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Assessing and protecting endangered marine species

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Documented extinctions of marine and anadromous species are rare, but extinction of species and extirpation of major populations have occurred – there are cases of near extinction – and there may be undocumented extinctions. Factors associated with known extinctions and near extinctions include specific life-history characteristics (e.g. low fecundity, high age at maturity, low mobility), habitat degradation, high value and high susceptibility to harvesting, ecological specialization. Harvesting mortality, targeted or incidental, is implicated in some known extinctions or near extinctions, and may act synergistically with other threats. Criteria to make assessments of risk of extinction more consistent have been developed, but given the limited experience to date with extinctions in the marine environment there have been questions about applying these to some marine species. The wide range of life history characteristics in marine species suggests that a range of approaches to assessing extinction risk will be needed. Protocols for defining significant population units are also required since protection of populations is part of protecting endangered species. Keeping species and populations well away from endangered status should be the main goal of conservation programmes. Implementation of precautionary conservation frameworks for exploited species could be a sound approach to preventing "endangerment".

Key words: anadromous species, endangered, extinction, extirpation, marine species, threatened, vulnerable.

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Introduction

Protection of endangered species has become an important part of global conservation activities through frameworks established under national legislation (for example in the USA, Australia, Japan) and international agreements (CITES, the Convention on International Trade in Endangered Species). We review current knowledge on extinction in the marine realm, addressing three main questions:

- Are marine species "endangered"?
- Is fishing potentially a factor in extinction?
- How can marine species be identified that are at real risk of extinction and worthy of extraordinary protection efforts?

Extinctions in the marine realm

Imperfect knowledge of the marine realm may lead to underestimation of numbers of extinctions and extirpations. Modelling of impacts on coral reefs has suggested that 1200 marine species (most undescribed) could have become extinct in the last few hundred years, and another million could soon become extinct (Reaka-Kudla, cited in Malakoff [1997]). These results are based on assumptions about biological diversity on reefs and on a model linking extinctions in rain forests to habitat destruction, and therefore speculative. The following discussion is based on documented cases of extinction, extirpation, and near-extinction (cases where status of the species gives cause for concern that extinction is a real risk).

Marine mammals

Three species of marine mammals are reported to be extinct: Steller's sea cow (*Hydrodamalis gigas*) (Forsten and Youngman, 1982), the Caribbean monk seal (*Monachus tropicalis*) (LeBoeuf *et al*., 1986), and the sea mink (*Mustela macrodon*), possibly a subspecies of the mink (*Mustela vison*) (Campbell, 1988). The last-mentioned is arguably not a marine mammal but a coastal mammal with an obligate relationship with the sea. Extirpated populations of marine mammals include the North Atlantic population of grey whales (*Eschrichtius robustus*) (Reeves and Mitchell, 1988) and the Gulf of St Lawrence population of walrus (*Odobenus rosmarus*) (Kingsley, 1998). Some other marine mammals are considered at high risk of extinction. The Mediterranean monk seal (*Monachus monachus*), Hawaiian monk seal (*Monachus schauinslandi*), Yangtze River dolphin (*Lipotes vexillifer*), Sea of Cortez porpoise (*Phocoena sinus*), the Northwest Atlantic and North Pacific populations of the northern right whale (*Eubalaena glacialis*), and the Northwest Pacific population of grey whale are at extremely low abundance compared to historical levels and are listed by IUCN with many other whales as critically endangered or endangered.

Some species or populations of marine mammals have rebounded from low levels after cessation of harvesting; for example, the Northeast Pacific population of grey whales, which currently numbers upwards of 20 000 animals, and the Bering-Chukchi-Beaufort population of bowhead whales (*Balaena mysticetus*), numbering some 8000 animals (Anon., 1999). The Pacific sea otter (*Enhydra lutis*) was extirpated from Canada's Pacific coast in 1929 but was reintroduced in the 1970s and the population has been growing rapidly, by some 20% per year (Watson *et al*., 1997).

Harvesting was a major factor in all known marine mammal extinctions and the life history and ecological characteristics of this group (low reproductive capacity, late maturation, visibility) make them particularly vulnerable to harvesting. Specific habitat requirements (rivers, beaches, coastal zones) and limited ranges that overlap with that of humans contributed to extinctions or near extinctions in some species. For species that have rebounded, increases are due to cessation of harvesting, low incidental kill, and lack of major damage to habitat.

