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Definitions of overfishing from an ecosystem perspective

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Ecosystem considerations may be incorporated into fisheries management by modifying existing overfishing paradigms or by developing new approaches to account for ecosystem structure and function in relation to harvesting. Although existing concepts of overfishing have a strong theoretical basis for evaluating policy choices and much practical use, they do not provide direct guidance on issues such as biodiversity, serial depletion, habitat degradation, and changes in the food web caused by fishing. There is, however, little basis for defining optimum fishing by using related metrics such as diversity indices, slopes of size or diversity spectra, or average trophic level of the catch, and these may produce ambiguous results. If ecosystem-based overfishing concepts are to assume a greater role in management, unambiguous, quantifiable, and predictive measures of ecosystem state and flux must be developed to index: (1) biomass and production by the ecosystem and relationships among its parts, (2) diversity at different levels of organization, (3) patterns of resource variability, and (4) social and economic benefits. Ecosystem considerations do not need to substitute for existing overfishing concepts. Instead, they should be used to evaluate and modify primary management guidance for important fisheries and species. In practice, they emphasize the need to manage fishing capacity, supported by broader use of technical measures such as marine protected areas and gear restrictions.

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Key words: biodiversity, ecosystem overfishing, fisheries management, habitat effects of fishing, serial depletion, trophic impacts of fishing.

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What is ecosystem overfishing?

> "*I shall not today attempt to further define the kind of materials I understand to be embraced within that shorthand definition; and perhaps I could never succeed in doing so . . . but I know it when I see it.*"
>
> Former USA Supreme Court Justice Potter Stewart, writing on "obscenity"

It is often suggested that many serious problems facing the world's living marine resources stem in part from the failure of management and governance structures to adopt a holistic "ecosystems approach" – fisheries management and species conservation being too narrowly focused on single-species stock status and control strategies. If so, then it is appropriate to consider how concepts such as sustainable fishing – and overfishing – would be defined, how systems might be assessed and managed, and what additional benefits could be expected from an explicit ecosystems orientation. What might be accomplished by defining ecosystem overfishing criteria and management measures that could not be achieved under existing overfishing paradigms? Can fisheries research provide a quantitative basis for defining ecosystem overfishing, and what monitoring information would be necessary to support ecosystem-based management?

Sustainability and biodiversity are frequently cited explicitly as objectives of ecosystem management (National Research Council, 1999). Yet, in a recent review, Larkin (1996) noted the difficulty of translating these concepts and others such as "ecosystem health" and "ecosystem integrity" into operational definitions sufficiently objective and measurable for use in resource management. Modern fisheries management, as it is increasingly embodied, requires qualitative and (preferably) quantitative measures of the expected benefits, costs, and risks associated with alternative policy choices, with respect both to target and non-target species. It is further argued that the full range of ecosystem "goods and serivces" be factored into this accounting (Lubchenco *et al.*, 1991; National Research Council, 1999). However, expanding the scope of benefit-cost analyses beyond the current focus on

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Table 1. Alternative approaches for including ecosystem considerations in definitions of overfishing.

Ecosystem perspectives on existing definitions	Ecosystem-based definitions
Focus on:	
● Established paradigms:	● Ecosystem properties:
– Growth overfishing species, assemblages	– System production/biomass
– Recruitment overfishing, stock recovery, resilience of species	– Trophic composition
– MSY/MEY at various levels of organization	– Diversity
– Protected species management (special cases of recruitment overfishing and stock recovery)	– Sustainability (variability)
	– Resistance to abiotic forcing factors
	– Habitat-modifying effects of fishing activities
	– Choices among multiple stable states
Choice of control (reference) points:	
● Primarily decision-theoretic	● Primarily heuristic
Emphasis on conservation of:	
● Parts	● Processes and interrelationships

resource stocks is difficult owing to the lack of sufficient science with which to assess the full range of potential interactions among species, their physical environment, and the policy choices that must be made (i.e., when, where, and how much to fish). The lack of such information has hindered the development of clear and measurable quantitative goals relating to emergent ecosystem properties. Likewise, institutional arrangements for managing whole ecosystems are rare, because marine resource management is only one of many human activities affecting marine systems. The most compelling unmet needs for ecosystem management are the clear articulation of objectives and the development of appropriate metrics of ecosystem attributes to gauge progress in attaining such objectives (Done and Reichelt, 1998). Despite these deficiencies, it can still be argued that many fisheries failures resulted not from the lack of consideration of ecosystem issues but because of systematic overfishing and destructive harvesting practices for which existing scientific paradigms offered appropriate prescriptive advice (ICES, 1995).

