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Can We Manage Our Multispecies Fisheries?

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Abstract

Fishery resources (fish, invertebrates, marine mammals, and reptiles) of the United States exclusive economic zone (EEZ, 3–200 nautical miles from the coast) are currently regulated under several pieces of key legislation enacted during the early 1970s. At that time, fishery science was only beginning to appreciate the interactions among species and fisheries as being potential impediments to simultaneous realization of competitive management goals. Many of the important management problems currently faced in the EEZ are exacerbated by the incompatibility of regulations promulgated separately under these statutes for ecologically or technologically related species. Reconciling the management of interacting species will require an institutional framework for evaluating the multispecies/multifishery consequences of management decisions and for articulating a clear set of compatible management goals for the various constituents. Traditional single-species biological reference points for fishery management must be re-evaluated to consider the effects of harvesting on ecosystem attributes such as stability, diversity, resistance, and resilience and on economic attributes, including optimization. Currently, dynamic mechanisms underlying species and fishery interactions are poorly understood. The scientific basis of decision making will increasingly have to come from research emphasizing the dynamic relationships of interacting species as well as the biological, economic, and technological factors contributing to fishery interactions. Such studies cannot replace traditional single-species, single-fishery analyses, but must complement and build on them.

Fishery resources in the United States exclusive economic zone (EEZ, 3–200 nautical miles from the coast) are primarily managed under statutory authorities developed in the early 1970s. The Marine Mammal Protection Act of 1972 (MMPA), the Endangered Species Act of 1973 (ESA), and the Magnuson Fishery Conservation and Management Act of 1976 (MFCMA) constitute the major regulatory authority for the conservation and utilization of living marine resources under the jurisdiction of the federal government. At the time Congress promulgated these acts, the scientific basis for resource management was only beginning to take into account the trophic and technological (mixed-species catch or multiple-fleet fisheries) interactions among resources (Larkin 1977). Far more prevalent a view at the time was the notion that each species existed more or less independently in a deterministic environment (Rodel 1975). Scientific inquiry mandated in support of these laws was primarily aimed at computing harvest effort levels corresponding to species-specific maximum sustainable yields (for fisheries), determining the status of marine mammal populations in relation to optimum sustainable population (OSP) sizes, or evaluating the feasibility of rehabilitating individual species threatened with extirpation. Optimality as a concept in fisheries management was primarily used in allocation of scarce resources and as justification for biological overfishing in the face of social or economic constraints on the management system.

Since these laws were passed, management plans for the conservation, protection, and recovery of living resources have been established for virtually all of the economically valuable or socially important species in the EEZ. Almost without exception, each of these plans has established management regulations for individual species or groups of technologically interrelated species. The implementation of these regulations has revealed numerous cases wherein the ecological interrelationships among species or the interjurisdictional nature of management problems have resulted in an infeasible set of management objectives. For example, fishing operations have resulted in unintentional marine mammal kills, impeding the recovery of mammal stocks to OSP goals (Smith 1983; Alaska Sea Grant 1984; Polacheck 1989). Such has also been the conflict in the southeastern United States between provisions of the Endangered Species Act, intended to conserve sea turtles, and the goal of fishery management to maximize catch of shrimp and associated species (Henwood and Stuntz 1987; Thompson 1988).

This chapter covers three areas. First, the institutional, ecological, and scientific impediments to simultaneous realization of multispecies management goals for marine fishery ecosystems are considered. Second, the feasibility of articulating and implementing ecosystem-level management objectives as an alternative to traditional biological reference points used in managing individual species or stocks is evaluated. Third, the scope of research programs necessary to support an ecological basis for management decisions is discussed.

Institutional Setting

Ecological relationships among various constituents of exploited marine communities have long been appreciated by scientists. By the turn of the twentieth century, the simultaneous management of interacting resources was being considered (Volterra 1926; Smith 1988). By the early 1970s, there was considerable recognition of the necessity for a systems approach to fisheries research and management (Dickie 1973; Regier and Henderson 1973; Andersen and Ursin 1973). Predator–prey analyses have subsequently formed an important component of fishery ecosystem studies throughout the world (see reviews in May et al. 1979; Beddington and May 1982; Mercer 1982). In a pair of articles separated by nearly 30 years, McHugh (1959, 1988) argued that mixed-species, multiple-gear fisheries obviated traditional species-oriented management programs. Yet resource management laws promulgated for U.S. coastal waters were primarily responsive to perceived problems in one or more important species or fisheries. The emphasis in implementing provisions of the MFCMA, the MMPA, and the ESA has been and remains primarily on single-species issues.

Interestingly, all three acts refer directly or allude to ecosystem or multispecies objectives as a basis for management action. The Endangered Species Act (PL 93-205) has as one of its stated purposes "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved." In the findings and declaration of policy for the Marine Mammal Protection Act (PL 92-522), Congress noted that "species and population stocks should not be permitted to diminish beyond the point at which they cease to be a significant functioning element in the ecosystem of which they are a part, and, consistent with the major objective, they should not be permitted to diminish below their optimum sustainable population." The act further stipulates that marine mammal populations "should be protected and encouraged to develop to the greatest extent feasible commensurate with sound policies of resource management and that the primary objective of their management should be to maintain the health and stability of the marine ecosystem. Whenever consistent with this primary objective, it should be the goal to obtain an optimum sustainable population, keeping in mind the carrying capacity of the habitat." The Magnuson Fishery Conservation and Management Act (PL 94-265) notes in its National Standards for Fishery Conservation and Management that "to the extent practicable, an individual stock of fish shall be managed as a unit throughout its range, and interrelated stocks of fish shall be managed as a unit or in close coordination." The Magnuson Act further states that conservation and management measures are designed to ensure that "irreversible or long-term adverse effects on fishery resources and the marine environment are avoided; and there will be a multiplicity of options available with respect to future uses of these resources." The act also stipulates that a fishery research program shall be carried out to acquire knowledge and information "concerning the interdependence of fisheries or stocks of fish, the impact of pollution on fish, the impact of wetland and estuarine degradation, and other matters bearing upon the abundance and availability of fish."

