Fisheries: Trends in Catches, Abundance and Management

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Abstract

Fisheries of the Chesapeake Bay (CB) and Northern Adriatic Sea (NA) are reviewed and compared with respect to constituents of the catch, trends, and management issues. Recent annual landings have been approximately 100,000 and 275,000 tons in the NA and CB, respectively. Clupeoid fishes (anchovies, sardines or menhaden) dominate the fish biomasses and catches in both ecosystems. Fisheries on anadromous and estuarine-dependent species are more important in CB, and diverse, demersal fisheries are relatively more important in NA. Although total catches have remained high, anchovy stocks in the NA collapsed in the 1980s, and oysters and shad/river herring stocks in CB declined to collapses during the past three decades. Eutrophication, overfishing, and problems of interjurisdictional management are common to the two ecosystems. The co-management of commercial and recreational fisheries is an issue in CB. Fish productivity and catches are higher in CB than in the NA on a per unit volume, area, and nutrient input basis. Yield per unit of primary production is slightly higher in the NA. A part of the difference between the two systems is accounted for by the dominance of landings and production of menhaden, a phytoplanktivore, from Chesapeake Bay. Recent progress in development of national and international management accords (Slovenia, Croatia, Italy) is evident in the NA, and interstate plans are now required in the CB. In both systems, prospects for continued high fisheries productivity depend upon effective ecosystem and fisheries management.

Introduction

Fisheries in the northern region of the Adriatic Sea (NA) and in Chesapeake Bay (CB) have existed for centuries and have played important roles in food production and the economies of the regions. Fisheries in the eastern Adriatic date to 100-200 A.D.' The earliest records of Adriatic fisheries harvests and documentation of a fishing industry date to the year 995, based upon archived records in the town of Zadar, Republic of Croatia [Rački, 1877]. In the CB, shell mounds (middens) and other evidence document a strong dependence and significant harvesting of Bay resources by native peoples hundreds of years before settlement by Europeans [Wharton, 1957; Mountford, 1996]. Fisheries in both the NA and CB remain important today, continuing to provide commercial harvests and, in addition, major recreational opportunities in CB. Presently, the fisheries in both ecosystems are under stress from habitat degradation and loss, overfishing, and probable changes in trophic status related to increased nutrient loading in the past several decades.

We compare and contrast the harvested fauna in fisheries of the NA and CB. There are notable similarities, especially in the dominance of shoaling clupeoid species in the pelagic fisheries, but there are contrasts as well. The NA is an extension of the

Mediterranean Sea, and its fauna is typically marine, including some boreal species. Salinities in the NA range from 5.0 to 38.6 psu, but low salinities are confined to a narrow band along its western margin [Boicourt et al., this volume], so that much of the NA is euhaline. In contrast, the CB is a large estuary, with a fauna that ranges from freshwater to marine species. Despite a broad range of habitats along the 0 to approximately 30 psu salinity gradient of CB, the diversity of fisheries is greater in the NA. Most of the catch in CB consists of species that are estuarine-dependent during some part of their life history. Anadromous fishes are important in CB, but are of minor consequence in NA fisheries. Overall, fisheries management is difficult in both systems because the fisheries are multijurisdictional, with most key species either broadly distributed across jurisdictions or migrating among regions during parts of their life cycles.

There is little direct evidence that links levels of fish production or catches in either ecosystem to levels of nutrient input. However, strong correlations between nitrogen inputs and primary production are expected [Iverson, 1990] and fish catches in many ecosystems are directly related to levels of primary production [Nixon et al., 1986]. Excessive anthropogenic increases in nutrient loading, especially nitrogen, during the past four to five decades have occurred in both NA and CB, leading to increased frequencies of hypoxia or anoxia in CB and to localized, but infrequent hypoxic events in NA [Boicourt et al., this volume; Newell and Ott, this volume]. It is presumed, but not demonstrated, that hypoxia limits or reduces fisheries productivity. Fish may be effective in sequestering nitrogen via consumption or in removing it by migrations [Deegan, 1993; Boynton et al., 1995]. These processes may be operating in NA and CB, especially in dominant planktivore fishes. The extent and importance of nutrient-fisheries interactions are poorly understood but are presently the subjects of major research programs in CB.

The morphology of the basins and the geological history and evolutionary trends of NA and CB are described in earlier chapters of this volume [Smodlaka et al., Boicourt et al., Stevenson et al., this volume]. The substantial differences in basin morphology and hydrography, especially volumes (larger in NA) and mean depth (shallower in CB) have implications for biological productivity and fisheries in the respective ecosystems.

The first ecological studies of the NA ecosystem were done by Lorenz [1863], who reported on regional hydrography, biota and distributions. This early work was followed by ecological studies in the Bay of Trieste [Graeffe, 1888], the Venetian lagoons [Vatova, 1928] and the Lim Channel [Steuer, 1933]. Steuer [1902] included the sardine *Sardina pilchardus* in his early studies of plankton in the Gulf of Trieste and the NA. Fewer classical works exist on CB fauna and fisheries but Wharton [1957] provided a detailed account of historical fishing and Hildebrand and Schroeder [1928] have summarized knowledge of CB fishes and fisheries.

Trophic states and overall production potentials of the NA and CB ecosystems have been discussed by Smodlaka et al. and Harding et al. [this volume]. The productivities of the two systems with respect to harvestable fisheries resources are influenced by basic morphologies, hydrography and salinity gradients [also see Boicourt et al., this volume]. The CB has a more extensive salinity gradient and seasonal temperatures that can range from 0 to 30°C during the year. Consequently, fisheries in the CB are primarily on estuarine-dependent species, contrasting with those in the euhaline NA, which tend to be principally a marine species.

Nutrient inputs to the two ecosystems have increased during this century as human populations in the watershed have increased [Smodlaka et al. and Seagle et al., this

volume]. It is likely that productivity potentials for fisheries also have increased. But, owing to lack of historical information and trends, little can be said about either positive or negative changes in productive potential of fisheries resources. While more nitrogen may be available for secondary and higher-level production, widespread increases in episodes of hypoxia and anoxia in the CB, and declines in submerged aquatic vegetation in CB, have negatively impacted benthic resources and fishes [Newell and Ott, this volume]. Hypoxia is less frequent and more localized in the NA, affecting a smaller fraction of this ecosystem. A greater fraction of phytoplankton production may fuel fish production in NA, while a larger fraction may support processes that cause oxygen depletion in CB [Boicourt et al. and Harding et al., this volume]. In both systems, the 'agricultural paradigm' may apply, in which overall higher fisheries yields are associated with increased nutrients and primary production [Nixon et al., 1986]. However, shifts in species and risks of losing production of some valuable fisheries resources under such conditions are not acceptable tradeoffs that can be tolerated in long-term management of NA and CB living resources.

Fisheries Yields and Trends

Catches in the entire Adriatic Sea by Italy and the former Yugoslavia exceeded 200,000 tons during the 1980s (Figure 1). Catches in the NA during the 1960s and early 1970s contributed 33-38% (45,000 - 58,000 tons) of the total. In recent years, the NA catches by Italy have declined significantly [Bombace, 1992, 1995], although comparable data for the Republics of Slovenia and Croatia are not available. The Italian catches in the NA declined by 40% from 132,750 tons in 1980 to 79,641 tons in 1992 (Figure 1 and 2). Declines in both pelagic (64%) and demersal (67%) finfish fisheries were recorded [Bombace, 1995]. Molluscan fisheries of Italy in the NA declined by 88% between 1980 and 1992 while a 15% increase in Italian landings of crustaceans was recorded during that period. In the former Yugoslavia, now the Republics of Slovenia and Croatia, the NA fisheries were relatively stable (demersal), or increasing (pelagic) from 1947-1971 (Table 2). Landings data are unavailable for Croatia and Slovenia since 1971.

Total fisheries catches in CB have increased since the turn of the century, and have been stable, or increasing slowly in recent decades (Figure 1). Since the 1970s, levels of catch generally have exceeded 250,000 tons (Figures 1 and 3). Most of the catch (80%) consists of a single clupeid species, the phytoplanktivore Atlantic menhaden *Brevoortia tyrannus*. Although CB fisheries statistics do not divide the catch into demersal and pelagic components, it is clear that the predominant contributor to the overall increase in landings in CB has been increased pelagic, menhaden catches. Landings of demersal and other pelagic species generally have declined or have shown no trend [Rothschild et al., 1981; Miller et al., 1996].

Problems and Concerns

The problems being experienced globally in managing fisheries also are prevalent in the NA and CB ecosystems. High fishing effort and associated overfishing are problematic. In the NA, some demersal resources, particularly elasmobranchs, were overfished decades ago [D'Ancona, 1926, 1950, 1955]. Levi and Giannetti [1972]

reported that some benthic stocks (mullet *Mugil* spp., trlja *Mullus barbatus*, norway lobster *Nephrops norvegicus*) in the northern and central Adriatic were heavily overexploited. In the CB, overfishing, both within the bay and on migratory coastal stocks, has impacted important CB fisheries. Several species of major importance (eastern oyster *Crassostrea virginica*, striped bass *Morone saxatilis*, American shad *Alosa sapidissima*, weakfish *Cynoscion regalis*) were overfished during the past 50 years [ASMFC 1985, 1989, 1992, 1996]. In the case of the eastern oyster, overfishing may have occurred during the late 19th century [Rothschild et al., 1994].