Marine fish and invertebrates

Four species of gastropod molluscs are reported extinct in recent historical time (Carlton, 1993). The eelgrass limpet (*Lottia alveus*) (Carlton *et al*., 1991), once widespread and relatively abundant from Labrador to Long Island Sound, was an obligate feeder on eelgrass and disappeared when eelgrass populations were decimated by disease. The rocky shore limpet ("*Collisella*" *edmitchelli*) and an Asian periwinkle (*Littoraria flammea*) were extremely rare, represented by one or a few museum specimens (Carlton, 1993). The horn snail (*Cerithidea fuscata*) was apparently restricted to mudflats in parts of San Diego Bay and disappeared following extensive development and modification of these areas (Carlton, 1993). Carlton (1993) reports some questions about the taxonomic validity of the latter three species but considers them species. The ship sturgeon (*Acipenser nudiventris*) has been listed by IUCN as extinct in the Aral sea.

Two species of large ray have been described as near extinct over large parts of their original ranges, the common skate (*Raia batis*) from the Irish Sea (Brander, 1981) and the barndoor skate (*Raja laevis*) from St Pierre Bank, Sydney Bight and the southern Grand Banks (Casey and Myers, 1998), although the barndoor skate has been taken fairly frequently in recent years in commercial by-catch and trawl surveys in deep waters off the Newfoundland Shelf (Kulka *et al*., 1996) and the Scotian Shelf. Although there may be some question as to just how close to biological extinction these species are, it is certain that their life-history characteristics make them extremely vulnerable to increased mortality from fishing (because they are non-target species, by-catch has probably been the major factor in their decline): late maturation, low fecundity, and high vulnerability to trawling from an early age.

White abalone (*Haliotis sorenseni*), once abundant and widely distributed along the California and Mexican coasts, has become extremely rare in recent surveys (Davis *et al*., 1996; Malakoff, 1997), following years of heavy harvesting. Severe population declines of northern abalone (*Haliotis kamtschatkana*) led to closure of the fishery off the British Columbia coast in 1990, and recent surveys have indicated that abundance has continued to decline following the closure (PSARC, 1998). Abalone are particularly vulnerable to harvesting because of their accessibility (highest abundance in the upper subtidal, deepest distribution about 100 m), and low mobility, and harvesting has probably been the major reason for the decline. Concentrations of animals are believed to be necessary for successful spawning, and thus low density may increase the risk of recruitment failure (Jamieson, 1989).

Musick (1998) and colleagues on the American Fisheries Society Endangered Species Committee have identified 68 marine species or stocks considered to be at risk of extinction in North America. The list includes several species of skates and sharks, sturgeons, a number of stocks of rockfishes and other species localized in Puget Sound, and several species of groupers and other serranids. Bluefin tuna and "some stocks" of Atlantic cod and Atlantic halibut are included on the list. Most of these species are exploited.

A workshop of IUCN's Species Survival Commission concluded that 118 species of marine fish species should be considered at risk of extinction (Hudson and Mace, 1996). Of the total, 70% were designated based on the IUCN A (decline) criterion, and there has been controversy about using this criterion for some marine species (see below). Groups prominent on this list included pipefishes and seahorses (36 species or 31% of those given a status), sharks and rays (15 species or 13%), groupers and other serranids (17 species or 14%), and coral reef species. Groupers are protogynous and highly attractive to harvesters, so that fishing may reduce the abundance of males in the population to critically low levels, a life-history trait which may contribute to high risk of extinction (Huntsman *et al*., 1999).

Thirteen species or subspecies of nearshore and estuarine fishes are listed by IUCN as endangered or critically endangered: the Totoaba (*Totoaba macdonaldi*) from the Gulf of California and Gulf of Mexico, the spotted handfish (*Brachionichthys hirsutus*) from Tasmania, the river pipefish (*Syngnathus watermayeri*) from South African estuaries, the delta smelt (*Hypomesus transpacificus*) from California, the New Grenada sea catfish (*Ariopsis bonillai*) from Colombia, beluga sturgeon (*Huso huso*), seven species or subspecies of *Acipenser* in the Mediterranean or Black Sea, the Baltic sturgeon (*Acipenser sturio*), and Sakhalin sturgeon (*Acipenser mikadoi*) from Japan and Russia (http: //www.iucn.org). Habitat alteration, reduced productive capacity, an introduced predator (for the spotted handfish) are cited as threats to many of these species, and for exploited species overexploitation can be a contributing factor.