What is not established in the current legislative and management structure is a mechanism for conflict resolution among competing resource interests. Perhaps more important, there is no formal requirement for evaluating the feasibility (or in fact the desirability) of attempting to simultaneously attain single-species objectives for various ecosystem constituents regulated under the acts. Fisheries goals that have been established are primarily those related to maximization (or at least optimization) of yields from relatively restricted species assemblages. Provisions of the MMPA and ESA seek to severely limit the kill of affected animals. A set of amendments to the MMPA allows for some harassment and incidental kill of marine mammals by fishing operations—for a 5-year period. The purpose of these exemptions is to gather information on the degree of interaction with marine mammals to be expected in various fisheries. Under these amendments, each fishery operating in the EEZ must be classified as to the likelihood of encounter with marine mammals. Those fisheries deemed to have significant encounters must submit to record-keeping requirements and embark scientific observers when asked to do so. What remains unclear is the basis for decision making once sufficient documentation of the fishery interactions with marine mammals has been gathered. Nevertheless, data on marine mammal–fishery interactions collected under this program will no doubt force a more integrative approach to conflict resolution in some cases.

Apart from the obvious cases of bycatch of species protected under one statute and taken in fisheries regulated under different laws, there are numerous cases wherein the multispecies interactions involve prey species that are regulated under different fishery management plans or, in fact, under the provisions of different statutes, than are their predators. Figure 27-1 depicts a simplified food web for some of the species constituting the pelagic fishery ecosystem off the northeast United States. There are three main prey species (herring, *Clupea harengus*; mackerel, *Scomber scombrus*; and sand lance, *Ammodytes dubius*) and a number of fish, marine mammal, and avian predators. Marine mammal and some avian predators are protected species. Some marine mammals are killed (pilot whale, *Globicephala* spp.; common dolphin,

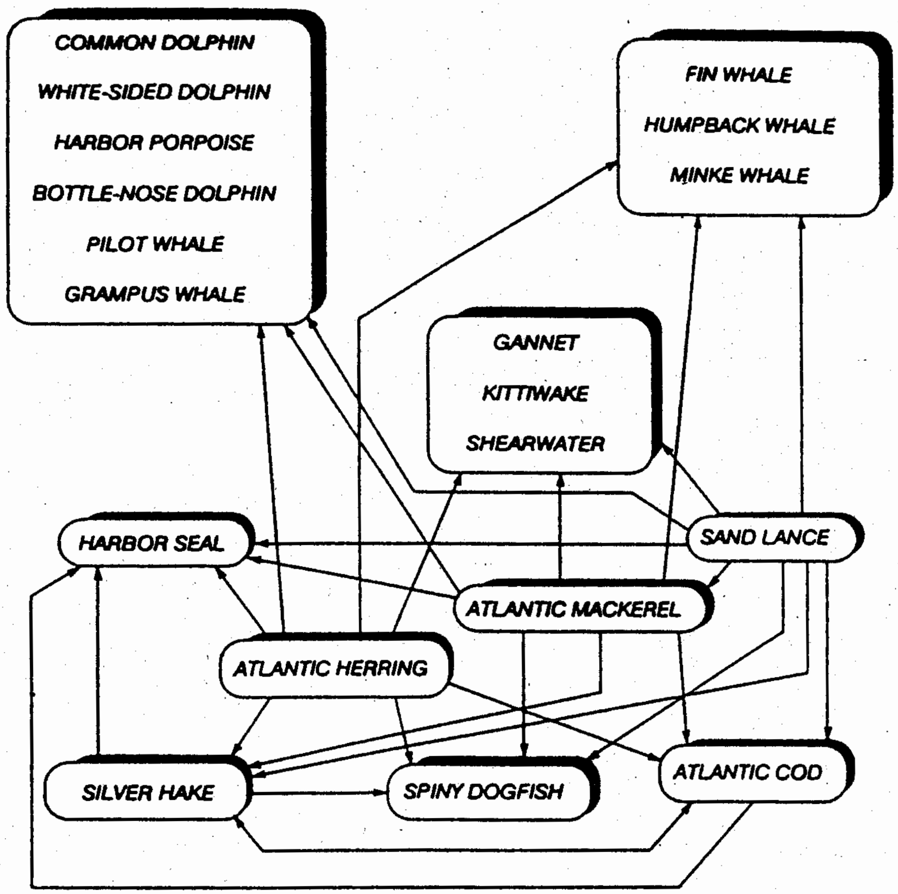

Figure 27-1. Predator–prey relationships among some fish, marine mammals, and seabirds of the pelagic ecosystem off the northeast United States. For the sake of clarity, not all predator and prey species are portrayed. Arrows indicate the direction of biomass flows, based on studies of feeding habits.

