Abstract

During the past decade unprecedented changes have been wrought in coastal lagoons, bays, and estuaries as a result of solid-fill causeway construction, dredging, bulkheading, and diversion of large quantities of fresh-water from the interior. Often the greatest change occurs in areas that have been noted for heavy fishery production. In some cases these changes are known to have reduced landings from such fisheries.

When conflicts of interest arise, the biologist is often called upon to decide for or against the proposed development. Normally these biological investigations are of an emergency character with little time allowed with which to conduct the investigation. In fairness to all parties, some technique is needed that will enable the biologist to extend his observations beyond the scope of the emergency investigation. Such might be provided by an animal or plant "indicator" species. The indicator ideally would have wide distribution throughout the coastal waters of the southeast, be common enough that it could be used in any area, and would give an indication of the traditional pattern of the hydrography as well as the probable pattern of local productivity.

Studies on the ivory barnacle (Balanus eburneus) of south Florida have shown the species is common and widespread. It shows variation in shape, growth rate, and population density with changes in the environment. Studies on animal and plant associates in the different environmental categories under which the barnacle exists have been shown to be useful in determining the probable productivity of the area under different hydrographic regimes.

Results are encouraging enough to make it seem likely that the barnacle can be used as a field tool for the biologist who is called upon to investigate emergency studies in coastal waters.

Effects of Civilization on Striped Bass and other Estuarine Biota in Chesapeake Bay and Tributaries [1]

ROMEO J. MANSUETI
Chesapeake Biological Laboratory
Solomons, Maryland

Abstract

Chesapeake Bay, a highly productive estuary along the mid-Atlantic Coast, annually produces commercially about 80 pounds of seafood per surface acre. Its major features and productivity have been subjected to great influences of civilization, some catastrophic, others moderate but sustained. The estuary has been remarkably resilient and is still considered a relatively unspoiled region. The man-made changes, many wasteful, and others beneficial, have not overall greatly reduced its potential productivity, although the carrying capacity (especially the bottom) has been reduced. Man has compensated partly for such changes by adding to the fertility of the waters.

The biota has been subjected to density-independent and density-dependent factors. The former has produced permanent and devastating effects through sedimentation, pollution, wet-land reclamation, and dams. The increased construction of dams, while continuing to affect fish movements, through water-flow regulation, will greatly endanger the existing biota by the alteration of circulatory, flushing, and tidal patterns of the lower estuary. Highway construction, detergents, pesticides, and radioactivity loom large in the future of estuaries. Density-dependent effects produced by man's systematic seafood harvests and his meager attempts at manipulating or cultivating estuarine crops have had little effect on the long-range productivity of the Bay. Marked

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changes in size and age composition of fish have occurred, but total biomass is apparently little changed by exploitation.

A hypothesis is advanced that civilization and striped bass populations are compatible, i.e., increasing fertilization by man may be indirectly responsible for the unusual increase in number and magnitude of dominant year-classes. Human population growth has produced increasing loads of silt, waste, and fertilizers which have been emptied into the estuary, creating many adverse conditions in the upper estuarine spawning areas of fish. The striped bass produces pelagic eggs and larvae that are adapted to the most favorable features of this spawning area. The chances of survival are higher for floating eggs and larvae over areas with high turbidity, low light penetration, low dissolved oxygen, excessive sedimentation than for demersal or semi-demersal eggs deposited by most other species using the same spawning area. The problem of excessive and uncontrolled mineralized fertilization in estuaries is discussed in relation to striped bass and other biota.

INTRODUCTION

THE OBJECTIVES OF THIS REVIEW are fivefold: (1) to summarize the important changes and their effects wrought by man in Chesapeake Bay and its estuaries; (2) to evaluate qualitatively, and quantitatively, where possible, the magnitude of these effects; (3) to document from the available sources the variety, quality, and extent of published material; (4) to list the deleterious effects of man-made changes on the biota and to suggest beneficial effects on certain forms; and (5) to prognosticate the future of the estuarine environment in view of human population growth and watershed utilization by man.

The problem of documenting objectively and quantitatively the enormous changes brought about directly or indirectly by man has been difficult. Statistical data on deforestation, sedimentation, and mortalities or changes in biota produced by contaminants or other foreign materials, have rarely been recorded. Essentially, a review of this type must be restricted to a somewhat dispassionate subjective approach, where generalities are reduced to their basic ingredients.

Sources and Treatment of Information

The basic approach consisted of these steps; (1) to outline the principal changes and effects produced by man in Chesapeake Bay; (2) to document from the scientific literature examples, and where enough studies are available for a particular topic, attempt to evaluate the phenomenon; (3) in the absence of scientific publications, to review the "popular" literature in conservation magazines and other quasi-objective publications which specialize in natural resources; (4) where scientific and popular accounts were unavailable, newspaper accounts by responsible writers were used since authoritative reporting in lieu of other material can be an important source of history; and (5) finally, to procure unpublished information known to colleagues or present in the files of the Chesapeake Biological Laboratory, Natural Resources Institute of the University of Maryland, Solomons, Maryland.

A vast amount of written material exists on siltation, industrial pollution, overfishing, wetland losses, etc. but much of it is opinionated, based on incomplete facts, and inaccurate, depending on the background and motivations of each writer. Notwithstanding these deficiencies, enough published material was checked on the effects of man-made changes in the watershed for the past 300 years to describe them in historical terms. In view of the varying quality of the source material, it is difficult to attempt anything more than a broad evaluation of the long-term effects of the major changes brought about by man. Some are obvious, others are less so, but nevertheless important. Therefore, much of the following presentation must be regarded as provisional and suggestive, rather than conclusive.

Many people contributed facts, leads, and ideas in the development of this paper. Mr. G. Francis Beaven and Mr. Donald Meyers, biologists at the Chesapeake Biological Laboratory, have been especially helpful.

RESULTS AND DISCUSSION

Chesapeake Bay, a highly productive estuary, produces annually about 80 pounds of seafood per acre (Quittmeyer, 1957:26). The area also is used extensively by a wide variety of maritime interests (United States Army Corps of Engineers, 1961:1-57). Activity in the Susquehanna River, part of the upper watershed of the Chesapeake, has also been very great (Mansueti, 1958:1-14). The seafood harvest of Chesapeake Bay states has remained at a relatively

