Marine catchment basin effects versus impacts of fisheries on semi-enclosed seas

J. F. Caddy

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Synchronous anthropogenic effects on marine coastal systems, particularly since World War II, make it difficult to separate effects of fishing from terrestrial inputs, especially those caused by nutrient runoff. Natural enrichment is vital to productive fisheries, but over the long term anthropogenic nutrient impacts generally predominate over fishery effects in semi-enclosed seas and affect biodiversity and susceptibility to fishing. Such impacts on marine fisheries beyond natural levels of outflow are referred to here as marine catchment basin (MCB) effects. They require coordinated actions within the catchment area to control them, since fisheries management actions alone are unlikely to be effective in rectifying ecosystem impacts. Net nutrient inflows may be positive or negative, depending on intensity and degree of retention by the receiving marine system and may promote ecosystem change and lead to ecological dominance by exotic species. Initially positive effects of enrichment may disguise the urgent need for coordinated environmental and fishery management measures in semi-enclosed seas. Fisheries impacts are serious, but may be secondary and synergistic, but potentially catastrophic under hypoxic conditions since eutrophic processes make demersal ecosystems particularly sensitive to disturbance of bottom habitats. Hence, fishing with bottom gear may impact bottom fauna and demersal resources within or above organic sediments affected by eutrophic processes and hypoxia. These effects show up as changes in the ratio of pelagic to demersal landings, and support broad-brush comparative studies of areas subject to different levels of environmental impact.

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Key words: anthropogenic effects, ecosystem impacts on fishing, (European) semi-enclosed seas, marine eutrophication, nutrients.

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Introduction

The role played by land-based run-off, either directly into the sea or through river discharges, has been of considerable interest to marine biologists. Cooper and Brush (1993) noted that both anoxia and eutrophication in Chesapeake Bay have been increasing since European settlement. Odum (1980), quoted in Winter *et al.* (1996), is associated with the ''outwelling'' hypothesis that states that estuarine systems produce more organic material and nutrients than are used internally and that excess production is exported to nearshore seas. The effects of nutrient run-off on semi-enclosed seas with limited oceanic flushing may show up sooner than on open ocean shelves. Even for open sea areas, temporary hypoxic conditions can cause mass mortalities (e.g., Haskin *et al.*, 1983), and in the Gulf of Mexico

(Rabalais *et al.*, 1996), extensive hypoxia associated with Mississippi River discharges exceeds in importance the immediate effects of fishing, given that resources are excluded from large areas. This paper stresses the importance of eutrophic phenomena, and contrasts their effects on ecosystems with those due to fishing.

Increasing biological productivity of semi-enclosed marine ecosystems (Caddy, 1993a) complicates a simple description of direct or mechanical effects of fishing, and hence needs to be summarized first. Semi-enclosed seas such as the Mediterranean and the Baltic and Black Seas were the cradles of human civilization, and have coexisted with moderate levels of anthropogenic influences for a long time, with impacts of industrial-scale fisheries only a recent addition. The combined downstream effects of growth in populations, industry, and agriculture in catchment basins, although difficult to quantify,

appear to have been accentuated especially since World War II.

Kerr and Ryder (1993) noted that "Few would disagree that a primary effect of eutrophication ... is elevated levels of primary production. In judicious measure, the ensuing effect on fishery production may not necessarily be judged unwelcome in human terms". Caddy (1993a) summarized evidence for this conclusion for semi-enclosed seas, and suggested that fishery production for formerly oligotrophic seas has increased in recent decades, with moderate enrichment from land.

Kerr and Ryder (1992) recognized four categories of eutrophication effects:

(a) modifications to the fish production environment through reduction of suitable habitats for spawning and larval survival, and increased vulnerability;
(b) changes in fish production habitat;
(c) change in species/communities due to introductions or replacement of oligotrophic species by those adapted to hypoxia;
(d) associated fishery effects of eutrophication and the presence of contaminants (e.g., linkage of flatfish papillomas with eutrophic conditions; Stich *et al.*, 1976).

Obviously (a), (b), and (c) can be easily confused with incidental effects of fishing, as one example will illustrate: trawling on muddy sediments adjacent to sea-grass beds suspends fines, hence reduces the euphotic zone, and might make photosynthesis by deeper grass beds unviable. A reduction of light penetration from algal blooms is associated with "cultural eutrophication", i.e., a human-generated increase in nutrient runoff. How to distinguish the two effects? Or should they be regarded as synergistic stresses to the ecosystem, as suggested by Rapport *et al.* (1985)?

Contemporaneous influences on coastal marine ecosystems

Fisheries landings (FAO, 1995) and fleet size (FAO, 1994a) confirm that both global fishing effort and landings have risen steadily since World War II. The increase in landings to a recent plateau in 1996 of some 87 million tonnes of fish and invertebrates is consistent with the "theory of fishing" which sees changes in fisheries production as a function of changing fishing intensity, modified by climatic factors.

The common assumption that the effects of fishing dominate and that changes in landings simply reflect changes in fishing effort may be misleading. As noted by Stromberg (1997), distinguishing between anthropogenic and natural effects requires "a significant understanding of the dynamics of ocean" that is not attainable by considering the effect of only a few key variables. Difference anthropogenic impacts on marine ecosystems, if contemporaneous, would be difficult to distinguish from the effects of fishing, given the highly variable background "noise" behind the signal. Environmental impacts on the freshwater components of catchment basin ecosystems are easily documented (e.g., Welcomme, 1995), but distinguishing these changes from those due to fishing in coastal waters still has to rely on anecdotal information or proxy variables.

Historical landings trends by FAO Statistical Areas (Grainger and Garcia, 1996; Caddy *et al.*, 1998) show that, for most regions, peak multispecies landings occurred in close sequence over the last few decades, as industrial fisheries have spread out from "core" aeras, largely in the northern hemisphere. The authors concluded that system productivity to fisheries is in most areas close to or beyond the top of the multispecies yield curve. Thus, the effects of environmental changes, whether anthropogenic or natural, are likely to predominate as long as the systems remain close to the fishing intensity providing the theoretical peak multispecies productivity.

