MULTIPLE USES OF MARINE ECOSYSTEMS

Andrew A. ROSENBERG

ABSTRACT

The ocean is used for a very wide range of human activities, from recreation to food production to transportation. Each of these uses has the potential to affect fishery ecosystems and hence affect fisheries production, ecosystem health, stability and biodiversity. Here, impacts are categorized as direct, indirect or complex. Direct effects relate to changes in the mortality rate of ecosystem components. Indirect effects relate to changes in the productive capacity of ecosystem components, while complex effects are combinations of factors that change both mortality rates and productive capacity. Examples are given for each of these types of effect.

Impacts also have three dimensions: spatial, temporal and complexity. To develop a coherent policy for addressing the impacts of multiple uses of marine ecosystems, how impacts occur in time and space, as well as how different factors interrelate are important considerations. A fourth dimension, detectability or quantifiability, could be added because many impacts of ocean use are very difficult to quantify. However, the lack of full scientific information on the magnitude of the impact of an activity in or on the ocean cannot be used as a reason for delaying policy action. The precautionary approach, widely included in international agreements on ocean management, applies and serves as a guide for policy-making.

Introduction

[1] Incorporation of ecosystem considerations into fisheries management policy requires an understanding, at least conceptually, of how other concurrent ocean uses influence ecosystem properties. Ocean uses include disposal of contaminants, marine transportation, oil and gas exploitation, undersea mining for sand and gravel, cables for communication, eco-tourism, aquaculture, recreational activities, as well as fishing and conservation and preservation. In a sense, climate change can be considered a competing use of the ocean because of the fundamental ecosystem changes it may cause.

[2] The term fisheries ecosystem is used here to describe the biological, oceanographic and physical environment that supports exploited species within a specific area. The concept of large marine ecosystems (LMEs) (AAAS, 1990) has been used in recent years to describe regional features of the marine environment in coastal areas. LMEs have distinct bottom topography, oceanographic features such as currents or water circulation, biological productivity and biodiversity, and are usually areas encompassing 200 000 km^2 or more. The LME can extend from riverine and estuarine environments out into the coastal ocean, and even far offshore. Examples include the North Sea, the Gulf of Mexico, the Benguela Current, the Iceland Shelf and so forth. Sherman (1994) identifies 49 LMEs globally and estimates that 95% of fishery yields comes from these LMEs. Here, the impacts of multiple uses on fisheries ecosystems can occur at the scale of LMEs or can be more localized in scope. However, it is important to recognize that even a seemingly localized impact can have wider ranging effects. The LME concept is helpful

Andrew A. ROSENBERG

Dean, Life Sciences and Agriculture
University of New Hampshire
USA

for thinking of the linkages of biological, chemical and physical factors across large areas of the coastal ocean. Affecting any one part of the LME potentially can have repercussions throughout the region.

[3] The impacts of multiple uses of the ocean on fisheries ecosystems can be categorized as direct effects, indirect effects and complex effects. As with most categorizations, the distinctions between categories are imperfect, but provide a framework for thinking about potential impacts. In addition to thinking about the type of impact, three dimensions for impacts should be considered, spatial, temporal and complexity. These dimensions are important considerations for policy making with regard to the extent, duration and evaluation of any particular management action designed to address the impacts on fishery ecosystems of multiple uses of the ocean.

Direct, indirect and complex effects

[4] A direct affect of a non-fishing activity on fisheries (or of a fishery on itself) occurs when that activity results in changes in mortality of fish stocks in the ecosystem. In terms of the population dynamics of a fish stock, fewer young fish or recruits to the stock survive to spawn as mature fish. This is illustrated in Figure 1, using a conventional picture of spawning stock and recruitment. As the slope of the line relating recruits to spawners increases, mortality of fish of pre-spawning age decreases. In other words, more young fish survive to reproduce. Conversely, if the slope of the line decreases, mortality increases and fewer young fish survive to reproduce.

