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THE LARGE MARINE ECOSYSTEM CONCEPT: RESEARCH AND MANAGEMENT STRATEGY FOR LIVING MARINE RESOURCES[1]

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Abstract. The principles adopted by coastal nations under the terms of the United Nations Convention for the Law of the Sea (UNCLOS) have been interpreted as supportive of the management of living marine resources from an ecosystems perspective. Large marine ecosystems (LMEs) are described as regional units for the conservation and management of living marine resources in accordance with the legal mandates of UNCLOS. The principal forces driving large-scale changes in living marine resources vary among LMEs. Progress in the research and management of living marine resources and their biomass yields can be enhanced by comparing the multiple stable states among LMEs with regard to the causes of stress or perturbation on the system and the feedback of the system to stress. Ecological considerations that are presently shaping the management of biomass yields in several LMEs in the Pacific, Atlantic, and Southern Oceans are discussed.

Key words: biomass yields; fisheries; large marine ecosystems; law of the sea; living marine resources; management; overexploitation; perturbations; research; regional; scale.

INTRODUCTION

Large marine ecosystems (LMEs) are extensive areas of ocean space of ≥200 000 km^2, characterized by distinct hydrographic regimes, submarine topography, productivity, and trophically dependent populations (Sherman and Alexander 1986). The ecological concept that critical processes controlling the structure and function of biological communities can best be addressed on a regional basis (Ricklefs 1987) is consistent with the LME approach to research on living marine resources and their management. Living marine resources represent a major component of the community structure and dynamics of LMEs. Nearly all the usable biomass of living marine resources from the ocean is caught and processed in the form of fisheries products. Changes in the abundance levels of millions of megagrams (metric tons) of fish, molluscs, and crustaceans through human intervention in fishing or from natural environmental perturbations can alter the structure and dynamics of LMEs, generating cascading effects up the food chain to predators, including cetaceans, pinnipeds, and sea birds, and down the food chain to the plankton.

For nearly 75 yr after the turn of the century, fishery scientists were preoccupied with single-species stock assessments, while during this same period biological oceanographers did not achieve any great success in predicting fish yield based on food chain studies. As a result, through the mid 1970s the predictions of the levels of biomass yields for different regions of the world ocean were open to significant disagreement (Ryther 1969, Alverson et al. 1970, Lasker 1988). A milestone in fishery science was achieved in 1975 with the convening of a symposium by the International Council for the Exploration of the Sea (ICES) that was focused on changes in the fish stocks of the North Sea and their causes. The symposium, which dealt with the North Sea as an ecosystem, following the lead of Steele (1974), Cushing (1975), Andersen and Ursin (1977), and others, was prompted by a rather dramatic shift in the dominance of the finfish species of the North Sea from a balanced pelagic and demersal finfish community prior to 1960 to demersal domination from the mid-1960s through the mid-1970s. Although no consensus on cause and effect was reached by the participants, it was suggested by the convener (Hempel 1978) that the previous studies of seven-and-a-half decades may have been too narrowly focused, and that future studies should take into consideration fish stocks, their competitors, predators, and prey, and interactions of the fish stocks with their environments, the fisheries, and pollution from an ecosystem perspective.

Since 1975, large-scale changes in the fish components and their cascading effects in other marine ecosystems have been reported. Within the Northeast Shelf Ecosystem of the United States, changes in the structure and community dynamics are attributed to the effects of human intervention in the form of excessive fishing mortality (Clark and Brown 1977, Sissenwine 1986). The overfishing caused multimillion megagram biomass flips among the dominant pelagic components of the fish community (Sherman 1988). The biomass flip, wherein a dominant species rapidly drops to a low level to be succeeded by another species, can generate cascading effects among other important components

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of the ecosystem, including marine birds (Powers and Brown 1987), marine mammals, and zooplankton (Overholtz and Nicolas 1979, Payne et al. 1990).

Other sources of perturbations to marine populations of concern to management agencies are the incidental catches of marine mammals and the growing impacts of coastal pollution on biomass yields. Efforts to reduce stress and mortality on mammal components of marine ecosystems from incidental capture during fishing operations are being pursued (Bonner 1982, Loughlin and Nelson 1986, Waring et al. 1990). Pollution problems at the continental margins of marine ecosystems that impact on natural productivity cycles, including increases in frequency and extent of unusual plankton blooms in the vicinity of high nitrogen and phosphorus loadings of estuaries, toxins in poorly treated sewage discharge, and loss of wetland nursery areas to coastal development are also being addressed (GESAMP 1990). The growing awareness that biomass yields are being influenced by multiple but differing driving forces in marine ecosystems around the globe has accelerated efforts to broaden research strategies to encompass the effects of food chain dynamics, environmental perturbations, and pollution on living marine resources from an ecosystem perspective. Mitigating actions are required to ensure the long-term sustainability of biomass yields of LMEs. It would appear, therefore, appropriate to implement the ICES paradigm of the mid-1970s and address both research strategies and management issues aimed at the long-term sustainability of living marine resources at the large marine ecosystem scale.

