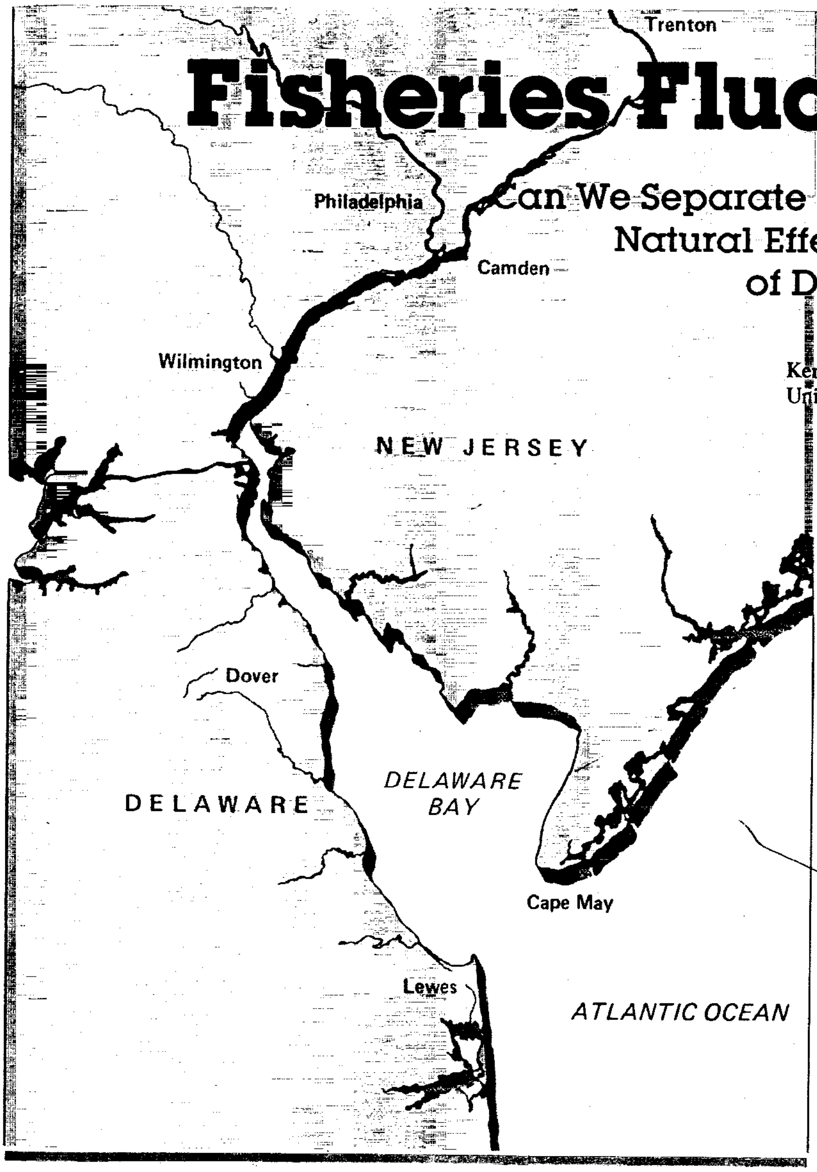
DELAWARE ESTUARY SITUATION REPORTS

This series of reports is devoted to discussion of current issues relevant to conservation, use, and development of Delaware Estuary resources, and of concern to managers, decision-makers, and the general public.

Fisheries Fluctuations

Can We Separate Manmade Effects from Natural Effects on the Abundance of Delaware Bay Fisheries?

Kent S. Price and Barbara Jacobs Dinkins
University of Delaware College of Marine Studies



The Delaware Estuary, a multi-purpose bistate resource.

If you've been a serious commercial or recreational fisherman in the Delaware Bay for twenty years or more, you've undoubtedly had questions about the fluctuations of certain fishes. Where are the winter flounder and puffers that were so abundant in the early 1970s? Why were striped bass as prevalent in the middle '70s as they were one hundred years earlier when fishery records were first kept, but today face extinction (Figure 1)? Why were croakers (hardheads) so plentiful in the late '40s that you could swamp your boat with the catch while today they are as rare as an endangered species? On the other hand, why do bluefish (Figure 2), weakfish, menhaden, and spot seem to be more abundant today then they were in the late 1950s and early '60s?

There are several reasons for these serious shifts in fish populations: first, there are manmade effects, including excessive nutrient enrichment and low oxygen levels from sewage and agricultural input, physical damage to spawning sites, the introduction of toxic materials from pollutants, and fishing pressure from both recreational and commercial fishermen; and second, there are climate or climate-related conditions, including temperature, precipitation, river flow, prevailing winds, and currents.

University of Delaware
Sea Grant College Program

Since the manmade effects are, to a significant extent, under our control, can we separate them from the climatic causes, which are beyond our control? If so, managers will be able to make better decisions for the benefit of our fisheries in the future.