All species of sturgeons are now listed by CITES, most on Appendix II. The basis for this decision was that international trade in caviar was contributing to a high risk of extinction for some species, notably from Central Asia. Because caviar and other sturgeon products cannot be differentiated as to species and origin, all species had to be listed under the "look-alike" provisions of CITES. The situation for sturgeons is a good example of the interaction of multiple factors threatening the continued survival of species: overfishing, poaching, and major changes to critical habitats. Sturgeon life-history characteristics (anadromy, slow growth, and relatively low fecundity) make them particularly susceptible to additional sources of mortality (Dumont, 1995; Rozengurt and Hedgpeth, 1989).

The extent to which some of the above "near extinctions" really represent a risk of biological extinction is still under discussion, but the general picture given presents the current state of knowledge of marine species, including species and groups that may be at particularly high risk of biological extinction.

Anadromous species

None of the six species of anadromous salmon (genus *Oncorhynchus*) of the North Pacific is extinct or at high risk of extinction throughout its range, but each species comprises hundreds or thousands of spawning populations and extirpations have occurred at the population level. At the level of the stream, at least 106 populations of salmon and steelhead have been extirpated on the west coast of the United States (Nehlsen *et al*., 1991), while 142 spawning populations representing 1·5% of the total number reviewed have been extirpated on the west coast of Canada (Slaney *et al*., 1996). Extirpations have also occurred at the stock complex or watershed level. "Interior" coho of the Columbia River are considered extirpated (Weitkamp *et al*., 1995), as are coho from the Sacramento River in California (Nehlsen *et al*., 1991), while California pink and chum salmon and Snake River (Idaho) sockeye are considered virtually extirpated (Nehlsen *et al*., 1991). Regarding near extirpations, by mid-1998 15 stock complexes (ESU's or evolutionarily significant units) of Pacific salmon or anadromous trout had been listed as endangered or threatened under the US Endangered Species Act and 19 others were proposed or candidates for listing (Dandelski and Buck, 1998).

Extirpations have been primarily due to blockage of freshwater migratory routes by dam construction, reduced survival caused by passage through dams and reservoirs, and deterioration or elimination of freshwater habitats required as spawning or nursery areas. Harvesting in mixed population fisheries probably has contributed to the decline of some populations (Nehlsen *et al*., 1991). Recent dramatic declines in salmon stock complexes in western Canada may include some extirpations owing to elimination of freshwater habitat; where habitat does not appear to be a major factor, a combination of decreasing marine survival rates resulting from changing ocean conditions and overharvesting in mixed population fisheries may be implicated (Bradford, 1998).

Abundance of Atlantic salmon (*Salmo salar*) has been declining throughout its range in the North Atlantic since the 1970s (DFO, 1998). Virtually every coastal state in continental Europe has reported extirpations of natural spawning runs (de Groot and Heesen, 1992). In Eastern Canada, spawning populations have been eliminated from 14 Atlantic coast rivers in Nova Scotia and from many rivers in the St Lawrence River drainage. Factors associated with declines and extirpations of Atlantic salmon populations are similar to those for Pacific salmon: modification of spawning and rearing habitat, degradation of water quality, dam construction. Acidification of spawning rivers (pH below 4.7 in rivers lacking salmon) is a factor in Nova Scotia. Harvesting pressure has been heavy for many decades and may be a contributing factor to some extirpations.

Anadromous striped bass (*Morone saxatilis*) were once considered at high risk of extirpation from some rivers in the USA and were considered under threat over much of their range by the 1970s, largely because of excessive fishing. Following stringent controls on fishing instituted in the 1980s, spawning now occurs throughout much of its historical range and recruitment and adult biomass are at historical highs. In Canada, striped bass have apparently been extirpated from three of five rivers known to have supported spawning populations (DFO, 1999); habitat loss is believed to be the largest contributing factor.

Summary

Extirpations of anadromous species from rivers or watersheds have been reported fairly widely. Factors associated with extirpations are generally similar to those for freshwater species: habitat degradation as the major cause, with harvesting and changes in survival due to variations in natural environmental conditions contributing in some cases (for comparison, for 70 freshwater extinctions reviewed, habitat modification was implicated in 71%, competition and/or predation from introduced species in 54%, overfishing in 29%, pollution in 26%, and hybridization or diseases or parasites in 4% each; Harrison and Stiassny, 1999). Harvesting is a factor in some anadromous extirpations, in some cases acting synergistically with other factors to put stressed populations "over the edge".