Delphinus delphis) during directed fishing on mackerel, primarily in joint venture fisheries with distant-water fleets. Mackerel fishing is regulated under a fishery management plan (FMP) developed by the Mid-Atlantic Fishery Management Council (under the MFCMA). Herring, sand lance, and spiny dogfish (*Squalus acanthias*) are currently not directly regulated in EEZ waters, except by a preliminary management plan (PMP) covering other finfish of the region. The PMP is promulgated primarily as a basis to exclude the declaration of harvestable surplus, which by statute must be considered for allocation to foreign fishermen. Atlantic cod (*Gadus morhua*) and silver hake (*Merluccius bilinearis*) are regulated under the Multispecies FMP for groundfish, developed by the New England Fishery Management Council. Although the FMP for groundfish implies consideration of the multispecies aspects of interacting species, the FMP has as its conservation goal the attainment of single-species equilibrium biological reference points for the 13 regulated species.

This relatively simple trophic system has undergone considerable change in fishery production, species dominance, and interspecies predation in the last two decades. Herring, mackerel, and silver hake stocks were intensively fished by distant-water fleets during the 1970s, resulting in very low stock sizes and ultimately the curtailment of directed fishing. Coincident with the decline of the dominant pelagic stocks of herring and mackerel, sand lance increased greatly in abundance in the late 1970s and early 1980s. Large whale species (humpback whales, *Megaptera novaeangliae*, and fin whales, *Balaenoptera physalus*) had utilized herring and (probably) mackerel as main forage items before this time. The demise of the herring population on Georges Bank brought with it an apparent shift in the distribution of whale predators to more nearshore areas, particularly those where concentrations of the more abundant sand lance could be found. An important whale-watch industry developed as it became more obvious that large whales occurred a few miles offshore.

More recently, stocks of mackerel and, to some extent, herring have rebounded, in part because of very low fishing mortality rates. Both of these species are currently in little demand by domestic markets. Thus, the impetus to catch them has primarily stemmed from foreign countries where domestic or third-country markets for these species are stronger. Fishing by foreign countries on these stocks has, however, been severely limited under various FMP and PMP provisions. The abundance of spiny dogfish has likewise increased dramatically in recent years. Fishing mortality on this small shark is currently quite low because of weak domestic market demand. Thus, the main species of the pelagic system have to some extent been allowed to proceed on trajectories primarily dictated by interspecies predation and competition. Sand lance has declined in abundance in recent years, coincident with increases in mackerel (a predator of larval and juvenile sand lance) and herring (a competitor with sand lance for zooplankton prey).

It is thus apparent that the productivity and species composition of fishery ecosystems are contingent not only on explicit management decisions, such as fishing certain stocks, but also on the implicit management decisions made for species of little market value (e.g., sand lance, spiny dogfish) or that are otherwise ignored. The ecosystem effects of specific management regulations are not generally evaluated in such decision making, and there is no mechanism for identifying a target ecosystem configuration or set of desirable attributes to be maintained within the ecosystems. If significant harvesting of mackerel, herring, and sand lance should occur, there would be serious concern about the ability of these prey resources to simultaneously support high levels of predatory fish and marine mammal stocks.

Even when there are limited trophic interactions among regulated species, the attainment of simultaneous goals for various species may be compromised by the interjurisdictional nature of fisheries. Figure 27-2 depicts the institutional and fishery interactions associated with demersal fisheries for groundfish and pandalid shrimp in the Gulf of Maine region. Four major categories of demersal fisheries can be defined, based primarily on gear: large-mesh trawls, small-mesh trawls, gill net, and shrimp trawling. These fisheries are interrelated by the mixed nature of the catch and the associated discards. Although each fishery targets a different set of species, interactions among fisheries occur when (1) small-mesh fisheries discard undersized individuals of target species for large-mesh fisheries, (2) large-mesh fisheries discard animals selected by the gear, but below the minimum landing sizes, and (3) the fisheries operate simultaneously or sequentially, the effort thus influencing the availability of shared species to competing fisheries. Discards of groundfish in small-mesh and shrimp trawls are considered particularly problematic because shrimp and other small-mesh trawl fisheries operate in nearshore areas that are the primary nurseries for groundfish species.

There are no less than eight separate regulatory entities (including the three states) that are directly involved in managing components of the demersal fishery complex in the Gulf of Maine. The New England Fishery Management Council has developed an FMP for 13 of the most valuable groundfish species. The goals of this FMP are to attain, on a species-by-species basis, the target levels of the percentage of virgin spawning stock biomass per recruitment thought to provide adequate protection to spawning fish. Primary regulations implemented under the groundfish FMP are minimum mesh size regulations (for large-mesh fisheries) and minimum landing lengths for eight of the species. The shrimp fishery is regulated separately by a subcommittee of the Atlantic States Marine Fisheries Commission (a compact of Atlantic coastal states). Shrimping regulations specify a closed season (May–November) and a bycatch limit restricting landings of groundfish to a percentage of shrimp landings. Small-mesh fisheries for silver and red hake (*Urophycis chuss*) are regulated under the multispecies FMP. Other small-mesh target species, including spiny dogfish, are nominally managed as "other finfish" by a preliminary management plan promulgated directly by the National Marine Fisheries Service. The three coastal states (Maine, New Hampshire, and Massachusetts) control territorial seas (0–3 nautical miles)