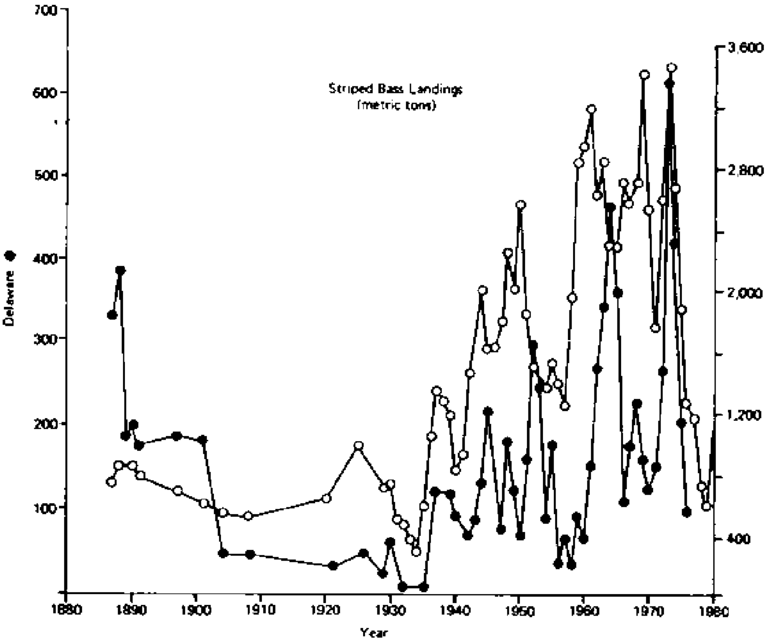


Figure 1. Striped bass landings in metric tons for the Delaware and Chesapeake Bays, 1880-1980.

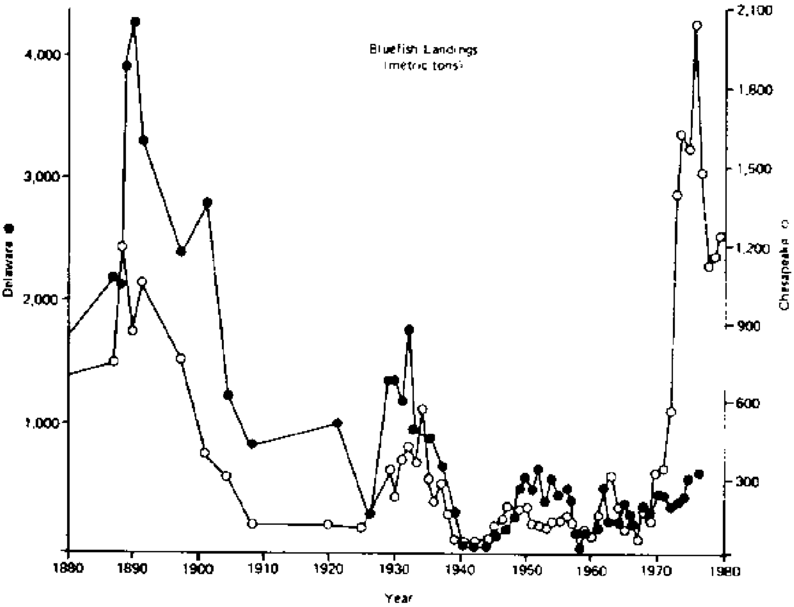


Figure 2. Bluefish landings in metric tons for the Delaware and Chesapeake Bays, 1880-1980.

STATUS OF THE DELAWARE BAY

The Delaware Bay's role as a major transportation corridor began not long after Henry Hudson sailed the *Half Moon* into the bay in 1609. One hundred years later, the bay was beginning to feel the effects of human activity—from sewage disposal to fishing. Two hundred years later, the bay was suffering from a wide range of pollution.

Recognizing the need to clean up the bay, the Interstate Commission on the Delaware River Basin (INCODEL) and the Delaware River Basin Commission (DRBC) joined to initiate basin-wide water pollution control in the late 1930s. Today the clean-up continues, with the recent completion of three major sewage treatment plants in Philadelphia.

Sewage discharge between Philadelphia and Wilmington in the Delaware River and contaminants from industrial and urban activity in the river have inhibited or in some cases eliminated the spawning runs of anadromous (swim up the river to spawn) fishes such as shad and striped bass, according to some fisheries biologists.

Are these biologists correct? Perhaps neighboring Chesapeake Bay, which is similar to the Delaware Bay in terms of the general ecological community and climate, can provide the answer.

Through the concern for fisheries as well as submerged aquatic vegetation and water quality in the Chesapeake, Congress mandated that the Environmental Protection Agency conduct a study of that natural resource in 1975. Results of the Chesapeake Bay study indicate that eutrophication (nutrient enrichment) and contamination by toxic materials in the heads of various tributaries may be contributing to declines in anadromous species (EPA, 1983).