Measurement of environmental driving functions usually depends on "proxy" variables that for instance signal when changes in nutrient enrichment may have occurred. For monitoring indirect effects of fishing, direct observations are needed, and these have also received little research attention. Fisheries landings, being among the few time series available, seem obvious variables for monitoring an ecosystem. However, they reflect both types of human impacts; hence a comparative approach between large marine ecosystems seems essential, before one can separate out short-term ecosystem effects of fishing on semi-enclosed seas (de Leiva Moreno *et al.*, in press).

During the 20th century, almost all anthropogenic signals have trended in a similar direction, namely towards increased stress on natural freshwater and inshore systems as well as on semi-enclosed marine ecosystems (Rapport *et al.*, 1985; Caddy, 1993a). Symptoms of this stress include simplifications of ecosystem complexity and dominance by r-selected species, but the original causes are difficult to distinguish. Figure 1 illustrates the contemporaneous nature of trends in time series available for those few variables, which actually or potentially affect aquatic systems on the global scale. Both world populations and industrial production of phosphate and nitrate fertilizers (spread largely within catchment basins) have risen over the same period that witnessed a dramatic increase in marine landings and fleet size. Regression analysis alone does not allow us to distinguish between the relative rates of change in these trends.

A simple index based on normalized linear regressions, the Linking Ratio (Stamatopoulos and Caddy, 1991), allows one to rank linear regressions of positive-value dependent variables in terms of their relative trend
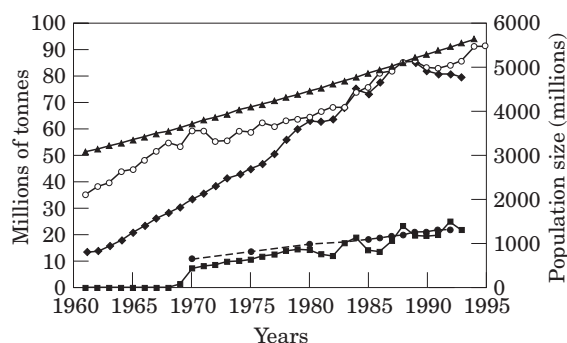
Figure 1. Synchronicity in global trends in world population (triangles); marine landings (open circles), nitrogen fertilizer use (diamonds); fleet capacity (solid circles), and phosphoric fertilizer use (squares). World population in millions; other variables in millions of tonnes.

Table 1. Linear regressions through global time series of several variables of relevance to the marine environment, ranked according to their linking ratios, 1960–1985+ (world population in millions – UN, 1997 and earlier; other variables in millions of tonnes: fleet capacity – FAO, 1994a; yield: marine landings – FAO, 1995; N, P: production of nitrogen and phosphate fertilizers, respectively – FAO, 1994b).

Dependent variable	Linear regressions	Linking ratio
World population	− 148 744 + 77.39*t	0.099
Fleet capacity	− 981.7 + 0.504*t	0.116
Yield	− 2971 + 1.535*t	0.134
N	− 4854 + 2.481*t	0.259
P	− 1515 + 0.772*t	0.386

against the independent variable time (Table 1). The common, close to linear increasing trend in all variables has been progressing more rapidly in the order: human population – fishing fleet size – marine landings – global usage of nitrogen and phosphorus fertilizer (Fig. 1). It would be misleading to imply from this that impacts on aquatic systems from land-based effects are greater than from fishing, except perhaps for enclosed water bodies. The main point is that whatever the relative rates of change, it would be incorrect to assume that impacts on marine ecosystems come solely from the fishery sector.

Evidently, post-war anthropogenic effects have been largely contemporaneous for a range of driving variables, and hence cannot easily be separated or studied independently for semi-enclosed seas.

Marine catchment basin approach

As summarized by Hornung and Reynolds (1995), the catchment basin is the smallest natural unit of landscape in models that link tightly connected aquatic and terrestrial ecosystems. This has long been recognized for freshwater riverine systems (Welcomme, 1995) and, for example, the North American Great Lakes (Regier, 1979). Some comparative approaches to semi-enclosed marine and freshwater ecosystems show broad similarities (e.g., Serafin and Zaleski, 1988). One conceptual framework that offers the opportunity of integrating land-use impacts with those on aquatic ecosystems is the marine catchment basin paradigm (MCB), which is defined (Caddy, 1993a; Caddy and Bakun, 1994) to include the marine aquatic ecosystem and the adjacent watersheds that drain into it (Fig. 2).

Systems under different nutrient regimes

Marine ecosystems are largely constrained by low nutrient levels, with generally nitrogen, and occasionally phosphorus or silicon, being the ''limiting factors'' for biological production. It may be misleading in evolutionary terms to compare aquatic systems receiving natural nutrient inputs with those subject to anthropogenic eutrophication, but Caddy (1993a) noted that there are features in common between upwellings and marine ecosystems subject to cultural eutrophication. Some of these features are also shared with ecosystems heavily stressed by overexploitation. These include: relatively small sizes and short life spans of the target species, short and simple food webs with low mean trophic level/diversity, few large, long-lived benthos, a predominance of small pelagic fish (planktivorous) species over demersal (piscivorous) species, and hypoxic/anoxic conditions applying close to the bottom, either seasonally or permanently. Under stress of eutrophication, however, new niches in previously oligotrophic systems may be progressively filled by ''exotics'' better adapted to hypoxic conditions than the original fauna and flora. In the Great Lakes, pelagic food chains were generally poorly developed prior to eutrophication (Regier, 1979), but large resident populations of small pelagic fish developed following eutrophication-driven pelagic production. The formerly dominant deepwater demersal fish community drew largely upon food reserves from benthos and near-bottom zooplankton, before hypoxia negatively affected these communities. The transitions in the environment of European semi-enclosed seas are shown schematically in Figure 3. Following Jones (1982) and Ursin (1984), a trophic web is here reduced to its main elements: dominant and subdominant pelagic and demersal piscivores, zooplanktivores, and herbivores. This simple semi-quantitative/conceptual model may reproduce some of the key features of poorly documented marine ecosystems subject to nutrient impact. The fragility of the demersal/benthic subsystem with increased organic deposition and consequent hypoxia is clearly evident.