Although extinction and near extinction of marine species and major populations have occurred, the low number of documented cases is remarkable. Because knowledge of the marine realm is difficult to acquire, there may be extinctions of which we are unaware, but knowledge of some groups (exploited species) and areas is good and one would have expected to find extinctions here if they were occurring. McKinney (1997) concluded with some caveats that terrestrial taxa tend to be more vulnerable to extinction today as in the past than marine species. Carlton (1993) noted the surprisingly low number of extinctions documented from marine gastropods, a well-collected group, and suggested either that extinction rates in gastropods are indeed low, or that "cryptic" extinctions are more common than recognized because of incomplete knowledge of taxonomy or of faunas.

Known marine extinctions or near extinctions have been due to specific combinations of factors: harvesting in combination with specific life-history and ecological characteristics (marine mammals, elasmobranchs, sturgeons), habitat degradation, sometimes in combination with overexploitation (nearshore fishes), sometimes in combination with rarity (gastropod molluscs), disease in combination with specialized life-history characteristics (eelgrass limpet).

Marine species might be said to be more or less resilient to threat based on life-history traits and ecological characteristics. Less resilient species would include those with: (a) "conservative" life-history characteristics (low fecundity, high age at maturity, rarity, narrow distribution, low mobility as young or adults; see papers in Musick [1999]), (b) a requirement for habitat susceptible to degradation due to human activities, (c) ecological specialization (obligate substrates or narrowly defined habitats, trophic or other specializations), or (d) high susceptibility to harvesting because of ease of capture and high value (e.g., syngnathids for traditional medicines; sturgeons for caviar, abalones; formerly, marine mammals). Conversely, other marine species have characteristics which should make them more resilient to extinction risk: "opportunistic" life-history characteristics (high fecundity, planktonic larvae, and highly mobile adults, low age at maturity), high abundance, and wide distribution.

Many marine species are known to undergo wide fluctuations in abundance. Collapses of small pelagic stocks and subsequent recovery after many years of apparent near extirpation are well documented (Csirke, 1988). The periodic appearance of large populations of Atlantic cod off west Greenland during periods of favourable conditions can be seen as an example of apparent near-extirpation and re-establishment (Buch *et al*., 1994). Declines and increases up to 10-fold are relatively common in exploited fish stocks (Hilborn, 1997). Such population fluctuations are often associated with harvesting, but also occur naturally: off the California coast, biomass of Pacific sardine has varied by a factor of 6 and northern anchovy (*Engraulis mordax*) by a factor of 9 over a period of two millennia (Baumgartner *et al*., 1995).

Assessing risk of extinction

Current approaches

An "endangered" label identifies a species as at a level of risk worthy of extraordinary protection and rebuilding efforts. Since these may have substantial impacts on economic activities, accurate identification of species at risk of extinction is an issue of considerable importance. The limited experience with extinction in, and the wide variety of life-history and ecological characteristics of, marine species complicate the task of assessing the risk of biological extinction.

Expert judgement has been the basis of assessments of extinction risk for some years, but several approaches have been developed to make the assessments more consistent within and across species groups. The Species Survival Commission (SSC) of the IUCN led development of a series of "criteria" for assessing risk of extinction (IUCN, 1996a), based on associated factors in a range of species groups: rate of decline in abundance, low absolute population size, small and/or declining range, fragmentation of populations, large abundance fluctuations. These characteristics are combined in different ways, and threshold values are provided that correspond to categories of risk: critically endangered (“extremely high risk of extinction in the wild in the immediate future”), endangered (“very high risk of extinction in the wild in the near future”), and vulnerable (“high risk of extinction in the wild in the medium-term future”).

CITES adopted new criteria for placing species on its Appendices in 1994 (IUCN, 1996b), which are based on similar biological indices, but which do not include identical quantitative threshold values for all species. The Nature Conservancy (http://www.consci.tnc.org) uses eight biological and threat factors (including, in addition to those listed for IUCN, number of “occurrences” or populations, threats, and sensitivity to human disturbance) to place species in five major risk categories ranging from “secure” (G5: common, widespread, and abundant) to “critically imperilled” (G1: extreme rarity or especially vulnerable to extinction). These approaches are all based mainly on terrestrial and avian species.