Recent findings and recommendations of the EPA Chesapeake Bay Program also have called attention to dramatic declines in living resources (submerged aquatic vegetation, freshwater spawning fisheries, and the oyster fishery) in Chesapeake Bay that are circumstantially linked to (1) increased plant nutrient levels in the upper portions of the main estuary and its tributaries, (2) the probable impact of toxic materials, sedimentation, and other human-caused effects on estuarine and freshwater spawning grounds of fisheries, and (3) seasonal low oxygen effects in deeper stratified waters and other localized areas of the Chesapeake Bay and its tributaries (Figure 3).

According to the Environmental Protection Agency, most of these effects (about 70%) are considered to reflect non-point source input (particularly nutrients) from agricultural, construction, urban development, and related activities in the 64,000 square-mile watershed of the Chesapeake Bay.

In the 13,000 square-mile watershed of the Delaware Bay, similar activities are occurring with similar effects on living resources.

Located in the area of the richest fisheries in the Middle Atlantic Bight (between Cape Cod and Cape Hatteras), where the ranges of northern and southern species of fishes overlap, the Delaware Bay has been the home of approximately 85 commercial species of fish, according to catch records covering the past 100 years.

Besides sturgeon, shad, oysters, lobster, blue crab, weakfish, bluefish and flounder, the menhaden has been a prolific and valuable fish in the area. For example, in 1953, Lewes, Delaware, led the nation in poundage of fish landed at nearly 400 million pounds. A large portion (360 million pounds) were menhaden–industrial fish processed for fish meal and oil.

During 1966, however, the menhaden processing plants closed due to lack of fish. The remaining food-fish trawlers also concluded operations because of the scarcity of food fish. A historical analysis indicates an almost complete collapse of every major commercial finfishery that once existed here due to a decline in fish availability (McHugh, 1981). The trawl fishery has not been reestablished because of regulatory restrictions, but Delaware Bay still supports a commercial gill-net fishery.

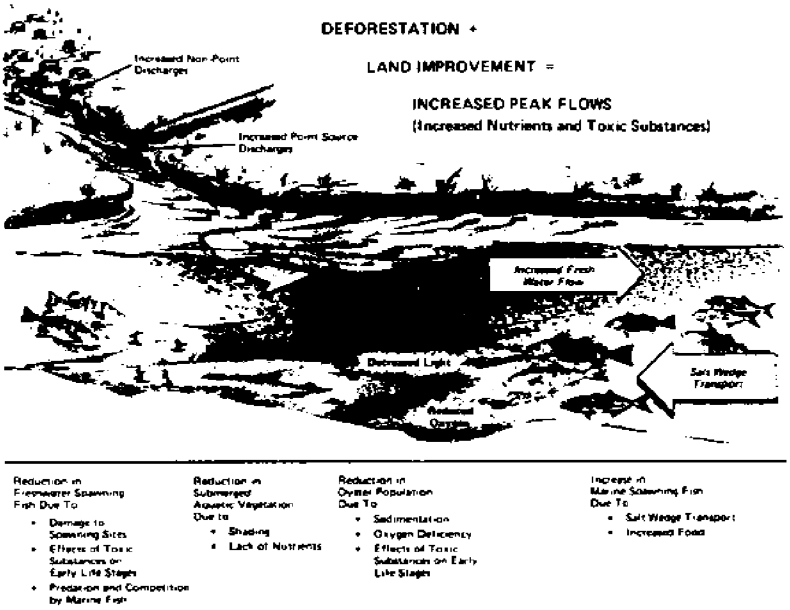


Figure 3. Conceptual framework of some probable interactions among climate, water quality, and some living resources in the Chesapeake Bay system.

CLIMATIC EFFECTS ON FISHERIES

Before we can fully understand the relationship between the success of a principal commercial species and water quality, toxic materials, and fishing pressure, we must first understand the impact of natural forces on that species.

A number of investigators have demonstrated correlations between variation in fisheries catches and climatic factors, including winter air temperature, sea surface temperature, freshwater runoff, salinity at spawning sites, and coastal circulation. These correlations suggest (but do not prove) relationships between climate or natural environmental variations and population fluctuations in fisheries.

In general, climate's effect on fisheries is species-specific and may produce positive or negative results. Positive climatic effects relate to improved spawning success, egg hatching, and survival of the larval and juvenile stages, which can contribute to an above-average year-class (year-class refers to the number of fish resulting from spawning in a given year).

However, negative climatic effects have the most influence on fisheries at the time of egg, larval, and early juvenile development since the eggs and larvae have limited mobility and are thus more vulnerable than at other stages in the life cycle. Whether or not the negative effect is direct or very indirect, it often affects a fishery at least through shifts in the physical and chemical characteristics of the environment and the matching of the larval fish food supply with the occurrence of the larval fish (see Figure 4) (Cushing, 1975).

