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Water Quality Criteria and the Biota of Chesapeake Bay

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Chesapeake Research Consortium, Incorporated

WATER QUALITY CRITERIA AND THE BIOTA OF CHESAPEAKE BAY

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University of Maryland   Virginia Institute of Marine Science

WATER QUALITY CRITERIA AND THE BIOTA OF CHESAPEAKE BAY

A report to the U. S. Army Corps of Engineers
Baltimore District
Contract DACW 31-73-C-0127

THE CHESAPEAKE RESEARCH CONSORTIUM, INC.

Smithsonian Institution
University of Maryland
Virginia Institute of Marine Science

COORDINATOR

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A Final Report

on

U. S. Army Corps of Engineers, Baltimore District

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THE EXISTING CONDITIONS REPORT ON THE BIOTA OF THE CHESAPEAKE BAY - A CONTINUATION

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INTRODUCTION

by

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The contract entitled "Existing Conditions Report on the Biota of Chesapeake Bay - a Continuation" issued to the Chesapeake Research Consortium by the Baltimore District of the Corps of Engineers was funded April 9, 1973, for Phase I, a period of six months. Upon acceptance of an interim report, Phase II was subsequently funded, with a completion date of Oct. 9, 1974. Funding was subsequently reduced but the termination date remained unchanged.

Phase I studies

Two projects begun under the first contract finally resulted in publications: 1) "A Scientific Personnel Resource Inventory: List and Index to Research Scientists Involved with the Estuarine Environment, Especially the Chesapeake Bay", 2) "A Taxonomic Code for the Biota of Chesapeake Bay". Expansion demands have necessitated production of a 10-page addendum to this code.

For the interim report, a list of 124 species believed to be among the most important in the Bay was provided. Abundance, distribution and economic importance entered into the selection.

A general ecological description of estuarine communities with especial reference to Chesapeake Bay was accomplished. Certain groups or communities, such as oysters, fish and wetlands were discussed in greater detail.

Water quality standards and criteria pertinent to the Chesapeake Bay were discussed briefly from various viewpoints.

Surveys designed to determine biological problems which might be solved by the model and assessment of critical biological research needs were planned for Phase II of the contract.

Phase II studies

Although funds were cut early in the course of this final effort, a reasonably voluminous report has resulted, much of the material having been provided by researchers unassociated with the project in the Natural Resources Institute of the University of Maryland. These individuals deserve recognition for the generally exhaustive treatment of the species for which they provided summaries.

Of the 126 species deemed important in the Bay, 30 have now been subjected to life history summaries. The variation in length of the summaries results in part from sufficient review of the literature (as in the waterfowl) and, on the high side, from exhaustive review of a much studied species, e.g. Fundulus heteroclitus. These studies should be of great interest to both researchers and managers, particularly if they can be updated as new information avails itself.

The study of communities, although not providing the coverage planned at the outset, does give a detailed picture of eelgrass and oyster communities, much of the information necessarily having to come from other areas but certainly more or less pertinent to Chesapeake Bay. The cut in funding precluded reporting on the extensive and important benthos and plankton communities.

The water quality study was planned to deal with eight major groups of pollutants but was cut to include only two, oil and chlorine. Although water quality criteria continue in a state of flux, it would seem essential to frequently synthesize existing knowledge and regulations.

The questionnaire on possible uses of the hydraulic model drew an unusually good response. The information and suggestions provided should go far in promoting use of the model to solve biological problems.

Compilation of a list of critical biological research needs was not done at the suggestion of the Corps when funds were curtailed. However, such information has been compiled earlier and many of the same needs probably still exist.

SECTION 1

ECOLOGICAL CONCEPTS AND ENVIRONMENTAL FACTORS AFFECTING CHESAPEAKE BAY

BY

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INTRODUCTION

It is imperative that a *water resource manager* understand ecological concepts. It is he who has the difficult duty of deciding, in spite of the limited knowledge available on dynamic characteristics of an ecosystem, whether or not to permit certain actions which may affect environmental parameters. He will have to contend with repercussions that arise if his decisions cause deleterious environmental effects. It is therefore necessary that scientists provide *managers* with detailed ecological information as soon as it is available in order to prevent as many harmful environmental effects as possible.