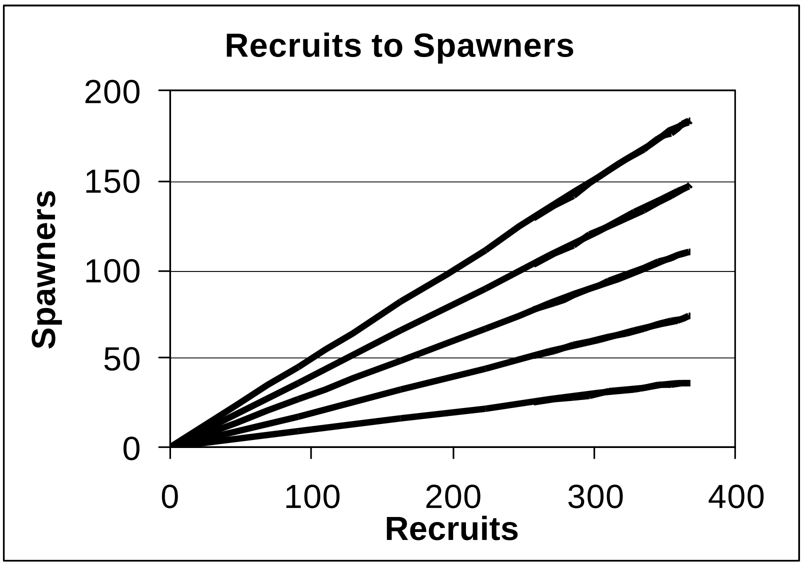

Figure 1. Simple population dynamics graph relating young fish or recruits to the number of mature fish or spawners they produce.

[5] By and large, the dominant direct effect on fisheries ecosystems is fishing itself (Jackson *et al.*, 2001). A large number of fisheries worldwide can be classified as overfished (FAO, 1999) meaning the level fishing activity in recent years is not sustainable and stocks are continuing to be depleted. It is not uncommon in overfished fisheries for the exploitation rate to exceed 50%, i.e. 50% of the standing stock of the target species is removed each year. This is a huge increase in mortality, given that the exploitation rate that is likely to give the maximum sustainable yield for many stocks is of the order of 15-20% per annum. This does not mean that the other types of impacts described in this paper are unimportant, but that overfishing, as a worldwide problem, must be addressed in every fishery ecosystem.

[6] By-catch is also a huge problem for fisheries worldwide (Alverson *et al.*, 1994) and is a direct effect of fishing on fisheries. By-catch can cause mortality of young stages of commercially important fish species. Increased mortality in young stages simply translates into fewer commercially valuable or mature fish some time later, a decreasing slope of the line in

Figure 1. There may be longer-term effects of increased mortality on productivity, though these are considered here to be indirect. This illustrates an important point: any particular activity may have – is even likely to have – all three types of effects, direct, indirect and complex. Exploitation of one component of the ecosystem can certainly directly affect another. In the Gulf of Mexico, the USA shrimp fishery has a direct impact on the fishery for red snapper because of the by-catch of juvenile fish during the course of shrimping (NOAA, 1999). Fishing activities can also directly affect other, non-commercially important species both through by-catch, or the direct impacts of fishing gear on bottom or other organisms. In terms of the fishery, direct impacts on non-commercially valuable species may indirectly affect the commercially important stocks.

[7] Conservation and preservation efforts may directly affect fisheries by lowering the fishing mortality rate. In this case, the effect may be positive or negative with regard to fish yield. Reduced mortality for an overfished resource may allow rebuilding and increased yields. Conversely, efforts to protect a large part of an ecosystem may result in a smaller proportion of the commercially important fish stocks available for exploitation. In the groundfish fishery in the northeastern USA, a recovery programme put in place to rebuild overfished stocks of cod, haddock, flounders and other species reduced fishing mortality significantly in the late 1990s. In simple terms, this resulted in an increasing slope of the lines in the relationship shown in Figure 1 for those fish stocks. The results of the conservation actions taken were initial reductions in yield from the fishery, followed by significant increases in yield, though recovery is not yet complete (Murawski *et al.*, 1999).

[8] Chemical or nutrient contaminants may result in large-scale die-offs of marine life through their respective toxicity. This increased mortality of organisms can occur at several levels simultaneously with a release of toxic substances, or the impacts may be different for different components of the ecosystem. For example, nutrient pollution can result in harmful algal blooms, such as brown tide (Laroche *et al.*, 1997) and increased mortality of zooplankton and larval fish (Whitledge *et al.*, 1999). This example illustrates that a non-toxic contaminant can result in direct effects as categorized here, namely increases mortality rates of organisms through secondary production of toxic substances. Of course there are also direct toxic impacts from contaminant releases such as oil spills (Rice *et al.*, 1996).

[9] Finally, other competing uses, such as mining exploration and operation, transportation or aquaculture, may result in direct impacts on the ecosystem. Mining operations can mechanically disturb the bottom, killing organisms directly. Exploration using explosive charges produces shock waves that can kill even at some distance from the site. Transport vessels or aquaculture activities may introduce new species to an ecosystem that prey on indigenous ecosystem components (Carleton and Geller, 1993). All of these types of impacts are easy to describe, but often difficult to quantify. However, direct impacts are more likely to be quantifiable than indirect or complex effects.