Increased rainfall is a common climatic effect. It sets off a kind of chain reaction, causing increased freshwater flow, which, in turn, may result in a number of other changes, such as increased turbidity and biological oxygen demand, decreased salinity, etc. These changes may be adverse to some species, like those sensitive to increased toxins or turbidity, but be beneficial to others, such as those requiring strong currents as transport mechanisms. For example, young oysters may be smothered by silt stirred up by strong currents, while striped bass eggs require a

2-3 mph current to keep the eggs in suspension during incubation and hatching.

A more direct example of the effect climate has on a fishery comes from scientists at the University of Rhode Island. Their recent study suggests that lower temperatures in the Narragansett Bay during the early 1970s may have resulted in a successful winter flounder year-class by reducing the migration of predators into the bay during the flounder's critical survival period during springtime (Jeffries and Terceiro, 1984).

The following are several examples of climate's effect on fisheries in the Delaware Bay.

Striped Bass

These fish spawn in fresh or brackish (< 3 ppt salinity) waters in the Chesapeake-Delaware Canal, Elk River, Potomac River, and upper Chesapeake Bay, from April to June. The semibuoyant eggs require a current for suspension and to avoid suffocation from silt. Hatching periods vary inversely with temperature. Larvae settle to the bottom as they begin to feed, preferring shallows with slow currents and sand or gravel bottoms.

The survival rate for striped bass and the subsequent success for their year-class have been positively linked to abnormally cold winters and high spring runoffs, which are interrelated. Cold winters result in above average food supplies in nursery areas due to increased availability of nutrients from ice scouring and high spring runoffs. This increased food supply increases the probability of larval survival and thus the success of the year-class (see Figure 4) (Setzler, et al., 1980).

Blue Crab

Blue crabs mate in the brackish areas of estuaries, but egg-laying peaks from July through September in the lower bay where salinity is higher. The eggs hatch into the first larval stage (zoea) 6 to 13 days after spawning and the second stage (megalopae) occurs in about 31 to 49 days (Sulkin, et al., 1982). Optimal salinities for zoea growth are 20 to 30 ppt and optimal temperature is about 25°C.

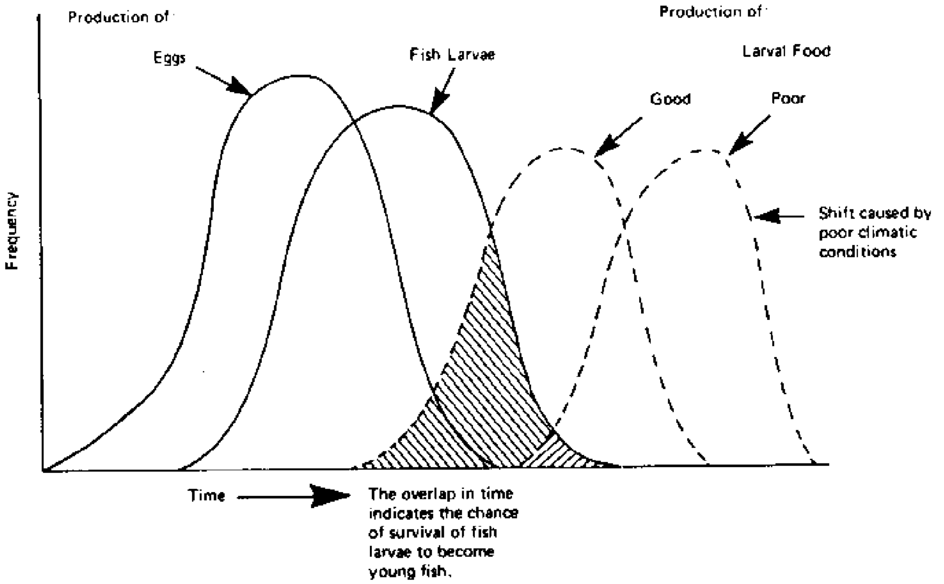


Figure 4. Effect of climate on fisheries at the time of egg, larval, and early juvenile development.

Currents are vitally important to the survival of blue crab larvae. After the eggs hatch into zoea in the surface waters at the mouths of estuaries, the net current at this layer sweeps them out into the ocean where they subsequently develop into megalopae (Sulkin et al., 1982). These older larvae must rely on continental shelf currents, which are controlled by global-scale climate and wind patterns, to return them at the appropriate time in their development to the mouths of estuaries adjacent to the shelf.

When North Atlantic continental-shelf circulation moves in a westerly or northwesterly direction, there is a higher probability that the young blue crabs will be returned to the estuary to live out the remainder of their lives.