Scientific terms should be so defined that a basic understanding of the topic under dicussion is established. It must be recognized that "the chief difficulty with ecological terminology is ... that many of the terms have conflicting definitions" (Hedgpeth, 1957). In spite of differences of opinion as well as of vagueness of definitions, the terms ecosystem and community are useful, and, according to Hedgpeth (1957), no one would seriously propose to abandon either term.

Ecosystem Concept

One of the most widely accepted definitions of an ecosystem is "any area in nature that includes living organisms and non-living substances interacting to produce an exchange of material between living and non-living parts ..." (Odum, 1959). This interaction is called the "physiology of ecology" by Hedgpeth (1957). It is important to recognize that circulation, transformation and accumulation of energy and matter through various trophic levels are inherent in the ecosystem concepts (Evans, 1956; Odum, 1959). Abiotic factors (the non-living part of the environment, including both inorganic and organic compounds) circulate their energy and matter by such physical processes as evaporation, precipitation, erosion and deposition (Evans, 1956). Producers, consumers and decomposers (biotic factors) utilize such means as photosynthesis, decomposition, herbivory, predation and parasitism for energy and matter transfer and storage (Evans, 1956). A *manager* must understand this transfer of energy and matter from one level to another. He also must recognize the regulatory mechanisms which limit abundance and influence their metabolic activities; some of the more important regulatory mechanisms are ones that affect growth, reproduction, death and behavioral patterns, e.g., migration. A disturbance of even one of these regulatory mechanisms may cause the ecosystem to cease to exist in its present identity (Evans, 1956).

Community Concept

The biotic portion of an ecosystem consists of organisms which form communities. The community concept must therefore be explored in order to understand the ecological impact of a community on the ecosystem in which it exists and vice versa. It is not the intention of this report to present the various ways of defining a community* nor to delineate a community from a population or assemblage, but rather to present a generalized concept of the interrelationships of organisms for *managers* to use in their work.

Odum (1959) defined a biotic community as "any assemblage of populations living in a prescribed area of physical habitat; it is a loosely organized unit to the extent that it has characteristics additional to its individual and population components". He pointed out that a biotic community can be further subdivided into *major* and *minor* communities. A major community is able to exist independently of all other communities because it has all the necessary components (abiotic substances, producers, consumers, and decomposers) for maintaining itself, except for energy from the sun. If the assumption by Reid (1961) that an estuary is a major community is accepted, then the organisms associated with one another within an estuary comprise minor communities. These minor communities are *dependent* upon neighboring organisms to a greater or lesser extent.

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* The term biocoenosis should be called to the attention of *managers*. Karl Mobius (1977) first used this term when he expounded on his concept of an ecological community. His concept is still used by Europeans, basically in the same context as our use of the word community. It emphasizes relationships between organisms and between them and the physico-chemical parameters in their environment.

Both biological composition and organization are included in the community concept (Reid, 1961). Community composition is the aggregation of organisms typically associated with one another. Evolutionary diversification, specialization and adaptation to various environmental conditions has resulted in distinct aggregations. A recognizable unity therefore prevails among certain organisms. A pattern, or organization, of these aggregations exists, determined by the flow of matter and energy (metabolism) throughout the community (Odum and Copeland, 1974).