There is no consensus on criteria for defining ecosystem overfishing, nor on a hierarchy of biological attributes for which ecosystems should be managed. However, it is possible to develop criteria by which a candidate ecosystem overfishing definition might be assessed. I compare the consideration of ecosystem perspectives on traditional paradigms used for defining and controlling overfishing with the concept of an explicit definition of ecosystem-based overfishing (Table 1). This dichotomy may be a useful, if artificial, device to focus critical thinking. Attributes of a broad definition of ecosystem overfishing are discussed, and a provisional definition, consistent with these attributes, is proposed. The criteria proposed are evaluated in the context of changes observed in three well-documented marine fishery ecosystems. I further discuss research and management implications of increased emphasis on ecosystem effects of fishing.

Traditional overfishing paradigms

Traditional concepts of overfishing (growth overfishing, recruitment overfishing, maximum sustainable yield – MSY, maximum economic yield – MEY, potential biological removals – PBR – of marine mammals, etc.) have their genesis in single-species population dynamics and stock assessment. These concepts implicitly include ecosystem attributes such as the assumption of logistic growth in production models or inclusion of natural mortality rates in dynamic pool models, but management advice is primarily generated for the single-species, single-fishery case. However, experience has taught us that for single-species concepts of overfishing to be relevant in the real world, elaboration of the concepts and models supporting them is needed to provide practical management advice consistent with important ecosystem considerations (Table 2). Ecosystem attributes that bear on the development of optimal fishing strategies for species and assemblages of resources include: technical (by-catch) interactions, biological interactions (including predation and density dependence), the impacts of abiotic (climatological) factors on species and fisheries, spatial processes (the geographic range of stocks and fisheries, and patterns of density and catchability), and temporal (seasonal, annual, decadal) scales. Considerable effort has been undertaken to evaluate the implications of these attributes as they apply to management under existing overfishing paradigms. In particular, research on biological interactions has focused on comparing the efficacy of single-species management reference points with those derived when accounting for species interactions. In practice, management has concentrated on issues arising from technological

Table 2. Ecosystem perspectives on overfishing definitions: comments and supporting literature indicate how existing single-species concepts have been modified to account for some ecosystem attributes.

Ecosystem attribute				
Technical interactions	Biological interactions	Climate forcing	Spatial processes	Temporal scale
Growth overfishing:				
Species, assemblages	Communities; density dependence	Variation in vital rates	Variability in stock overlap	Equilibrium vs. transitional effects
Recruitment overfishing:				
Relative status of assemblage components	Depends on functional response of predators	Variation; serial correlation in recruit survival	Depensatory fishing and natural mortality at low stock sizes	
Stock recovery:				
Avoiding stock depletion	Changes in natural mortality; competition among species	Greater uncertainty in recovery at low stock sizes	Density-dependent range; effects on catchability; MPAs	Differential recovery rates among commercial stocks
MSY/MEY:				
Maximize individual stock yields; optimize assemblages	Community optima	Regime-dependent yields		Ability to maintain desired state; discount rate for MEY
Protected species management:				
By-catch management	Adequacy of prey; effects as predators			Differential dynamics of protected and target species
Selected literature:				
Beverton and Holt, 1957; Murawski, 1984; Sainsbury, 1984; Pikitch, 1988; Alverson *et al.*, 1994	Brown *et al.*, 1976; Pope, 1979; Hildén, 1988; Rice *et al.*, 1991; Sullivan, 1991; Sparre, 1991; Brander and Mohn, 1991; Overholtz *et al.*, 1991; Bax, 1998; Flaaten, 1998; Gislason, 1999; Hollowed *et al.*, 2000	Myers *et al.*, 1995; Steele, 1998; Hoffman and Powell, 1998	MacCall, 1990; Allison *et al.*, 1999	

interactions caused by species co-occurrence. The utility of approaches such as marine protected areas (MPAs) requires information on spatial processes, which is only recently receiving appropriate attention. Mapping of ecosystem attributes into overfishing concepts (Table 2) represents the translation of theory into practical considerations for management, as it is currently done.