Menhaden

Menhaden range from Nova Scotia to Florida. In the mid-Atlantic Bight, menhaden spawn offshore but near the mouths of estuaries. There are two spawning seasons for this species—a short first period in May and June as adults migrate north toward New England, and a second major period in September and October as the fish migrate back south to the Carolinas. Spawning is reported to have occurred at temperatures from 13° to 20°C and at optimal salinity of 10 to 22 ppt. The egg incubation period is about 48 hours.

Like blue crab larvae, menhaden larvae are highly dependent on continental shelf currents for their return to the mouth of the estuary for growth. When the larvae reach a length of about 10 to 30 mm, they enter the estuary and move toward fresh water. This larval migration lasts from December to May and like spawning, also has two peaks: one in November and December and a major peak in February and March. The water temperature when the larvae begin to enter the estuary can be very important to survival of the larvae and therefore to stock size (Wang and Kernhan, 1977). If temperatures are below 3°C when the larvae begin to enter the estuary or drop too close to that level after the larvae enter the estuary, high mortalities usually occur.

The larvae remain in their estuarine nursery grounds until they change into juvenile fish. Then they return to the deeper waters of the lower estuary. As temperature drops in the fall, these juveniles move out to ocean waters.

HUMAN IMPACT

As you can see, natural forces, such as climate, can play a significant role in the success of a fishery. But those of us who live on the Delaware Bay's watershed, or who use the bay for industrial or recreational activity, also make an impact on the natural resource's fisheries through nutrient input, pollution, and commercial and recreational fishing.

Nutrients

We contribute nutrients to the estuary primarily through agricultural and sewage discharge. These fertilizers increase levels of various forms of phosphorus and nitrogen, which, in turn, may cause large crops of phytoplankton to grow.

If the composition of the phytoplankton bloom matches the nutritional requirements of the young fish, this form of nutrient enrichment in its early stages can actually benefit portions of the estuarine system.

But as nutrient enrichment intensifies, the standing crop of phytoplankton increases and may shift in species composition to less desirable food species (for example, blue-green algae in tidal fresh portions of estuaries). This shift occurs because the less desirable forms out-compete the more desirable algal forms at high nutrient concentrations. As particulate carbon and turbidity increase in conjunction with higher standing crops of phytoplankton and summer stratification (layering) of the water column, they collectively contribute to increased variations in concentrations of dissolved oxygen in surface waters and extended periods of near oxygen depletion in bottom waters.

Although the negative impact of oxygen depletion is obvious, it varies according to species tolerances and its severity can be enhanced by stratification and moderated by various mixing processes in the estuary. For example, eels and catfish can withstand low oxygen for much longer than can shad and striped bass. As a body of water, the Chesapeake Bay is more prone to low oxygen in its deeper parts than the Delaware Bay due to a slower flushing rate and stronger stratification that reduces oxygen exchange with the atmosphere.

Finally, nutrient enrichment is thought to have a detrimental effect on submerged aquatic vegetation (SAV), such as eel grass and widgeon grass, because nutrient loading stimulates phytoplankton growth and the growth of small plants (epiphytes) on the leaves of SAV. Both phytoplankton growth and epiphytes shade SAV, and current data implicates increased shading as the predominant cause of the SAV decline in our bays (see Figure 3) (EPA, 1983).

Pollution

Monitoring the effects of pollutants on fisheries populations seems like it should be an easy task, but unfortunately, it is not. In a study of fourteen U.S. estuaries, the specific linkage between nutrients (one example of a pollutant) and fisheries proved difficult to demonstrate (Nixon, 1983).

In 1980, C. J. Sindermann, National Marine Fisheries Service fisheries biologist, described in some detail the difficulty of isolating and quantifying pollution effects on resource species—as distinct from effects of natural environmental variations.

"That chemical pollutants cause stress and death in individual marine animals can be easily demonstrated, and has been repeatedly," he said. "Descriptions of lethal and sublethal effects of heavy metals, petroleum compounds and halogenated hydrocarbons [also] abound in the experimental literature. [However], that stress from chemical pollutants can have significant quantifiable effects on resource species abundance (apart from localized effects in severely contaminated coastal and estuarine zones) is much more difficult to demonstrate, and has not been documented satisfactorily."

A recent review of ecological stress in the New York Bight (Mayer 1982) further supports the viewpoint that, even in an area as heavily impacted as the New York Bight, it is nearly impossible to demonstrate pollution-induced changes in the growth and distribution of populations of plankton invertebrate communities and fishes.

On the other hand, a group of scientists led by University of Delaware scientist Dr. Melbourne Carriker (1982) indicate that temporal and spatial trends exist in the distribution and abundance of some bottom-dwelling organisms in lower Raritan Bay and the New York Bight Apex as a result of pollution. That is to say, bottom-dwelling species are reduced in number where pollution levels are high although individual highly tolerant species may increase in number as other species decline.