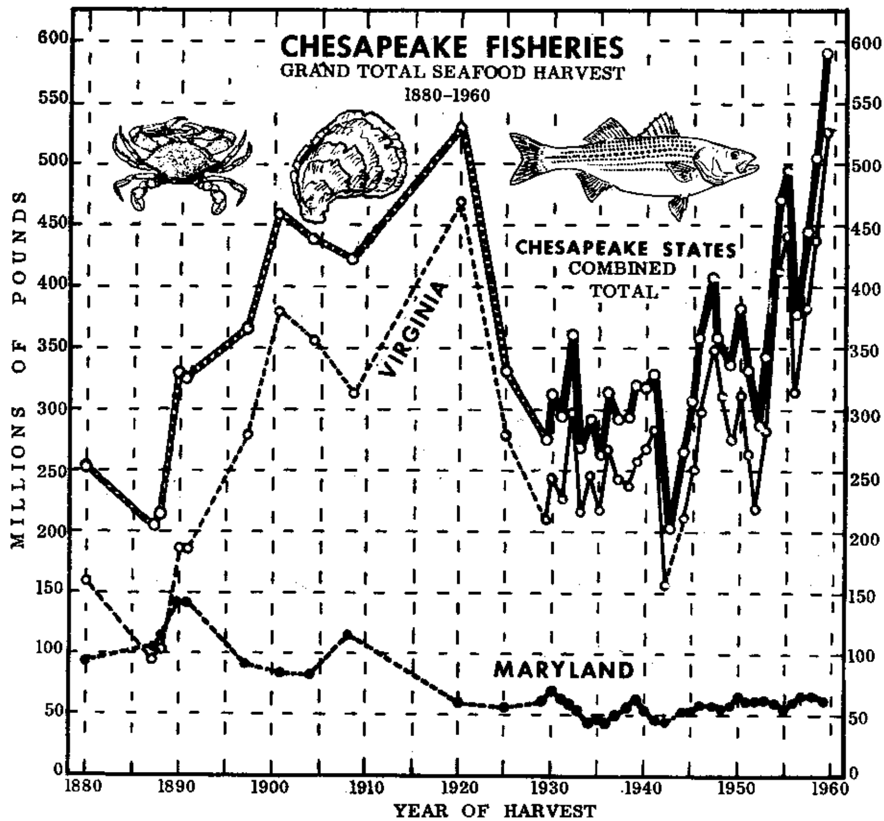

FIGURE 1. Trend of seafood harvest of all shell- and fin-fisheries in the Chesapeake Bay states for the period during which records were available. Broken lines signify lapses in the records. Data based on catch records derived from official Maryland and Federal sources.

stable level in Maryland or increased in Virginia waters during the past eight decades (Figure 1). Early reports by white explorers in Chesapeake Bay indicated the apparent existence of large finfish and shellfish resources (Arber, 1910; Meehan, 1897:320; Hall, et al, 1910; McAtee, 1918:9; Beatty and Croom, 1940:73-86; Mansueti and Kolb, 1953:64) but many such statements were exaggerated, biased, or based on isolated observations, depending on the observer and the incentive for the reports. Seafood resources then were probably not much more abundant than the level at peak production in the late 1800's. While the carrying capacity of the Bay has been reduced somewhat, man has offset this loss in small measure by adding to its natural fertility.

Chesapeake Bay's major features and productivity have been subjected to many influences of civilization, some catastrophic, others moderate but sustained, and some of a short-term minor nature. Odum (1961:1) described some of the background of man's use of estuaries. Indirect changes in the estuarine environment and its organisms have been produced by man, of which that by Indians were minor (Reynolds, 1889:252-6; Gay, 1892:151; Meehan, 1897:313-4; Maxwell, 1911:65, 95; Marye, 1938; Stearns, 1943:6, 9, 20-8; Weslager, 1950:39-41; Marye, 1955:139-40; and Odum and Odum, 1959:137-8). The early colonists exerted occasionally marked but local effects on the watershed and seafood resources in a few areas (Meehan, 1897:321, 328; Mansueti and Kolb, 1953:53, 64, 125, 143, 240). The most important, intensive and serious changes occurred simultaneously with the explosive population growth beginning in the mid-1800's (Pearl, 1925:14). At the same time as these indirect effects were manifested, man began to affect directly the estuarine fin and shellfisheries through use and abuse. Such long range river use as proposed by Wolman, et al (1961:1-10) is being challenged by Cumberland (1961:15-8). representing the generally new approach to such problems of great significence. The combined effects of the intensive topographic changes, water manipulation, and seafood exploitation, have been in some respects in competition with similar natural changes.

Density-Independent Effects

DEFORESTATION AND SEDIMENTATION: The most extensive damage to the environment and its biota are traceable to density independent changes. That is, wholesale agricultural, industrial, and domestic use by man of the estuarine watersheds resulted in great changes in the topography, and the effects have in some cases been partially or totally destructive, regardless of the numbers of organisms. The processes operating in an estuarine ecosystem are complicated, and the environment in general is one of great productivity, instability, and wide ranges in salinity, temperature and oxygen (Ingle, 1954:64-7; Pritchard, 1951:365-9; Newell, 1959:61-5; Odum, 1961:1-4). Virtually all the virgin forest in the Chesapeake Bay watershed had been utilized before 1900, although it is now known that the area was not entirely wooded (Marye, 1955:141). Deforestation (Bond, 1959:17-9), freshets (United States Forest Service, 1943:12-3; Stearns, 1943:12), erosion (Cumberland, 1961:8-15), siltation, and sedimentation during the 1800's, which increased with each succeeding decade, began to have serious effects on the watershed and estuary (Brehmer, 1959:27; Bartsch, 1960:119). A conservative estimate suggests that roughly half of the former upper estuarine spawning areas for fish and shellfishery areas for oysters, *Crassostrea virginica,* (Beaven 1946:131), have been destroyed or shifted downstream by sedimentation in Chesapeake Bay. Many formerly well-known spawning areas for anadromous fishes are no longer suitable or greatly restricted in area. Sedimentation has had profound effects on the depths, contours, and quality of the estuarine bottoms (Gottschalk, 1944: 2-3; 1945:233-7; Weiss, 1950:39; Ratledge, 1959:14-5; Stephenson, 1959:13). Probably every part of the Chesapeake and its smaller estuaries has been so affected by the multiplicity of factors listed above, but the end point of sedimentation has had its greatest effects at the head of tidewater, and least effects in the deeper channels.

FRESHETS, DROUGHT, AND THERMAL CHANGES: Excessive precipitation or drought conditions, the extremes of which have been produced partly by man (Ashbaugh and Brancato, 1958:28), causes excessive dilution by fresh water in the estuary and destroys huge crops of moderately euryhaline oysters (Cumming, 1916:225; Beaven, 1946:131; Engle, 1946:136-7; Frey, 1946:14); or during long periods of no rainfall, increased salinity causes fish mortalities among euryhaline species (Truitt and Algire, 1930:58-9). Air temperatures have shown a slight upward trend in the last half century (Baum and Havens, 1956:445), and these have probably shifted spawning and activity time-wise for some organisms. Abnormally heated water in rivers by industrial power plants such as the Pepco (Potomac Electric Power Company) Plant in the Potomac River and one contemplated in the Patuxent River bring about marked local changes that affect the sedentary fauna and attract fishes during the colder periods (Elser, 1961B:1; Hynes, 1960:136-9). The effects can be subtle, and sudden temperature changes can exert serious changes among many estuarine forms (Brehmer, 1959:28).

CONTAMINANTS FROM MAN-MADE SOURCES: Industrial, domestic, agricultural, mining, and dredging activities have kept pace with human-population growth in the Chesapeake watershed (Cumberland, 1961:13-7), and a great variety of contaminants and other pollutants have been poured in the waterways. Pollution is a normal condition in a developing economy, and in spite of many safeguards, it has been intensive, highly localized, and destructive. Despite the magnitude of all types of pollution. Chesapeake Bay has been remarkably resilient. It has maintained a high ecological quality and has continued to produce seafood crops on a sustained or increased level, even though commercial fishing pressure has shown little increase.