[10] An indirect effect occurs when an activity results in changes in the productivity, from reproduction or somatic growth, of commercially important fish populations. In population dynamics terms, productivity changes due to reproduction can be depicted through the relationship between the number (or biomass) of spawners and the young fish or recruits that they produce. Figure 2 illustrates this, again using a conventional plot of spawners versus recruitment (note the axes are reversed from Figure 1). As the height of the curve decreases, the spawning stock is less productive. In other words, a given number of spawning fish produce fewer progeny.

[11] Productivity due to growth can also be affected by activities in the ecosystem. For example, if food resources are reduced through direct effects on prey species or competition with other organisms such as introduced species, fish may grow more slowly and the size of a spawning fish at the same age may be less. This, in turn, may result in fewer eggs or less viable eggs being produced by that mature fish than prior to the impact.

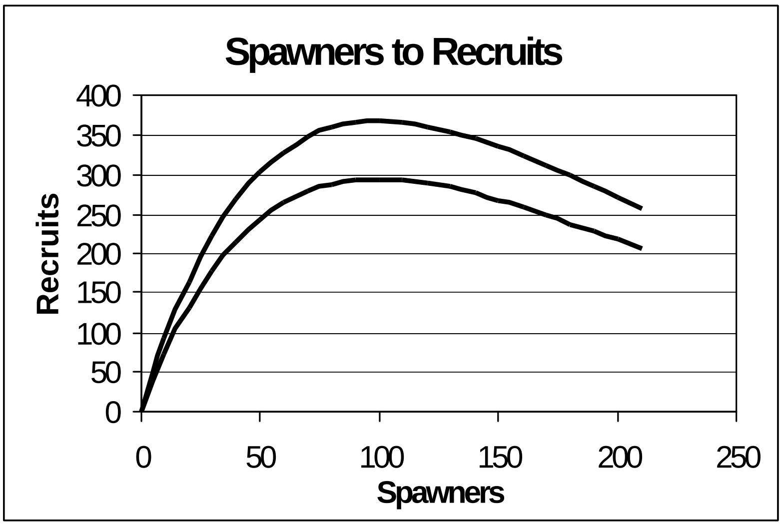

Figure 2. Simple population dynamics graph relating number of mature fish or spawners to the number of young fish or recruits they produce.

[12] For example, habitat destruction due to mining operations can result in reduced productivity because loss of habitat can reduce growth during young stages or reduce reproductive success. Climatic changes may reduce forage fish availability, thereby reducing productivity of commercially important species. This seems to have occurred in the Bering Sea with the reduction in stocks for herring and capelin due to a climatic regime shift (NRC, 1996). Conservation and preservation efforts may increase productivity through increased abundance of prey or increased availability of high quality habitat. The USA Northeast fishery recovery efforts may again provide an example of this effect. One of the primary management measures used for this fishery was the establishment of large, year-round closed areas in 1995 that have remained closed for the last six years. These areas were established in primary habitat for many species on George’s Bank, one of the most productive fishing grounds in the world. The recovery of commercially important stocks of fish and scallops is clearly due to reducing the direct impact of fishing mortality, but is also probably due to the indirect effect of habitat recovery (Murawski *et al.*, 2000). Indirect effects of chronic contaminants are also an increasingly important and worrying phenomenon. Nutrient loads from the Mississippi River, emptying into the Gulf of Mexico, have resulted in the loss of a large amount of bottom habitat in the Gulf through the creation of a large hypoxic (low dissolved oxygen) zone of up to 18 000 km^2 (Rabalais, *et al.*, 1999). While mobile organisms can move away from the area, the habitat is no longer available to them, and productivity reductions are highly likely, though difficult to document. Other examples of indirect effects on fisheries ecosystems may arise through mining, transportation or aquaculture activities. Mining operations may chronically disturb habitat, reducing its productivity for some organisms; ship noise can disturb the habitat of animals such as whales that may be important components of a fishery ecosystem; and introduced species from ship ballast water or aquaculture can compete with indigenous species, reducing their productivity (Carleton and Geller, 1993). These effects are difficult to quantify, though it is often possible to determine that an impact is occurring, even if its magnitude is unknown (Rose, 2000).