Sindermann (1980) argues that "to insist on demonstrations of easily discernible effects on overall species abundance is to establish too harsh a criterion of pollution damage. A much more acceptable concept is that effects of pollution, clearly demonstrated on even a single individual or a local population, must be considered a cause for management action to protect the total population—just as is the case with humans."

Such evidence is often in the form of pathologies such as (1) cellular and genetic damage to eggs, embryos, and larvae resulting from exposure to contaminants, (2) fin erosion and sores of the body associated with exposure to degraded environments, and (3) latent infections, particularly those of a viral nature, which may be provoked into active disease by pollution stress (Sindermann, 1980, and Mayer, 1982).

Impacts of Overfishing

Overfishing—through commercial and recreational fishing—occurs in two ways: through growth overfishing and recruitment overfishing. In growth overfishing, too many fish are caught when they are relatively young so that the exploitable population contains a low percentage of older individuals. The catch is dominated by relatively small fish that should be permitted to grow to a larger average size before harvesting (Figure 5a).

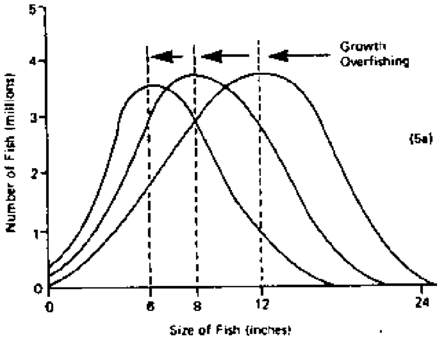


Figure 5a. Growth overfishing (dominated by relatively small fish).

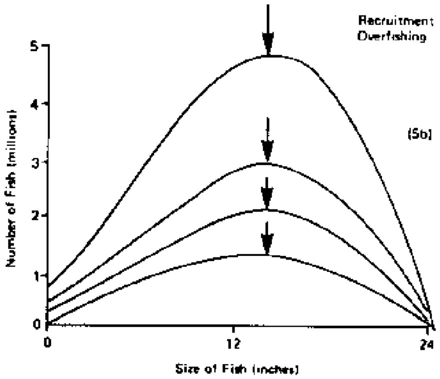


Figure 5b. Recruitment overfishing (spawning stock is reduced by excessive catches).

In recruitment overfishing, however, the spawning stock is reduced by excessive catches to a level where it cannot maintain the numbers of fish in the total population. Subsequent year-classes contain fewer and fewer fish (Figure 5b). The net result from both types of overfishing is that the catch per unit of effort, in both average weight caught (growth overfishing) and their number (recruitment overfishing), progressively declines (Cushing, 1975).

Typically, however, with the exception of a few carefully studied fisheries in the Chesapeake and Delaware bays (e.g., Atlantic menhaden), the effects of overfishing are poorly understood. Historically, catch statistics (landings) cannot be related to species abundance because the effects of fishing efforts, reporting error, and market demand are virtually unknown and cannot be adjusted for use with previously collected statistics. However, new data-collecting techniques will permit the use of catch statistics in estimating population size.

Therefore, although there has been a longstanding concern that overfishing by commercial and recreational interests has caused declines in local fisheries, there is little statistical evidence to support the claim or to interpret the level of effect for most Chesapeake and Delaware Bay fisheries (Rothchild, et al., 1981).

However, one important conclusion of the Emergency Striped Bass Research Study is that "the level of fishing mortality affects that magnitude of the contaminant mortality that the stock can withstand and vice versa." That is to say, overfishing can reduce the resiliency of the stock to rebound from toxic material stresses and vice versa.

These two forces—pollution and overfishing—may well be reducing the stocks of anadromous (freshwater spawners) species, which have declined dramatically over the past ten years. But through enactment of a recent fishing moratorium, striped bass populations are increasing considerably.

How can we better understand the impacts of climate, pollution, and fishing and their interactions on fisheries? A simple diagram of a hypothetical example, Figure 6, may help. In good climatic years, spawning fish produce ten times their number of young fish. In poor climatic years, they produce the same number of fish as there are adult fish. For the sake of simplicity, we assume that mortality in the young fish is equal and essentially nonexistent from natural causes like predation and disease, under both good and poor climatic conditions. The young fish reach spawning age and die after spawning in one year. Mortality from pollution and fishing are equal at 25% of the young fish. Therefore, 50% of the population survives to spawn the next year.

As shown in Figure 6, after only two generations there are 100 times as many fish available under good climatic conditions as there are under poor climatic conditions. If both fishing and pollution mortality are eliminated, under poor climatic conditions the population remains stable and would be four times larger (100,000 vs. 25,000) after two generations. Under good climatic conditions, the population would also grow and be four times larger (10,000,000 vs. 2,500,000) after two generations.

Obviously, Figure 6 is a highly simplified model that probably does not describe the real world, but it does suggest that

1. the effects of climate are likely to be the most significant effects on the population of a fishery.
2. pollution and fishing mortality can dramatically decrease the fish population when climate is poor but does not dramatically affect population growth when climatic conditions are good for the survival of young fish.

