member states through passage of acts similar to the Atlantic Coastal Fisheries Cooperative Management Act, which presently governs the ASMFC. In addition, interstate management should be required to be compliant with regulations implemented under the SFA.
4. No new fishery should be allowed to progress without prior fishery-independent stock assessments, definition of essential fish habitat, evaluation of potential ecosystem impacts, and preparation of a provisional FMP.
5. Access to all fisheries should be restricted to ensure their economic efficiency, and individual catch shares should be considered for many fisheries (Pew Oceans Commission 2002).
6. Overcapacity in existing fisheries should be eliminated through buyouts with safeguards against re-entry, and retraining programs should be available for workers displaced in the fishing industry (Pew Oceans Commission 2002).
7. Established fishery management tools (i.e., catch quotas, etc.) should be augmented with the use of MPAs for some fisheries.
8. Fishery management targets and thresholds for long-lived species should be changed from achieving maximum sustainable yield or minimum SPR to restoring and maintaining a diverse age structure in populations sufficient to ensure against recruitment overfishing, and to maintain ecosystem structure and function.
9. Funding must be substantially increased for fishery research and management if sustainable fisheries are to be achieved.

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