In the CB, declines of anadromous fishes began in the 18th century [Wharton, 1957], a consequence of damming tributaries, which denied access to spawning areas. Construction of impassable dams continued into the 20th century and anadromous stocks, particularly sturgeons and alosids (shads and river herrings) suffered greatly. Declines in water quality, e.g. hypoxia, and in the amount and quality of spawning habitat [Boicourt et al. and Stevenson et al., this volume] undoubtedly also played a role in the declines of anadromous fishes.

Both the NA and CB have experienced increased eutrophication during recent decades, caused by anthropogenic, nutrient loading of major tributaries, principally the Po River in the NA and the Susquehanna River in CB [Harding et al. and Sellner et al., this volume]. While increased eutrophication potentially may lead to local increases in fisheries production and yields through enhancement of plankton production, as apparently has occurred in the NA, it also can cause increasing hypoxic and anoxic conditions which may harm benthic and demersal fishes and invertebrates [Bombace, 1992]. The problems of hypoxia and anoxia with respect to living resources are of major concern in the CB [Smith et al., 1992], although documented effects are limited to specific life stages of some benthic invertebrates and fishes. While hypoxia and anoxia have not been shown to cause declines in CB fisheries catches, some species, e.g. eastern oyster, did suffer loss of habitat and declining productivity as hypoxic conditions expanded [Gottlieb and Schweighofer, 1996; Newell and Ott, this volume].

High nutrient levels also caused habitat shifts that may have had negative consequences for fisheries production. Major declines in submerged aquatic vegetation in CB (greater than 80 percent loss) during the past 40 years are linked to the increases in nutrient loading [Stevenson et al., this volume]. The loss of such important nursery habitats, which offer food and protection from predation for juvenile fish and invertebrates remains a serious concern to fisheries scientists and managers.

Developing and achieving effective management programs for fisheries is problematic in both NA and CB. Stock assessments to determine abundance trends or effects of fishing on exploited resources either have not been carried out or have not been periodically reviewed in the CB [Richkus et al., 1992]. In the past, data on CB fishing effort was collected sporadically or is completely lacking [Rothschild et al., 1981] and the same apparently is true in the NA. Until recently, reporting of catches was not mandatory in the NA. While problems of interjurisdictional management persist, there is progress towards reaching international agreements for management of NA stocks [EU Declaration, Crete, 1994] and in instituting interstate agreements for assessment and management of major CB stocks [CBP, 1988; Richkus et al., 1992]. A burgeoning recreational fishery in the CB, for which data on catch and effort are poor or lacking, but which takes the biggest fraction of the catch for some species, contributes to the management problem.

Fisheries Resources: Comparisons and Contrasts

Pelagic Fish

The biomasses of pelagic fishes in the NA were believed to total approximately 450,000 tons in the 1960s [Stirn, 1969; Zavodnik 1970]. The pelagic biomass, estimated by hydroacoustics methods, now largely consists of sardine (*Sardina pilchardus*), and apparently was maintained near the 450,000 ton level through the 1980s, although estimated biomass was highly variable from year to year [Bombace, 1992].

Fisheries for pelagic species in the NA are carried out by paired-vessel, midwater trawling [Cingolani et al. 1996]. Pelagic fishes, particularly the sardine *Sardina pilchardus*, have always yielded the highest catches throughout the history of Adriatic fisheries [Županović, 1993]. Two additional species, the European anchovy *Engraulis encrasicolus* and the sprat *Sprattus sprattus* also are important. Anchovy is most abundant along the western coast of the NA [Cingolani et al. 1996; Regner, 1996], which is strongly influenced by the Po River and its associated high organic load, high organic production and high zooplankton prey abundance. Although anchovy spawns throughout the Adriatic Sea, there are distinct and relatively important spawning areas, especially in the western NA [Regner 1996]. Stirn [1969] studied trophic relationships of anchovy and found a direct link between the diatom *Nitzchia*, the cladoceran *Penilia*, and the anchovy. The anchovy fishery in the NA has been in a state of near collapse since the mid-1980s in the Italian [Bombace, 1992], and in the Slovenian and Croatian fisheries (Figure 4), although Cingolani et al. [1996] reported some signs of recovery in the most recent years. The collapse of anchovy cannot be ascribed solely to overfishing or to environmental changes, but its rapid decline is reminiscent of the "disappearance" of mackerel *Scomber scombrus* in the Adriatic [Mužinić, 1973], a heavily fished population that never recovered and which may have been replaced by other pelagic species.

Catches of sardine have dominated pelagic fisheries in recent years in the eastern NA (Figure 4). The sardine forms a genetically unique stock in the NA [Alegria-Hernandez, 1983, 1985; Alegria-Hernandez et al., 1986; Sinovcic et al., 1991]. Its migration patterns, which are strongly related to spawning seasons, indicate that there are two subpopulations in the NA itself [Mužinić, 1973; Skrivanic and Zavodnik, 1973]. The marked variability in annual catches of sardine in the Adriatic is believed by some scientists to show periodicities of 8 and 11-year intervals associated with solar activity [Regner and Gacic, 1974].

In CB, the commercial fishery on menhaden, which is reduced to meal and oil products, is the only major pelagic fishery. Catches in recent years from the CB and its plume have exceeded 200,000 tons. Most landings are made by purse seiners which, by regulation, can only operate in Virginia waters of CB [Austin et al., 1994]. Catches have been stable or increasing slightly over the past 25 years (Figure 3).

The menhaden is a phytoplanktivore and, as such, is believed to be important in the CB nutrient budget and as a primary prey of large piscivorous fish such as striped bass and bluefish *Pomatomus saltatrix* [Boynton et al., 1995; Hartman and Brandt, 1995]. The CB serves as an important nursery for juvenile menhaden in addition to supporting a fished population. The menhaden stock is healthy, and recruitment levels were above average for many years [ASMFC, 1986], although recruitments have declined significantly during the mid-1990s [Cadrin and Vaughan, 1997]. Despite the stable

condition of the fishery, the stock technically is overfished, in the sense that yield could be increased if fishing effort were directed less at young age classes [Ahrenholz, 1991; Vaughan and Merriner 1991; Vaughan and Smith 1991].

Demersal Fish

Catches of demersal fish are lower than the pelagic catches in both the NA and CB. Trawl fisheries and artisanal fisheries exploit a wide variety of demersal species in the NA. Although catches of demersal fishes by Italy in the NA declined during the 1980s [Bombace, 1995] and overall catch-per-unit-effort (CPUE) in research trawling declined by approximately 40% (Figure 5), CPUE for most major species declined little or varied substantially without apparent trend in surveys carried out between 1982 and 1992 (Figure 5) [Piccinetti and Piccinetti-Manfrin 1994]. The standing stock of demersal fishes in the NA, based upon the CPUE data, was estimated to be 14,451 tons. Maximum sustainable yields (MSY) for the NA demersal species are not known, although Bombace [1995] believed that the trawl fisheries had surpassed MSY, leading to the observed decline in catches.

Only a few demersal or semi-pelagic species (Figure 6) contribute substantially to the CB commercial catch. Trends in commercial landings, principally from poundnets (traps) and gillnets, generally have declined in the past 50 years. CPUE indices of juvenile abundances in research surveys (pre-recruit surveys) also indicate downward trends in the major demersal species [Bonzek et al. 1995], which consist of three sciaenids (weakfish; Atlantic croaker *Micropogonias undulatus*; and spot *Leiostomus xanthurus*) and the summer flounder *Paralichthys dentatus*. The downward trend in landings of these species (Figure 6) and declines in their prerecruit abundance are attributed to coastwide overfishing of these migratory species, which are fished over a large part of the coast in the eastern USA [e.g. ASMFC, 1996]. In the freshwater, upper CB and in its tidal tributaries, both landings and stock abundance of the demersal catfishes, primarily *Ictalurus punctatus*, have increased in recent years [Sauls et al., in press]. Annual landings of catfish in the upper Bay and tributaries averaged approximately 1,040 tons in the period 1985-1992.

Increasing frequency and extent of hypoxic and anoxic conditions in the NA and CB pose concerns for demersal fisheries. Demersal fishes may be especially vulnerable to low oxygen levels during periods when the NA and CB are strongly stratified [Bombace, 1992; Smith et al., 1992]. Breitburg [1988, 1992] has shown that demersal fish communities associated with oyster reefs in CB are negatively impacted by hypoxic conditions that occur during summer months.