Scientific and Legal Rationale to Management of LMEs

The legal framework for supporting the management of living marine resources from an ecosystem perspective can be found in the United Nations Convention for the Law of the Sea (UNCLOS) (Belsky 1989*a*, *b*). Nearly 95% of the usable annual global biomass yield of living marine resources is produced within the boundaries of the exclusive economic zones (EEZs) of coastal nations (e.g., fishes, crustaceans, molluscs, algae). Under the terms of UNCLOS, coastal nations assume responsibility for:

1) ensuring through proper conservation and management measures, that the maintenance of the living resources in the EEZ is not endangered by overexploitation.

2) promoting the optimal utilization of the living marine resources in the EEZ without prejudice to the need for conservation of those resources; and

3) the obligation to protect and preserve the marine environment and to take all measures necessary to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution from any source to other states and their environment (Juda and Burroughs 1990).

Although FAO world fishery statistics show an upward trend in annual biomass yields for the past three decades, it is largely the clupeoids that are increasing in abundance (FAO 1989). A large number of stocks have been and continue to be fished at levels above long-term sustainability. Are the variations in abundance levels among the species populations constituting the annual global biomass yields indicative of: (1) natural variability in regional ecosystem states? (2) pollution?, or (3) overexploitation? The principal driving forces for biomass changes vary among ecosystems (Sherman et al. 1990*a*).

On a global scale the loss of sustained biomass yields from LMEs from mismanagement and overexploitation has not been fully investigated, but is likely very large (Gulland 1984). It is clear that "experts" have been off the mark in earlier estimates of global yield of fisheries biomass. Projections given in "The Global 2000 Report" (United States Council on Environmental Quality 1980) indicated that the world annual yield was expected to rise little, if at all, by the year 2000 from the 60×10^6 Mg reached in the 1970s. In contrast, estimates given in "The Resourceful Earth" (Wise 1984) argue for an annual yield of $100–120 \times 10^6$ Mg by the year 2000. The trend is upward; the 1987 level of global fishery yields reached 80.5×10^6 Mg (FAO 1989). The lack of a clear definition of actual and/or potential global yield is not unexpected, given the limited efforts presently underway to improve the global information base on living marine resource yields. However, marine ecosystems are complex. Variations in time and space of their constituent elements are demanding to monitor, assess, and predict. Interventions by humans can have a stabilizing or destabilizing influence on the natural variability, and cause or accelerate large-scale shifts in ecosystems. Can information on the cause and effect of these shifts provide insights that can be used to improve management strategies? We are entering a time of uncertainty about the effects of change on human and environmental stresses on living marine resources. The consequences of additional stress on the structure and function of ecosystems sustaining the global fisheries are poorly understood. The present array of single-species and multispecies models needs to be augmented to consider variability from spatial and temporal effects on species interactions and environmental conditions.

The temporal and spatial scales influencing important processes in biological production in the sea have been the topic of a number of studies. The selection of scale in any study is related to the process under investigation. An excellent treatment of this topic can be found in Steele (1988). He indicates that in relation to general ecology, the best known work in fish population dynamics is represented by the early studies of Schaefer (1954) and Beverton and Holt (1957). Evolution to more holistic ecological models was introduced in the energy flow approach of Steele (1965), following the

TABLE 1. List of Large Marine Ecosystems for which syntheses relating to principal, secondary, or tertiary driving forces controlling variability in biomass yields have been reported in Conference and Symposium volumes through October 1990.

Large marine ecosystem	Volume*	Authors
United States Northeast Continental Shelf	1	M. Sissenwine
	4	P. Falkowski
United States Southeast Continental Shelf	4	J. Yoder
Gulf of Mexico	2	Richards and McGowan
	4	Brown et al.
California Current	1	A. MacCall
	4	M. Mullin
	5	D. Bottom
Eastern Bering Sea	1	Incze and Schumacher
West Greenland Sea	3	Hovgård and Buch
Norwegian Sea	3	Ellertsen et al.
Barents Sea	2	Skjoldal and Rey
	4	V. Borisov
North Sea	1	N. Daan
Baltic Sea	1, 5	G. Kullenberg
Iberian Coastal	2	Wyatt and Perez-Gandaras
Adriatic Sea	5	G. Bombace
Canary Current	5	C. Bas
Gulf of Guinea	5	Binet and Marchal
Benguela Current	2	Crawford et al.
Patagonian Shelf	5	A. Bakun
Caribbean Sea	3	Richards and Bohnsack
Gulf of Thailand	2	T. Piyakarnchana
Yellow Sea	2	Q. Tang
Sea of Okhotsk	5	V. V. Kusnetsov
Humboldt Current	5	Alheit and Bernal
Banda Sea	3	Zijlstra and Baars
Bay of Bengal	5	S. N. Dwivedi
Antarctic Marine	1, 5	Scully et al.
Weddell Sea	3	G. Hempel
Kuroshio Current	2	M. Terazaki
Oyashio Current	2	T. Minoda
Great Barrier Reef	2	Bradbury and Mundy
	5	Kelleher