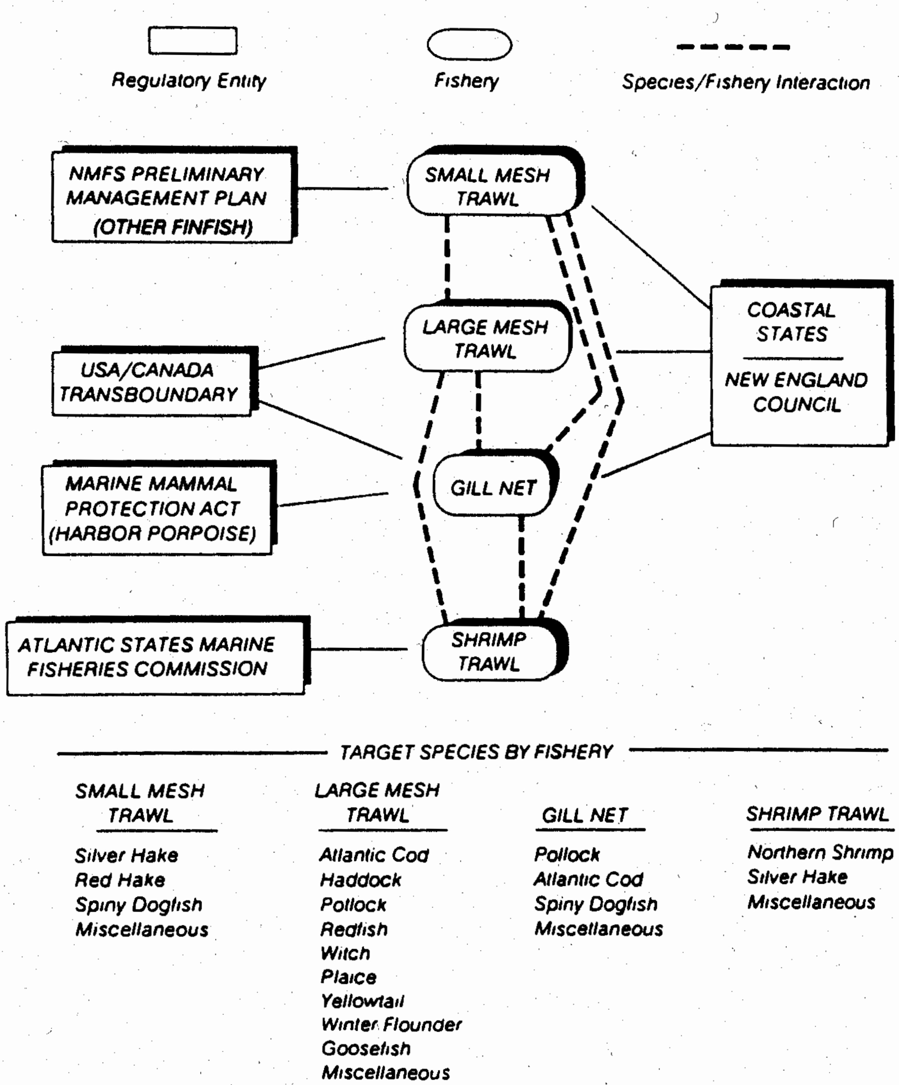

Figure 27-2. Schematic of institutional and fishery interactions among Gulf of Maine demersal fisheries. Dashed lines indicate fishery interactions resulting from multiple fisheries catching the same species but with different partial recruitment-at-age patterns.

and impose separate management programs that regulate portions of the contiguous groundfish and shrimp stocks. Some of the groundfish stocks of the region are distributed or migrate across the United States–Canada maritime boundary and are thus subjected to vastly differing management schemes in each country's waters. Finally, gill-net fishing in the Gulf of Maine has been classified as a fishery in which there may be frequent takes of marine mammals (harbor porpoise, harbor seal, and others). In the next several years, logbook data and at-sea observer coverage will further document the extent of marine mammal take. Regulation of this fishery will depend on the exploitation rate caused by incidental kills in relation to the trajectory of the marine mammal populations with respect to OSP goals.

Target spawning biomass-per-recruit levels for most Gulf of Maine groundfish species regulated under the multispecies FMP are currently not being achieved. Stock sizes and catches of the groundfish stocks have generally declined in response to significant increases in overall fishing effort in recent years. Shrimp and hake stocks have fared better than groundfish stocks in recent years and landings have been good. There has, however, been considerable debate over the potential negative effects of catch and discard patterns within the small-mesh fisheries, because such discarding may affect the attainment of groundfish management targets. The situation is complicated because individual vessels usually participate in several of both the large- and small-mesh fisheries on a seasonal basis. In winter months, effort is transferred from the large-mesh trawl and gill-net fisheries primarily to the shrimp fishery. Curtailment of the shrimp fishery would result in a significant short-term revenue loss to fishermen and would increase effort in alternative fisheries (such as large-mesh trawling) that already have excess effort. Likewise, further regulation of the gill-net fishery to reduce harbor porpoise bycatch may drive effort into other fleet sectors (small- and large-mesh trawling), thereby potentially exacerbating overfishing of groundfish stocks.

Some debates over the merits of regulating small-mesh fisheries of the Gulf of Maine center on potential technological innovation to minimize the bycatch of sublegal groundfish in the shrimp fishery (with so-called separator trawls) and around reductions in the geographical distribution and overall level of effort in small-mesh fisheries (Murawski et al. 1991). What has not developed is a clear consensus on an overall objective function from the several demersal fisheries as an interacting system rather than a series of nonrelated fisheries. Clearly, the attainment of percentage of spawning biomass-per-recruit targets for all important species simultaneously is highly improbable because of the technological interactions among fisheries. Potential criteria for developing an overall strategy include revenue and profit maximization, species diversity of landings and stock abundance, stability in overall catches or catch rates, employment maximization, and minimization of marine mammal kills. Currently, however, most debate focuses on addressing single-species issues. Without an overall perspective and management approach, it is doubtful that a consensus for resolution of fishery interaction issues can be developed. No single regulatory entity has the mission to do so.