Anadromous and Catadromous Fishes

Anadromous fish historically have included the most prized finfish species in the CB. These fishes are less important in the NA. In the NA, catadromous eel *Anguilla anguilla* is caught primarily by Italy and its catches are stable or have declined a bit since the 1970s (Table 3). Catadromous American eel *Anguilla rostrata* is landed from CB waters. Part of the CB catch is exported for human consumption and part is used as bait in the fishery for blue crab *Callinectes sapidus*. Catches of eel in CB during past 30

years have fluctuated in the 200 to 550 tons range, with no apparent trend. The variable landings of euryhaline mullets *Mugil* spp. in the NA have declined by about 50% in Italian catches since 1970, but no trend is evident in Slovenian or Croatian landings from 1972-1981 (Table 3).

As noted earlier, dams or other obstructions that made tributaries impassable to spawning adults caused the major declines in anadromous fishes in CB. These declines began in the 17th and 18th centuries [Wharton, 1957]. Continued declines occurred throughout the 20th century, but a sudden drop in landings in the 1970s (Figure 7), concurrent with failed recruitments and reduced adult abundances of several species, was alarming.

The American shad, once the most valuable fish in CB commercial landings, collapsed in the 1970s and presently is under a fishing moratorium throughout the CB. Its catches declined from nearly 8,000 tons in the late 19th century to <5 tons in 1994. The closely-related hickory shad *Alosa mediocris* and two smaller species *A. pseudoharengus* and *A. aestivalis* (collectively referred to as alewives or river herrings), also declined precipitously during the 1970s (Figure 7), leading to speculation that deteriorating water quality on spawning grounds and in larval nurseries had been the cause. Anecdotal evidence of unreported bycatches of alosids in offshore trawl fisheries suggests that bycatch mortality also may have been a factor in the collapse of the river herring stocks [ASMFC, 1985].

The striped bass probably is the most sought-after species in CB today. Like many CB fish, it is exploited by both commercial and recreational fisheries. In the 1970s and 1980s, the CB stock collapsed, and both landings (Figure 7) and recruitments plummeted. In this case, overfishing was identified as the major causative factor [ASMFC, 1989; Richkus et al., 1992; Leffler, 1993; Field, 1997]. A moratorium on fishing and a remarkably successful stock rebuilding program have restored striped bass to its former abundance [Field, 1997]. The recovery of adult stock has been accompanied by recent high recruitments that have accelerated the rate of recovery, and demonstrated that nursery habitats remain adequate to support production of larvae and juveniles.

The semi-anadromous white perch *Morone americana*, which primarily inhabits tidal tributaries and freshwaters of CB, has experienced a decline in mean annual commercial landings from 858 tons in the 1960s to 329 tons in the 1980s (Figure 7). The abundance of the stock is thought to be stable at present [CBSAC, 1995], although no formal assessment has been carried out.

Freshwater Fish

The 0 to 30 psu salinity gradient in the CB provides opportunities for freshwater fishes to inhabit the uppermost bay and its tidal tributaries. Both recreational and commercial fisheries exploit some species. Annual, averaged commercial landings of major species from 1985-1992 were 1,416 tons, including yellow perch *Perca flavescens* (30 tons), carp *Cyprinus carpio* (56 tons), gizzard shad *Dorosoma cepedianum* (290 tons), and the previously mentioned catfishes (1,040 tons).

Molluscs

A suite of suspension-feeding lamellibranchs, and pelagic and demersal cephalopods contribute significantly to NA landings. Harvested shellfishes are most abundant in the northwestern NA, in the enriched sediments of that region. Largest catches of molluscs in the NA are made by Italy, although significant and valuable fisheries also are found in the eastern NA, with harvests by Slovenia and Croatia (Table 2; Figure 8). The single, most important species of shellfish is the striped Venus *Chamellea gallina*, which has yielded >10,000 tons annually in recent years [Bombace, 1995]. Smaller harvests of scallops *Pecten jacobeus* and *Chlamis opercularis*, and of mussels *Mytilus galloprovincialis* are made. Although there was no observed decline in landings, Bombace [1992] noted that the stocks were heavily fished and that overfishing probably is occurring at the recent effort levels. Šimunović et al. [1985] estimated the scallop biomass to be approximately 22,000 tons in the early 1980s.

A fishery for several species of cephalopods– squids, cuttlefishes, and octopus, which are captured in bottom trawls, is important in the NA (Figure 8). Three species dominate the landings: the European squid *Loligo vulgaris*, the common cuttlefish *Sepia officinalis* and the musky octopus *Eledone moschata*. Landings in recent years have averaged 3,000-5,000 tons. No declines in landings of cephalopods have occurred in the NA and research trawling did not detect declines in CPUE (Figure 5) [Piccinetti and Piccinetti-Manfrin, 1994]. In fact, landings of European squid and common cuttlefish may have increased recently, possibly in response to increased effort and market demand.

Molluscan fisheries in CB are less diverse than those in the NA and were dominated by the eastern oyster. Oyster harvests exceeded 50,000 tons (meat yield) annually in the late nineteenth century, but have declined steadily to a fishery collapse in the 1980s (Figure 9). The concomitant loss of the oyster's high capacity to filter phytoplankton may have contributed importantly to the eutrophic state of the bay [Newell, 1988]. Overfishing, habitat loss and, most recently, diseases have led to the demise of the oyster in CB [Rothschild et al., 1994].

A fishery for soft clam *Mya arenaria* in CB presently yields 1,048 tons (meat) annually (1985-1992 mean). Mean yields during the 1960s exceeded 3,000 tons but have never fully rebounded since freshwater floods associated with Hurricane Agnes inundated the CB in 1972. A smaller, but growing, fishery for hard clams, *Mercenaria mercenaria* in the lower CB has yielded 416 tons (meat), on average, from 1985-1992.

The problem of eutrophication, a consequence of elevated nutrient inputs, is common to the NA and CB ecosystems. Benthic, molluscan resources potentially are severely impacted by resulting hypoxic and anoxic conditions in deeper parts of the systems. In the CB, large areas of bottom are not habitable by oysters or other benthic fauna during the summer anoxic period. Overfishing contributes to the eutrophication problem by removing oysters that could filter high phytoplankton stocks and thus reduce the overall hypoxia stress on the CB system [Ulanowicz and Tuttle, 1992].

Crustacea

There are relatively small, but important crustacean fisheries in the NA. Two species predominate: the spinous spider crab *Maja squinado* contributes most to the landings followed by the mantis shrimp *Squilla mantis*. Most of the crustacean landings are made

by Italy, but up to 18% of the annual catches were made in the eastern NA by Slovenia and Croatia (Figure 8) in years where statistics are available. There are no apparent declining or increasing trends in the NA crustacean fisheries or in research-trawling CPUE (Figure 5).

In the CB, blue crab is the only crustacean fishery. Blue crab is the most valuable of CB's commercial fishery resources and, while resilient to fishing, its future status concerns fishery managers. Commercial catches in recent years have been in the 30,000 - 40,000 ton range. There also is a large recreational fishery for which there are no landings statistics. A decline in commercial catch in 1992 (Figure 9) and indications of declining abundances caused concern, but a recent stock assessment indicates that the stock, although heavily exploited, is not in danger of collapse, and perhaps has returned to an average level of abundance in the 1990s after a period of high abundance in the 1980s [Rugolo et al., 1997].

Productivities, Fishery Yields, and Species Interactions

Overall, the CB is more productive than the NA. The level of mean annual primary production (g Cm^{-2} yr^{-1}) is nearly six times higher in CB than in NA [Harding et al., this volume]. For the entire ecosystems, approximately 3.4 times more carbon is fixed annually in CB than in NA (5.18×10^{12} g C vs 1.51×10^{12} g C). The annual fish catch is about 2.8 times higher in CB than in NA, a value somewhat lower than the primary production differential between the two ecosystems. Fish yields, standardized to unit areas or volumes, are substantially higher in the CB. At recent catch levels of approximately 100,000 and 275,000 tons yr^{-1} in the NA and CB, respectively, catches in the CB are 4.5 times higher per unit surface area and 23.6 times higher per unit volume (Table 1). The relatively high productivity and fisheries yield of CB compared to that of the NA is in accord with expected high values for estuaries in general [Nixon, 1988; Houde and Rutherford, 1993]. In the central Adriatic Sea, a positive correlation between annual levels of primary production and pelagic fish CPUE was demonstrated [Marasovic et al., 1988], suggesting a dependence of fish production on primary productivity; unfortunately, comparable analyses are not available for the NA.

Observed fisheries yields in both the NA and CB are higher than expected relative to their respective primary production levels, based upon Nixon's [1988] empirical relationship between fish yield and primary production for marine and estuarine ecosystems. At primary production levels of 80 and 450 g $Cm^{-2}yr^{-1}$, respectively, the predicted fish yields from NA and CB, applying Nixon's [1988] equation, are 10.0 and 145.4 kg^{-1} ha^{-1} yr^{-1}, respectively. These predicted values are approximately 19% and 61% of the actual landings in NA and CB during the 1980s (Table 1).