* (1) Sherman K., and L. M. Alexander, editors. 1986. Variability and management of large marine ecosystems. American Association for the Advancement of Science Selected Symposium 99. Westview, Boulder, Colorado, USA. (2) Sherman, K., and L. M. Alexander, editors. 1989. Biomass yields and geography of large marine ecosystems. American Association for the Advancement of Science Selected Symposium 111. Westview, Boulder, Colorado, USA. (3) Sherman, K., L. M. Alexander, and B. D. Gold, editors. 1990. Large marine ecosystems: patterns, processes, and yields. American Association for the Advancement of Science, Washington, D.C., USA. (4) Sherman, K., L. M. Alexander, and B. D. Gold, editors. *In press.* Food chains, yields models, and management of large marine ecosystems. AAAS symposium proceedings volume. Westview, Boulder, Colorado, USA. (5) American Association for the Advancement of Science (AAAS). *In press.* Stress mitigation and sustainability of large marine ecosystems. Proceedings of a symposium held 1–6 October 1990, Monaco. AAAS, Washington, D.C., USA.

early pioneering approach of Lindeman (1942). However, as noted by Steele, they are unsuitable for consideration of temporal or spatial variability in the ocean. The concept of large marine ecosystems (LMEs) defines the scale of study as on the order of thousands of kilometres with regard to fish and fisheries yields, and represents consideration of spatial and temporal energy flow in relation to both human and natural factors determining variability (Sherman and Alexander 1986). In this approach, large-scale climatic or environmental changes are examined in relation to fisheries-yield patterns of marine ecosystems over a number of decades. Changes in the fish communities of LMEs can trigger a cascade effect involving higher trophic levels of marine mammal and bird populations, and lower trophic levels of phytoplankton and zooplankton, and the economies dependent on the resources of the ecosystems. A list of reports describing the effects of biological and physical perturbations on the fisheries biomass yields of 28 large marine ecosystems is given in Table 1. The questions generally posed by these investigations are not dissimilar from those posed a few years ago by Beddington (1984):

> *There are a number of scientific questions which are central to the rational management of marine communities, but all revolve around the question of sustainability.*
>
> *What levels of mortality imposed by a fishery will permit a sustainable yield? Are there levels below which a fish population will not recover? Can judicious manipulation of the catch composition of the fishery alter the potential of the community to produce yields of a particular type, e.g., high value species? Can a community be depleted to a level where its potential for producing a harvestable resource is reduced?*
>
> *With the exception of the first question, these questions and others like them are rarely explicitly addressed in the scientific bodies of the various fisheries' organizations. Instead, such bodies concentrate on the estimation of stock abundance and the calculation of allowable catch levels, although often implicit in the advice given by these bodies to management are a set of beliefs about the answers to such questions.*

Given the increasing number of responsibilities of government agencies for: (1) managing fisheries, (2) protecting endangered species, (3) mitigating pollution, (4) reducing environmental stress, and (5) restoration of lost habitat, it is not surprising that there is growing interest in approaching solutions to resource management problems from an ecosystem viewpoint. The topic of change and persistence in marine communities and the need for multispecies and ecosystem perspectives in fishery management relate to the reports of changing states of marine ecosystems (Sugihara et al. 1984). Collapses of the Pacific sardine in the California Current ecosystem, the pilchard in the Benguela Current ecosystem, and the anchovy in the Humboldt Current ecosystem, are but a few examples of cascading effects on other ecosystem components including marine birds (MacCall 1986, Croxall 1987, Burger 1988, Crawford et al. 1989).

Progress in fisheries research and management can be enhanced by comparing the multiple stable states among LMEs with regard to the cause of stress or perturbation on the system and the feedback of the system to stress as a quasi-experimental manipulation. As pointed out by Sugihara et al. (1984), fisheries exploitation generally falls short of a fully controlled manipulation. However, they do note in the continental slope area off Spain, within a region designated as the Iberian coastal ecosystem by Wyatt and Perez-Gandaras (1989), that the

> *. . . fishermen are clearing large hake, chimera, and sharks from a portion of the continental slope with the hope of creating a shrimp fishery. The possibility of a comparison of data on this system before and after removal of these fishes will make this perhaps the first large-scale marine fishery/removal experiment deliberately done under quasi-controlled conditions.*

This "quasi-controlled" experimental approach to management is not unique to the Iberian Coastal ecosystem. In the Yellow Sea ecosystem intensive fishing effort resulted in the depletion of demersal fish stocks and biomass yields. Between 1958 and 1968 fisheries yields declined from 180 000 Mg to <10 000 Mg. The fishing then shifted to pelagic stocks, reaching a level of 200 000 Mg in 1972, followed by reduction to <20 000 Mg of herring and mackerel in 1987. The fisheries of the Yellow Sea by 1982 had shifted from demersal species to pelagic anchovy and sardine with a total annual yield of all species 40% lower than the 1959 total (Fig. 1). The demersal fishing remains in a depleted state. In an effort to maximize economic yield, high-value species are being considered for introduction into the coastal waters of the Yellow Sea ecosystem to enhance the demersal fisheries. Chinese scientists are experimenting with the "grow-out" of juvenile fleshy prawn. They have experienced modest success in harvesting these introduced prawns in an ecosystem where the natural predator field has been reduced through overexploitation; now fishermen harvest catches of 10 000 Mg/yr of high-economic-yield shrimp (Tang 1989). In the Adriatic Sea ecosystem, artificial reefs or substrates were experimentally introduced for incorporating superfluous primary producers to enhance biomass yields of benthic molluscs, fish, and crustaceans (Bombace et al. 1989).