Elaborating existing overfishing concepts as an approach to resource management has the advantage of building upon the strong theoretical basis developed so far. This includes a quantitative basis for optimization of fishery yields, minimization of fishery impacts associated with protection of some species, and, because of the long history of information collected, a quantitative basis for risk assessment (Smith *et al.*, 1993; Wade, 1997). In theory, existing overfishing concepts can be extended to an even wider array of exploited and non-exploited species, with models developed to evaluate the increase in interaction effects that will accompany the inclusion of more stocks. However, the practicality of this has limits. Because of the structure of most fishery management plans, emphasis is generally placed on conservation of individual species, particularly those having significant current or past economic importance. Trade-offs between species yields to accomplish optimum aggregate yields or other objectives related to protected species are usually extremely difficult to establish, owing to the specialization among fisheries and targets, and to the mandates of various laws and interest groups to restore populations to their theoretical maxima. Thus, current management is characterized as being concerned primarily with "conservation of the parts" of systems, as opposed to the interrelationships among them (Table 1). The limitation of the current approach is that, in most situations, considerations of links to non-economic species or habitat effects of fishing gears are qualitative at best. Diversity (e.g., genetic, stock structure within species, or interspecies) is not an explicit objective, and maintenance of functional relationships among various ecosystem components may be confined to a few critical links, if it is considered at all.

Ecosystem overfishing definitions

Considerable scientific research has recently been directed to evaluating ecosystems with regard to the determinants of fish production (e.g., primary production, trophic efficiency, species diversity) and the factors influencing important ecosystem processes and interrelationships (Pauly and Christensen, 1995). Concern for biodiversity stems, in part, from the finding that overfishing of higher-trophic-level fish stocks (i.e., piscivores) generally results in refocusing of fishing effort on planktivores and a concomitant decline in the average trophic level of the landings (Pauly *et al.*, 1998). Owing to trophic efficiencies, fishing at lower trophic levels is less problematic and should result in increased yields. However, food webs may be significantly disrupted by this pattern of "fishing down the food chain", with cascading implications for the stability of stocks and ecosystems (Christensen and Pauly, 1995; Christensen, 1996; Pace *et al.*, 1999). A fishing strategy involving sequential depletion of higher-trophic-level stocks thus seems risk prone (Christensen, 1996).

One characteristic of overfished ecosystems is sequential depletion of economic stocks (Orensanz *et al.*, 1998). Switching between target species occurs when resources of economic importance are markedly reduced in abundance by overfishing and when there are other more abundant stocks available. Piscivores and valuable invertebrate stocks are particularly vulnerable to this fishing pattern (Christensen, 1996; Oresanz *et al.*, 1998). Overfishing and depletion of some stocks may become so severe that they may be regarded as economically extinct. The symptoms of ecosystem overfishing include: reductions in diversity; reductions in aggregate production of exploitable resources; decline in mean trophic level, increased by-catch; greater variability in abundance of species; greater anthropogenic habitat modification (Hall, 1999); and, in extreme cases, change to alternative stable species regimes (Steele, 1998). The key question is: can these symptoms constitute a quantitative basis for defining ecosystem overfishing and for developing control strategies to prevent or recover overfished systems?

Indices of species diversity, trophic composition, and ecosystem productivity have been applied widely in fisheries science. For example, the slope of the multispecies size-spectrum of fishes has been used to interpret changes in overall harvest patterns within and among ecosystem (Rice and Gislason, 1996; Bianchi *et al.*, 2000). The slope of the descending limb of the spectrum integrates rates of growth, recruitment, and natural and fishing mortality (Murawski and Idoine, 1992); changes in the slope are indicative of the cumulative effects of these processes. Diversity-at-size distributions (diversity spectra) of fishes also exhibit a descending right-hand limb. Intensive and/or size-selective fisheries may reduce diversity in larger ecosystem components faster than in the ecosystem as a whole. Different diversity measures have a specific sensitivity to changes in weight or numbers, dominant or rare species occurrences, evenness among species and other attributes, and some indices will increase with more intensive exploitation. Thus, no consensus has developed on the utility of traditional diversity indices as a measure of ecosystem overfishing (Jennings and Reynolds, 2000; Rice, 2000).