Fish production (i.e. biological productivity of potentially harvestable resources, including invertebrates) is much higher in the CB than in the NA. Iverson's [1990] equation relating fisheries production to new-nitrogen-dependent primary production was applied to roughly estimate the potential fish productivity at two trophic steps above primary producers in CB and NA. Estimates of fish production at trophic level 2 (i.e. zooplanktivore or primary carnivore), a level that may approximate the average harvested trophic level in the two ecosystems, were 100.5 and 967.2 kg^{-1} ha^{-1} yr^{-1} in NA and CB, respectively. Thus, predicted fish productivity per unit area for potentially harvestable resources is 9.6 times higher in CB than in NA. Commercial catch levels in the 1980s

(Table 1) represented 52.6% and 24.7% of the predicted NA and CB fish productions. These statistics suggest that the NA is more heavily exploited than is the CB.

Other relative measures or indicators of fisheries harvests also emphasize the more productive nature of CB. Fish yields per unit nitrogen or phosphorous input are 6-7 times higher in CB than in NA (Table 1). While total nitrogen and phosphorous loadings are higher in the NA [Smodlaka et al., this volume], loads standardized to a unit volume are approximately four times lower for nitrogen and three times lower for phosphorous in NA than in CB. Loads standardized to a unit area are about 1.3 times higher for nitrogen and 1.6 times higher for phosphorous in the NA than in CB.

Approximately 152 tons of phytoplankton C are required to generate a ton of observed fisheries yield (as carbon) in the NA, but 189 tons are required in the CB. However, expressed relative to predicted 'fish' productivity at trophic level 2, approximately 80 tons of phytoplankton C are required to generate one ton of 'fish' production (as carbon) in the NA, while 47 tons are required in the CB. The discrepancy between relative masses of 'fish' produced (predicted) and harvested (observed) with respect to available primary production in the two ecosystems suggests that the NA is more heavily exploited. An alternative possibility is that fish production in CB actually is lower than predicted by Iverson's [1990] equation. This alternative seems possible since a large fraction of annual primary production in CB may settle out and fuel oxygen depletion [Harding et al., this volume] rather than secondary production.

The large yield from fisheries in the CB, relative to resource inputs, is partly a consequence of the fishing strategy. The largest landings in CB fisheries consist of menhaden, a clupeid fish that feeds primarily on phytoplankton, and which occupies a trophic position only one level above the primary producers. Clams, mussels, scallops and oysters occupy a similar trophic position in the NA fisheries, but none of those species dominates the fishery to the extent that menhaden dominates in CB. High productivity and a relatively efficient fishing strategy that targets an abundant herbivore have combined to support the high fishery yield from CB.

Before their dramatic declines, anadromous fishes (e.g. alosids) contributed substantially to CB catches. But, most of their production and biomass were attained outside of the CB. The same holds true for migratory species which seasonally inhabit CB (e.g. bluefish and weakfish). Their catches--small in recent years--once constituted a significant fraction of the total CB landings, but the biomass supporting those landings may be largely produced outside of the CB system.

Key species that interact strongly play important roles in the fisheries of NA and CB. The clupeoid fishes (sardines, menhaden, anchovies) dominate in both ecosystems and support major harvests. They also provide a prey resource for predator species and, as such, are an important trophic link between plankton and piscivores. In the NA, the major clupeoid fishes, all of which are primarily zooplanktivores, are subject to intensive fishing, but in CB, the bay anchovy *Anchoa mitchilli* is not fished, although this zooplanktivore is numerically the most abundant fish in the bay [Houde and Zastrow, 1991] and may exert significant pressure on its zooplankton prey resource [Luo and Brandt, 1993; Wang and Houde, 1995]. The bay anchovy and, especially, the menhaden are the major prey of large predators such as bluefish, weakfish, and striped bass in CB [Hartman and Brandt, 1995] and play key roles in the bay's trophic network [Baird and Ulanowicz, 1989]. Although many aspects of the ecology and population biology of key species are known, the functional linkages between prey abundances, habitat quality and predator production have yet to be quantitatively defined in the NA and CB. In CB, both

bottom-up (resource regulation of upper-level productivity) and top-down (consumer regulation of lower trophic levels) processes appear to be important [Malone et al., 1986; Houde, 1987; Verity, 1987]) and the same probably is true in the NA.

Elasmobranchs (sharks and rays) are important in the traditional fisheries of the NA. Annual landings of these key predators, which are believed to regulate benthic community dynamics and contribute to 'biological equilibrium' in benthic communities [Volterra, 1926; D'Ancona, 1955], have fluctuated nearly tenfold during the first half of the 20th century [D'Ancona, 1950]. Landings were especially depressed during the World Wars, rebounding rapidly in following years. It is probable that fluctuations in elasmobranch biomasses, attributable to fishing, had unmeasured but important effects on demersal fish and benthic invertebrate communities in the NA.

The oyster formerly was the major filterer in CB. After its collapse, no substitute grazing organism has occupied its place. Increasing eutrophication and its consequences to key species or communities, especially the potential harm brought by hypoxic conditions to benthic communities [Pihl et al., 1991; Dauer et al., 1992], concern scientists and managers in both NA and CB. Although poorly documented, increased biomass and blooms of undesirable phytoplankters and gelatinous zooplankters may be more frequent in both systems [Verity, 1987; Vučetić, 1987; Degobbis 1989; Fonda Umani et al., 1992; Harding, 1994; Marshall, 1995], a worrisome sign that the historical balance between nutrients, productivity at lower trophic levels, and harvests of traditional fishery resources is now stressed and poised to fail.

Management Regimes

The problem of shared stocks, especially those that 1) migrate seasonally into and out of jurisdictions, 2) are distributed over many jurisdictions, or 3) migrate in response to life history patterns, are common to NA and CB fisheries. Moreover, regulation of fishing effort has been difficult, and determining appropriate levels of effort and gears to achieve optimum harvests is problematical. Historically, fisheries of the NA were shared by Italy and the Republics of Croatia and Slovenia. In the 1990s, with the emergence of Croatia and Slovenia as independent nations, the need for international management has increased. In the CB, fisheries by the states of Virginia and Maryland historically were managed independently, in disregard of the common stock status and migratory nature of many species. Beginning in the 1980s, with the emergence of the Chesapeake Bay Program, joint stock assessments and fishery management plans have been developed by bay jurisdictions, including the states of Virginia, Maryland, Pennsylvania, and the District of Columbia [CBP, 1988; Austin, 1992; Richkus et al., 1992].

The United Nations, through its Food and Agriculture Organization (FAO) and the General Fisheries Council for the Mediterranean, has taken a leading role in promoting research assessment programs and in guiding development of management regulations in the Adriatic Sea. The European Union (EU) Mediterranean Management Program and national management regimes were developed as a consequence of the EU MEDITS 1994-1997 Program (Mediterranean Trawl Surveys), although few regulations actually were implemented until recent years. Trawl fisheries in the NA now are regulated with respect to minimum mesh sizes, and Italian management authorities have imposed closed seasons in some heavily utilized fisheries. In Croatia, a "New Law on Marine Fishery," was passed in 1994 which will limit gears and effort in the coastal and trawl fisheries,

although it apparently will not regulate the fisheries for pelagic fish. Although management is difficult at the international level, collaborative research and assessments of living resources have been carried out for many years by the Institute of Oceanography and Fisheries, Split (Croatia) and the Laboratorio di Biologia Marina e Pesca, Fano (Italy) through the "Pipeta" trawl-survey program, which was implemented from 1982-1996 [Piccinetti and Jukić, 1983].

A hierarchy of management authorities and agencies exists in the CB region. Stocks such as blue crab, which essentially spend their juvenile and adult lives in the confines of the bay, are regulated by the states surrounding the bay. Coastal migratory species, for example menhaden and striped bass, which migrate seasonally along the coast, but which mostly remain within three nautical miles of it, are regulated primarily by the Atlantic States Marine Fisheries Commission (ASMFC). Species that both migrate and which may occur offshore (3-200 nautical miles) during a part of their life, e.g. summer flounder, are primarily managed by federally-supported Regional Management Councils. In the case of migratory species, the Chesapeake region states have developed management plans to insure that CB fisheries are in compliance with regulations that are imposed on a larger geographic scale.

The needs of management are similar in the NA and CB and, indeed, resemble those in most exploited aquatic ecosystems throughout the world. Better measures of fishing effort are needed and the means to control fishing effort when required are prerequisites to effective management. Regular stock assessments that include targets, thresholds and reference points for managers to select in regulating catches are too often lacking in the NA and CB. Basic landing statistics must be improved in the NA to account for large segments of the coastal catch that presently may go unreported. Recreational fishing, a major source of fishing mortality in CB and a potential future source in the NA, is poorly evaluated at present. Research on multispecies management, including unfished but ecologically important species, and on ecosystem approaches to management [Miller et al., 1996] can lead to more knowledgeable management of key resources. Although these needs are widely recognized in the NA and CB regions, single-species assessments and management remain standards for the present and probably will continue as standards for many years.