INDUSTRIAL SOURCES: Industrial pollution is limited to larger metropolitan regions, and the effects are local and vitiated by the assimilative and flushing action of the estuary. This is true in the Patapsco River at its confluence with Chesapeake Bay (Olsen, et al, 1941:38-40; Davis, 1948; Garland, 1952:69-70, 77, 81), and in the Potomac River (Wolman, et al, 1957:386, 403). While chemical toxins and similar materials have produced biotic destruction on a local, temporary level, no long-range losses to economically important marine species in the whole Chesapeake area can be traced to it (Massmann, et al, 1952:1, 169; Weiss, 1952:180). The study by Galtsoff, et al, (1947:182-4) is a classic example of intensive contamination on oysters. Increased shipping activity has increased the burden of oil pollution in the Bay (Lincoln, 1936: 556-7), in spite of restrictive legislation, and the raw sewage load from these vessels is also increasing. In general, cooperation between interested people and strict regulations are bringing industrial pollution under control and possibly it will be completely managed in certain areas in the future.

AGRICULTURAL SOURCES: Agricultural pollution has produced beneficial and destructive effects; fertilizers have increased an uncontrollable type of productivity, some deleterious (Galtsoff, 1956:414; 1959:128-9; Wolman, et al, 1957:426), while poor farming practices have resulted in serious loss of habitat through erosion and sedimentation, and pesticide washings have produced serious mortalities among many estuarine organisms (Loosanoff, 1960: 89-92; United States Department of Health, Education, and Welfare, 1961:17; Barry, 1961:52-4). Many such mortalities go undetected, especially among sessile organisms, but the increasing incidence of fish kills, some of which can be traced to careless pesticide use, suggests that this problem will increase for all organisms. Highway and large-scale building construction has contributed heavily to the sedimentation rate, and it is competing importantly with poor farming practices as a major cause of landscape loss. The destructive effects of various forms of inert materials on aquatic life are well-known (Buck, 1956: 259; Wilson, 1960:269-71). Conservation groups are trying to minimize such massive sources of pollution by exercising controls on a large-scale watershed basis. The obstacles are great, but this approach holds the most promise, although little progress has been made in any part of the Chesapeake area except for the Potomac drainage.

DOMESTIC SOURCES: Domestic pollution has produced some public health hazards in Chesapeake Bay, but has locally, and sometimes abnormally, improved productivity and growth of estuarine organisms, especially among algae (Wolman, et al, 1957:428-9; Heukelekian, 1960:250) and filter-feeding organisms. The practice of certain watermen of "fattening" their oysters in tidal areas condemned as being sewage-laden (Cumberland, 1961:14-5), and then "cleaning" them in unpolluted waters, has been restricted greatly by enforcement authorities in recent years. The fact that soft-shelled clams, *Mya arenaria*, accumulate coliform organisms (Lear, 1960:39) precludes similar treatment for this species. Also, they cannot be eaten raw as are oysters and hardshell clams, *Mercenaria mercenaria*, which do not store pathogens. In general, sewer rivers are not being utilized well (Renn, 1956:71); control and balance of treated effluents can prove of great importance in estuarine production in the future. One of the most serious growing problems, as yet largely uncontrolled, is the increased introduction of detergents in the major waters of the Chesapeake watershed (Maryland Water Pollution Control Commission, 1961:1-11). Detergents are known to be extremely lethal to aquatic organisms and greatly modify the environment (Hynes, 1960:66-7, 75, 107, 120).

MINING AND DREDGING OPERATIONS: Mining pollution and major dredging operations are of variable importance in the Chesapeake watershed. Coal mining operations in the upper Susquehanna River have produced coal dust which occurs downstream to below Harrisburg (Reid, 1936:544-5). Although this material is being systematically removed, it still contributes to the unfavorable bottom conditions, so that it may be responsible for the failure of several attempts of stocked American shad, *Alosa sapidissima*, to spawn successfully above the various dams (Mansueti and Kolb, 1953:130-1; Whitney, 1961:4). Dredging of oyster reef shells (Bentley, 1960:24) may create serious changes on the bottom and increase sedimentation on adjoining areas with some loss to bottom organisms, although Hammer (1960:8) pointed out that operations to date have not seriously affected oysters. These shells, the origin of some of which have been described by Nelson (1960:220), are currently being mined in the upper bay and contemplated from the upper James River. Manning (1957:25) pointed out that hydraulic dredging operations for soft-shelled clams are destructive only on an extremely local basis, and that aquatic weeds destroyed are a small part of the total quantity available to wintering waterfowl in Chesapeake Bay. Baltimore harbor dredging operations, with its dumping operations in the Chesapeake Bay Channel off Kent Island, as well as other spots (Associated Press, 1961:B-2), has not been fully evaluated, but wintering populations of striped bass, *Roccus saxatilis*, may be immediately affected. In general, dumping of slag, garbage, trash, etc. into the bay destroys existing bottom communities, reduces the area of potential oyster bottom for future rehabilitation, but in turn it may be the basis for new communities of encrusting organisms.

UNDERWATER EXPLOSIVE EXPERIMENTS: Military agencies have used Chesapeake Bay as an experimental area for underwater explosives for the past two decades. Studies have shown that while such activities bring about local mortalities of fishes, blue crabs, *Callinectes sapidus*, and oysters, they have had no long range effects on the abundance of estuarine organisms either locally or bay-wide (Chesapeake Biological Laboratory Staff, 1948:35-42; Coker and Hollis, 1950:443-4; and Tiller and Coker, 1955:15-18). Naval authorities, however, have attempted to minimize such local kills by scheduling their firings in areas where fish are absent or scarce; i.e., virtually no explosives are set in deep-water areas containing overwintering congregations of fish.

RADIOACTIVE POLLUTION: Radioactive pollution in the bay is not presently a problem although natural radioactivity (Folsom and Harley, 1957:32) and fallout effects may exist at a low level. The construction of the Peach Bottom nuclear power-plant in the lower Susquehanna River, nine miles above Conowing Dam, and near the head of Chesapeake Bay poses many problems in industrial radioecology (Renn, 1957:26-7). The possibilities of accidents from atomic-powered vessels and structures, while remote, must be anticipated. The Associated Press (1959:36) reported the selection of three atomic-waste dumping sites off the mouth of Chesapeake Bay and two off the Maryland seaside. All of these could represent sources of contamination from migratory fish. Also, estuarine biologists should be further concerned because of the predilection of shellfish to accumulate radioactive substances (Boroughs, et al, 1957:82-3; Chipman, 1960:12).

CANALS, DAMS, AND OTHER MAJOR STRUCTURES: Major structures on or near estuaries have also had some effects. Three important canals—Chesapeake and Delaware Canal completed in 1829, Chesapeake and Ohio Canal completed in 1850, and the Susquehanna Tidewater Canal begun in 1822 and discontinued in 1906—have exerted little destructive effects on biota, but have increased water area and habitat for certain species of fish. The proposed Pocomoke-Chincoteague Canal (Jones, 1961:27) may raise salinity levels in the Chesapeake Bay tributary to such a point that the famed cypress swamp may be destroyed. The construction of Conowingo Dam cut off some anadromous fish from part of their spawning grounds in the lower Susquehanna River, while Triadelphia and Rocky Gorge dams have affected the upstream movements of river herrings, *Alosa pseudoharengus* and *A. aestivalis*. The newly created reservoirs and millponds, which also reduced access to minor spawning areas for fish on the Delmarva peninsula, created extensive new habitats for many native, introduced, and a few estuarine species. The fishway problem in several dams are intense, and in the case of Conowingo Dam, a recent study concluded that conditions upstream and the reaction of the introduced fish during the survey precluded the need for fish passage, except for the elvers of the American eel, *Anguilla rostrata*, (Whitney, 1961:2). Although a small fishway was installed in the dam at Little Falls, in the Potomac River, above Washington, D.C., the area has not attracted enough fish to be considered successful (Covell, 1961:E-4). Construction of bridges and tunnels have only temporarily affected a small part of bottom communities.