Recent increases in landings for core seas that have long been subjected to high levels of fisheries
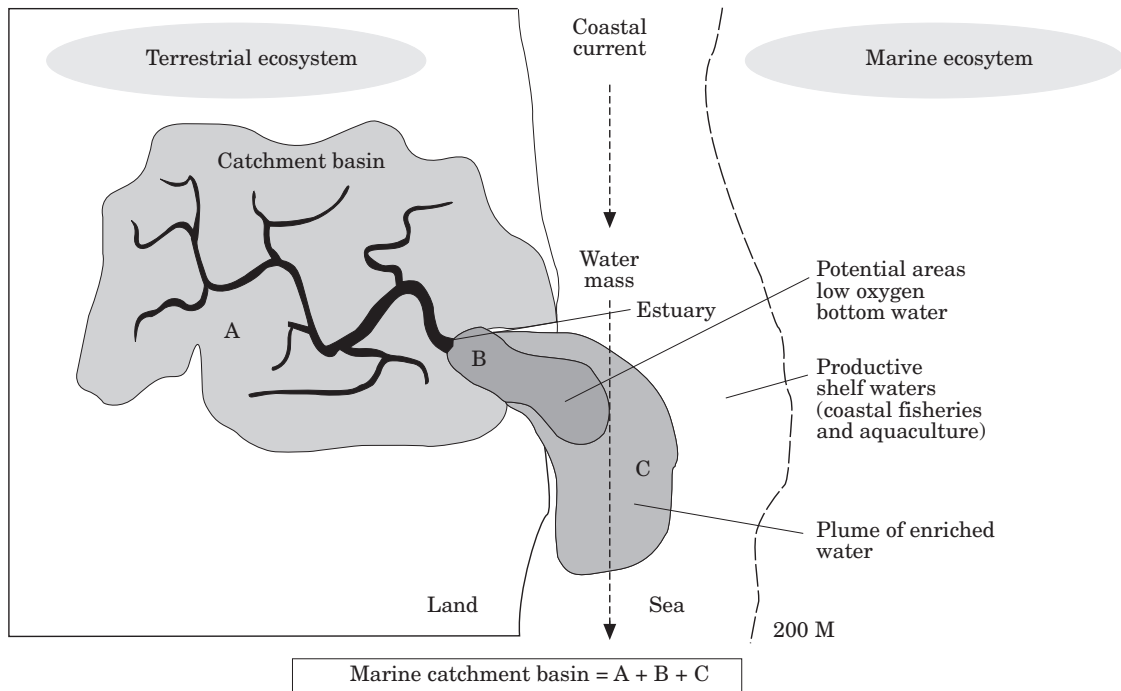
Figure 2. The marine catchment basin includes the catchment basin draining into the sea, the estuary, and the plume, and hence affects the coastal current or semi-enclosed area it drains into.

exploitation are difficult to explain using the theory of Beverton and Holt (1957) or the production model of Schaefer (1954) and later authors. Apparently, increases in basic productivity have been occurring (Boddeke and Hagel, 1995; and Thurow, 1997). It is certainly hard to maintain that the much lower fishery production in the Mediterranean Sea in the 1960s and 1970s than in the 1980s and 1990s was entirely due to the presence of unexploited resources during the earlier years (Caddy, 1993a).

"Fishing down the food chain" has been proposed as a mechanism to explain historical increases in yield of species lower in the food chain in the North Sea (Daan, 1989) or even globally (Pauly *et al*., 1998). These authors see increases in lower trophic level production as resulting from the relaxation of predation pressure by depleted top predators. This mechanism is undoubtedly important in environmentally stable ecosystems, but may have had less impact in semi-enclosed seas in the long term than bottom-up effects resulting from run-off. The recent increase in planktivores in the Yellow Sea (Tang, 1993) and the Seto Inland Sea (Nagasaki and Chikuni, 1989) could equally, or better, be explained by bottom-up enhancement of lower trophic levels. This is also consistent with observations in coastal North Sea waters (Boddeke and Hagel, 1995; Dethlefsen, 1989) and has similar consequences, namely a reduction in the mean trophic level of landings from the ecosystem as

a whole. Such eutrophicated systems would come to resemble the upwelling types of short and broad food pyramids.

The two hypotheses lead to similar effects and therefore they cannot easily be distinguished, although one should beware of predictions from models that assume steady-state primary production. Increased predation on planktonic herbivores presumably reduces grazing on phytoplankton. This top-down effect could lead to increases in phytoplankton standing stocks, perhaps even resulting in stronger stratification of water masses owing to reduced light penetration (Northcote, 1988). However, when increases in herbivores are preceded by increased nutrient inputs, bottom-up effects may also be significant.