Regulations and measures to control fish harvests and fishing effort apparently are more prevalent in CB than in the NA. Nevertheless, high fishing mortality rates and their impacts on fisheries resources are common in both systems. Application of intensive management measures has met with mixed success in CB. For example, conservative management, after a stock collapse, fully restored the striped bass fishery [Leffler, 1993; Field, 1997]. On the other hand, despite management measures, alosid stocks remain at historically low levels, the oyster fishery is collapsed, and many fisheries on migratory species remain depressed as a consequence of coastwide overfishing [Richkus et al., 1992; Miller et al., 1996]. The potential for management to restore fisheries is less clear in the NA. Many trawl fisheries and benthic molluscan fisheries are believed to be overexploited and potentially would improve under effective management regimes. On the other hand, the causes of collapse of the anchovy fishery in the NA are unclear and it is uncertain that management measures would improve the fishery. In the short term, traditional fishery management can protect or restore many resources in the two systems. However, in the longer term, environmental management, and measures to protect and restore habitats and water quality, will be the key to sustainable fisheries in the NA and CB.

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TABLE 1. Comparative Fish Production and Fish Yields from the Northern Adriatic Sea and Chesapeake Bay, scaled to surface area, volumes, nutrient inputs, and primary production [see Smodlaka et al., 1998; Seagle et al., 1998; Harding et al., this volume].

Fish Yield or Production	Northern Adriatic	Chesapeake Bay	CB/NA
Approximate Recent Fish Yield (tons yr^{-1})	100,000	275,000	2.75
Approximate Recent Fish Yield (kg ha^{-1} yr^{-1}) [a]	52.9	239.1	4.52
Approximate Recent Fish Yield (tons km^{-3} yr^{-1}) [a]	157.5	3,716.2	23.59
Fish Yield/Nitrogen Input[b]	0.30	1.81	6.03
Fish Yield/Phosphorus Input[b]	3.5	25.4	7.25
Fish Yield (C)/Primary Production (C)[c]	0.0066	0.0053	0.81
Predicted Fish Production[d] (kg ha^{-1} yr^{-1})	100.5	967.2	9.62
Predicted Fish Yield[e] (kg ha^{-1} yr^{-1})	10.0	145.4	14.54
Primary Production(C)/Fish Production(C)[f]	79.6	46.5	0.58

[a] Chesapeake Bay areas and volumes are for Chesapeake Bay system [Table 2, Smodlaka et al., this volume].
[b] Nitrogen and phosphorous loadings are 'total' loadings [Table 1, Smodlaka et al., this volume], converted to mass.
[c] Primary production values are 80 and 450 gCm-2 yr^{-1}, respectively, for the Northern Adriatic and Chesapeake Bay [see Harding et al., this volume].
[d] Based upon equation in Iverson [1990], assuming fish wet weight is 10% C, and calculated for two trophic levels above the primary producers. $FP = (0.083\ P_e - 3.08) \cdot E^e \cdot C$ where FP = fish production (g m^{-2}), P_e = primary production (gCm^{-2} yr^{-1}), E = nitrogen transfer efficiency = 0.28 and C = 36.0, the factor to convert gCm^{-2} yr^{-1} to fish biomass (g m^{-2} yr^{-1}).
[e] Based upon equation in Nixon [1988]. $\log_e FC = 1.55 \log_e P_e - 4.49$ where FC = fish catch (kg ha^{-1} yr^{-1}) and P_e = primary production (gCm-2 yr^{-1})
[f] Fish production is the "predicted" production, calculated based upon equation in Iverson [1990], assuming fish wet weight is 10% C, and calculated for two trophic levels above the primary producers.

TABLE 2. Catches (tons) by category from the Northern Adriatic. Croatian (west coast of Istra) and Slovenian annual catches (tons) for 1947-1971.

Year	Fish		Cephalopods	Molluscs	Crustaceans	Total
	Pelagic	Demersal				
1947	2,058	468	47	504	48	3,125
1948	2,976	484	56	446	65	4,027
1949	2,638	594	37	704	70	4,051
1950	4,293	545	22	281	149	5,344
1951	3,249	581	30	11	118	4,021
1952	1,682	588	30	—	68	2,388
1953	2,760	477	36	3	42	3,336
1954	3,941	599	44	3	85	3,678
1955	2,800	577	50	2	56	3,496
1956	4,499	527	54	3	108	5,195
1957	4,574	494	47	3	188	5,328
1958	4,662	481	55	2	291	5,562
1959	5,125	442	74	3	210	5,941
1960	3,839	519	68	2	137	5,636
1961	9,118	520	57	1	115	9,973
1962	5,944	582	42	1	66	6,730
1963	7,597	553	27	1	65	8,341
1964	8,263	626	32	1	105	9,157
1965	8,387	570	39	3	87	9,375
1966	8,530	801	49	5	98	9,559
1967	9,492	834	79	1	175	10,661
1968	7,933	615	52	3	80	8,760
1969	6,607	563	86	10	74	7,439
1970	7,727	572	74	39	89	8,710
1971	9,088	665	70	27	108	10,099

Note: Catch from eastern coast are made by Slovenia and west coast by peninsula Istra (Croatia); Source: National Statistical Department of Republic Croatia-Zagreb; Gamulin-Brida.

TABLE 3. Annual Catch (tons) of Catadromous Eel, *Anguilla anguilla* and Euryhaline Mullet *Mugil* spp. from the Northern Adriatic, 1970-1992.

Year	Italy		Slovenia & Croatia	
	Anguilla	*Mugil*	*Anguilla*	*Mugil*
1970	677	2,091	–	–
1971	1,736	2,338	–	–
1972	785	3,659	2	62
1973	–	–	3	119
1974	37	2,028	1	101
1975	36	2,606	2	60
1976	56	2,798	3	119
1977	933	2,698	2	87
1978	780	2,325	3	78
1979	–	–	3	92
1980	267	1,668	2	70
1981	264	1,789	2	108
1982	244	1,301	–	–
1983	191	1,103	–	–
1984	81	273	–	–
1985	–	–	–	–
1986	189	912	–	–
1987	487	1,352	–	–
1988	159	1,051	–	–
1989	135	1,204	–	–
1990	–	–	–	–
1991	210	1,348	–	–
1992	156	1,348	–	–

Source: ISTAT – Rome, and Croatian National Department for Statistics.

Figure Captions

Figure 1. Annual trends in total commercial fisheries landings (metric tons) from the entire Adriatic Sea, Northern Adriatic Sea (all countries, 1949 - 1971), Northern Adriatic Sea (Italy only, 1980 - 1992), and Chesapeake Bay (1952-1995).

Figure 2. Trends in annual Northern Adriatic Sea landings, 1970-1992, by landings categories. (a) Pelagic and demersal fish. (b) Molluscs and crustacea. (c) Total.

Figure 3. Trends in annual Chesapeake Bay commercial landings of finfish, menhaden, molluscs, and crustacea. (a) Menhaden and remaining finfish. (b) Molluscs and crustacea.

Figure 4. Trends in annual sardine, sprat, and anchovy landings from the Northern Adriatic Sea by Slovenia and Croatia, 1970-1992.

Figure 5. Trends in catch-per-unit-effort (CPUE) statistics, based upon research trawling, for several species from the Northern Adriatic Sea. [Data from Piccinetti and Piccinetti-Manfrin, 1994]. (a) All demersal species combined. (b) Crustacea. (c) Cephalopoda. (d) Elasmobranchs. (e) Teleosts. (f) *Squilla mantis*. (g) *Nephrops norvegicus*. (h) *Loligo vulgaris*. (i) *Sepia officinalis*. (j) *Eledona moschata*. (k) *Mullus barbatus*. (l) *Trisopterus minutus capelanus*. (m) *Merluccius merluccius*.

Figure 6. Trends in annual commerical landings of four demersal species from Chesapeake Bay. (a) Atlantic croaker and weakfish. (b) spot and summer flounder. (c) Total.

Figure 7. Trends in annual commerical landings of anadromous fish from Chesapeake Bay. (a) striped bass and white perch. (b) American shad and other alosids. (c) Total.

Figure 8. Trends in annual landings of "shellfish" from the Northern Adriatic Sea. (a) Shelled molluscs, 1975 - 1992 and cephalopods, 1949 - 1971. (b) Crustacea, 1949 - 1971; Italy only, 1972 - 1986.

Figure 9. Trends in annual commerical landings of "shellfish" from Chesapeake Bay. (a) Eastern Oyster (meat yield). (b) Blue crab.

Figure 1.