[13] A complex effect occurs when the combined impacts of three or more factors affect the marine ecosystem upon which fisheries depend. To combine indirect and direct effects, again in simple population dynamics terms, we can overlay the graphs of productivity and mortality, as shown in Figure 3. Now, because the axes must coincide, increasing slope of the straight lines representing the relationship between the number of recruits and the spawners they produce implies increasing direct mortality. Reduced height of the curve relating the number of spawners back to the number of recruits they produce implies reduced productivity. In combination, higher mortality and reduced productivity result in reduced fishery yield over the long term.

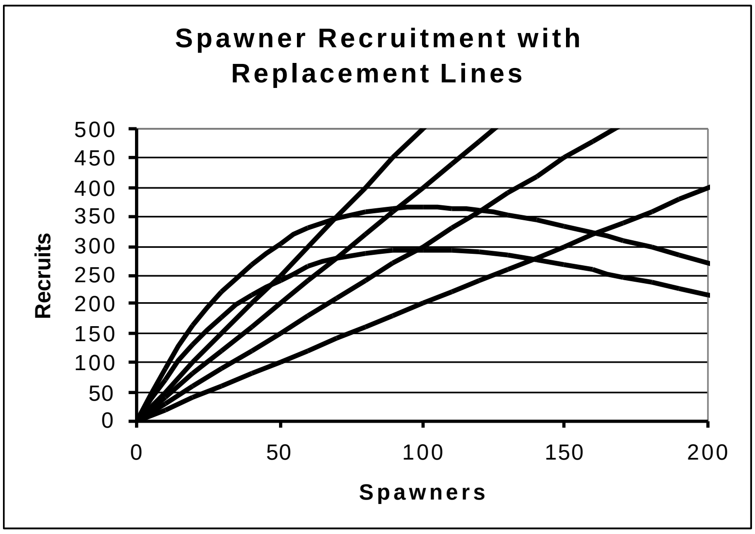

Figure 3. Simple population dynamics graph relating number of mature fish or spawners to the number of young fish or recruits they produce (curved lines). Then the number of young fish related to the number of spawners they produce (straight lines). The latter are referred to as replacement lines because they indicate how the stock replaces itself from young fish to spawning fish.

[14] For example, heavy fishing and habitat loss combine in a complex effect. Overfishing increases mortality and may reduce productivity, due to reduced spawning stock (e.g. Figure 3) and a reduction in productive habitat due to fishing gear impacts, mining, contaminants or climatic changes exacerbates the loss in productivity. An important point here is that complex effects mean that factors interact such that it is not possible to conserve or recover ecosystem productivity by simply addressing one of the factors, even if that factor was responsible for the initial decline in production. For example, if climatic shifts such as those in the Bering Sea reduce the productivity of the ecosystem, fishing impacts must still be reduced to prevent further productivity losses, even if the initial decline was not due to overfishing. The plight of Steller's sea lions in the North Pacific is a case in point. The western population of sea lions has declined over 80% over the last two decades due to a variety of factors, such as climatic regime shifts and incidental take by fishermen. Though fisheries may compete for prey with sea lions, it is unlikely that the initial large decline was due to fishing. However, recovery of the sea lion populations, initially affected by other factors, may now be hindered by localized intensive fishing for their prey species (Loughlin, 1998).

[15] Habitat loss and contaminants may combine to reduce the productivity of ecosystems. Habitat loss reduces the available areas for feeding, growth, spawning or nursery grounds, and contamination may reduce the suitability of the remaining habitat, even if large-scale mortality does not occur. Such an affect occurs in nearshore or estuarine areas with the combined effects of filling of the estuary and runoff from developed land (Chesney *et al.*, 2000). In this case, the complex effect is the combination of two indirect impacts. Similarly, aquaculture may cause habitat degradation and cause competitive interactions between farmed and wild fish, which in combination reduce the productivity of the ecosystem and hence fisheries.

[16] These categories are not exclusive and the lines between them are somewhat blurred. Nevertheless, they provide a useful classification of competing uses of the ocean. However, there are only a few classes of interactions that can be quantified with regard to the extent of the effect. It is sometimes possible to quantify direct effects by estimating mortality rates over time. Less frequently, productivity can be quantified over time. Rarely are we able to understand enough about complex interactions to quantify their impact. The scientific challenge, then, is to improve our understanding, and ultimately our ability to enumerate and quantify the impacts of competing uses of the oceans.