As a basis for defining optimal harvest policies for ecosystems, the use of indices measuring species diversity and trophic composition creates several fundamental problems. Because there is little theoretical basis for how these indices change in response to harvesting, a specific index value is not necessarily associated with an optimum resource state. While arbitrary thresholds may be established (a minimum slope of the size spectrum, a minimum diversity index, etc.), it is not possible to predict how specific management measures would affect these metrics. More complex models would be required that take into account functional interrelationships among components. As the indices are based on multi-species information, the relationship between species compositions and these metrics will be confounded, posing the complication that major changes in economically or ecologically important species will be subsumed in the overall index. If these metrics are intended only to measure system complexity and functional relationships, then they may be adequate. However, they are probably insufficient to address fishery management concerns related to key economic or protected species.

Despite these problems, it is important to link the totality of management measures within fishery systems to system production and diversity, in ways that cannot at present be accommodated into traditional overfishing paradigms. Comprehensive definitions of overfishing, incorporating multiple organizational scales (management stock, species, assemblage, community, ecosystem), could help to identify ecosystem attributes that are not adequately addressed under single-species management. Such definitions could also help in evaluating trade-offs among managed components when incompatibilities exist.

Attributes of ecosystem overfishing

At any organizational level, the foremost consideration in any definition of overfishing is that the status of the resource can be quantified relative to the definition. Even if the specific target level (fishing mortality, stock size, mean trophic level, slope of biomass spectrum, etc.) is determined arbitrarily, the resource assessment and evaluation system must supply accurate and reliable information to determine status of the resource. Ideally, the definition should also relate to the optimization of some ecosystem characteristic, leading to tangible benefits resulting from fishing at or below the overfishing thresholds. In principle, any quantitative definition of overfishing can be cast in a risk framework, although the link between the failure to achieve definitions (e.g., overfishing) and specific consequences has yet to be established for any of the propsed ecology-based metrics.

Apart from our ability to quantify resource status, what other attributes are appropriate to definition of ecosystem overfishing? Larkin (1996) indicates that there are three primary elements of ecosystem management: sustainability of yields, maintenance of biodiversity, and protection from the effects of pollution and habitat degradation. Translating these goals into control strategies requires that management actions be linked to measurable attributes, the most important of which are:

- Biomass and production of important system components – Total system production available for harvest (“surplus production”) is generally maximized at an intermediate level of biomass for ecosystems as well as individual stocks. Reduction of biomass to low levels induces greater variability in yields and recruitment, and increases the likelihood of unpredictable regime shifts caused by ecological disrupture.
- Diversity – Excessive exploitation can influence diversity at various levels of organization, owing to size (genetic) and species selectivity of fisheries. When fisheries alter the relative abundance patterns among stocks, predator-prey relationships may be disrupted with cascading effects through the food chain. Although extirpation of stocks and extinction of species in the marine environment is rare, many once-abundant species have been fished to depletion.
- Variability – Several types of resource variability (temporal, spatial, resistance and resilience, recovery times of depleted resources) can be used as measures of sustainability. Highly perturbed systems tend to exhibit greater year-to-year variation in yields (particularly at the stock level) and recruitment. Geographic distributions of stocks may change with abundance (MacCall, 1990), influencing relationships among species. Different stocks may recover at different time scales.
- Social and economic benefits – The explicit inclusion of socio-economic benefits in ecosystem management implies that the systems are managed for the highest net benefits to society consistent with other biological objectives.

Existing management programmes address some of these considerations, but comprehensive management of the ecosystem must address them all. Traditional approaches to defining overfishing emphasize yield maximization, through maintenance of stock biomass of selected species. Yield goals (at least at the stock level) are broadly consistent with optimization of economic benefits. Valuation of total socio-economic benefits is complicated in the case of protected species, and in implementing MPAs for purposes of nature conservation. Resource stability is usually considered an implicit goal of fisheries management, but greater emphasis is needed as sustainability and diversity of resources becomes an explicit objective of stock and ecosystem management.

It is inconceivable that any single metric could result in the simultaneous achievement of optima related to the ecosystem attributes listed above. Thus, there is no specific ecosystem analogue to single-species definitions of overfishing – no value of a single metric, that if attained, would result in the avoidance of ecosystem overfishing. This is not to say that concepts such as MSY cannot be used to aid in the development of optimum harvesting strategies for significant parts of the ecosystem consisting of assemblages of interacting species (Pope, 1979).