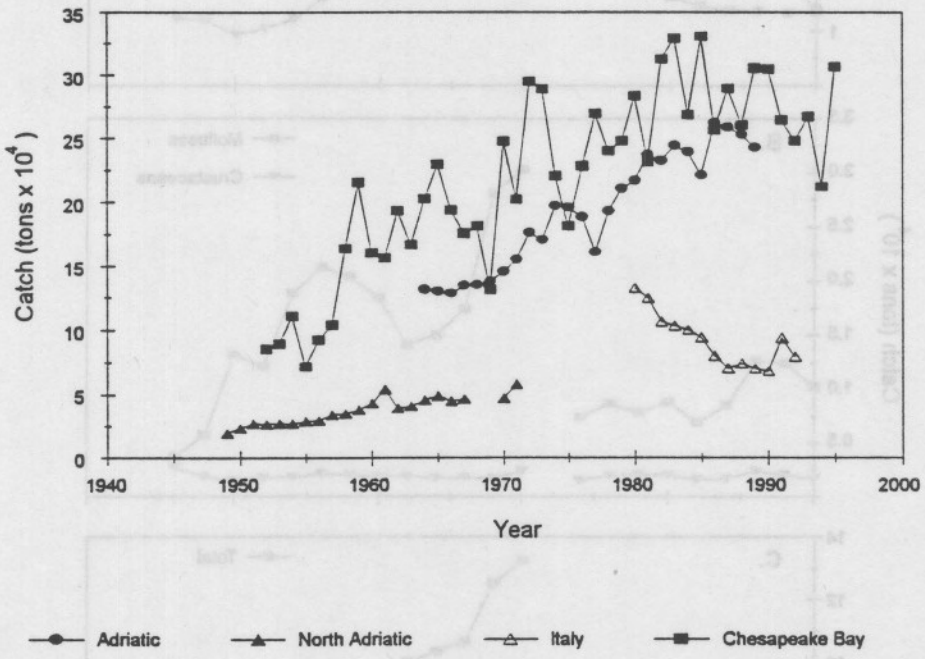

Catch (tons x 10^4)
35
30
25
20
15
10
5
0
1940
1950
1960
1970
1980
1990
2000
Year
Adriatic
North Adriatic
Italy
Chesapeake Bay

Figure 2.

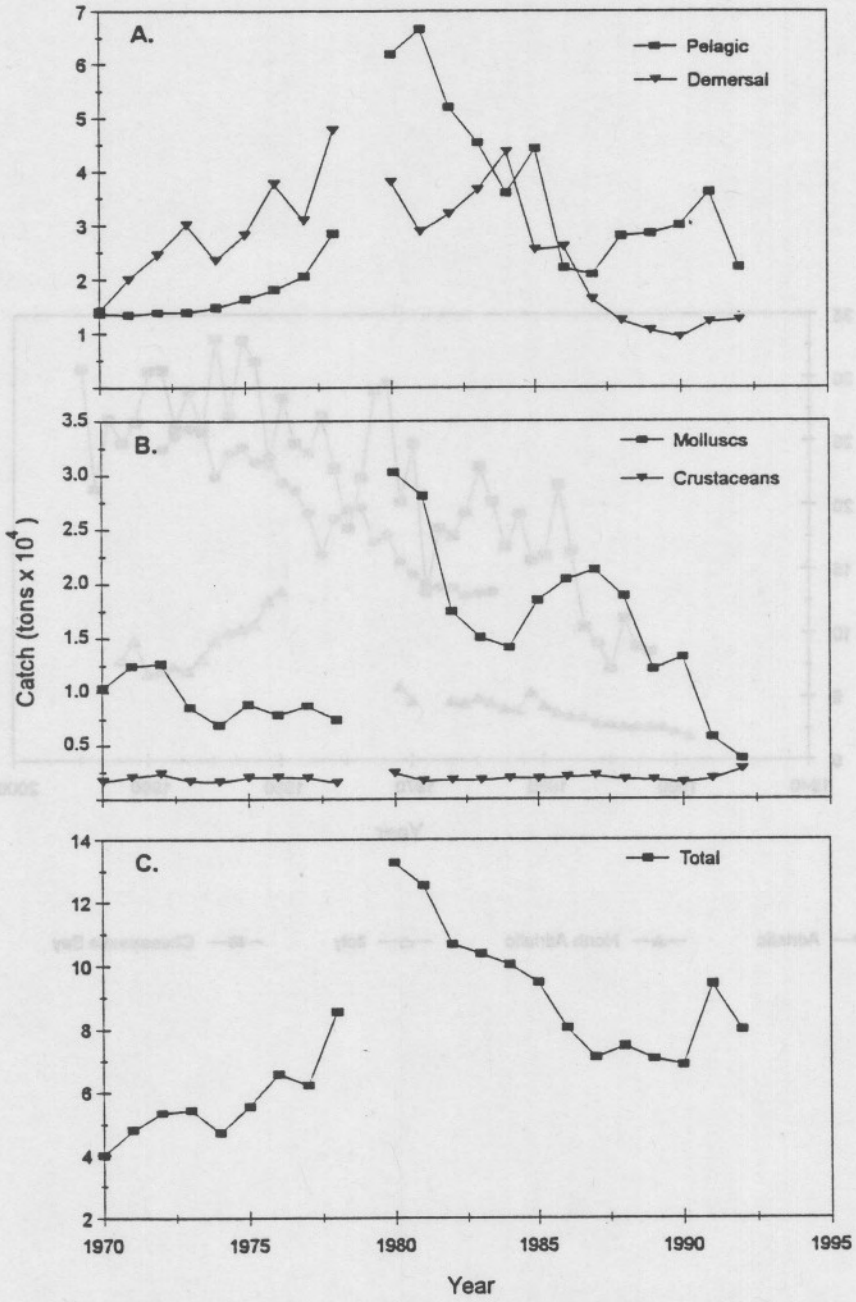

A.
Pelagic
Demersal
B.
Molluscs
Crustaceans
C.
Total
Catch (tons x 10^4)
Year
1970
1975
1980
1985
1990
1995

Figure 3.

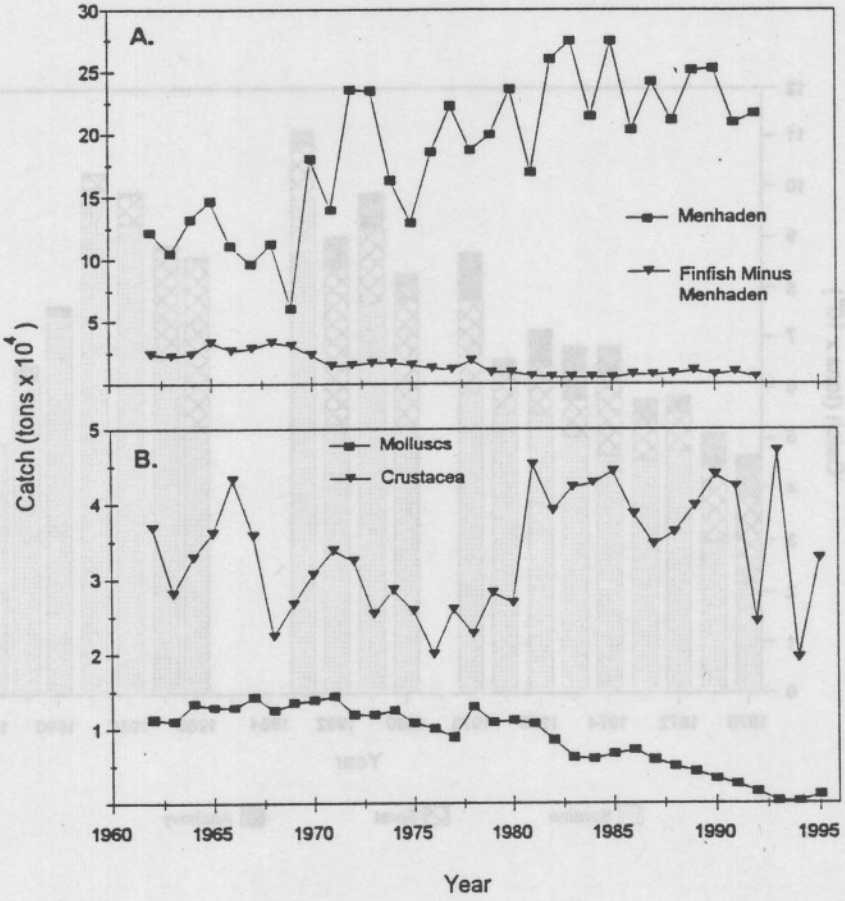

A.
B.
Menhaden
Finfish Minus Menhaden
Molluscs
Crustacea
Catch (tons x 10^4)
Year
30
25
20
15
10
5
4
3
2
1
1960
1965
1970
1975
1980
1985
1990
1995

Figure 4.