The concept of management to maximize benefits, taking account of the long-term value of learning about factors affecting renewable resources, has been described as adaptive management strategy by Walters (1986), Walters et al. (1988), and Collie (*in press*). The key to their strategy is to recognize and model alternative hypotheses about factors affecting fish production. They use two approaches. The passive approach identifies optimal management strategy based on average conditions across different stable states of the ecosystem. The active approach manipulates the population size to distinguish among alternative hypotheses. This is necessary in order to interpret principal forces driving changes in abundance levels in fish production among environmental, biological, and fishing effects. Sissenwine and Cohen (*in press*) have suggested that adaptive management strategy should be considered for the United States Northeast Shelf ecosystem to test hypotheses about species interactions and develop strategies to return the system to a more favorable state that will enhance biomass yield levels. In the application of adaptive management, options for mitigating the results of overexploitation or environmental perturbation appear to hold promise, but it is necessary to move with extreme caution given the uncertainties of multispecies interactions in LMEs. Although discussion of mitigation is speculative, those projects with potential for adaptive management should be carefully evaluated and tested.

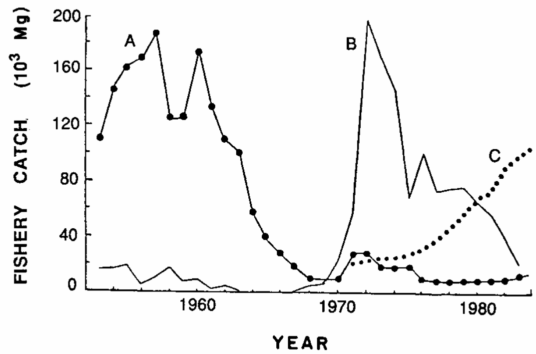

FIG. 1. Annual catch of dominant species of the Yellow Sea ecosystem, 1953 through 1984 (from Tang 1989): (A) small yellow croaker, *Pseudosciaena polyactis*; and hairtail, *Trichiurus haumela*; (B) Pacific herring, *Clupea harengus pallas*; and Japanese mackerel, *Pneumatophorus japonicus*; (C) half-fin anchovy, *Setipinna taty*, and scaled sardine, *Harengula zunasi*.

LMEs as Management Units

The topics of change and persistence in marine communities, and the need for multispecies and ecosystem perspectives in fisheries management, were reviewed at the Dahlem Conference on Exploitation of Marine Communities in 1984 (May 1984). The designation and management of LMEs is, at present, an evolving scientific and geopolitical process (Morgan 1988, Alexander 1989). Sufficient progress has been made to allow for useful comparisons to be made of the different processes influencing large-scale changes in the biomass yields of LMEs (Bax and Laevastu 1990). For example, a comparison of the sources of major mortalities of fish in five different ecosystems shows clearly that fish–fish predation is the largest single cause of mortality. Exploitation by humans approaches the level of fish predation in the North Sea, where consider-

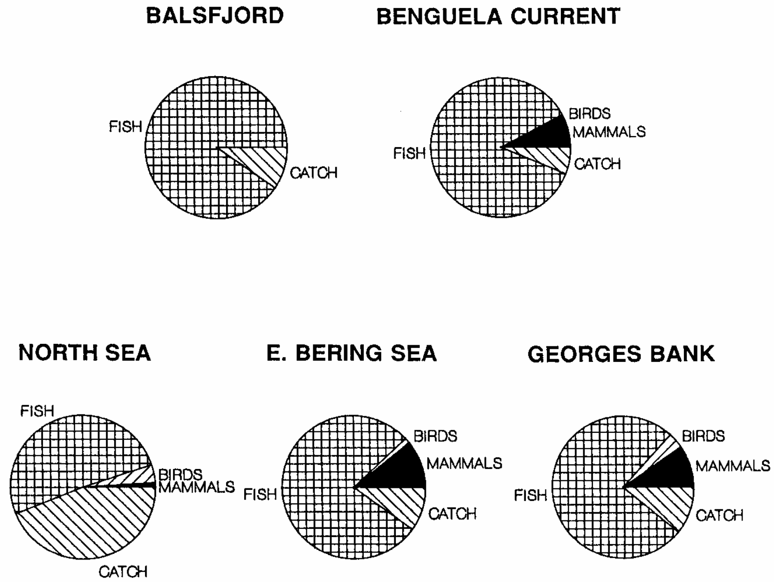

FIG. 2. Sources of major mortalities of fish in five different ecosystems (from Bax and Laevastu 1990).

able fishing effort is directed to species underutilized in other ecosystems (Fig. 2).