MARSH AND WETLAND RECLAMATIONS: Many areas in the Chesapeake Bay watershed have been reclaimed for many reasons: metropolitan expansion, mosquito control, additional land for agricultural, domestic, and industrial use, and as dumps for waste materials (Renn, 1956:470-1). The importance of such areas has been emphasized by many workers, and Odum (1961:1-4) has provided the most compelling description of their importance to the high productivity of estuaries. Adverse effects have been recorded for many wetland species, especially muskrats (Dozier, 1947:402-19; Harris, 1951:201). Losses in general have not been great, but great problems are contemplated in the near future when speculators and local agencies clamor for reclamation of the extensive wetlands on the Delmarva peninsula.

GENERAL EFFECTS OF DENSITY-INDEPENDENT FACTORS: Historical data indicates that habitat destruction, particularly through sedimentation, dam construction, and some pollution, was effective even before the 1800's; but that the major changes occurred after this time. Those changes brought about indirectly by man-made activities seem to be the most insidious and difficult to halt, since no one activity can be definitively controlled. Watershed management of deforestation, poor agricultural practices, and other major activities, hold the most promise of beneficial results. On the other hand, those conditions arising from industrial, domestic, or specific agricultural activities can be controlled under some conditions, and their management shows promise of alleviating many serious conditions of pollution. Man-made density-independent factors will continue to be the most important features of civilization on natural populations, no matter how well controlled.

Density-Dependent Effects

Man's primary motivation for harvesting estuarine seafood products, aside from their nutritive value, has been related to the abundance and ease in exploitation. Hence, his fishing efforts have been dependent on the density of the seafood resources. The direct influence of man's attempt to harvest fully the estuarine seafood resources, the industry of which has been considered of minor importance in Chesapeake Bay (Quittmeyer, 1957:1, 3-4), has had variable effects, some leading to no perceptible effects and others to depletion of certain species. Although Figure 1 shows that seafood harvests have been stable or increasing, important changes in the species composition and relative importance of different species have taken place. Even during the 1920's when fishing effort was less restrictive than today, catches overall were relatively stable (Hilderbrand and Schroeder, 1928:16).

EARLY FLUCTUATIONS IN SEAFOOD SUPPLY: Many species exhibited marked fluctuations in supply and availability throughout their range even before extensive exploitation or commercial fishing had begun. This was especially true for American shad, bluefish, *Pomatomus saltatrix,* and striped bass, *Roccus saxatilis,* (Ferguson, 1877:1-12; Brooks, 1905:213; Bigelow and Schroeder, 1953:386-7, 400-1). The principal reason sedentary oysters and clams, and migratory species such as shad, herring, and perches were exploited during colonial times was because shellfish could be conveniently harvested, or because the fish traversed estuaries to the river banks of communities in many inland areas. Even then, the available supplies were said to vary from year to year. These fluctuations emphasize the importance of meteorological and hydrographic conditions as factors affecting populations, rather than exploitation as a primary cause.

EFFECTS OF HIGH EXPLOITATION: Within the last century, especially between the Civil War and 1900 when seafood harvests reached their peak, exploitation was high, and wide fluctuations and important declines in landings were evident. These have been attributed to fishing effort, supply and demand, and natural fluctuations in abundance, conditions of which were so interwoven that they cannot now be separated. The socio-economic aspects continue to compete strongly with the biological features in the analysis of changes in the commercial fisheries of the Bay. Few important species have been over-fished. While many moderately valuable species are more or less being fully utilized, some important food and game species and presently non-commercial species are under-utilized. The American shad, the oyster, and the Atlantic sturgeon, *Acipenser oxyrhynchus,* are three important species that

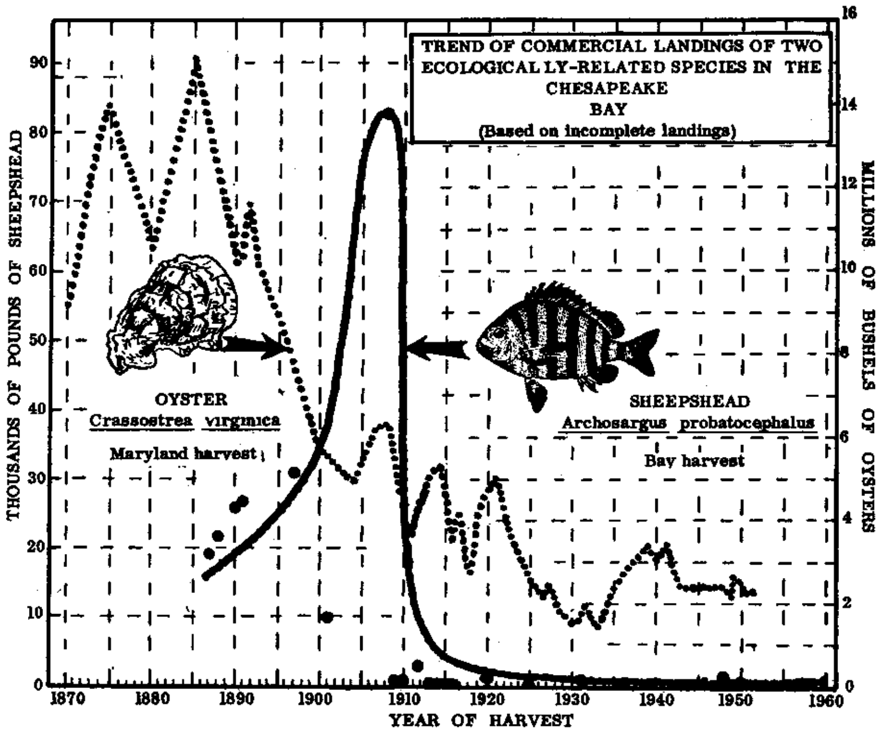

FIGURE 2. Trend of commercial landings of two ecologically related species in Chesapeake Bay to suggest the possible relationship in the decline of oyster environment with the apparent decline of sheepshead. Data based on catch records derived from official Maryland and Federal sources. The black dots represent recorded landings of sheepshead from which the black trend line was drawn.

have classicially been considered overexploited, but it is more probable that their low abundance is due primarily to their considerably reduced spawning and producing grounds and secondarily to exploitation in the past. These species have been unable to recover biologically in spite of their high biotic potentials, suggesting Allee's principle, that is, a species does not thrive unless the adult population density remains at a certain, presumably high, level (Odum and Odum, 1959:443-4). Figure 2, for example, shows the general trend of the oyster decline and its hypothetical relationship to the ecologically-related sheepshead, *Archosargus probatocephalus*, which has never been extensively exploited by man in Chesapeake Bay.