Impacts of fishing on enriched ecosystems

The above sections set the scene for describing the characteristic impacts of bottom gear in semi-enclosed seas and other ecosystems associated with enrichment. These include upwelling and eutrophicated areas, where bottom sediments with high organic content and hypoxic, or potentially hypoxic, overlying water masses may be found. Stratification, although generally associated with a lack of tidal mixing and low nutrient systems, may also affect the degree to which land-based
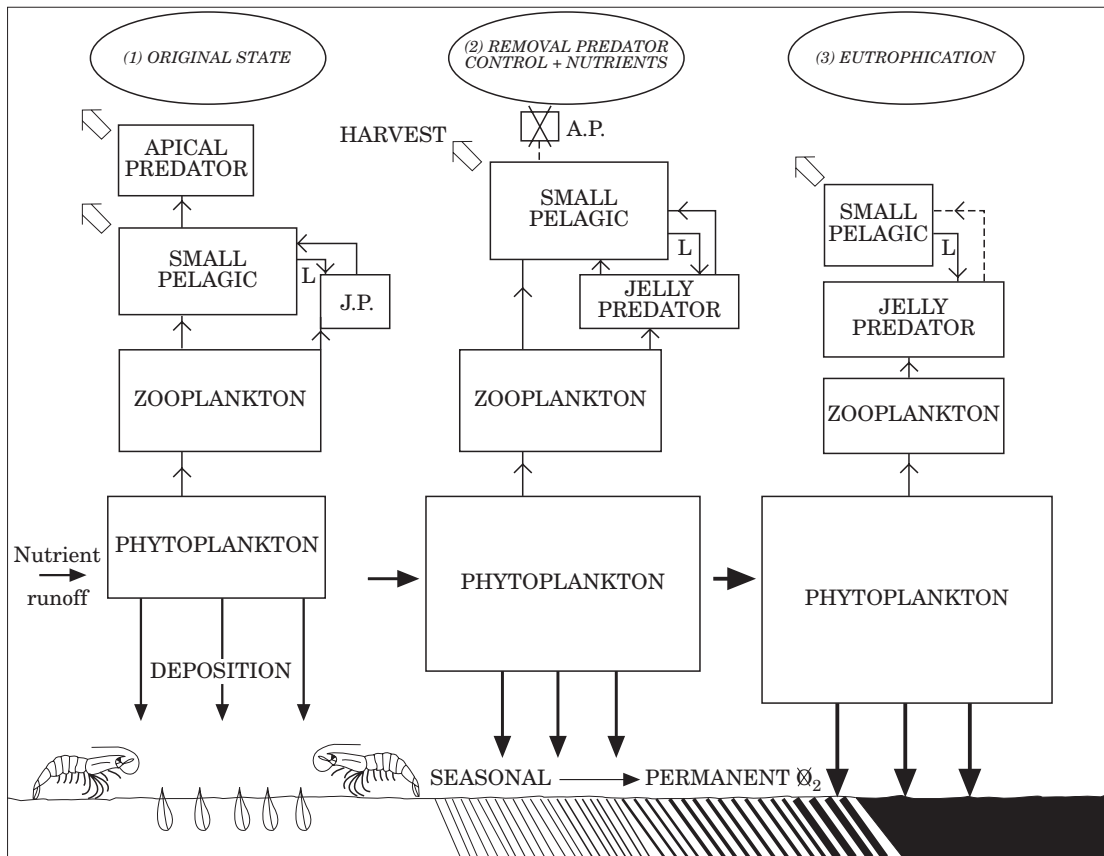
Figure 3. Schematic presentation of three stages of development reflecting the synergistic impact of increasing fishing intensity and nutrient run-off on marine food webs, and bottom hypoxia. Width of arrows indicates fluxes between compartments, and boxes are roughly related to the logarithm of biomass. Deposition of organic material only shown for phytoplankton, but occurs from all levels (L=larvae; dashed arrow=reduced flow).

nutrients in surface run-off impact marine ecosystems (D'Adamo *et al.*, 1992).

Bottom gears may be used over a range of habitats from hard-bottom ecosystems with abundant epifauna and plant cover to anoxic fine mud bottoms. Identifying the relative position of a fishery along this cline from enclosed to exposed inshore shelves (Fig. 4) may be critical to an assessment of the indirect impacts of harvesting. Ideal trawling and dredging grounds roughly correspond to habitats close to the centre of the cline. However, it is postulated that a transition in time may have occurred from clean bottom habitats to low oxygen bottom water overlying anoxic organic sediments in some areas recently subjected to eutrophication.

Impacts of fishing on benthic ecosystems

According to underwater observations in the Bay of Fundy and Gulf of St Lawrence, continued scallop dragging removes epifauna and fine sediments if current speeds are high, while a sheet of fines was seen drifting several centimetres over the bottom if current speeds were low and scallop mantle cavities in adjacent areas were filled with silt (Caddy, 1989). The direct effects of dredging on fine sediments are burial of uncaught scallops and subsequent aggregation of predators in the gear track (Caddy, 1968).

Levelling of reefs by dredging reduces areas less susceptible to siltation that are suitable for shellfish reefs and epifauna (Kennedy, 1989). Not only the impact of low summer temperatures (Dickie and Medcof, 1963), but also smothering by silt from dredging, are likely contributing factors to scallop mass mortalities reported from the Northumberland Strait, Canada.

The volume of silt run-off in Lingayen Gulf, Philippines, has increased enormously due to sheet erosion, especially in the wet season, caused by slash and burn agriculture, logging, and mining (Gaurin, 1990). This may be typical of many tropical MCBs and likely overshadows indirect effects of fishing on the ecosystem. In eutrophic areas such as the Gulf of Thailand (Abe and Petpiroon, 1991), phosphorus and other materials
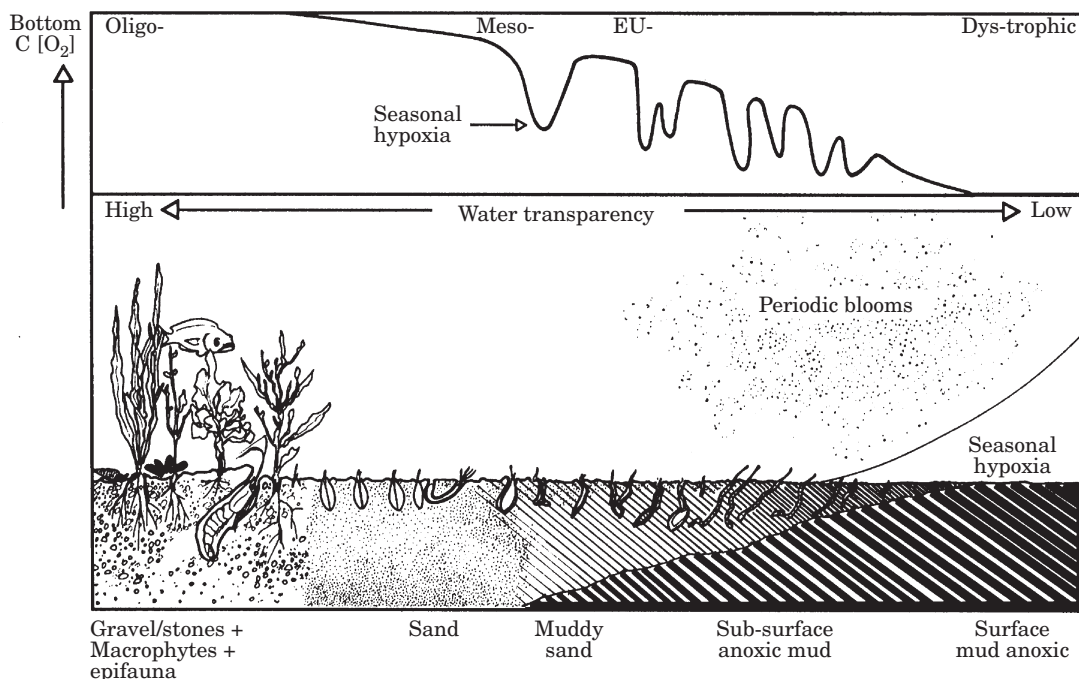
Figure 4. Diagrammatic representation of the transition from coarse oxygenated and vegetated benthic ecosystems to intermittently hypoxic environments and fine organic sediments (after Diaz and Rosenberg, 1995).