Managers should realize that community composition is paralleled in different geographical areas. Species substitution occurring in parallels of the "Macoma" community in the Arctic, the boreal, and the Northeast Pacific is illustrated in Figure 1. Examples of niche substitution

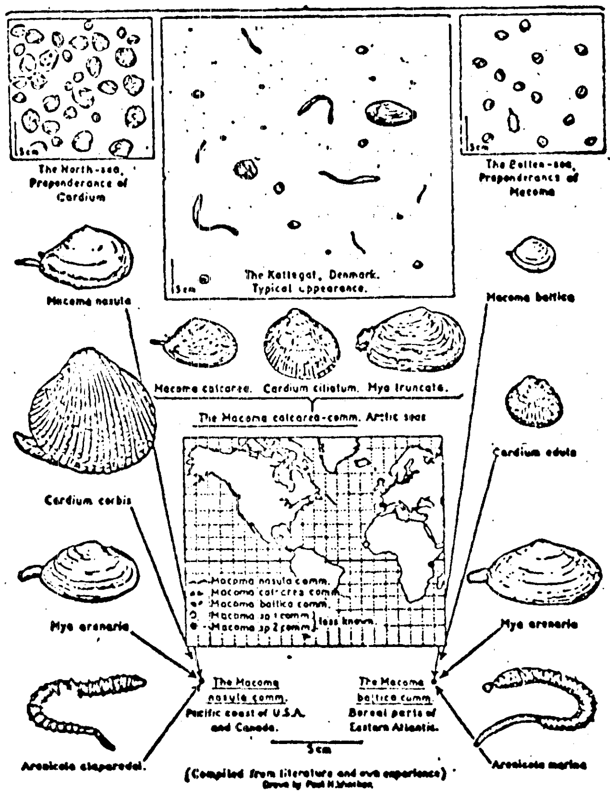

Figure 1. Diagram showing the parallelism between the Arctic, the boreal, and the Northeast Pacific Macoma communities (Thorson, 1957).

by various invertebrates living in the different physico-chemical estuarine conditions of the Chesapeake Bay, of San Francisco Bay and in European estuaries are given in Table 1. Basically, the types of communities found in particular geographical regions depend upon the energy relationships of the environment, species characteristics and species functions (Reid, 1961).

According to Odum (1959), "Community names like names for anything should be meaningful but kept as short as possible. Otherwise, the name will not be used". He classified communities in three ways: by their major structural features, by the physical habitat in which they live and/or by their functional attributes, such as community metabolism. The first two means of classification are presently the most commonly used. A major structural feature often used to designate a community is a dominant species or an ecological dominant, i.e., the organism(s) controlling the energy flow or producing the greatest productivity. Classification of a community by its physical habitat is essentially self explanatory. Two physical characters by which a bay community can be classified are salinity gradients and seasonal temperature variations. Acting individually or together, both of these factors can restrict both transient and resident community organisms to particular spatial and temporal distributional patterns (Swartz, 1972).

The least used means of community classification, by a functional attribute, is probably the best for comparison of all communities (terrestrial, freshwater, estuarine and marine). This method was utilized by Odum and Copeland (1974) in classifying coastal systems. It involves community metabolism determination including the fixation, utilization, and transfer of energy through the trophic levels from primary producers through the carnivores. Any alteration of a trophic level results in a shift in community metabolism which causes a change in community structure. An example of community structure alteration caused by the modification of food chain relationships is illustrated in Figure 2.

An ultimate goal of *water resource managers* of the Chesapeake Bay should be the prevention of major alterations of community structure. All human activities have some impact on the environment. *Managers* of the Chesapeake Bay should recognize that the disappearance of organisms about

Table 1. Taxonomic parallels of common estuarine endemic species of Chesapeake Bay in European estuaries and San Francisco Bay area (Boesch, 1971).

CHESAPEAKE BAY	EUROPE	SAN FRANCISCO BAY
Nemertean A	Prostomatella obscura ?	
Peloscolex heterochaetus Oligochaete C (*Peloscolex*)	*Peloscolex heterochaetus* *P. benedeni*	'Oligochaeta'
Hypaniola grayi	*Hypania invalida*	
Scolecolepides viridis		
Hydrobiae	*Hydrobia ulvae* complex	
Macoma balthica *Macoma mitchelli*	*Macoma balthica*	*Macoma inconspicua*
Leucon americanus		
Cyathura polita	*Cyathura carinata*	
Chiridotea almyra	*Mesidotea entomon*	*Synidotea laticauda*
Gammarus daiberi *G. tigrinus* *G. palustris*	*Gammarus duebeni* *G. zaddachi* *G. salinus*	
Leptocheirus plumosus	*Leptocheirus pilosus*	
Melita nitida	*Melita plamata*	
Corophium n. sp. *C. lacustre*	*Corophium volurator* *C. lacustre*	*Corophium spinicorne* *C. stimpsoni*