Declines in availability and/or violently fluctuating production of other important species (Atlantic croaker, *Micropogon undulatus;* spot, *Leiostomus xanthurus;* weakfish, *Cynoscion regalis;* menhaden, *Brevoortia tyrannus;* blue crab, *Callinectes sapidus;* bluefish, and striped bass) have occurred independently of man's exploitation, although his influence on the gross estuarine-marine environment may somehow be related to these population changes. With the exception of the blue crab and striped bass, all of these spawn outside Chesapeake Bay, although their larvae and young use the estuary as a nursery area. It is significant that stable or increasing availability, accompanied by some fluctuations, has occurred in Chesapeake Bay during the last two decades with species spawned in the estuary (American shad, white perch, *Roccus americanus;* yellow perch, *Perca flavescens;* chain pickerel, *Esox niger;* carp, *Cyprinus carpio;* white catfish, *Ictalurus catus;* channel catfish, *Ictalurus punctatus,* and others). This may be due to stable or increasing fertility of the estuary, in spite of its uncontrollable features and of sustained commercial and increasing sport fishing pressure. Some of these, such as white perch, carp, river herrings, yellow perch, and soft-shelled clams, are apparently under-exploited. It can be concluded that in spite of fishing activities and species-specific fluctuations in abundance, availability and commercial catches are still maintained at a relatively stable level. It is important to note that while the total biomass has not been greatly affected, the size and age composition of certain species, such as the striped bass, has definitely been reduced by exploitation.

Management by Regulation of Estuarine Resources: Man's attempt at seafood management by regulation and environmental change has not been optimal for primarily socio-economic reasons. This is particularly true in shellfish management, where scientific oyster culture is capable of much higher production than presently realized (Glude, 1951:399-402). Maryland and Virginia differ in seafood regulations and management emphasis. Conflicts of interest have existed between the two States (Marshall, 1949:431) and between different groups of fishermen, but clashes have not been based on biological arguments. The current furor on the Potomac compact is related to these differences.

The Maryland Fish Management Plan, a controlled-catch program, which stabilized the number of licensed netters, the amount of gear, and much of their effort at the pre-World War II level, has been accompanied by a slightly increasing trend in the commercial fin-fish harvest (Mansueti and Kolb, 1953: 221-25). Tiller (1945:7-8) claimed that the management plan had immediate beneficial effects in the form of more striped bass at larger size than obtained before the enactment of the Plan, while Walburg (1955:14-16) concluded that the increased yield of American shad was due to increased fishing effort, in spite of the stabilizing influence of the Plan. Muncy (1959:96) further indicated that the widespread replacement of nylon nets over linen contributed to increased catches beginning about 1950. There is evidence however, to indicate that catches were better in the early stages of the plan, but records were unfortunately incomplete to show this fact. Walburg further suggested that the effects of the Maryland plan on migratory stocks of fish were obscured by Virginia fishermen's effort and harvest, although Whitney (1961:19) and Mansueti (1961:20-9) showed from tagging that American shad and striped bass originating in Maryland waters were later harvested principally in Maryland, and virtually none in Virginia. In general, the Plan's effects are yet to be fully evaluated, but there are indications of benefit.

Many fishery regulations are biologically unsound; minimum length limits, for example, of 8 inches in the white perch probably results in important losses to natural mortality of three or four age groups up to this size (Mansueti, 1961:199-200). The maximum weight limits of 15 pounds in striped bass in Maryland have resulted in some waste to Maryland fishermen. The lack of any limit for anglers in Virginia and outside coastal waters where larger striped bass are known to migrate illustrates further the illogical aspects of Maryland's regulation. The striped bass is also the principal case in point in the commercial netter-sport fishermen controversy in Chesapeake Bay. The problem is based on a conflict of interests and the desire of relatively inefficient anglers, who spend substantial sums of money in pursuing the angling recreation, for exclusive franchise of fishing rights from the highly efficient netters. The small number of the latter group, it is argued, serve as hunters or agents for a large population of consumers who may or may not fish. Sport fishing interests were successful in closing two medium-sized estuaries (Magothy and Severn Rivers) to commercial netting in 1946. Since that time angling has been poor in the two rivers. Catch rates and harvests have been less than that recorded in other Chesapeake Bay tributaries where angling and netting coexist. The rationale behind the support of commercial harvests by management agencies is that from biological and conservation viewpoints, commercial fishing is a valuable activity (Russell, 1942:73, 95; Allen, 1954:159-60). The burgeoning increase in anglers and the economic importance of sport fishing in Chesapeake Bay, however, may dictate management from a strictly economic and political viewpoint sometime in the future.

Biological Management: Stocking of new species, except for certain game fishes, of eggs and young of resident or migratory species has not resulted in long-term beneficial effects (Muncy, 1959:10-12). Introduction of certain foreign species (carp; goldfish, *Carassius auratus;* water chestnut, *Trapa natans,* (Uhler, 1944:300-1; Beaven, 1955:1-2); watermilfoil, *Myriophyllum spicatum,* (Springer, et al, 1961:1-6) into the estuary has actually created serious problems of competition and habitat loss. The extensive list of introduced species, principally centrarchids, catfishes, and the walleye, *Stizostedion vitreum,* into tidal fresh and slightly brackish waters have been more or less beneficial, but the real effects of the introduction have yet to be assessed.

Manipulating populations and their environment seems a promising method of increasing production and rehabilitating stocks in low supply. Planted oyster bars, especially by private leasing, are socio-economically controversial, although scientifically sound (Brooks, 1905:218-24; Glude, 1951:400-2). Attempts at rehabilitating the long-depleted oyster bars by reef construction based on the mining of old buried oyster shells in upper Chesapeake Bay was begun in 1959, and they promise to have some long-term beneficial effects.

There are indications that if the oyster cannot be rehabilitated, then there will be a gradual transfer of effort toward partly replacing its low availability with the under-exploited soft-shelled clam. Fishing reefs, while in the untried experimental stage, may be valuable in increasing the carrying capacity of an area on a limited basis, but will best serve to concentrate fish, without increase in actual numbers. Arve (1960:58) found that fish catches were much greater over planted shell-bottom than over unplanted control bottoms, but Elser (1961A:10) found no difference, suggesting the need for extensive research on fishing reefs in general.

General Effects of Density-Dependent Factors: In general, fishing activities by man are influenced by the abundance or scarcity of a resource, Economic factors also exert important influence on his effort. Rarely has he reduced a species beyond the point of unprofitable return before another species could be utilized in its place. Estuarine organisms have been more affected by density-independent changes wrought by man on the environment than by exploitation; the former is greatly obscured and poorly supported with quantitative data; the latter ostensibly well-documented by catch records. The important effect of exploitation has been to alter greatly the size and age composition of a species, rather than to reduce the biomass. Thus, in Chesapeake Bay, with few exceptions, the great changes in the environment and population numbers of organisms cannot be attributed to fishing activities. Assuming that environmental conditions will remain stable or improve, then there is little danger that man's fishing activity at its present level of intensity can have any important effects on overall seafood production.

Relationship of Striped Bass Abundance to Fertilization in Estuaries

General Comments on Fish Crops and Artificial Nutrients: The purpose of this section is to suggest that the unusual increase in number and magnitude of dominant year-classes in the striped bass may be related to man-produced nutrients, especially from highly treated sewage. In spite of the vast quantities of artificial fertilizers entering North American estuaries, it is remarkable that none of the larger estuarine animals have been shown to benefit somehow from the long-term view. The striped bass's eggs and larvae are uniquely qualified to take advantage of these artificial effects, especially in the general spawning areas where brackish water meets tidal fresh water in the upper estuaries. This is an area of unusually rich plankton production, with specific hydrographic features, optimal light penetration, and reduced suspended materials.