REGULATORY CONCERNS

Fisheries management agencies want to maximize harvest of key commercial and recreational species without jeopardizing the ability of the populations to sustain themselves. However, one of the deficiencies in fisheries science today is the inability of scientists to provide managers and planners with long-range predictions of population and ecosystem change.

This information will ultimately depend on the ability of climatologists to predict climatic change in the atmosphere and the ability of oceanographers to predict the response of the ocean and our bays to such climatic changes. Ideally, the fisheries biologist should also better understand these secondary effects of climate on the success of fisheries species.

For managers to assess the effects of overfishing, catch and effort statistics need to be compiled for commercial and recreational fishing activity that accurately reflect fishing effort. That is, in addition to knowing the number of anglers, it is also necessary to know the time spent fishing by each angler and the amount of gear fished during that time.

Finally, there is a need to better understand the effects of human-caused inputs into our waterways, particularly those that change water quality through the introduction of nutrients and toxic substances, as well as how these substances affect populations of fish and the balance of the entire ecosystem.

When the effects of climate, water quality, and overfishing and their interactions are understood more fully, managers may better address conflicts between commercial and recreational fishermen, allocate fisheries resources in a more scientific manner, and generally protect and develop fisheries resources for the public good in a more effective way.

For example, when recreational and commercial fishermen are at odds—trying to pin the demise of a species of fish on one another, fisheries management specialists may be able to show that the decrease in stock is really part of a long natural cycle where the species is declining due to subtle changes in the climate of the region.

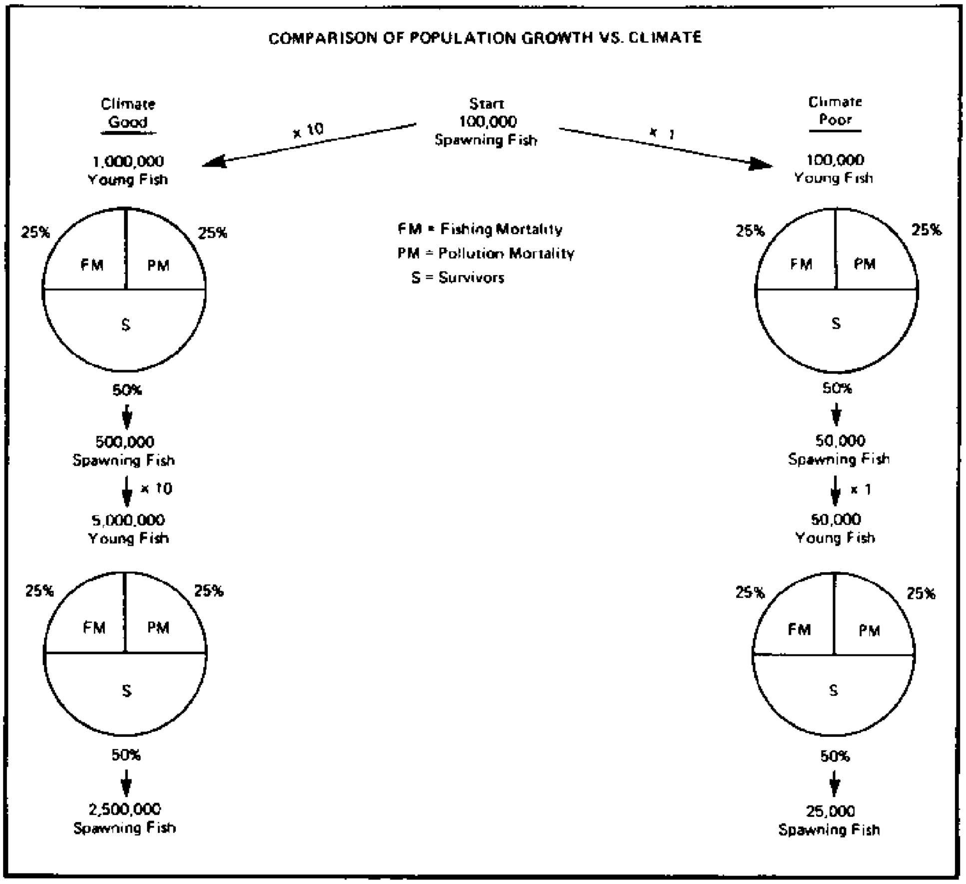


Figure 6. Comparison of population growth vs. climate.

Or perhaps fishermen are complaining that sewage treatment plants are affecting fishing when in reality nutrient enrichment caused by agricultural activities and other non-point sources is really the culprit. Each of these examples has been shown to be true in selected situations.