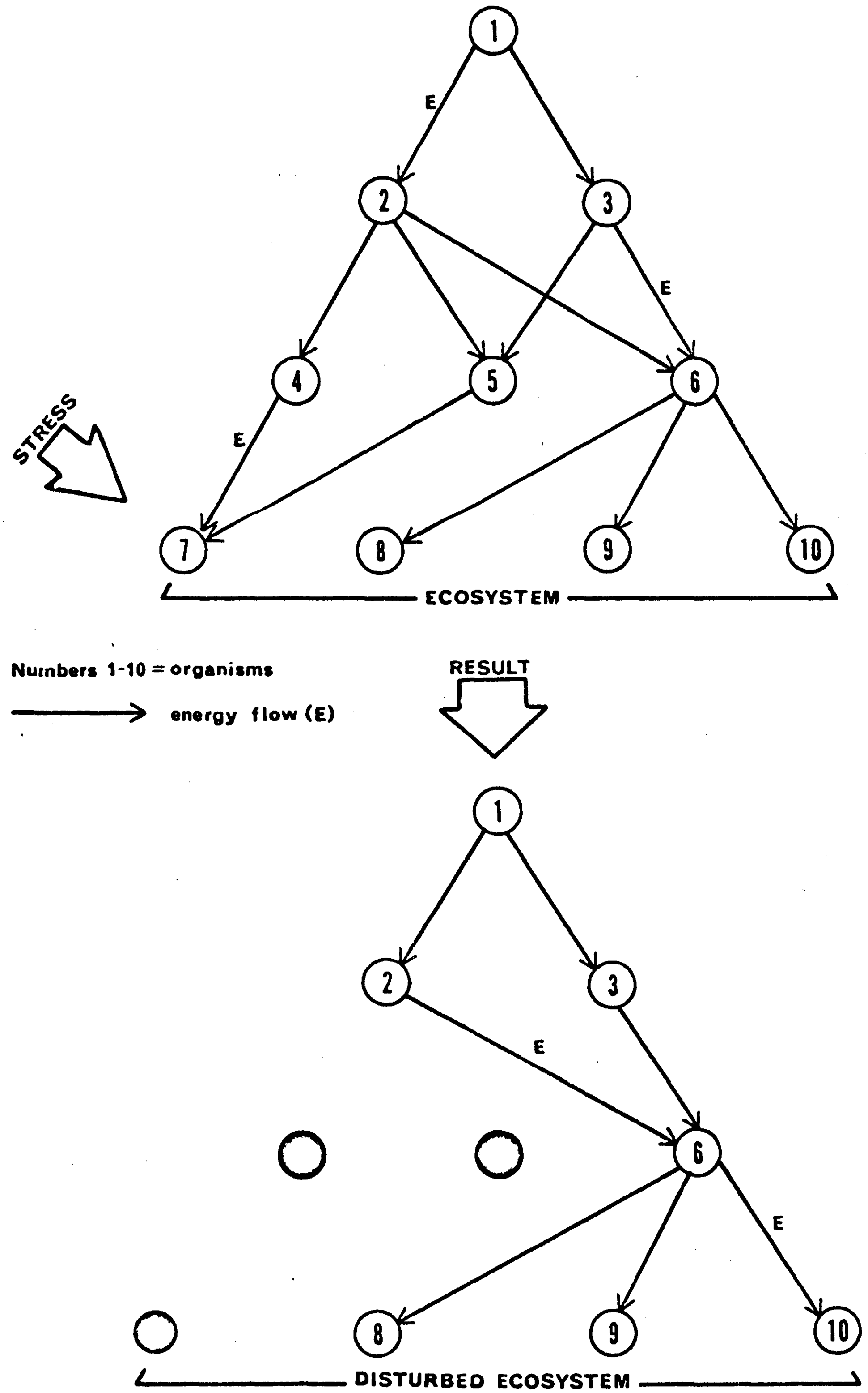

Figure 2. An example of how stress can modify food chain relationships and ultimately affect energy flow in a simple ecosystem (modified from McErlean and Kerby, 1972).