Alterations by man in the Chesapeake Bay watershed have had adverse effects on many organisms; few examples can be given to show advantages. Changes in terrestrial habitats from forests to fields, for example, have benefitted certain game birds and mammals (Allen, 1954:63-5). The beneficial effects of organic pollution on certain organisms have been extensively documented by biologists and sanitary engineers. Thus, the population growth of bacteria, algae, certain tubificids, chironomids, and other invertebrates have served as classic examples (Wolman, et al, 1957:426-7; Odum and Odum, 1959:439; Hynes, 1959:27; Newell, 1959:62; Mohr, 1960:238). Although the beneficial effects of artificial fertilizers from the huge metropolitan areas on the coastal areas of North America have been alluded to by many writers, few people outside Europe have presented clear-cut examples.

Controlled introduction of modified sewage has been used by some investigators in the pond culture of carp (Schaeperclaus, 1933:172; Falck, 1934: 228), and this source of fertilizer elsewhere has a long history of use. Radebaugh and Agersborg (1934:448-9) demonstrated in an experimental lagoon that treated sewage effluents will support carp, catfishes, and other fish populations. They felt that this method of fertilization had great economic importance, as did Uhler (1956:457) who suggested that filter beds of sewage disposal plants be used to create new feeding and nesting grounds for waterfowl. Hardy (1956:66) pointed out that Graham (1938) showed that the abundant source of phosphates and nitrates in the southern North Sea opposite the opening of the Thames estuary was derived from the sewage of London. This region frequently developed a rich growth of phytoplankton that had marked effects on the fish production of the area. Hardy stated further that Carruthers (1954) recently summarized the work of K. Kalle of the Oceanographic Institute at Hamburg who also correlated the Thames drainage upon the fish populations

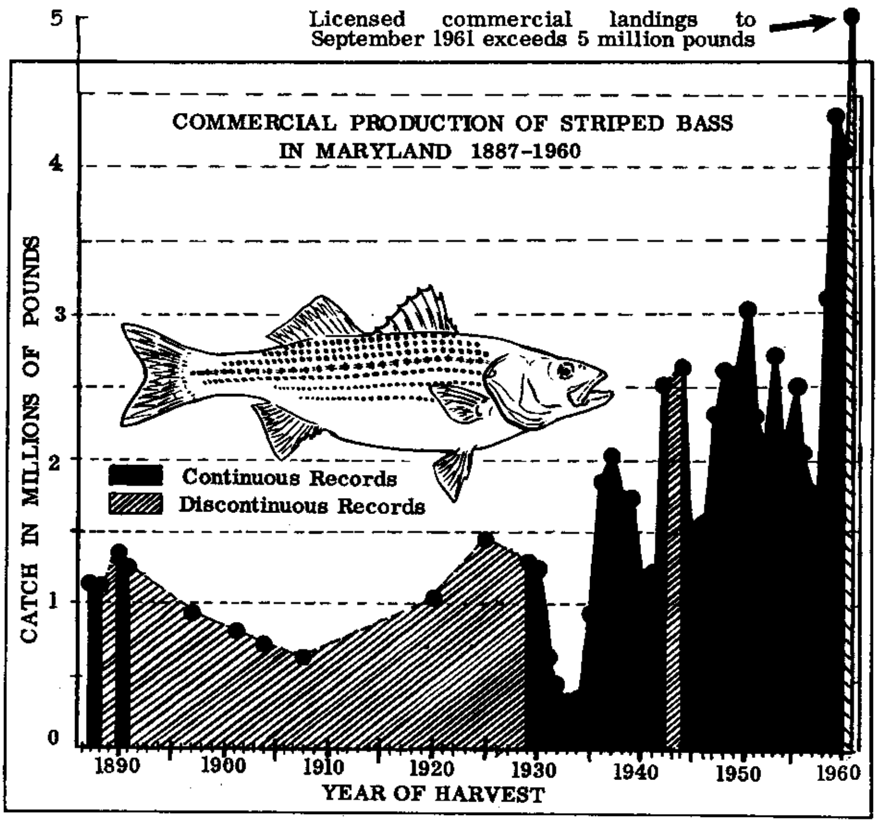

FIGURE 3. Trend of landings of striped bass, *Roccus saxatilis*, from Chesapeake Bay in Maryland to show the apparent increases in the frequency and magnitude of dominant year classes as reflected by peaks essentially two years after a hatch.

of the area. He showed that the catch of fish in this region is per unit area "about double the corresponding catch made in the rest of the North Sea, in the English channel and in the Kattegat/Skagerak region . . . and is about 25 times the catch reckoned for the Baltic Sea as a whole." Kalle believed that two-thirds of this higher average catch may be attributed to the rich supply of nutrients from the population of London. There is no comparable example for flowing systems for North America, although Langlois (1941:192) believed that roily, turbid waters benefitted catfish, carp, and sheepshead in inland waters. Fishery biologists have cited many isolated examples of fishes tolerant to conditions near sewage outfalls (Metcalf, 1942:196-7).

Dominant year-classes of striped bass have occurred in Chesapeake Bay during the last three decades during these years: 1934, 1940, 1942, 1943, 1946, 1948, 1950, 1954, 1956, 1958, and possibly 1961. Raney (1952:70) mentioned even earlier ones: 1896, 1898, 1904, and 1920. Figure 3 generally indicates the frequency and magnitude of the successful year-classes. They have occurred about every two or four years, where records occur, with no cyclical evidence. Preliminary examination of Maryland commercial catch records indicate that there has been a coincident increase in the catch-per-unit-effort two years after a successful hatch for most of the aforementioned years. Increases in the supply and catches cannot be explained entirely by increased fishing effort. Markedly successful year-classes of striped bass have also occurred in North Carolina in recent years (Sykes, 1961:personal correspondence), and apparently in California (Lyman and Woolner, 1961:40), independent of the Chesapeake Bay production. Assuming environmental factors are of primary importance in these successful year-classes (Raney, 1952:70), the phenomenon of increasing number and magnitude of the year-classes might be related to increasingly favorable conditions in the spawning areas. No clear-cut factors of hydrographic, meteorological, or biological origin are available to explain the increases. Trautman (1939:280-6) and Langlois (1941:193-4) pointed out that fish are highly selective in spawning and that man can have an unfavorable effect on the available spawning sites. Langlois also suggested (p. 190-2) environmental changes induced by civilization affected the dominant year-classes of certain species, and that successful hatches of saugers, for example, followed roily water conditions. In the case of striped bass, the eggs and larvae seem particularly adapted to survive abnormal hydrographic conditions that would be unfavorable or lethal to other species, due to their pelagic nature.

HYPOTHESIS: The following hypothesis is developed: civilization and striped bass populations are compatible, i.e., increasing fertilization from artificial and natural sources brought down to the estuary by run-off and freshets may be indirectly responsible for the dominant year-classes. It must be emphasized that at this time fertilization is uncontrolled and unpredictable, and that it can have deleterious as well as beneficial effects on striped bass.