Among the ecosystems being managed from a more holistic perspective are: the Yellow Sea ecosystem, where the principal effort is being carried out by the People's Republic of China (Tang 1989); the multispecies fisheries of the Benguela Current ecosystem under the management of the government of South Africa (Crawford et al. 1989); the Great Barrier Reef ecosystem (Bradbury and Mundy 1989) and the Northwest Australian Continental Shelf ecosystem (Sainsbury 1988) under management by the state and federal governments of Australia; the Antarctic marine ecosystem under the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and its 21-nation membership (Scully et al. 1986, Sherman and Ryan 1988). Within the EEZ of the United States, the state governments of Washington and Oregon have developed a comprehensive plan for the management of marine resources within the Northern California Current ecosystem (Bottom et al. 1989).

The Northern California Current ecosystem

A multidisciplinary team of scientists and policy experts has prepared a plan for managing the Northern California Current as a large marine ecosystem. The objective of the plan is to minimize the risks of human disturbance that could lead to large-scale and irreversible changes to the ecosystem. According to D. L. Bottom of the Oregon Department of Fish and Wildlife, management activities within the northern California Current region presently are scattered among a large number of state and federal agencies whose jurisdictions divide the ecosystem along geographic and resource boundaries. Different agencies are responsible for managing marine birds, marine mammals, sport and commercial fisheries, pollutant discharges, dredging and disposal, and oil, gas, and mineral development. Preparation of a resource management plan for the Northern California Current ecosystem represents an important step toward integrated management. Ultimately, a regional structure or process will be necessary to coordinate management activities in Oregon with those in the state of Washington. Regional management is necessary to direct local resource uses in a manner that will minimize the risks of single or cumulative effects on an entire ecosystem. Species composition and oceanographic conditions indicate that the northern California Current region (Cape Mendocino, California, to Vancouver Island, British Columbia) represents an ecological unit that is appropriate for regional planning and management.

Research activities in the Pacific Northwest are segregated among many agencies and institutions. An integrated program of research is needed to assure that the sum of individual environmental studies yields the understanding that is required to manage the entire ecosystem. The Oregon Plan addresses several scales of information to support ecosystem management in the northern California Current region. Area-wide surveys are necessary to understand large-scale variability and to direct local development activities in a manner that will minimize risks to the ecosystem. Studies of single and local environmental effects are needed to develop lease stipulations, making siting decisions, and monitor performance (Fig. 3). Considering the high

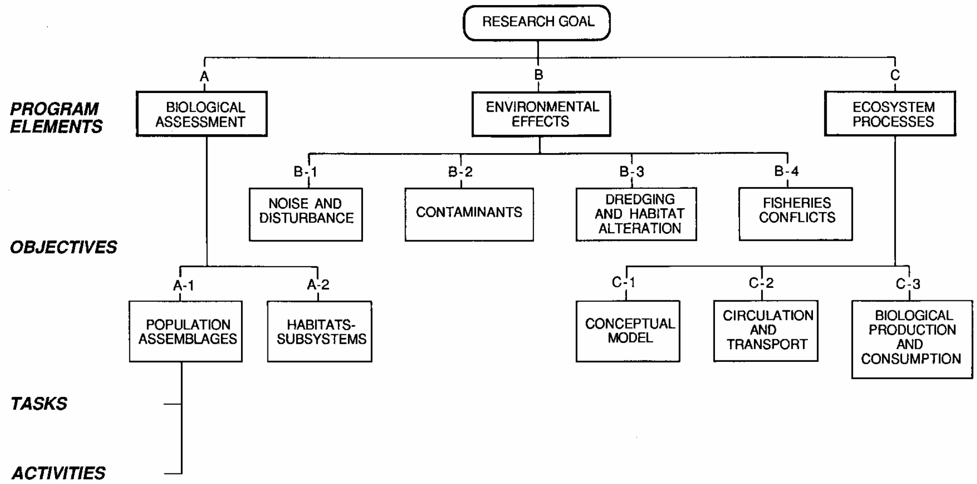

FIG. 3. Research objectives and tasks in the Ecosystem Processes Program Element of the Northeastern California Current Ecosystem study plan (from Bottom et al. 1989).

cost of oceanographic studies, wherever possible individual research activities should also consider the broader regional goals that are a mutual concern of many research agencies and institutions. The plan will be used to encourage cooperation among the many research interests in the northern California Current ecosystem (Bottom et al. 1989).

The Northeast United States Shelf

For three-and-a-half centuries the Northeast Shelf ecosystem has supported large, important common-resource fisheries. Utilization of the biomass yields from the fisheries extends from the export trade in salt cod of the early colonial period to the intensive exploration of total finfish biomass in the late 1960s and early 1970s. Heavy fishing mortality imposed on the resources by European factory fleets precipitated the passage of legislation by the United States in 1976 creating a Fishery Management Zone (FMZ) from the territorial seas of the United States seaward 200 miles. In 1983, the FMZ was declared by Executive Order of the President as part of the United States Exclusive Economic Zone (EEZ).