There has been controversy over the applicability of the IUCN criteria set to marine species. For the first time, a number of marine fish species were listed in the 1996 IUCN Red List of Threatened Species (IUCN, 1996a), many based on the decline criterion (details on marine fish assessments are given in Hudson and Mace [1996]). Some of these were commercial species still at high abundance despite abundance declines (e.g. haddock (*Melanogrammus aeglefinus*), Atlantic cod (*Gadus morhua*), yellowtail flounder (*Pleuronectes furrugineus*): vulnerable; redfish (*Sebastes fasciatus*), Atlantic halibut (*Hippoglossus hippoglossus*): endangered). Many fisheries biologists felt that the decline criterion was too conservative, identifying species as at risk when in fact the risk of extinction was very low (Matsuda *et al.*, 1997). For example, Atlantic cod was identified as vulnerable on the basis of an abundance decline of at least 20% within 10 years or three generations. On the other hand, the criteria based on low absolute abundance or small range may not be precautionary enough for many marine species. The SSC has initiated a review of the IUCN criteria, including further examination of their applicability to marine species. An initial conclusion was that marine species are not well served by the present criteria (Isaac and Mace, 1998). A workshop on criteria for marine species was held by the IUCN in January 1999 and other workshops are planned that would contribute. The review is expected to be complete in 2000.

FAO will lead a review of the application of the CITES criteria to marine fish species during 1999 and 2000. An approach to developing criteria for assessing extinction risk in marine fish has been proposed as part of an American Fisheries Society project (Musick, 1999).

Possible approaches

Any system or approach to assessing risk of extinction (e.g., criteria sets) will have to recognize that there are classes of marine creatures with different levels of resilience to increased mortality and with different habitat requirements. The IUCN, and similar, criteria sets may be appropriate for some marine creatures but may require modification for others. Flexibility and experimentation will be required to develop approaches for all groups.

Simple criteria-based approaches on their own may not be possible or appropriate for some groups, given the limited experience with extinction in the sea, although criteria or standards will always be necessary to ensure consistency of assessments. As with assessments of stock status, consideration of a wide range of biological indicators and of data on all aspects of species status will probably be necessary.

Various approaches have been and can be proposed for modifying existing criteria or developing new criteria for assessing extinction risk, for example:

- comparing rates of decline with natural fluctuations in abundance, rather than comparing these to fixed threshold values for all species;
- using different rates of decline for different groups of species (Musick, 1999);
- disappearance of populations as an indicator of species extinction risk;
- linking a decline to a lower abundance threshold, i.e. any decline in abundance would only be considered an indicator of extinction risk below some critical abundance value (Matsuda *et al.*, 1997);
- evaluation of threats to habitats of species that have specific requirements.

Grouping species by resilience as indicated by life-history traits, ecological characteristics, and habitat requirements could be used as a screening procedure to identify species at particular risk. Much work has been done along these lines; for example, sharks, rays, and sturgeons are generally agreed to be a susceptible group because of their life-history traits. A more formal screening process would help to systematize assessments of extinction risk.

What units need to be protected?

Protection of populations is generally recognized to be an essential part of endangered species protection and recovery. The Convention on Biological Diversity calls for legislation for the protection of “threatened species and populations”. The US Endangered Species Act allows listing of “any subspecies of fish or wildlife or plants, and distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature” (Waples, 1995). IUCN’s Red Lists include “subpopulations” defined as “geographically or otherwise distinct groups ... between which there

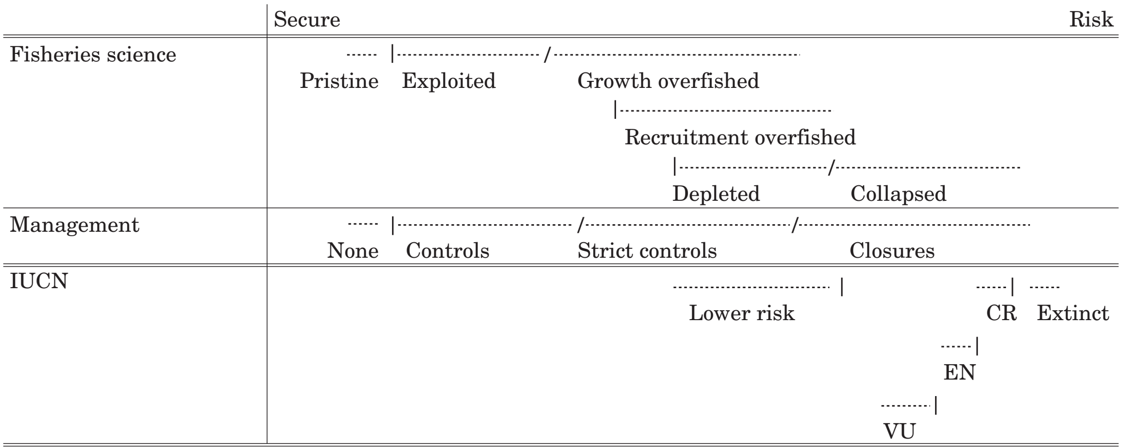

Figure 1. Approximate/tentative relationship between fisheries science categories and IUCN categories of threat (CR = critically endangered; EN = endangered; VU = vulnerable). Oblique lines or no vertical lines suggest limits of categories not clearly defined.