Even though a single, utilitarian metric of ecosystem overfishing cannot be defined, the development of explicit ecosystem overfishing criteria may be appropriate to judge the cumulative effects of various management programmes. By using such criteria, it may be possible to establish multiple tiers of measures to address issues not adequately covered by species-oriented management. Based on this approach, a comprehensive set of ecosystem overfishing criteria may be proposed. Ecosystems can be considered overfished when cumulative impacts of catches (landings plus discards), non-harvest mortality, and habitat degradation result in one or more of the following conditions:

- Biomasses of one or more important species assemblages or components fall below minimum biologically acceptable limits, such that (1) recruitment prospects are significantly impaired, (2) rebuilding times to levels allowing catches near MSY are extended, (3) prospects for recovery are jeopardized because of species interactions, or (4) any species is threatened with local or biological extinction;
- Diversity of communities or populations declines significantly as a result of sequential "fishing-down" of stocks, selective harvesting of ecosystem components, or other factors associated with harvest rates or species selection;
- The pattern of species selection and harvest rates leads to greater year-to-year variation in populations or catches than would result from lower cumulative harvest rates;
- Changes in species composition or population demographics as a result of fishing significantly decrease the resilience or resistance of the ecosystem to perturbations arising from non-biological factors;
- The pattern of harvest rates among interacting species results in lower cumulative net economic or social benefits than would result from a less intense overall fishing pattern or alternative species selection;
- Harvests of prey species or direct mortalities resulting from fishing operations impair the long-term viability of ecologically important, non-resource species (e.g., marine mammals, turtles, seabirds).

If these criteria are used to modify management programmes based initially on more-quantitative overfishing criteria for species and species groups, the effect is likely to result in more conservative management of fishing capacity and greater attention to habitat and species-interaction effects of possible measures. While it would be difficult to conclude that an ecosystem was being systematically overfished if, for example, optimum fishing mortality was not achieved for a few species in the system, the recovery of depleted species of past economic or ecological importance may justify additional measures not usually associated with single-species management. Would the application of these criteria lend anything substantive to existing management programmes? To examine this question, I applied these criteria to three case studies of fishery ecosystems generally believed to exhibit signs of ecosystem overfishing (Hall, 1999; Table 3).

Discussion

High exploitation rates characteristically influence abundance and yields of resource species, but at what point should managers be concerned with ecosystem effects? In the three case histories reviewed (Table 3), prescriptive advice to improve fishery yields of important, high-value species groups recommended reductions in fishing mortality (effort) to levels far below those of the recent past. In the Gulf of Thailand and the North Sea, fishing mortality on demersal resources remains well above recommended rates, but aggregate yields remain high, even if they may not be maximized. For the Northeast USA shelf, the decline in the groundfish resource, combined with restrictive management directed to that component, has resulted in the predictable scenario of serial depletion. Likewise, the average trophic level of the Northwest Atlantic catch has declined in response to the scarcity of higher-level predators (Pauly *et al.*, 1998).

Situations such as those existing off the Northeast USA could benefit greatly from a more formal mechanism to incorporate ecosystem perspectives in the development of management goals and conservation measures. Fishery management plans in the northeastern US are currently developed for sets of stocks linked by technological interactions, traditional fisheries, and/or life histories (groundfish, scallop, small pelagics, etc.). Most regulatory effort concentrates on historically important species groups; only recently have programmes been enacted for some other component species to which effort has been shifted. By-catch of species under strict management measures in these alternative fisheries can be problematic, and trophic interactions (e.g., between small pelagics and groundfish, or groundfish and dogfish) are considered peripherally (if at all) in establishing measures for controlling mortality on particular target species or assemblages. A comprehensive approach to effort management would anticipate shifts among targets and provide a fresh perspective on system-wide optimum harvests. The practice of allowing many species to remain outside any management control until they show signs of overfishing encourages excess capacity and serial depletion, and exacerbates by-catch problems.

Management of the Gulf of Thailand ecosystem would also appear to require more explicit consideration of ecosystem effects. The current dominance of shrimps and cephalopods causes a different stream of benefits from the one that would be derived under a reduced exploitation scenario, which is projected to result eventually in a species configuration similar to the one observed in the early period of the fishery (Christensen and Pauly, 1998). Achieving this goal may not be possible without management measures geared to alter trophic interactions and species dominance. Comprehensive effort control has been suggested for this system as well (Panayotou and Jetanavanich, 1987; FAO, 1997).