The pelagic eggs and larvae of striped bass are preadapted to rapid, rough, silt-laden, and turbid waters. The species produces large buoyant eggs, which can apparently withstand extensive buffeting. The large perivitelline space may serve as an important breathing chamber (Mansueti, 1958B:7). Practically all other species spawning in tidal fresh and brackish waters in spring produce demersal or semi-demersal eggs. Striped bass eggs, however, float at or near the surface; they become semi-buoyant in slow-moving waters, such as at slack tide, and they then occur near the bottom. Observations and col-

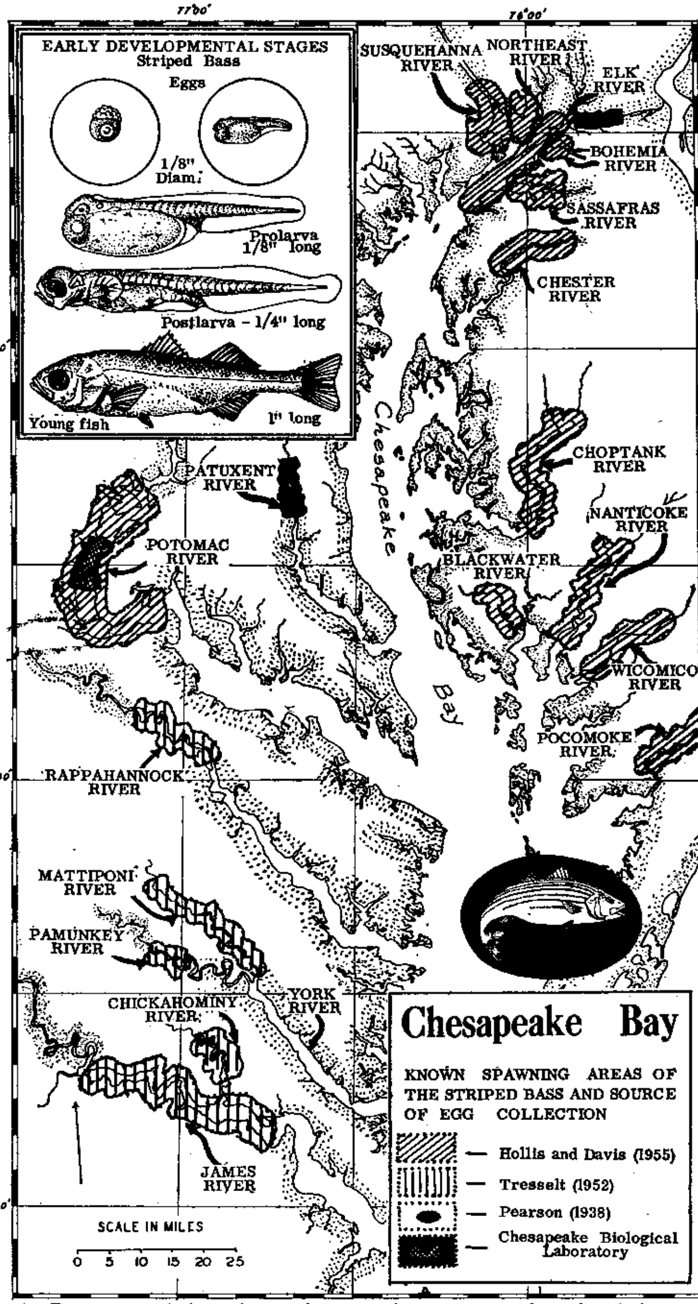

FIGURE 4. Range and location of spawning areas of striped bass, *Roccus saxatilis,* in Chesapeake Bay, with illustrations of selected early developmental stages.

lections of eggs made in the Potomac River at Quantico in May, 1959, Patuxent River at Lower Marlboro in May, 1957, and in the Chesapeake and Delaware Canal near the Elk River at Chesapeake City in May, 1957, indicated that eggs were crowded toward the surface and were at the mercy of the prevailing current, tide, and wind-driven masses of water. For example, when observed in the Patuxent River at Lower Marlboro, several hundred thousand eggs were stranded in a window about two to three feet wide on the beach after surface waters were subjected to persistent west winds.

The spawning of striped bass occurs in tidal fresh and slightly brackish waters, and the location varies from year to year depending on a variety of hydrographic conditions (Figure 4). After the eggs are produced, they are transported at or near the surface by the net downstream flow of the estuary; those that sink during slack before flood tide will be carried upstream again by the net upstream movement of the more saline bottom water (Pritchard, 1951:375). By the time they hatch they are carried to the point where the increasing salinity neutralizes and precipitates the negatively-charged suspended particles (Nash, 1947:162). Here the turbidity is somewhat reduced, light penetration is optimal for the estuary, and photosynthesis by phytoplankton produces blooms which are grazed upon by increasing numbers of zooplankters. Figure 5 is a gross simplification of the interaction and sequence of all these factors in relation to spawning of fishes in tidal fresh water in a typical estuary in Chesapeake Bay. Additional nutrients provide for exceptional blooms and hence excellent grazing conditions for striped bass larvae. Brooks (1905:8-13), Nash (1947:167), and others, have described generally the dynamics of this food chain. Of all the fishes able to benefit from these conditions, the striped bass appears to be best adapted; although larvae and free-swimming young of other species also utilize the area. Extensive townet samples in the areas of lowest salinities in the Patuxent River indicate a predominance of early developmental stages of striped bass; eggs, larvae, and young of white perch, clupeids, percids, centrarchids, and cyprinids occur less abundantly.

Eggs and larvae of many of the species represented in the above-mentioned families are mostly restricted to the bottom and mid-water areas where light penetration is low, turbidity high, and sedimentation is accelerated (Nash, 1947:162). Although tidal changes and water movement keep many of them suspended, the majority of demersal and semi-demersal eggs and larvae without large oil globules are at a disadvantage in the bottom areas. After reaching the free-swimming stage, many of the survivors swim toward the surface, especially at night, and they actively compete in feeding with the striped bass young. Evidence suggests that this competition has little effect on the striped bass, not so much because the striped bass is an efficient grazer, but because the available zooplankton is generally very great in this enriched area.

Problems of Uncontrolled Artificial Fertilization: The behavior of estuaries under future conditions of increasing fertilization, principally from highly treated mineralized sewage, is not now predictable, although some basic knowledge is available to achieve this end (Pritchard, 1960:25-7; Newell, 1959:64, 68-9). Figure 5 depicts provisionally in highly simplified terms the nature of the fertilization in relation to spawning of striped bass and the stratified nature of a typical estuary in Chesapeake Bay. It is based on data and concepts suggested by Hynes (1960:94), Nash (1947:162-4), Frey (1946:11-24, Massmann, et al (1952:113-31), Newell (1959:62-3), Wolman,