is little exchange (typically one successful migrant individual or gamete per year or less)".

To apply the "distinct" population provision of the US Endangered Species Act for anadromous salmonids, the National Marine Fisheries Service implemented the concept of the "evolutionarily significant unit" (ESU) as the appropriate unit for protection (Waples, 1995). Its application depends on a two-part test: "An ESU is a population (or group of populations) that (1) is substantially reproductively isolated from other conspecific population units, and (2) represents an important component in the evolutionary legacy of the species." NMFS policy (Waples, 1991) outlines the types of evidence to be considered in evaluating the two criteria, which may include for criterion (1) movements of tagged fish, natural recolonization rates, measurements of genetic differences between populations, and evaluation of the efficacy of natural barriers, and for criterion (2) phenotypic and life-history traits (size, fecundity, migration patterns, age, and time of spawning).

The ESU concept has been recognized by some systematists as a significant advance in applying current concepts of identifying units of biological diversity for conservation (Mayden and Wood, 1995). By combining elements of a "separateness" and "uniqueness" it provides a basis for identifying units that should be protected from extinction. Definition of populations of aquatic organisms is a rapidly evolving scientific field (see Nielsen, 1995), but the ESU concept provides a framework for discussion of the best approach to protection of populations.

Precautionary conservation frameworks

Most of those interested in conservation would agree that prevention of "endangerment" should be the goal of conservation programmes: species and populations should be kept well away from the "danger zone" of significant extinction risk. Endangered species protection protocols operate at the low end of the range of species abundance, while fisheries resource conservation protocols operate at higher abundance levels with the general goal of keeping stocks "healthy" and productive (Fig. 1). The main difference between the two approaches is that endangered species protocols are based on automatic or mandatory provisions upon listing, while most current fisheries conservation protocols involve some discretion in defining the actions to be taken once the stock assessment is complete. One aspect of implementation of the precautionary approach to fisheries resource conservation is to trigger pre-agreed conservation action when stocks or species hit stated biological reference points (Serchuk *et al.*, 1997), and thus to invoke conservation protocols automatically.

Implementation of precautionary approaches is generally seen as desirable and indeed is a commitment under several recent international agreements (e.g., the UN Agreement on Management of Straddling and Highly Migratory Fish Stocks). Nevertheless, protocols based on objective reference points have not been implemented as widely in fisheries management worldwide as might be desired. Fish populations remain susceptible to overharvesting (either in directed fisheries or as by-catch) as technology improves and demand for fish increases, and there have been numerous instances of stock collapses and severe declines in abundance in recent years. Implementation of precautionary, objectives-based conservation frameworks remains highly desirable to contribute toward prevention of "endangerment" as well as to strengthen fishery resource conservation.

Conclusions

Marine species appear not to have been as subject to extinction as terrestrial or freshwater species, although there may be unknown extinctions or extirpations. Anadromous species have been more susceptible to extirpation of significant populations than marine species because of obligate use of freshwater environments.

Although the number of known extinctions is low, there is no reason to assume that extinction is not a potential problem in the sea, as cumulative human impacts are increasingly felt on semi-enclosed seas (Caddy, 1993), estuarine, and coastal areas.

Harvesting has contributed to some of the known extinctions, extirpations, and near-extinctions, usually because the species had low resilience to additional mortality.

Assessments of extinction risk that are accurate and appropriately precautionary are essential to determine which species require specific protection measures, but simple approaches are unlikely to work for marine species because of the limited experience with extinctions to date and the wide variety of life-history characteristics.

Extinction risk can be assessed in a preliminary way by scanning life-history and ecological characteristics for species with low resilience to additional sources of mortality.

Endangered species protocols are similar to precautionary frameworks for fisheries resource conservation, which apply automatic conservation measures when specified biological limits are reached. The latter could be powerful tools for preventing species from becoming endangered if these were more widely applied.

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