Ecological Realities

The ecological determinants of multispecies/multifishery interaction result from three basic processes: (1) co-occurrence of animals in space and time; (2) simultaneous capture because of indiscriminate harvesting technique; and (3) interdependencies among species because of predator–prey or competitive interactions. Co-occurrence is a requisite for simultaneous capture, but the selection of co-occurring species can be influenced by choice of gear (e.g., trawls, set lines, gill nets). Similarly, co-occurrence is necessary for predation, but predation effects are dictated by numerous other processes including predator–prey size compatibility and behavioral characteristics.

Some of the most vexing of current multispecies management problems arise from what are scientifically the most tractable of the above determinants of species interaction. Two examples of the conflict between resource protection statutes and fishery management occur in the controversies surrounding the capture of protected sea turtles in shrimp fishing and the unintentional killing of marine mammals in fishing operations. In both of these cases, the conflict arises because of the inadvertent killing of the protected species, which are not allowed to be marketed. Attempts to minimize such negative interactions have had as their scientific goal understanding the ecological and behavioral attributes of the species involved, so as to determine the finest time and space scales at which interactions occur. These studies have been the basis for technological development (conservation fishing gear and procedures) as well as area–time management of the fisheries aimed at minimizing interactions. Research on mixed-species assemblages has as its basis the need to evaluate spatial and temporal patterns in resource co-occurrence as a basis for optimizing fisheries on mixed resources (Murawski and Finn 1988). Environmental determinants of species abundance and distribution are thus important ecological relationships to be considered in multispecies studies.

Species interactions and community structures are influenced in part by what explicit management decisions are made (extraction or protection of particular components), along with an array of implicit management decisions for unregulated resources. Fishery ecosystems will act to integrate these decisions within the constraints imposed by primary production, trophic efficiency, and such factors as ecosystem stability, resilience (return rate after per-

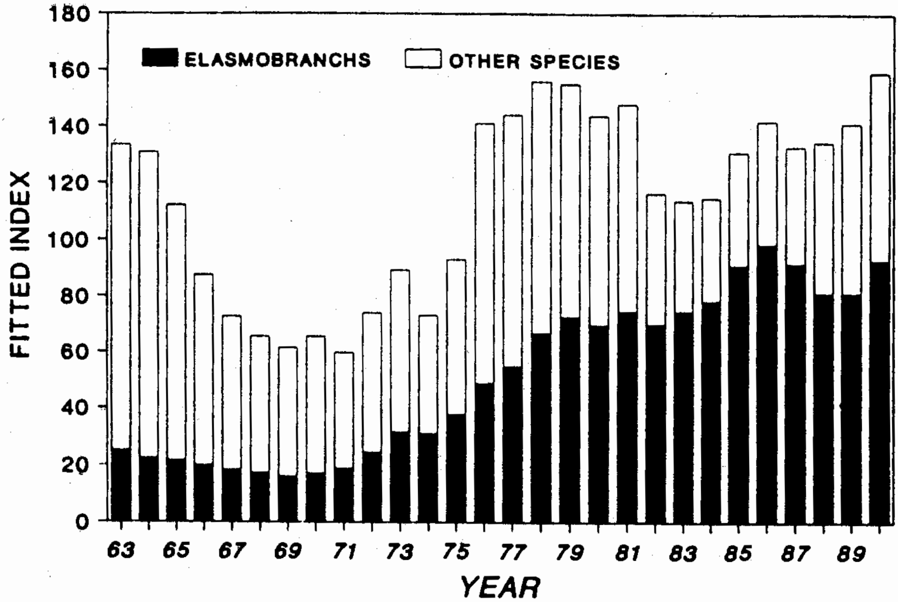

Figure 27-3. Bottom trawl survey abundance indices (in kilograms per tow, smoothed) for total mixed-species catches on Georges Bank, 1963–1990. Species are aggregated into two categories: small elasmobranch species (primarily spiny dogfish and seven species of skates) and other species (dominated by commercially valuable gadoid and flounder species).

turbation), and resistance [production flux related to species change (May 1974; Pimm 1982)]. The end result of the integration of these factors may be fishery ecosystems that are perfectly functional (and balanced), but that exhibit a number of undesirable characteristics from a biological or economic perspective.

An example of system state changes in reaction to alternative harvest policies is illustrated by groundfish fisheries from the Georges Bank region off the northeast United States. Figure 27-3 presents trawl survey data collected by the Northeast Fisheries Center. Trawl survey data are separated into two groups: small elasmobranchs (spiny dogfish and skates), and others (primarily commercially valuable gadoids and flounders). Abundance of both categories decreased precipitously during the 1960s, primarily in response to pulse-fishing by distant-water fleets. The proportion of elasmobranchs to other species remained relatively constant through this period, because distant-water fleets used virtually all trawlable species for human consumption or industrial purposes. Since the late 1960s, total trawlable biomass has increased to levels exhibited before intensive distant-water fisheries, but the proportion of elasmobranch biomass to that of other species has generally reversed. Marketable species have declined steadily in abundance since 1977, with spiny dogfish and skates constituting the bulk of research vessel catches in recent years. These patterns are corroborated by the species composition of commercial catches monitored at sea (Figure 27-4). Interestingly, multispecies size composition (relative numbers by length interval) has remained comparatively stable over the period, notwithstanding the dramatic changes in species composition (Murawski and Idoine 1989). This may imply that energy transfer among various functional trophic levels is a conservative process of such ecosystems and is thus preserved over a wide range of species compositional states. Whether species changes on Georges Bank are the result of biological interactions among species or are simply the result of differential fishing mortality rates remains conjectural. However, total biomass in the system does seem to have again reached a threshold. The ability to increase the abundance of marketed species may thus be limited by predation from or competition with the elasmobranch species.