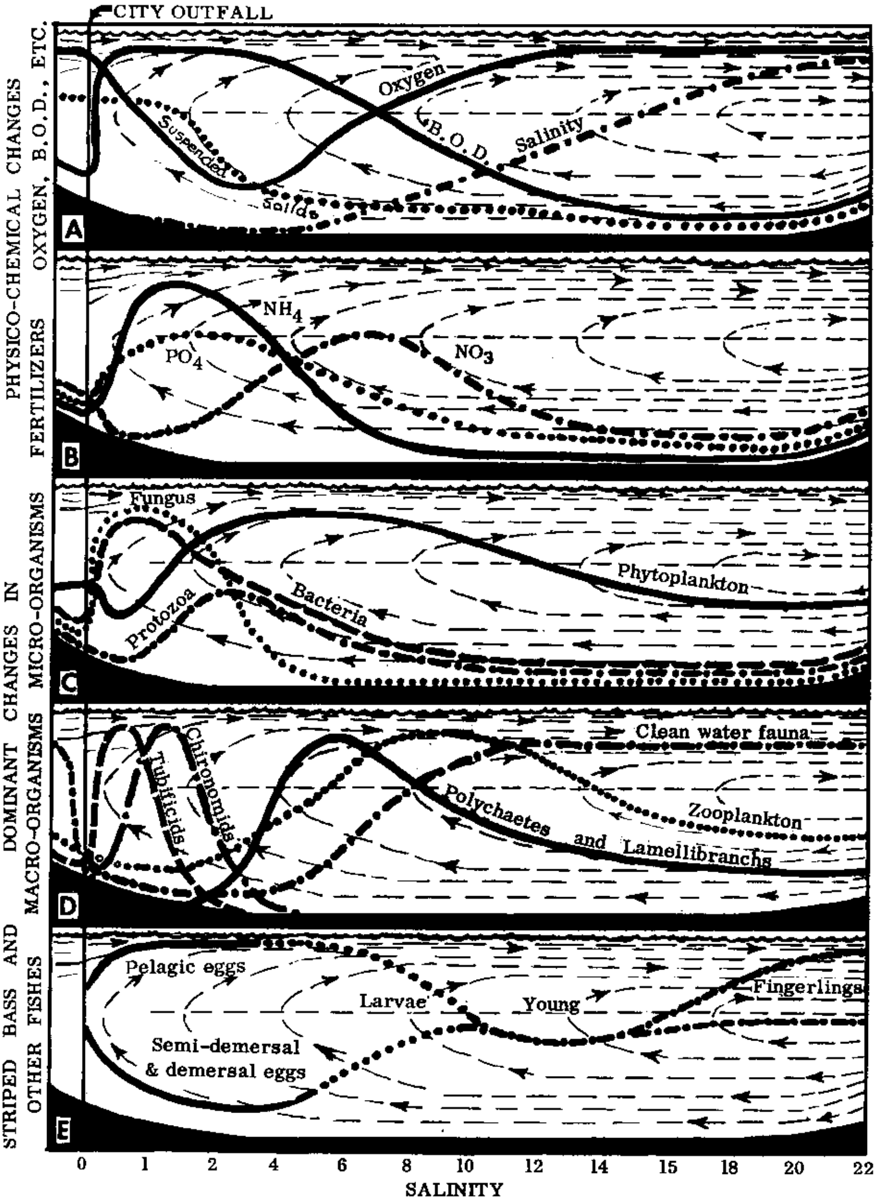

FIGURE 5. Gross simplication of hypothetical changes in a typical two-layered estuary of Chesapeake Bay brought about by mineralized fertilizers produced by man downstream from a metropolitan outfall: A and B — physical and chemical changes; C and D — changes in microscopic and larger biota; and E — relationship to species of fish spawning in tidal fresh or slightly brackish water. Based on ideas and data from Hynes, Nash, Wolman, et al., Pritchard, Massmann, et al, Frey, Newell, and original data.

et al (1957:426-9), and Pritchard (1960:25-7), with particular reference to the Potomac and Patuxent Rivers. The graph cannot possibly indicate the potentially dangerous effects of fertilization on algal growths in estuaries. As is well known, estuarine circulation results in a sort of nutrient trap, and the tidal cycles enhance the metabolism of such materials. Those estuaries with long flushing periods would potentially present the greatest dangers of forming algal concentrations, while those with short removal times might dispose of nutrients before they are effectively used. In general, a flowing system will be more productive than a standing system. Thus, the difficulties with algal growths which have increased in inland areas would not be as great in estuarine regions. Back River and the Potomac River estuaries, both with long flushing periods, may be exceptions since they are examples that harbor the disagreeable aspects of over-fertilization (Wolman, et al, 1957:426). Also, the analogous cases with water chestnut and watermilfoil growths in the Potomac estuary and upper Chesapeake, which may have been enhanced by increasing fertility, must be recognized as conditions that might become more complicated. Useful enrichment of estuarine waters by organic matter and nutrient salts can be achieved only by controlled and balanced fertilization. Pollution and fertilizers which may contain carbohydrates, phosphates, and nitrates may fail to produce desirable results because neither the rate of discharge nor the concentrations of the nutrients are controlled. The resulting inbalance of nutrients may enhance reproduction of useless and sometime harmful microorgaisms which replace the useful forms (Galtsoff, 1959:128).

The above mentioned qualifications and warnings concerning the dangers of increasing fertilization suggest the great need for model studies of the estuary and river basins. The model could be used to determine the changes in tidal range and circulation that would result from the effects of physical alterations and barriers. One constructed on a large enough scale might be useful in ecological problems. Dr. Ruth Patrick of the Academy of Natural Sciences of Philadelphia has constructed a small river model to investigate pollution problems. Wolman, et al (1957:424) have suggested the construction of a model of the Potomac River estuary, while Dr. William Hargis, Director of the Virginia Fisheries Laboratory, recently suggested that a huge model of the Chesapeake Bay system be constructed over an area consisting of several acres. Such models, in addition to illuminating problems of hydrography, might be useful in planning estuarine fertilization experiments. This kind of an approach is necessary before fish populations can be controlled in estuaries.

CONCLUSIONS

1. Civilization has produced great changes in the aquatic environments of Chesapeake Bay. Large amounts of soil and nutrients have been removed from the landscape, and most of it has markedly affected depths, bottom communities, water circulation patterns, and the species composition and abundance of estuarine biota. These changes, many wasteful, some inevitable, and others beneficial, have not overall greatly reduced the potential productivity, although the carrying capacity of the Bay has been reduced. Man has compensated for such changes by adding to the fertility of the waters. In spite of all the changes wrought by man up to now, Chesapeake Bay has been remarkably resilient, and it is still considered a relatively unspoiled region.

2. The biota has been subjected to density-independent and density-dependent factors. The former has produced permanent and devastating effects through sedimentation, pollution, wetland reclamation, and dams. Although the dams may reduce some migratory fish movements, their principal danger in the future on existing estuarine life will be the effects on the circulation, flushing, and tidal patterns through water-flow regulation upstream. Highway and general construction, detergents, pesticides, and radioactivity also loom large in the future of estuaries. Density-dependent effects produced by man's systematic seafood harvests and his meager attempts at manipulating or cultivating estuarine crops have had little effect on the long-range productivity of the Bay. Marked changes in size and age composition of fish have occurred, but total biomass is little changed by exploitation. He has yet to extirpate a species before the unprofitable return forces him to exploit another available resource.

3. A hypothesis was advanced that civilization and striped bass populations are compatible, i.e. increasing fertilization by man may be indirectly responsible for the unusual increase in number and magnitude of dominant year-classes. Human population growth has resulted in increasing loads of silt, wastes, and fertilizers in the estuary, and these have created high turbidity, low light penetration, low dissolved oxygen, high B. O. D., and excessive sedimentation in the upper estuarine spawning areas of fish. The striped bass produces pelagic eggs and larvae that are preadapted to these waters, while demersal or semi-demersal eggs deposited by other species that spawn with striped bass have less chance of hatching or surviving under these conditions. Also, probably more of the buoyant floating eggs and larvae of striped bass reach the area where salinity neutralizes and precipitates the suspended particles. Here turbidity is reduced, light penetration is optimal, and photosynthesis creates a rich productive grazing area for zooplankton. Other species, of course, reach this area, but they probably do not produce excessive competition for striped bass.

4. The problem of excessive and uncontrolled mineralized fertilization into estuaries with low flushing times is very great since they might produce tremendous algal blooms, with consequent deleterious effects on many organisms. An imbalance in such nutrients could enhance reproduction of useless or harmful micro-organisms to replace the useful forms. Beneficial enrichment of estuarine waters by organic matter and nutrient salts can only be achieved by controlled and balanced fertilization. There is an urgent need now for the construction of a huge model of the Chesapeake Bay watershed to investigate various problems of hydrography, pollution, fertilization, and other subjects that will contribute to reliable prediction and control of estuarine populations.

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