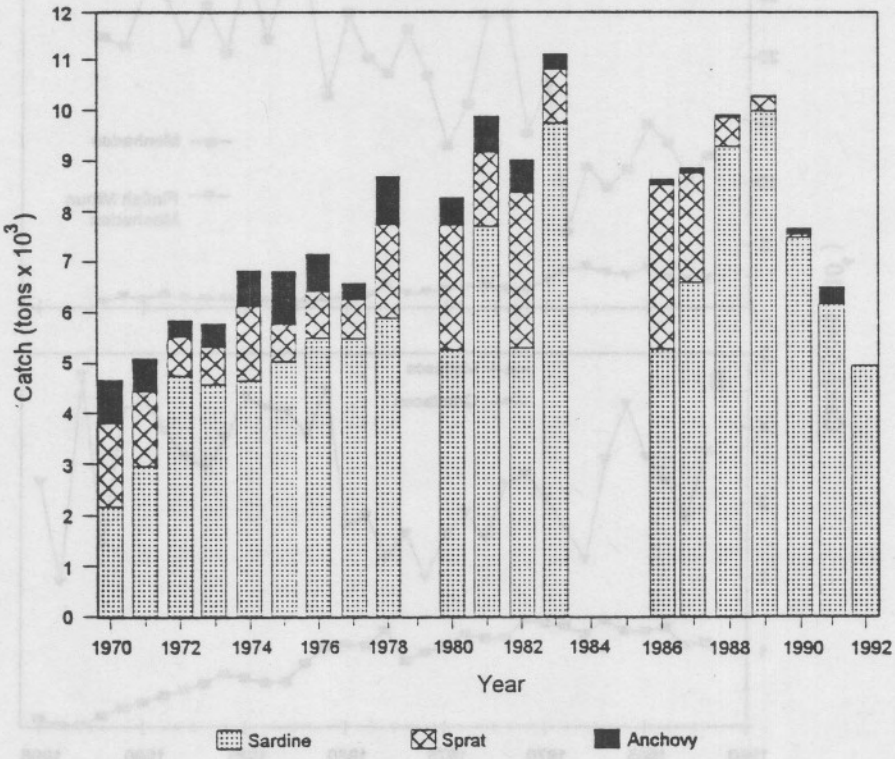

Catch (tons x 10^3)
0
1
2
3
4
5
6
7
8
9
10
11
12
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
Year
Sardine
Sprat
Anchovy

Figure 5.

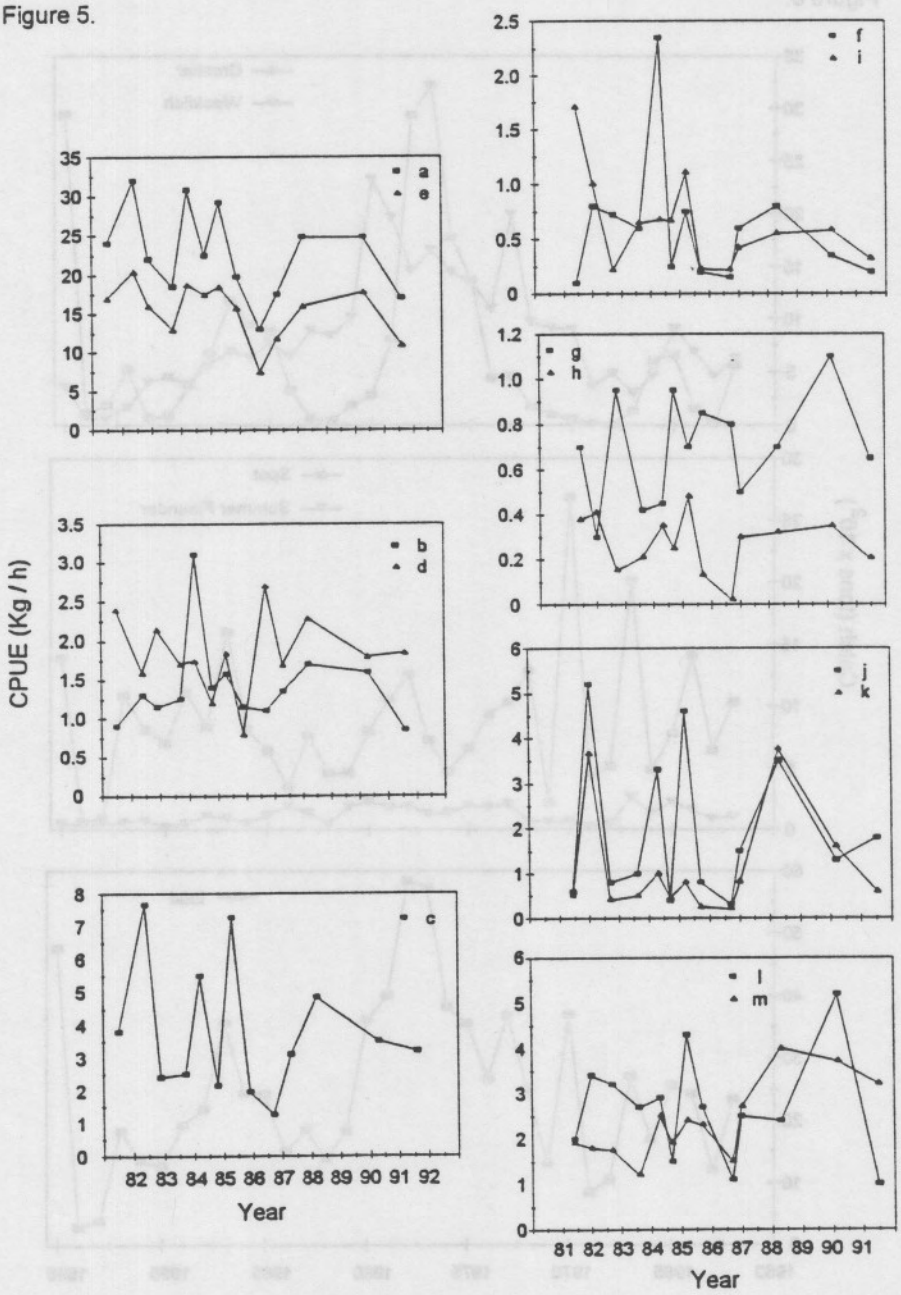


Figure 6.

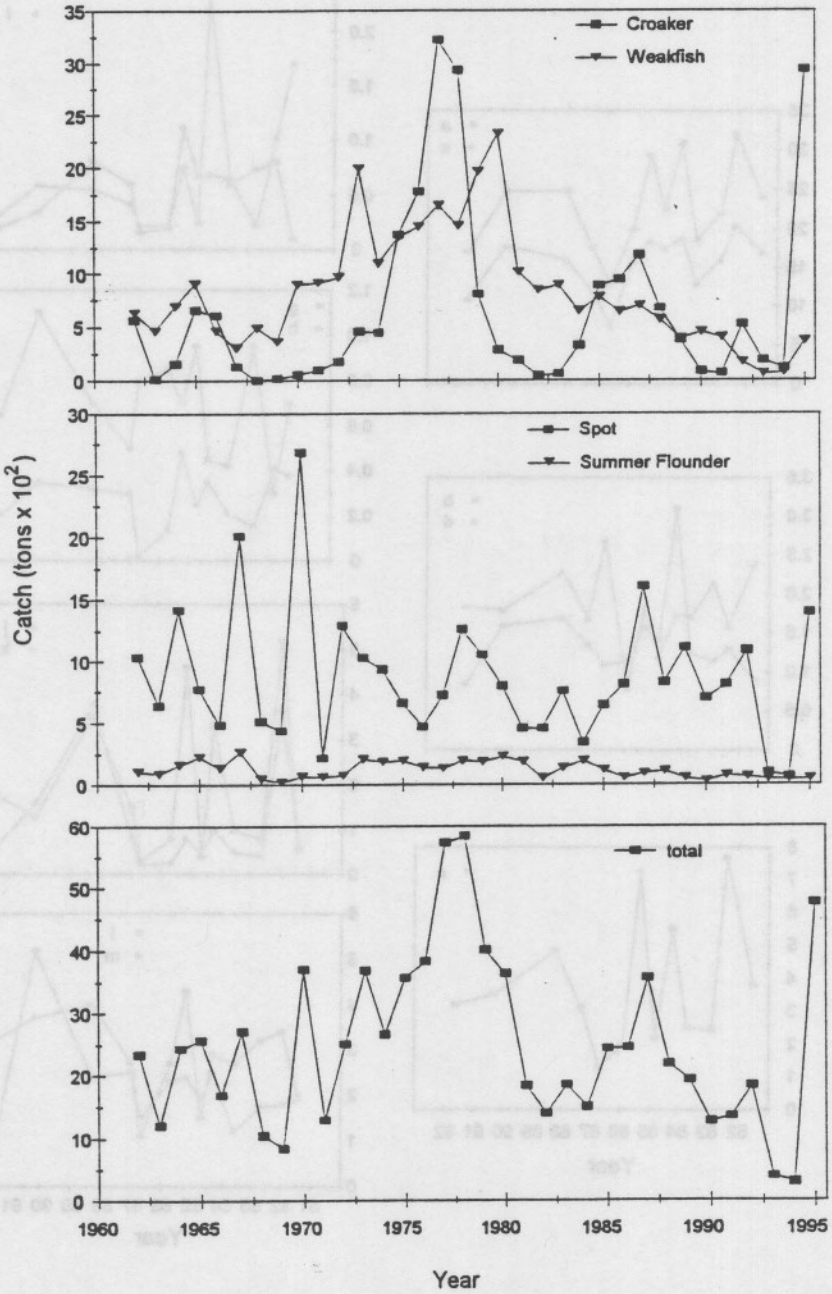

Croaker
Weakfish
Spot
Summer Flounder
total
Catch (tons x 10^2)
Year
0
5
10
15
20
25
30
35
40
50
60
1960
1965
1970
1975
1980
1985
1990
1995

Figure 7.