Scientific Challenges

Management goals of preserving rare or otherwise protected species while allowing interacting fisheries to occur will test not only the ability of managers to effect appropriate system-based management policies, but also the ability of scientists to refine their understanding of the ecological determinants of species co-occurrence. Similarly, the goals of developing engineering solutions to reduce inadvertent captures while minimizing impact on otherwise legitimate fishing operations represents a very rigid set of specifications that bound a management resolution. The relative importance of the various criteria rests in the institutional and political arenas.

Our ability to direct fishery ecosystems toward a set of specific management goals is fundamentally dependent on our understanding of how such systems operate and how they respond to a complex set of simultaneous perturbations. The most robust set of predictions of community change are those based on empirical observation of the system at previous times, all else being equal (Sainsbury 1988). One problem with this approach is that even when time-series of data are sufficiently long, they usually encompass only a few selected ecosystem components (e.g., economic resources). Even then, our knowledge of dynamic relationships among components is usually fragmentary (Daan 1980).

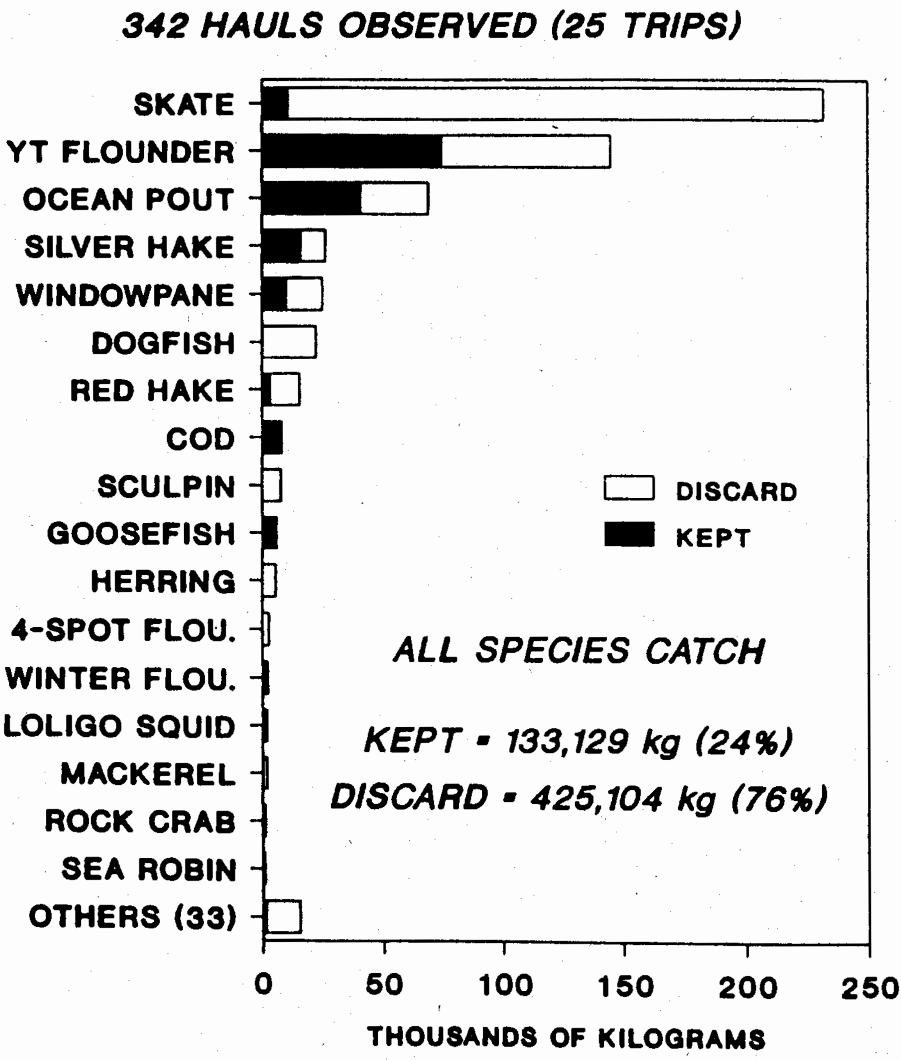

Figure 27-4. Species composition and disposition of the catch from otter trawl fishing for yellowtail flounder off the northeast United States in 1990. Data were obtained from trips on which scientific observers sampled catches at sea on a tow-by-tow basis. Landings from the trips are represented by the black bars and discards by open bars. Primary reasons for discards are the lack of markets for large quantities of some species (skates, dogfish, sculpin, etc.) and fish below legal minimum sizes (yellowtail flounder, Atlantic cod).

In the absence of historical analogy with which to predict ecosystem change, we must try to decipher the dynamic mechanisms underlying species and fisheries interactions. The basis for predicting changes in yield to a particular single- or mixed-species fishery (Y_i) involves analyzing the individual and cumulative effects of effort changes (*df*) in all associated fisheries (*j*):

$$dY_i = \frac{\delta Y_i}{\delta f_1} df_1 + \frac{\delta Y_i}{\delta f_2} df_2 + \ldots \frac{\delta Y_i}{\delta f_J} df_j$$

The matrix of partial derivatives of yield contingent on change of effort in each fishery (the Jacobian) specifies the relative magnitude and sign of yield change (tonnage or value) as a function of effort in the individual fisheries (ICES 1989). The individual matrix elements subsume the species interrelationships (predator–prey and competition) and the partial fishing mortality rates (F) generated on the mix of species taken by competing fisheries. Estimation of the elements of the matrix is an important requisite for management since it allows one to evaluate alternative management scenarios with respect to single- and multispecies goals.