Obviously, a better understanding of the linkages and interactions between natural and manmade factors would benefit the public as well as fisheries managers. However, at the heart of this controversy is stock resiliency—the source of the furor surrounding declining fisheries such as stripers. We *can* control fishing mortality quickly, directly, and relatively economically by limiting fishing. Reducing toxic stresses, environmental degradation, and other human-related factors is much more lengthy, indirect, and expensive, but is the *ultimate* solution. To maintain our fisheries, one of our most valuable resources, we must do both. Thus, our first move should be to take immediate regulatory steps to reduce fishing mortality where necessary, while beginning to collect the environmental data that will serve us in developing the real solution to our problem.

REFERENCES

Albert, R. C. 1982. *Cleaning up the Delaware River.* Delaware River Basin Commission.

Carriker, M. R., et al. 1982. "Effects of Pollutants on Benthos." In *Ecological Stress and the New York Bight: Science and Management,* ed. G. F. Mayer. Columbia, SC: Estuarine Research Foundation.

Cole, H. A. 1975. "Marine Pollution and the United Kingdom Fisheries." In *Sea Fisheries Research,* ed. by F. R. Harden-Jones, 277-303. London: Wiley.

Cushing, D. H. 1975. *Marine Ecology and Fisheries.* U.K. : Cambridge.

Environmental Protection Agency. 1983. "Living Resources: A History of Biological Change." In *Chesapeake Bay, A Profile of Environmental Change.* Washington, DC: U.S. Government Printing Office.

Galtsoff, P.S. 1964. *The American Oyster* Crassostrea virginica *Gmelin.* U.S. Fish & Wildlife Service Fisheries Bulletin 64. Washington, DC.

Jeffries, H. P., and M. Terceiro. 1985. "A Cycle of Changing Abundancy of Fishes in the Narragansett Bay Area." In *Marine Ecology Program Series* vol. 25(3):239-244.

Mayer, G. F. 1982. *Ecological Stress and the New York Bight: Science and Management.* Columbia, SC: Estuarine Research Federation.

McHugh, J. L. 1981. *Marine Fisheries of Delaware.* Fisheries Bulletin vol. 79(4): 575-599.

Merriner, J. V. 1976. *Aspects of the Weakfish,* Cynoscion regalis *(Sciaenidae), in North Carolina.* U.S. National Marine Fisheries Service Fish. Bulletin vol. 74: 18-26.

Nelson, W. R. 1979. A larval transport mechanism for Atlantic Menhaden. In *Climate and Fisheries,* 125-126. University of Rhode Island: Center for Ocean Management Studies.

Nixon, S. W. 1982. Nutrient dynamics, primary production and fisheries yields of lagoons. The International Symposium on Coastal Lagoons, Bordeaux, France, September 1981. *Oceanol. Acta 1982:* 357-371.

Nixon, S. W. 1983. Estuarine ecology—a comparative and experimental analysis using 14 estuaries and the MERL microcosms. Final report to the U.S. Environmental Protection Agency. Chesapeake Bay Program under Grant No. X-003259-01.

Oglesby, R. T. 1977. Relationship of field yield to lake phytoplankton standing drop, production, and morphoedaphic factors. *J. Fish. Res. Board Can.* vol. 34:2271-2279.

Setzler, E. M., W. R. Boynton, K. N. Wood, H. H. Zion, L. Lubbers, N. K. Mountford, P. Frere, L. Tucker, and J. A. Mihursky. 1980. *Synopsis of Biological Data on Striped Bass,* Morone saxatilis *(Walbaum).* NOAA Tech. Report NMFS Circ. 433.

Sindermann, C. J. 1980. "Pollution Effects on Fisheries—Potential Management Activities." *Helgolander Meeresunters* vol. 33:674-686.

Sulkin, S. D., C. E. Epifanio, and A. J. Provenzano. 1982. Proceedings of a workshop on the recruitment of the blue crab in mid-Atlantic Bight estuaries. Maryland Sea Grant.

Wang, J. C. S. and R. J. Kernehan. 1977. *Fishes of the Delaware Estuaries: A Guide to the Early Life Histories.* Towson, Maryland: Ecological Analysts, Inc.

Wise, J. P. (Ed.). 1974. *The United States Marine Fishery Resource.* Contr. NOAA-NMFS MARMAP.

Acknowledgements

The authors wish to gratefully acknowledge the assistance received from the following individuals: Nicholas Biasotto and Tracey Bryant, University of Delaware Sea Grant Program, editors; and Pam Donnelly, typesetter; and Tony Fletcher, graphic artist, both of the University of Delaware College of Marine Studies.

This publication is the result, in part, of research sponsored by NOAA Office of Sea Grant, Department of Commerce, under Grant No. NA83AA-D-00017 and NA85AA-D-SG033. The U.S. Government is authorized to produce and distribute reprints for governmental purposes, notwithstanding any copyright notation that may appear hereon.

Published by the University of Delaware Sea Grant
College Program. Publication number DEL-SG-07-86.
(5/86.1200)