The LME encompasses 260 000 km^2, extending from the Gulf of Maine in the north to Cape Hatteras in the south (Sherman et al. 1988). The shelf ecosystem is among the most productive in the world. The annual biomass yields (e.g., crustaceans, molluscs, fish, algae) contribute $\$10^9$ annually to the economy of the coastal states from Maine to North Carolina. Uses of the Northeast Shelf ecosystem as a source of petrogenic hydrocarbons and as a repository for wastes has heightened concerns for the "health" of the ecosystem and its capacity for sustainable production of usable biomass. Adding to the concern is the loss of wetlands, aerosol fallout, and runoff of nitrogenous particulates contributing to coastal eutrophication. The strategic monitoring system required to measure long-term spatial and temporal variability of fish and other components of the ecosystem has been supported by the National Marine Fisheries Service and its Northeast Fisheries Center for several decades (Sherman et al. 1980, 1987, 1988, Sissenwine 1986, Azarovitz and Grosslein 1987, Brown 1987, Fogarty et al. 1987, Hennemuth and Rockwell 1987, Theroux and Grosslein 1987).

The offshore waters of the Northeast Shelf ecosystem do not show any adverse impacts of pollution. Impacts have been limited to periodic shellfish closures in small embayments to protect human health from pathogens; mortalities of benthic molluscs and crustaceans from anoxic events associated with unusual phytoplankton blooms; disease outbreaks among species being cultured for market (e.g., mussels, clams, oysters); and the periodic incidence of biotoxin-bearing dinoflagellates causing shellfishing closures as a protection to human health. Measured against increasing pollution-induced losses of marine resources, it is clear that the major impacts on living resources of the shelf ecosystem are the result of excessive fishing mortality (CUD 1989). The structure of the fish community has been significantly changed by overfishing over the past two decades. The highly valued gadoids have been significantly overfished and are in a depleted state. A growing mackerel and herring biomass is undergoing recovery from the overfishing of the early 1970s, and a large increase has occurred in low-valued elasmobranchs (spiny dogfish, skates) (Fig. 4); the latter component has increased within the Northeast Shelf ecosystem on Georges Bank from ≈24% of the fish biomass in 1963

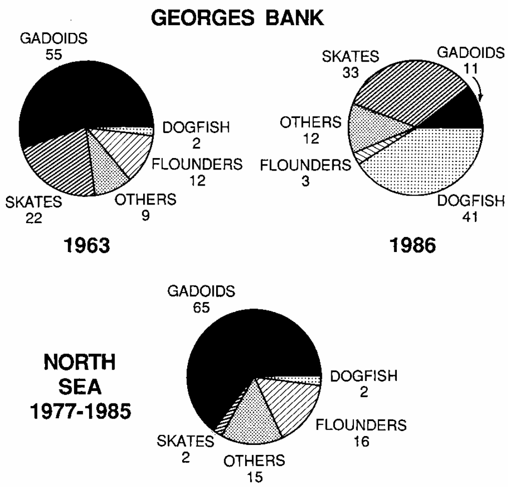

FIG. 4. Species shifts and abundance of small elasmobranchs (dogfish and skates) on Georges Bank within the Northeast Continental Shelf ecosystem of the United States compared with the North Sea ecosystem (from Sherman et al. 1990*b*).

to 74% in 1986. Management measures have been ineffective in enhancing the recovery of the highly valued gadoids. The major difficulty in achieving improved management results is the lack of selectivity of trawling and the large number of vessels engaged in the fisheries. Consideration is being given to the application of adaptive management strategies aimed at reducing the losses of long-term biomass yield of highly valued species through a controlled manipulation of predatory stocks (e.g., small elasmobranchs) when it can be quantitatively demonstrated that this is the best decision among an array of plausible options.

Comparative ecosystem studies can be instructive in the improvement of management strategies. For example, spiny dogfish and skates are predators of young gadoids, including cod and haddock. Their increase in abundance adds to the predation stress on gadoids on Georges Bank and in other areas of the Northeast Shelf ecosystem. The present fishery for small elasmobranchs in the Northeast Shelf ecosystem and on Georges Bank is rather limited. However, in the North Sea ecosystem where dogfish and skates are regularly fished, they represent only 4% of the fish biomass. Therefore, their predation impact on gadoids in the North Sea is diminished. The percentage composition of gadoids to other fish components of the ecosystem is significantly higher (Fig. 4).

Considerations in any management protocol for the Northeast Shelf ecosystem will need to account not only for the multispecies fish interrelationships, but also for the impacts of pollution on the nursery grounds of fish stocks and the interactions between fish and protected species, including pinnipeds and cetaceans.

No declining trend in the lower end of the food chain (e.g., phytoplankton, zooplankton) has been detected since the early 1900s (Sherman et al. 1983, 1987). The major driving force of the biomass yields of the Northeast Shelf ecosystem is human predation, thereby providing maximum options for the management of biomass yield from an ecosystem perspective (Sissenwine 1986, Sissenwine and Cohen, *in press*).