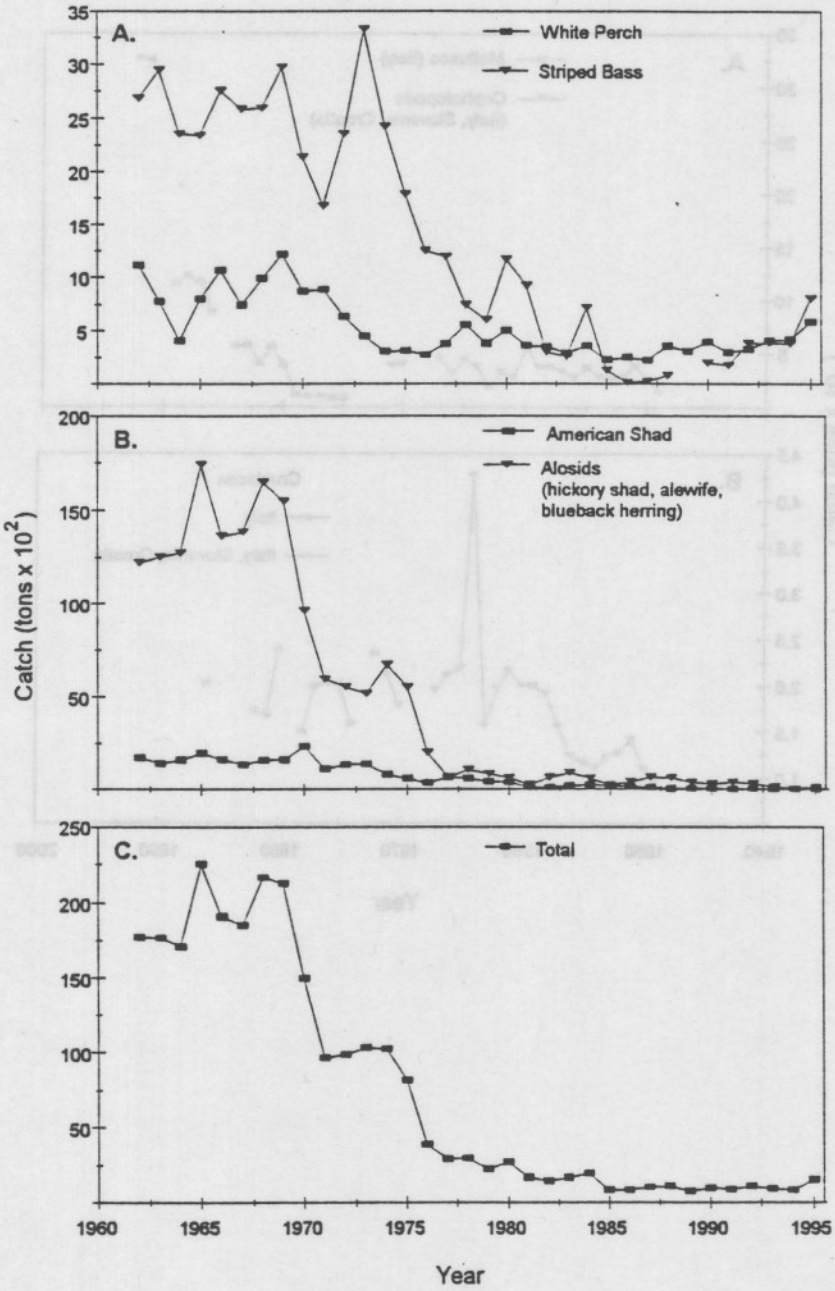

A.
White Perch
Striped Bass
B.
American Shad
Alosids
(hickory shad, alewife,
blueback herring)
C.
Total
Catch (tons x 10^2)
Year
35
30
25
20
15
10
5
200
150
100
50
250
200
150
100
50
1960
1965
1970
1975
1980
1985
1990
1995

Figure 8.

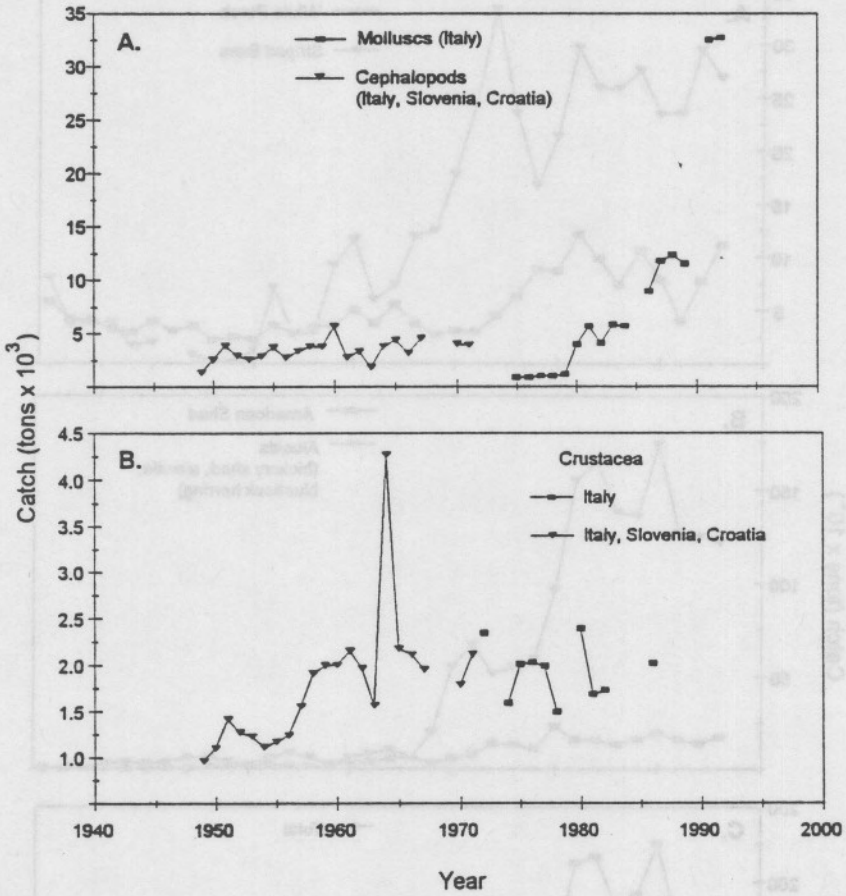
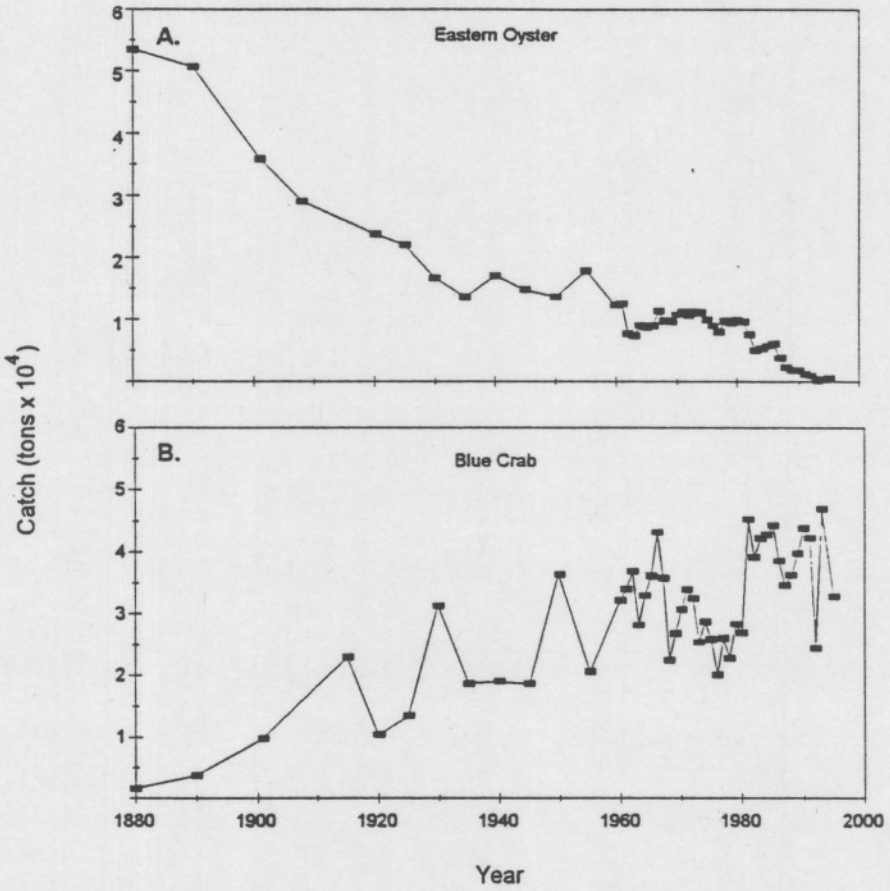

A.
Molluscs (Italy)
Cephalopods
(Italy, Slovenia, Croatia)
B.
Crustacea
Italy
Italy, Slovenia, Croatia
Catch (tons x 10^3)
Year
35
30
25
20
15
10
5
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1940
1950
1960
1970
1980
1990
2000

Figure 9.


A.
Eastern Oyster
B.
Blue Crab
Catch (tons x 10^4)
Year
1880
1900
1920
1940
1960
1980
2000