Spatial, temporal and complexity dimensions

[17] The impacts of multiple uses should also be considered in three dimensions in order to develop a coherent policy. For example, overfishing can be either localized with depletion of resources in a small area but not necessarily throughout an LME, or region-wide. The short-term impacts of the direct effect of overfishing may be corrected by immediate conservation actions, but longer-term impacts require more comprehensive planning for adjusting fishing capacity to the productive capacity of the resource. If overfishing is occurring in areas of degrading habitat, then the complexity of the impacts require additional policy considerations.

[18] The spatial dimension is about more than just the scale of impacts on a fishery ecosystem. Distance from the coast is also a critical feature of many types of impacts, such as those due to contaminants. As a generalization, most contaminants are introduced near to shore and disperse and are diluted moving away from the source. Of course, an oil spill can occur offshore, but most oil production, and even shipping resulting in accidents, occurs relatively close to the coast. The types of factors resulting in impacts described in this paper tend to be concentrated in nearshore areas. So the encounter rate with potentially impacting factors will increase. This is even true of most conservation and preservation efforts, though conservation in the Antarctic Southern Ocean is a counter example.

[19] Temporally, the distinction between short-term and long-term impacts is straightforward, even if policy-making for long-term impacts is not. This dimension may also be thought of as the gradient from acute to chronic effects. Direct effects are acute and may often be addressed with short-term policy decisions. Indirect effects are chronic by and large and require long-term solutions. Contaminant inputs such as nutrients from the Mississippi River result from a very large area, so the spatial dimension is large, but are chronic and require long-term policy actions. It can also be expected that the recovery of a fishery ecosystem from chronic impacts will take a long time. Even if nutrient loads in the Mississippi River were reduced quickly, the hypoxic zone in the Gulf of Mexico would probably persist for many years.

[20] The complexity of impacts cannot be ignored in policy development. Impacts on fisheries ecosystems are unlikely to be independent of one another in the sense that reversing the impact depends on addressing only a single factor. While overfishing may be a dominant direct effect in many ecosystems, other factors, such as habitat loss due to contamination or direct modification, need also to be considered. An illustration of ecosystem impacts of high complexity is the current situation with Pacific salmon in the USA Northwest (Lichatowich, 2001). Salmon have been subject to overfishing for many stocks, but their habitat has been very broadly affected. Now, fishing has been greatly reduced, but habitat for many life stages of the various salmon species is damaged or unavailable due to damming of rivers, water withdrawal for agriculture, contaminant impacts and other factors. Most salmon stocks in the Northwest are now considered threatened or endangered. The complexity of the impacts is very great and consequently the management actions needed are very complex, to say nothing of the political dimensions of the problems.

[21] The types and dimensions of effects are summarized, in a simplified way, in the following table.

	Direct	**Indirect**	**Complex**
Spatial	Smaller, greater nearshore	Larger, can extend throughout LME	Variable, both local and LME-wide
Temporal	Short term, acute	Long term, chronic	Short through long term
Complexity	Low	Higher	Highest

Policy implications

[22] An additional dimension could be added: detectability or quantifiability. Direct effects are the easiest (though not necessarily easy) to quantify. Complex effects are hard to detect and very hard to quantify. This is not to say that they do not exist, or that there is no scientific evidence for them. Most importantly, the difficulty of quantifying effects is not a reason to ignore them in policy development. The policy challenge is to address these impacts in the absence of complete or quantitative information. Here, the precautionary approach to resource management can serve as a guide (Bodansky, 1991; FAO, 1995; Jordan and O'Riordan, 1999; Rosenberg, in press). Fundamentally, fishery management policy should be cautious if a negative interaction is reasonably likely to occur, even if the extent of that interaction is unknown. In practice, this means restraining competing uses that may damage fisheries irrevocably, particularly in highly sensitive areas. For example, mining and drilling activities should be viewed very sceptically if they are proposed near or in areas of high fisheries production. Even if there is a lack of conclusive evidence that such activities are harmful, caution should be exercised, particularly when the potential risks to the ecosystem are high. In addition, if it is clear that an indirect effect has occurred or is unlikely to be avoided in future, fisheries should be restrained so that the, now reduced, productive capacity of the ecosystem is accounted for. If the productivity of a fish stock has been compromised because of, for example, habitat loss, that stock will be unable to withstand the same fishing pressure as before the loss. Regardless of whether the loss in productivity was due to fishing or other causes, it is important to reduce fishing pressure so as not to compound the error of habitat loss with the error of overfishing.

[23] Overall, competing uses of the oceans are likely to be complex from a management policy perspective. They are also likely to have a major, even dominant role in fisheries management in the near future.

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