Ecosystem considerations have long been an element of debate and scientific inquiry in the management of the North Sea, and sophisticated models and supporting data have been developed and used (Pope, 1991). These investigations have refuted the commonly held notion that increases in mesh size would necessarily result in improved groundfish yields (Beverton and Holt, 1957; Pope, 1991). However, multispecies assessment has not discerned a causal link between groundfish abundance and increased removals of industrial species and small pelagics, nor has such research established that interspecific predation is a determinant of year-class size. Related research on seabirds has not linked breeding success to intensive harvesting of their prey (Furness, 1999). Single-species assessment has benefited through the calculation of more realistic natural mortality rates by including the effects of predation, and this has influenced perspectives on long-term yield potentials from the system. Results of more broad-based ecosystem research and monitoring (e.g., linking resource species to fluctuations at lower trophic levels) could become even more important if management successfully addressed overfishing of key components of the resource (Daan *et al.*, 1996).

Ecosystem approaches, whether implemented as perspectives on traditional overfishing paradigms, or through explicit ecosystem-based definitions, require research and advisory services not typically provided by fish stock assessment science. Regardless of the approach, additional ecosystem monitoring and research is necessary, with increased emphasis on species interactions, diversity (at all levels of organization) and variability (at various temporal and spatial scales). However, this does not necessarily imply that traditional programmes collecting fishery-dependent and fishery-independent information should be abandoned. On the contrary, existing programmes will need to be expanded to allow monitoring of catches and abundances of a wider array of species, to complement research and modelling on trophic interactions and other process-orientated studies. Such research is necessary if ecosystem considerations are to assume a greater role in resource management, particularly as habitat protection becomes a priority and measures such as marine protected areas are used more widely to enhance resource and non-resource species protection.

The most appropriate way forward probably is to use existing overfishing paradigms and build complexity contingent on mechanisms likely to be important in particular fishery systems. Such has been the model for several systems, where increasingly complex analytical models were developed in response to the limitations of more parsimonious approaches (e.g., the development of multispecies yield-per-recruit incorporating predation). In some cases, results of this incremental approach have challenged the tenets of management under existing paradigms (Gislason, 1999). Thus, building on existing approaches need not result in a *status quo* view of biological principles supporting fishery management.

A high priority is the development of simple, robust indices of ecosystem state that gauge important properties associated with production, diversity, and variability. General principles appropriate to the management of ecosystems may yet emerge from meta-analyses of intensively studied ecosystems (Pauly *et al.*, 1998), but a key feature of any quantitative metric of overfishing is the ability to predict the outcomes of specific management measures. Retrospective and modelling studies of these metrics, derived from the well-studied systems, could be used to assess their predictive value with regard to state variables of interest. Some tools already exist to evaluate energy accruing to ecosystem components under various harvest strategies (Pauly and Christensen, 1995; Christensen and Pauly, 1995; Christensen, 1996), and these techniques have been applied retrospectively to provide context to observed species changes (Christensen and Pauly, 1998). More general application of these approaches in fisheries management could serve to define the limits to system production (e.g., multispecies MSY) and could identify trophic bottlenecks and general constraints imposed by energy flux and accumulation in various components. Mass balance approaches, taken together with enhanced population dynamics models incorporating species interactions, can provide the framework to define and evaluate robust indicators of ecosystem overfishing and the implications of their use in management of ecosystems and specific components.

Finally, given a lack of comprehensive ecosystem-based information, how should fishery management proceed? Numerous case histories, including those reviewed here, suggest that significant overfishing scenarios could have been avoided and resource conditions improved, had conservative single-species or species-assemblage management principles been followed, a point emphasized by the National Research Council, 1999. Management will always be concerned primarily

Table 3. Evaluation of proposed criteria for defining ecosystem overfishing applied to three well-documented marine fishery/ecosystem cases.