Global strategy

There is a growing awareness of the utility of the LME approach to resource management among marine scientists, geographers, economists, government representatives, and lawyers (Byrne 1986, Christy 1986, Alexander 1989, Belsky 1989*b*, Crawford et al. 1989, Morgan 1989, Prescott 1989). Effective management strategies will be contingent on the identification of the major, secondary, and tertiary driving forces causing large-scale changes in biomass yields. Management of species responding to strong environmental signals will be enhanced by improving the understanding of the physical factors forcing biological changes, whereas in other LMEs, where the prime driving force is predation, options can be explored for implementing adaptive management strategies. Remedial actions are required to ensure that the pollution of the coastal zone of LMEs is reduced and does not become a principal driving force in any LME. Concerns remain regarding the socioeconomic and political difficulties in management across national boundaries, as is the case of the Sea of Japan ecosystem, where the fishery resources are shared by five countries (Morgan 1988), or the North Sea ecosystem, or the 38 nations sharing the resources of the Caribbean Sea ecosystem. For at least one LME, the Antarctic, a management regime has evolved, based on an ecosystem perspective in the adoption and implementation of the Convention for the Conservation of Antarctic Marine Living Resources. Syntheses have been completed regarding the principal forces driving variability in biomass yields for 22 LMEs (Fig. 5). Effort is underway to manage fisheries biomass yields from an ecosystems perspective for seven LMEs within the United States Exclusive Economic Zone (Fig. 6). Within each of the LMEs, research is conducted on principal ecosystem components including the environment (e.g., temperature, regional climate, salinity, O_2 levels, variability in water movements), assessments of fish, mollusc, and crustacean resources, zooplankton, ichthyoplankton, cetaceans, pinnipeds, and sea turtles, and habitat protection of the wetlands and coastal zone including protected areas.

A systems approach to the management of LMEs is depicted in Table 2. The system allows for the LMEs to serve as the link between local events (e.g., fishing, pollution, storms) occurring on the daily-to-seasonal temporal scale and their effects on living marine resources, and the more ubiquitous global effects of cli-

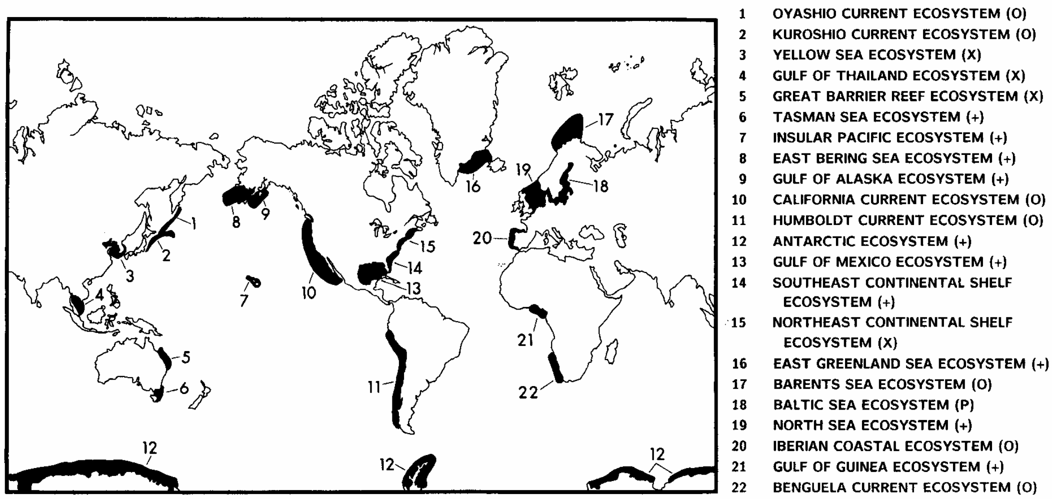

FIG. 5. Predominant variables influencing changes in fish species biomass in large marine ecosystems. Predominant variable: Predation (X); Environment (O); Pollution (P); Inconclusive Information (+).

mate changes on the multidecade time scale. The regional and temporal focus of season to decade is consistent with the evolved spawning and feeding migrations of the fishes, the keystone species of most large marine ecosystems. These migrations are seasonal and occur over hundreds to thousands of kilometres within the unique physical and biological characteristics of the regional LME to which they have adapted. As the fisheries represent most of the usable biomass yield of the LMEs, and fish populations consist of several age classes, it follows that measures of variability in growth, recruitment, and mortality should be conducted over multi-year time scales. This is necessary in order to interpret environmental, biological, and fishing effects on changing abundance levels of the year class to the populations of the species constituting the fish community, their predators and prey, and physical environment.

Consideration of the naturally occurring environmental events and the human-induced perturbations affecting demography of the populations within the ecosystem is necessary. Based on a firm, scientific understanding of the principal causes of variability in abundance and with due consideration to socioeconomic needs, management options can be considered for implementation from an ecosystems perspective.