sedimentate out from estuarine plumes, but under anoxic conditions with disturbance such as by trawling, nutrients and contaminants may be released again into the overlying water (Petersen *et al.*, 1996), leading to nutrient recycling and algal blooms.

Sediment suspensions decrease light for macrophyte photosynthesis and are believed to have contributed to the disappearance of sea-grass meadows and to affect recruitment and juvenile feeding areas (Sanchez-Jerez and Ramos-Espla, 1996). Plumes of fines can be transported long distances, and are easily resuspended by tidal currents from areas previously trawled (Schoellhamer, 1996). The critical shear stress for sediment resuspension increases if the bottom is left undisturbed due to biological and chemical bonding of sediment grains (Churchill *et al.*, 1994). This means that once disturbed, fine sediments subject to tidal currents do not immediately settle and consolidate.

The use of bottom gear on benthic ecosystems subject to eutrophication is inadvisable, but its long-term impact is probably secondary though synergistic to anthropogenic impacts of eutrophication. Temporary hypoxia leads to ecological stress (Diaz and Rosenberg, 1995) and is exacerbated by dredging or bottom trawling, which risks eliminating macrophytes, benthos, and near-bottom fish that are already close to their limits of tolerance of hypoxia (Hansson, 1985). Fishery-induced stress in these circumstances accelerates replacement of oligotrophic forms by species adapted to eutrophic

conditions. Trawling or dredging are likely to accelerate seasonal die-offs during warm seasons, and seasonal closures may be appropriate. Intensive use over anoxic soft-mud sediments is not recommended, because it results in release of toxic hydrogen sulphide and pollutants, recycling of nutrients and blooms of phytoplankton, and clogging of stressed filter feeders with fine sediments.

Enrichment may cause a decline in mean trophic level as measured by the pelagic/demersal landings (P:D) ratio for the Seto Inland Sea (Tatara, 1991) and for the Yellow Sea (Tang, 1993). P:D ratios for Eurasian seas (see De Leiva Moreno *et al.*, 2000) combine the effects of enrichment and fishing, with enrichment perhaps predominating as deduced from their ordering in relation to their perceived degree of eutrophication (Fig. 5).

Ecosystem effects in semi-enclosed seas

One way of approaching the question of the effects of fishing relative to other anthropogenic effects is to ask whether a change in intensity and type of fishing pressure could reverse the ecosystem effects observed and ensure resource continuity? We may consider the case of the Baltic cod. A progressive reduction in exploitation rate will bring the rate of decline of recruited age classes closer to a value equivalent to the natural mortality rate. However, recruitment depends on an oxygenated water column of more than 100 m to
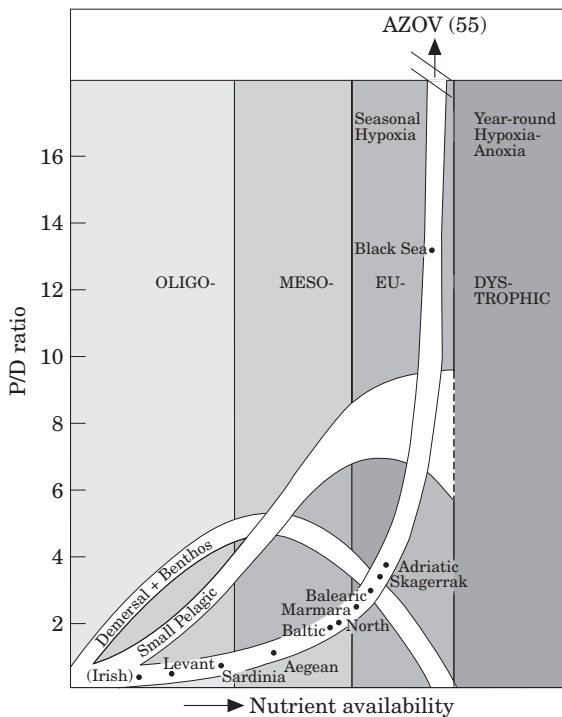
Figure 5. Ordination of the ratio between the landed weight of small pelagic fish versus demersal fish and crustaceans (P:D ratio) for 11 Eurasian semi-enclosed marine area, subjectively segregated into 4 categories along the oligo- to dystrophic cline based on qualitative environmental information (see de Leiva Moreno, in press, for details on P:D ratios).

avoid eggs sinking into hypoxic water. Therefore, survival of viable cod stocks seems mainly a function of controlling MCB processes such as nutrient run-off to the Baltic and is likely to be affected to a lesser extent by harvesting.