Criterion	Study case: Gulf of Thailand demersal fishery	Study case: Northeast USA continental shelf	Study case: North Sea
	Rapid increases in effort during 1960s led to substantial and precipitous declines in small prey species and large predator fish, as well as intermediate-size predators. High landings were maintained despite declines in abundance of important demersal fish species through the early 1990s	Rapid build-up of effort (primarily by distant water fleets) during 1960s and 1970s, resulted in excessive harvest rates for virtually all species. Harvest rates on high-valued groundfish and flounder species peaked again in the mid-1980s as a result of domestic overfishing	Roundfish fishing mortality rates have steadily increased since 1945. The ''gadoid outburst'' of the 1970s increased populations and yields, which have subsequently declined. Increased harvesting of industrial species and small pelagics is a concern
Biomass of one or more important species fall below minimum biologically acceptable limits	Abundances of important demersal fish species declined through the early 1990s to one-tenth of their levels in the 1960s	Biomass of most resource species dropped to a historic low and productivity was reduced during the 1960s, and again in the early 1990s. In recent years management has successfully reduced exploitation rates on principal groundfishes but harvest rates on other components increased to non-sustainable levels	Although biomasses of important resource stocks (roundfishes, pelagics) have fluctuated downward since the 1980s to, and below, minimum acceptable levels, signs of persistent recruitment overfishing have not been apparent
Biological diversity declines significantly	Continued high yields, despite species replacements, suggest change in species dominance. Ecologically and economically important components have been decimated. The resource is not as diverse as it was in the 1960s	Dominance of species groups changed as a direct result of excessive fishing and sequential depletion. Despite improved management, sequential depletion of non-traditional target species remains a significant factor	Diversity of the system has fluctuated without trend
Harvesting leads to increased year-to-year variation in populations/catches	The sustained intensive trawl fishing has not induced greater interannual variation in aggregate landings	Declining stocks of high-valued species resulted in ''recruitment'' fisheries with greater interannual fluctuations in landings of species	Variation in recruitment or catches does not appear to have increased
Significant decrease in resilience or resistence of the ecosystem to perturbations	Although diversity of the system is lower overall, there is no clear trend of decreased resilience to non-biological perturbations		
Lower cumulative net economic or social benefits than might be obtained with less intense fishing	A large and increasing proportion of the recent landings comprises squid and cuttlefish, which increased in abundance following declines of their competitors (small demersal prey species) and predators (large fish). Net benefits from the demersal fish community are lower than under a lower effort scenario, but increased shrimp landings provide substantial alternative benefits	Bioeconomic analyses indicate hundreds of millions of dollars in additional benefits accruing from rebuilding of depleted resources and their efficient management	Changes in dominance (''gadoid outburst'' of the 1960s; apparent negative relationship between abundance of pelagic stocks and gadoids) do not appear to be related to the direct effects of fishing, or harvest-induced changes in species interactions. Several non-target fish species have increased in abundance since 1970, but the causes are unclear

Table 3. (*Continued*)

Criterion	Study case		
	Gulf of Thailand demersal fishery	Northeast USA continental shelf	North Sea
Fishing impairs long-term viability of ecologically important non-resource species	Effects on non-resource species are unclear (virtually all fish species are consumed in one form or another)	Small pelagic prey species remain abundant and underexploited. By-catch of turtles and marine mammals are of significant concern	Effects of large-scale removals of prey species has had no obvious detrimental effects on seabird breeding success
Selected literature	Panayotou and Jetanavanich, 1987; FAO, 1997; Christensen and Pauly, 1998; Hall, 1999	Brown *et al.*, 1976; Alverson *et al.*, 1994; Mayo *et al.*, 1992; Edwards and Murawaski, 1993; Fogarty and Murawski, 1999	Pope, 1991; ICES, 1995; Rice and Gislason, 1996; Daan *et al.*, 1996; Heessen and Daan, 1996; Furness, 1999

with a subset of species of overriding economic, ecological, or social value. Rather than supplanting current management approaches, ecosystem considerations may increasingly be used to modify regulations intended primarily to conserve these high-value species, to address ecosystem concerns such as by-catches, predator-prey demands, and the side-effects of fishing effort. In all likelihood, advice resulting from the explicit incorporation of ecosystem affects will further emphasize the need for conservative management of the fishing capacity of single- and multi-purpose fleets to avoid sequential depletion and trophic imbalances resulting from species- and size-selective harvesting. Technical management measures that have benefits to both target and non-target species and that may enhance ecosystem functions, such as broader use of MPAs (Allison *et al.*, 1998) and restrictions on the use and design of fishing gears, will increasingly be used to address habitat issues arising from fishing and other anthropogenic impacts on marine ecosystems.

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