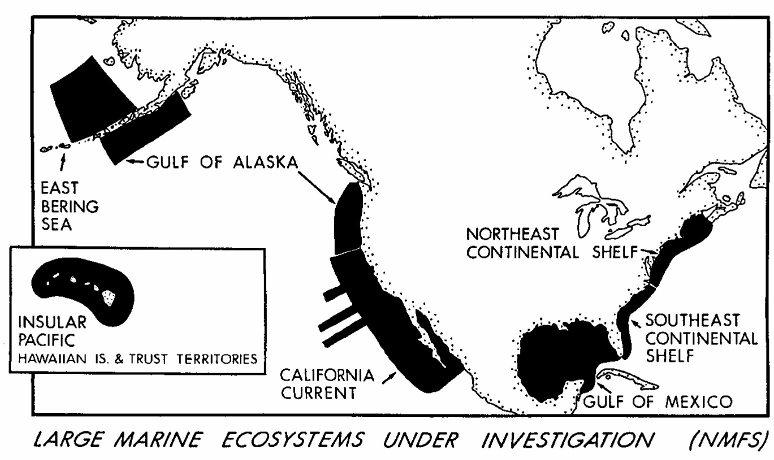

FIG. 6. Large marine ecosystems of the United States where the National Marine Fisheries Service of NOAA is conducting research. Projection based on NOAA folio map number 7 (NOAA 1988).

TABLE 2. Key spatial and temporal scales and principal elements of a systems approach to the research and management of large marine ecosystems.

Spatial	Temporal	Unit
1. Spatial-temporal scales		
1.1 Global (world ocean)	Millennia–decadal	Pelagic biogeographic
1.2 Regional (exclusive economic zones)	Decadal–seasonal	Large marine ecosystems
1.3 Local	Seasonal–daily	Subsystems
2. Research elements		
2.1 Spawning strategies		
2.2 Feeding strategies		
2.3 Productivity, trophodynamics		
2.4 Stock fluctuations, recruitment, mortality		
2.5 Natural variability (hydrography, currents, water masses, weather)		
2.6 Human perturbations (fishing, waste disposal, petrogenic hydrocarbon impacts, aerosol contaminants, eutrophication effects)		
3. Management elements—options and advice—international, national, local		
3.1 Bioenvironmental and socioeconomic models		
3.2 Management to optimize fisheries yields		
4. Feedback loop		
4.1 Evaluation of ecosystem status		
4.2 Evaluation of fisheries status		
4.3 Evaluation of management practices		

TABLE 3. Selected hypotheses concerning variability in biomass yields of Large Marine Ecosystems. References can be found in Table 1.

Ecosystem	Predominant variables	Hypotheses
Oyashio Current, Kuroshio Current, California Current, Humboldt Current, Benguela Current, Iberian Coastal	Density-independent natural environmental perturbations	Clupeoid population increases: Predominant variables influencing changes in biomass of clupeoids are major increases in water-column productivity resulting from shifts in the direction and flow velocities of the currents and changes in upwelling within the ecosystem.
Yellow Sea, U.S. Northeast, Continental Shelf, Gulf of Thailand	Density-dependent predation	Declines in fish stocks: Precipitous decline in biomass of fish stocks is the result of excessive fishing mortality, reducing the probability of reproductive success. Losses in biomass are attributed to excesses of human predation expressed as overfishing.
Great Barrier Reef	Density-dependent predation	Change in ecosystem structure: The extreme predation pressure of crown-of-thorns starfish has disrupted normal food chain linkage between benthic primary production and the fish component of the reef ecosystem.
East Greenland Sea, Barents Sea, Norwegian Sea	Density-independent natural environmental perturbations	Shifts in abundance of fish stock biomass: Major shifts in the levels of fish stock biomass within the ecosystems are attributed to large-scale environmental changes in water movements and temperature structure.
Baltic Sea	Density-independent pollution	Changes in ecosystem productivity levels: The apparent increases in productivity levels are attributed to the effects of nitrate enrichment resulting from elevated levels of agricultural contaminant inputs from the bordering land masses.
Antarctic marine	Density-dependent perturbations	Status of krill stocks: Annual natural production cycle of krill is in balance with food requirements of dependent predator populations. Surplus production is available to support economically significant yields, but sustainable level of fishing effort is unknown.
	Density-independent natural environmental perturbations	Shifts in abundance in krill biomass: Major shifts in abundance levels of krill biomass within the ecosystem are attributed to large-scale changes in water movements and productivity.

The final element in the systems approach is the feedback loop that allows for evaluation of the effects of management actions at the fisheries level (single species, multispecies) and the ecosystem level, with regard to the concept of resource maintenance and sustained yield. It will be necessary to conduct supportive research on the processes controlling sustained productivity of LMEs. Within several of the LMEs, important hypotheses concerned with the growing impacts of pollution, overexploitation, and environmental changes on sustained biomass yields are under investigation (Table 3). By comparing the results of research among the different systems, it should be possible to accelerate an understanding of how the systems respond to and recover from stress; the comparisons should allow for narrowing the context of unresolved problems and capitalizing on research efforts underway in the different ecosystems.

Global change in the form of ozone depletion, warming, and the greenhouse effect may become a source of stress on the biomass production of the oceans. The rather dramatic decades-long fluctuations in marine biomass yields, when considered in light of the growing concerns over global change, may serve to accelerate the movement toward adoption of LMEs as regional units for the conservation and management of living marine resources under existing maritime law.

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