The estimation of the Jacobian for technologically interrelated fisheries (such as the open-access Gulf of Maine system) may be every bit as complex as that for systems linked by biological interactions (ICES 1989, 1991). This is because of the complex set of factors determining fleet interactions, such as those controlling effort transfer among competing fisheries, the effects of catch and discards for mixed-species fisheries, and (in the case of economic yields) the economics of fishery production in relation to species abundance.

When fisheries target predators as well as prey, the Jacobian includes the feedback loops of instantaneous predation mortality rates (M2) on each prey species (i) and age group (j) caused by each predator species (k) and age group (l):

$$M2_{ijkl} = f[N_{ij},\ N_{kl}] \,|\, N_{ijkl} \ \forall \text{ i, j, k, l}$$

where $M2_{ijkl}$ is a function of the stock abundance (N) of prey species/age ij and predator species/age kl, and is contingent on the abundances of all potential predator and prey species (N_{ijkl}). The functional relationships between predation mortality rates and predator abundance in complex, many-species ecosystems depend on the availability and vulnerability of various alternative prey resources that are suitable for each predator group. Predation rates on particular species/ages of prey are thus likely to be highly dynamic. Abundance of each predator group is, of course, partially determined by the level of fishing mortality on them and by non-predation related sources of natural death (M1 + M2 = M). These equations apply as well to predator species that are not caught in directed fisheries but that may suffer mortality because of inadvertent bycatch, such as marine mammals (Harwood and Croxall 1988).

The estimation of dynamic feeding relationships depends on considerable knowledge of prey selectivity among the various predator species and ages, as well as the functional relationships of predation mortality to prey abundance (Holling 1965; Murdoch et al. 1975). Although estimation of such a set of variables or of functions is indeed a complex undertaking, it is within the capacity of current technical expertise and abilities to sample it in situ.

Such a project is ongoing for the North Sea fishery ecosystem (ICES 1989, 1991). A nine-species system including gadoids [cod; haddock (*Melanogrammus aeglefinus*); whiting (*Merlangius merlangus*); saithe (*Pollachius virens*); Norway pout (*Trisopterus esmarkii*)], herrings [Atlantic herring; sprat (*Sprattus sprattus*)], and others (mackerel; sand eel, Ammodytidae) is being modeled to evaluate the system-level effects of manipulating the harvesting intensity on fisheries for both predators and prey. The impetus to model the North Sea as a multispecies system stems from the long-term decline in stock biomasses of commercially important predator species (e.g., cod, haddock, whiting) combined with the development of large-scale industrial fisheries for prey species including sand eel, sprat, and Norway pout (Figure 27-5). Are these industrial fisheries for prey negatively influencing the human consumption fisheries for predators? A key element of the modeling has been an intensive stomach sampling program conducted in 1981 (the "Year of the Stomach" program), supplemented by additional years of feeding data for selected predators (cod, whiting).

The North Sea modeling approach has included a combination of retrospective analyses to tune the system to known fluctuations in catches of the various species as a basis of a forecast model for predicting changes in predation mortality rates in response to alternative fishing scenarios and fluctuations in recruitment. Results so far have challenged the scientific basis of some of even the most fundamental of single-species calculations supporting the fishery management decision process. For example, traditional yield-per-recruit analysis suggests that higher equilibrium cod yields would result from an increase in the trawl mesh size used when fishing for cod (see Figure 27-5). Multispecies calculations indicate, however, that because of the proportionally higher predation rate of larger cod on their young, and the release by the larger mesh of other species preying on young cod, the effect of increasing mesh size is, in fact, to reduce not only long-term cod yields but also yields for a variety of other species and the multispecies aggregate