Simple ecosystem models based on assumptions of steady-state productivity (ECOPATH II; Christensen and Pauly, 1992), inevitably suggest that top-down controls are predominant between adjacent trophic levels. In the case of the Black Sea (Christensen and Caddy, 1992), anchovy and sprat stocks and available zooplankton food sources ultimately depend on nutrient-driven phytoplankton production (i.e., bottom-up effects). A drastic reduction in harvests of small pelagics increases their biomass and hence leads to grazing down of zooplankton. This in turn could decrease water transparency by reducing zooplankton control on the standing stock of phytoplankton, and hence would tend to promote effects similar to eutrophication. Conversely, increased harvesting would promote growth of zooplankton populations, and this favours increases in passive or unselective feeding zooplanktivores such as *Aurelia aurita* and *Mnemiopsis leydei*, which are likely to be more efficient at high densities of zooplankton.

However, *M. leydei* also preys on larval fish. Nutrient inputs thus also risk leading to pelagic stock declines such as have been observed in the Black Sea (Shiganova et al., 1998; Berdnikov et al., 2000). The tentative conclusion again is that fishery manipulation alone, without reducing nutrient inputs, is unlikely to restore impacted ecosystems of semi-enclosed seas to a more favourable condition.

One feature of fishing strategies in the Mediterranean that also has major implications is the early age at first capture (age 0+) of demersal fish with codend stretched mesh sizes of <40 mm (Caddy, 1993b). The continued increase in landings over the last few decades (Fiorentini et al., 1997) seems paradoxical in light of the apparently low survival and small proportion of mature fish in the commercial catches. Increased nutrient inputs to a formerly oligotrophic system may be one aspect of the explanation, and reduced availability of adults to fine mesh gear, and their protection in refugia consisting of rocky outcrops and shelf slopes, may be another. Relaxation of predation low in the food web owing to fishing down of predators seems unconvincing as a sole explanation, because landings of top predators such as hake and swordfish have generally risen late in the time series. In fact, this rise followed a peak in production of small pelagics in the 1980s (Fiorentini et al., 1997), suggesting a possible bottom-up effect.

Some case studies

A few regional examples illustrate some fishery and environmental characteristics of semi-enclosed marine systems subject to nutrient run-off, and provide insights into the indirect impacts of harvesting.

Mediterranean

Early studies in biological oceanography established the low biological productivity of Mediterranean waters, and until the 1970s, fishery production per shelf area was well below the world's average (Gulland, 1971). Evidence has accumulated (Caddy et al., 1995) that fisheries productivity has been rising with time, especially in northern statistical areas under the influence of the rivers Rhone, Po, Ebro, and, for the Aagean, inflows of enriched Black Sea and Marmara water. It seems even likely that a significant proportion of yield increases since the 1970s is not due just to increased effort, because exploitation was generally considered to be at least at MSY levels in the 1970s, especially for demersal resources.

The recent increase in landings has been most pronounced in the northern Mediterranean, characterized by more river run-off, denser populations, tourism, and intensive agriculture. This is in marked contrast to the low production per shelf area under the oligotrophic conditions that apply along arid southern and eastern

shelves, especially since the construction of the Aswan barrage. In addition to the north–south gradient, an original west-east gradient was described by Murdoch and Onuf (1972) related to the progressive impoverishment of nutrients in Atlantic water as it moves towards the eastern basin. Yields per shelf area have more recently gone up in the eastern Mediterranean/Aegean Sea (Caddy *et al.*, 1995), and Friligos (1989) has described the recent increases in eutrophication resulting from coastal run-off in Greek waters and from the enriched inflow through the Marmara Sea.

Episodes of anoxia in the northern Adriatic have led to local fish kills. The trend from the 1960s to 1980s (Degobbis, 1989) was towards increased eutrophication (UNEP, 1996), with higher phytoplankton production, reduced water transparency, and localized hypoxia (Pucher-Petkovic *et al.*, 1988), and increased sardine biomasses (Marasovic *et al.*, 1988). Under conditions of reduced circulation, high oxygen demands caused by nutrient loading from the River Po causes local summer kills of benthos. A ceiling in fishery yield was reached in the early 1990s (Caddy *et al.*, 1995). Perhaps coincidentally, Ivancic and Degobbis (1998) suggested that nutrient run-off from the River Po decreased during the last decade, owing to reduced use of phosphate detergents in the watershed, a phenomenon paralleled in the Rhine-Waddensea MCB (Boddeke and Hagel, 1995).

Judging from satellite imagery (NSF/NASA, 1989), the south-eastern (Levant) and much of the southern Mediterranean (apart from immediately offshore the Nile Delta) are strongly nutrient-limited. Recently (Fiorentini *et al.*, 1997), landings in the Aegean Sea and also in the Levant have been increasing. Given the 80-year mean period of water retention in the Mediterranean (Murdoch and Onuf, 1972), further increases in land run-off are likely to continue converting the northern parts from an oligotrophic to at least a mesotrophic system at some time during the 21st century.

There is a growing concern (Sanchez-Jerez and Espla, 1996) about impacts of inshore trawling on sea-grass beds, where the high marketability of small fish and shellfish leads to the use of fine mesh "rapido" gear similar to the beam trawl. This gear digs 7 cm into the bottom (Giovanardi *et al.*, 1998) and catches epifauna, infauna, and small fish. For some countries there is a ban on trawling within a given depth zone or distance from the coast or close to estuaries, which is rarely fully enforced. In southern Tunisian waters, a negative impact of trawling on bottom vegetation has been associated with commercial interest in penaeid shrimps whose early life history stages are associated with sea-grass beds. To discourage trawling on sea-grass beds and other sensitive habitats, anti-trawling reefs have been proposed for some inshore areas (Gullen *et al.*, 1991).
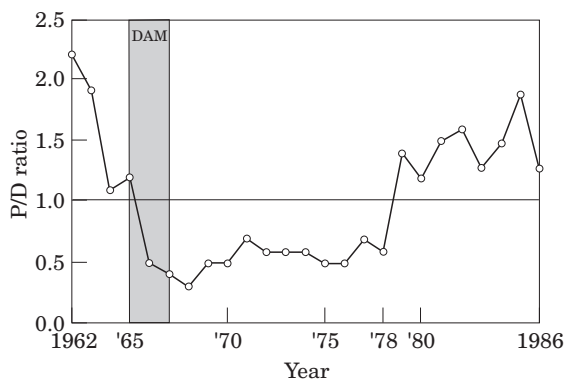

Figure 6. The ratio between pelagic and demersal landings off the Nile Delta prior to and subsequent to construction of the Aswan Dam (from Halim *et al.*, 1995). The later rise in pelagic production appears to be linked to enriched drainage water discharged from the Delta (NSF/NASA, 1989).

Other specific problems are associated with trawling for hake and deepsea red shrimp (*Aristes* sp.), which affects epifauna of rocky shelf edge and slopes. Another damaging deepwater harvesting gear is the St Andrews Cross used for harvesting precious red corals (*Corallium rubrum*), an iron bar hung with chains. This gear has now been abandoned in most countries (Anon., 1989) in favour of harvesting by divers, which produce more localized, if intense, impacts on rock epifauna.

High mortality in early post-settlement stages of shellfish is associated with catastrophic events such as low oxygen in summer, and summer die-offs regularly wipe out millions of dollars worth of stocks of *Chamelea gallina* clams. A management response to the risk of trawling or dredging under conditions of hypoxia could be seasonal closures, but there is no evidence of the application of this type of preventive measure in the Adriatic. Here, summer clam kills may lead to subsequent prohibition of hydraulic harvesting, and closures during the period of spatfall (Carlo Froglia, CNR Ancona, pers. comm.).

The construction of the Aswan Dam in the Nile, which began in 1960 and was completed in 1967 (Halim *et al.*, 1995) appears to have had impacts on fish yield in the Levant. The effects were opposite to the usual trend owing to eutrophication and seem to confirm the importance of nutrients on marine fisheries yields. Nutrient inputs to the eastern Mediterranean declined by roughly an order of magnitude and were accompanied by a significant decline in sardine landings. This showed up as a change in the ratio of landings of pelagic to demersal fish during and following construction (Fig. 6). The P:D ratio seems to provide a robust indicator of nutrient availability.

The recovery of fishery production around the Nile delta in recent years is associated with increased inputs from large cities and other sources of nutrients draining

from the Nile delta into the Mediterranean. This may be associated with the diffuse plume of enriched water inferred from chlorophyll *a* imagery of NSF/NASA (1989) immediately offshore from the delta in the 1980s. Kapetsky (1984) suggested that similar sources of cultural eutrophication were responsible for fisheries productivity of delta lagoons as high as 400–700 kg/hectare.

Black Sea

The Black Sea, with its large catchment area and low flushing to the Mediterranean, is particularly vulnerable to nutrient inputs, and its waters below 200 m or so have been anoxic since before historic times (FAO, 1993). The impacts of nutrient runoff were especially severe on the NW Shelf, mainly under the influence of the Danube (Zaitsev, 1992; Mee, 1992; FAO, 1994c). Although anoxic bottom water has long characterized deeper basins, anoxia has progressively extended onto some shelf areas, at least seasonally.

Regular acoustic surveys of pelagic fish (Ivanov and Beverton, 1985) showed that increases in small pelagic biomass in the 1970s occurred contemporaneously with rises in landings/harvests, which is difficult to explain under steady-state system productivity. Demersal fish predators were reduced in the 1970s and 1980s (for Black Sea turbot (*Psetta maeotica*), owing to deteriorated shelf conditions), while population declines of migratory pelagic predators (*Pomatomus saltator, Sarda sarda*, and dolphins) occurred well before recent anchovy increases (Ivanov and Beverton, 1985; and Zaitsev, 1993).

Mee (1992) notes that by the 1990s, a major part of the northwestern Black Sea was "critically eutrophic". He quotes figures for total phosphorus inputs of 60 000 t per year, plus 340 000 t of inorganic nitrogen from the Danube alone, which is more than double the loading entering the North Sea from the Rhine and four times the amount entering the Baltic (GESAMP, 1990). Judging from experience in the Black Sea, the impact of high nutrient inputs is not negative in itself for pelagic fish. However, eutrophication and increased zooplankton provided an opportunity for the exotic ctenophore *Mnemiopsis* to dominate the pelagic ecosystem (Volovik *et al.*, 1995). This has had drastic consequences for key pelagic resources, notably the anchovy. Even here, however, the story is not a simple one. After almost doubling under the influence of increased fishing and nutrient inputs, anchovy catches dropped to almost one tenth of the peak value, apparently largely as a result of the *Mnemiopsis* invasion. In recent years, the system appears to have habituated in part to this pest and anchovy landings have risen again. Has reduced nutrient run-off also played a part here? Preliminary results with a model (Berdnikov *et al.* 2000) for the Black and Azov Seas pelagic biome suggest ways by which the addition of a new pelagic predator to a marine ecosystem may radically change the ecological balance and the interactions of its components, and overshadow the effects of fishing.

Sorokin (1994) noted that nutrient discharge onto the shallow northwest shelf rose by an order of magnitude between 1965 and 1974/1975, causing phytoplankton blooms and turbidity which adversely affected extensive macrophyte (*Phyllophora*) beds, by severely reducing the euphotic zone. These algae formerly contributed oxygen to near-bottom shelf water. Anoxia and growing hydrogen sulphide levels in turn made the extensive *Mytilus* beds collapse, the main biofiltering agency on the shelf, and led to a toxic-shock effect to the sea as a whole. Zaitsev (1993) observed that despite the overriding influence of environmental change, trawling and harvesting seaweeds and mussels also contributed to this process: fines silted over benthos, further reduced transparency, thereby seriously affecting light penetration to *Phyllophora* beds, and led to release of hydrogen sulphide from anoxic sediments.

Baltic Sea

With a large inhabited catchment area, the Baltic has also witnessed a long-term trend from oligotrophic to eutrophic conditions (Lehtonen and Hilden, 1980; Nehring and Matthaus, 1989; Hansson, 1985; Hansson and Rudstam, 1990). The net export of nutrients is reported to have increased from some 10 000 t of phosphorus and 300 000 t of nitrogen at the end of the 19th century, to around 80 000 t and 1.2 million t, respectively, in recent times.