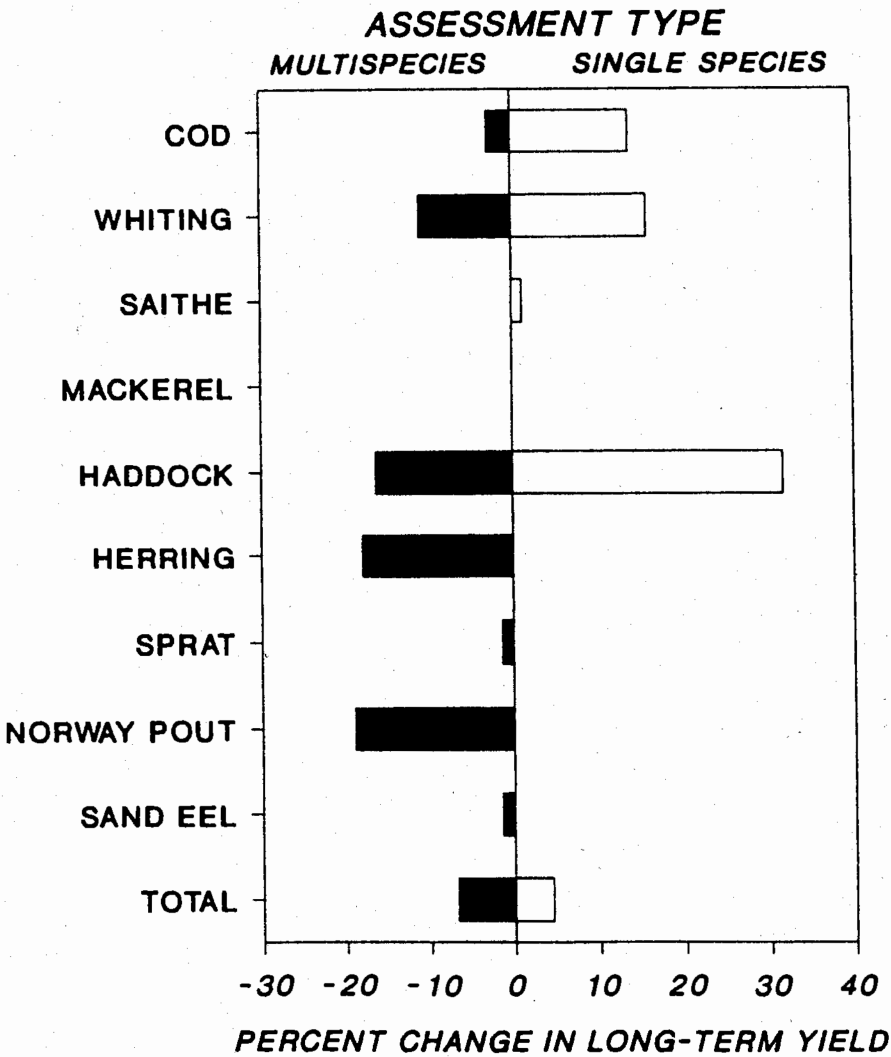

Figure 27-5. Percentage changes in long-term fishery yields for North Sea stocks resulting from an increase in trawl mesh size from 85 to 120 mm for the directed fishery for cod. Results are presented for traditional single-species/multi-fleet analyses, and for multispecies/multi-fleet analyses including interspecies predation rates. Lower yields in the multispecies cases result from greater predation rates from larger predatory fish (cod, whiting, haddock, saithe) released by the larger mesh (ICES 1989).

(see Figure 27-5). An ecosystem-level approach to this system thus indicates that even simple manipulations of the fishery may have complex interaction effects. Given the importance of these specific conclusions regarding the North Sea system, a repeat of the intensive 1981 stomach sampling project will be conducted in 1991 to better refine and validate the dynamic fishery models being constructed. An ecosystem-level approach thus need not entail a bottom-up understanding of all trophic levels contributing to fishery yields. As in the above example, fishery interaction studies are compatible with, and in fact require a basis in, traditional single-species population dynamics studies.

The challenges of providing a sound scientific basis for multispecies management relate both to understanding dynamic processes governing interactions and the precision of measurement of ecosystem change relative to the hypothesized process at work. It is possible, and indeed likely, that several alternative models of processes governing ecosystem change may be equally plausible, especially when beginning to analyze such problems (such as the Georges Bank example; see Figure 27-3). Sainsbury (1988) noted that three alternative models of fishery community change include (1) multiple single-species responses, assuming little interaction among species or fisheries; (2) biological interactions (predation and competition) governing system outcomes; and (3) changes in the physical environment (climate or habitat) that may alter community structure. Given our uncertainty about which of these mechanisms may dictate community dynamics, management of such systems must be regarded as experimental. Conducting fishery management programs as semi-controlled experiments implies that the system will be monitored with sufficient precision and scope to allow for testing of the original hypotheses of mechanisms governing the community. The scientific challenge then is to develop alternative hypotheses of mechanisms likely to govern community changes, and to put in place sampling programs that will ultimately allow rejection of untenable hypotheses.

Discussion

Can we manage our multispecies fisheries? Clearly, the operational word here is "manage." We can and are now manipulating our fishery ecosystems through a combination of explicit regimes (e.g., fishery regulations and protection statutes) and a series of implicit decisions for components for which there is little commercial or societal interest. The totality of such explicit and implicit manipulations determines current ecosystem structures and productivity. A far more compelling question is: Can we identify a target ecosystem structure and, through a series of management actions, manipulate the ecosystem toward that desired structure? A major impediment to achieving such a scenario is the lack of an institutional mechanism for doing so. Surprisingly, ecosystem goals can be and have been the subject of a number of international conservation agreements. Conservation objectives adopted under the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) include (1) prevention of any harvested populations from falling below levels ensuring greatest net increment to stable populations, (2) maintaining ecological relationships between harvested, dependent, and related populations, (3) restoring depleted populations, and (4) preventing or minimizing risks of ecosystem change that are not reversible over two or three decades (Sherman and Ryan 1988). The International Commission for the Northwest Atlantic Fisheries (ICNAF) adopted a "second tier" quota system (less than the sum of individual species quotas) expressly incorporating the interdependence of harvested populations and the mixed nature of fisheries into management regulations (Anthony and Murawski 1986). Implementing objectives similar to those of ICNAF and CCAMLR for the U.S. EEZ resources will necessarily engender contentious debate among various segments of the harvesting industries and those interested in protection of certain species in the ecosystems. The issues will be politically difficult to resolve and will tax the ability of current science to provide adequate bases for decision making. However, the consequences of failing to resolve such issues are that the ecosystems will integrate whatever explicit and implicit decisions are made, whether desirable or not. We will simply have to accept the level of and variability in production and species mix dictated by the cumulative effects of external forces (fishing, pollution, and physical environmental variability) and internal structuring mechanisms that regulate energy compartmentalization and flux. As a society, we will have to be more cognizant that our consumer preferences for types and sizes of living marine resources and our decisions regarding which species to exclude from exploitation may have complex feedbacks into the ecosystems that produce these resources (see Figure 27-4). Management approaches to resolving multispecies conflicts have generally been based on systems of disincentives (e.g., bycatch quotas, area and fishery closures). More effective management of these conflicts might result from positive incentive plans, but they have not been widely explored. As we more fully utilize the diverse resources of our marine fishery ecosystems and extend protected status to a wider array of endangered and threatened species, the necessity to consider multispecies effects and to find more workable approaches to their mitigation becomes ever more urgent.

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