Nehring (1992) showed that almost continuous decreases in oxygen concentrations have occurred since 1977 and that concentrations of nitrate and phosphate, partly owing to their remobilization from anoxic sediments in the presence of hydrogen sulphide, have been increasing from 1958 to 1989. Thurow (1997) concluded that the fish biomass in the early 1900s was around 2 million t, but by the 1980s had increased almost fourfold. Hence it would be incorrect to make the conventional assumption that the roughly tenfold rise in landings over the same period means that the sea was underfished early in the century. Rather, this reflects increasing pelagic productivity of a once nutrient-limited system. Obviously marine mammals played an important role in the Baltic food chain earlier on. Durant and Harwood (1986) estimated that the 1900 seal population consumed roughly 240 000 t of fish annually. Seal populations are now considerably smaller, but it is hard to see how reduced predator control could explain a fourfold difference in yield, even though it has undoubtedly had some influence. Again, the increase in yield seems predominantly a bottom-up enrichment effect rather than a top-down effect.

The long-term trend towards anoxic bottom water (Rosemarin, 1990) has particularly affected Baltic cod in

Table 2. Subjective ranking of the relative impacts on fisheries in semi-enclosed seas in recent years in relation to the ratio of the area of surrounding watershed to sea surface (from Caddy, 1993a; ratio for the Mediterranean excludes the watershed of the Nile; P:D is the ratio between landings of small pelagic planktivores to demersal fish).

Area	Ratio	Relative impact
Mediterranean	0.6	Enrichment in the north; still oligotrophic in south and east. Fish production showed steady rise. P:D close to unity.
Seto Inland Sea	1.2	Three phases of eutrophication noted. Fish production rose continuously, but P:D increased.
North American Great Lakes	3.3	Varies between lakes, but transition from oligotrophic to mesotrophic in historic times, with ''exotic'' pelagic species introduced in recent decades.
Baltic Sea	4.2	Anoxia in deeper basins has intensified. Pelagic fish yield has increased but demersal/shellfish production declined.
Black + Azov Seas	6.2	Anoxia in deeper basins moved onto shelves in 1970s: benthic/demersal production collapsed. Pelagic fish production rose in 1970s and 1980s, temporarily decimated by jelly predators in early 1990s.

recent years. Clearly, this species is close to its limits of ecological tolerance, which is reflected in the increase in P:D ratio from about 2 in 1976 to over 10 in 1993. Some short-term cod stock recoveries may be due to higher than usual inflow of North Sea water in the 1990s and deepening of the oxycline (ICES, 1996).

Seto Inland Sea
The inland sea of Japan has long been subject to nutrient run-off effects from its crowded and industrialized littoral. Three periods of eutrophication were recorded, beginning with the pre-war period and fishery yields averaging less than 150 000 t (Nagasaki and Chikuni, 1989). A further rise to about 240 000 t landings occurred in the 1960s, when maximum fisheries development was attained. A third plateau occurred in the 1970s at around 400 000 t, and these last two phases were linked by Tatara (1991) to increased primary production and a move to a higher proportion of pelagic planktivores, as opposed to demersal fish plus piscivores, in the catch.

Ratio of catchment area to semi-enclosed sea

One qualitative index that represents fairly well the susceptibility of a semi-enclosed marine ecosystem to run-off effects is the relative area of the catchment and of the receiving sea. Table 2, modified from Caddy (1993a), shows that this index broadly parallels susceptibility to nutrient impacts in European waters. For example, despite fairly intensive anthropogenic changes, the Mediterranean with its small catchment area seems more resistant to destructure change than the Black and Baltic Seas where the ratio is much higher. On the other hand, intensive anthropogenic transformation of small catchment areas (e.g., the Seto Inland Sea) can accentuate eutrophic effects.

Conclusions

The foregoing sections illustrate that it is important to study overall anthropogenic effects on semi-enclosed systems before ascribing all impacts to fisheries. It is important for coastal fisheries biologists to follow limnologists and take a broader perspective, considering impacts stemming from adjacent catchment areas as well as fishery impacts.

The first conclusion from this discussion is that not all levels of nutrient run-off can be considered as a purely negative phenomenon from the fisheries perspective, even though the impact might be negative for some other sectors of society. The same conclusion seems to apply here as was drawn with respect to fisheries theory: radical changes in biotic components may affect the physics and chemistry of a water body as well as vice versa. The scientific focus should probably be, however, on looking at marine catchment basin phenomena as a whole, identifying acceptable upper limits to nutrient run-off, and focusing elsewhere in the diagnosis on the effects of non-biodegradable and toxic-waste discharges, pesticides, organic chemical residues, and other toxic by-products of industry and agriculture.

The dramatic effects of nutrient enrichment on ecosystems of semi-enclosed seas involve ecosystem change, the dominance of planktivores, introduction or expansion of hypoxia-resistant species, and disappearance of those adapted to oligotrophic conditions. Fishing down apical predators should theoretically contribute to increases in prey biomass, but these top-down effects and those of bottom-up increased in production owing to nutrient enrichment are probably synergistic for the small pelagics. Which is the most important? It seems unlikely for semi-enclosed seas with highly populated littoral zones that fishing alone will lead to extinction or population collapse of shelf demersals and invertebrates. However, impacts of excess nutrients and hypoxia in

changing ecosystem components and biodiversity, and the fragility of the demersal/benthic system under these circumstances, is clearly evident.

The issue of controlling the impacts of trawling and dredging of sediments subject to high oxygen demand appears to be an important one. The impacts may be more widespread than apparent from the literature, because monitoring and experimental work on hypoxia have been inadequate so far. Rare direct observations of trawling over organic bottoms suggest that resuspension of fines, with low dissolved oxygen and toxic levels of hydrogen sulphide, could pose major physiological stresses, and also lead to recycling of nutrients and further phytoplankton blooms.

A precautionary approach to harvesting from habitats subject to seasonal hypoxia, and the associated risk of seasonal kills of valuable benthos and demersal fish, would suggest caution in the use of fishing gear that disturbs the sediment during periods of high risk.

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