which little is known or a change in the abundance of particular organisms can be critical enough to jeopardize the stability of an estuarine community (Swartz, 1972).

Limiting Factors

The survival of an organism and the stability of the estuarine community in which it lives are both influenced, positively and negatively, by the environmental factors with which they interact. These environmental factors are collectively called "limiting factors" by ecologists. The concept of limiting factors is based on two basic principles. Liebig's "law" of the minimum, as stated by Odum (1959), is "the essential material (necessary for growth and reproduction) available in amounts most closely approaching the critical minimum needed will tend to be the limiting one". Shelford's "law" of tolerance, on the other hand, states basically that the well-being of an organism is controlled by the qualitative or quantitative deficiency or excess of any one of several factors that approaches the tolerance limit of an organism (Odum, 1959). In other words, ecological minima and maxima affect biotic behavior and even survival. Odum (1959) pointed out that, although the physical requirements of an organism are fulfilled, the failure of biological interrelations may still cause death. Subsidiary principles to these laws as listed by Odum (1959) are:

1. "Organisms may have a wide range of tolerance for one factor and a narrow range for another."

2. "Organisms with wide ranges of tolerance for all factors are likely to be most widely distributed."

3. "When conditions are not optimum for a species with respect to one ecological factor, the limits of tolerance may be reduced with respect to other ecological factors."

4. "The limits of tolerance and the optimum range for a physical factor often vary geographically (and also seasonally) within the same species."

5. "Sometimes it is discovered that organisms in nature are not actually living at the optimum range (as determined experimentally) with regard

to a particular physical factor. In such cases some other factor or factors are found to have greater importance."

6. "The limits of tolerance for reproductive individuals, seeds, eggs, embryos, seedlings, larvae, etc., are usually narrower than for non-reproducing adult plants or animals.

The two laws, Liebig's "law" of the minimum and Shelford's "law" of tolerance together with the subsidiary principles constitute the concept of limiting factors.

An example of limiting factors is graphically illustrated in Figure 3. Three physical factors are acting on a hypothetical burrowing animal: salinity, substrate and tides. The requirements for survival are (1) salinity not much lower than sea water, (2) a sandy substate and (3) a limited amount of exposure such as that occurring between mid and low tide. A study of Figure 3 shows that in the available area, a minimum of two factors limits the animal to the area described.

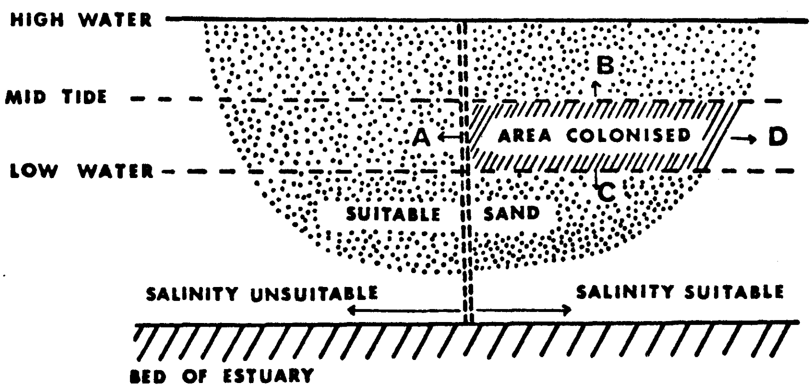

Figure 3. Diagram to illustrate limiting factors in an estuary (Day, 1951).

Management should be aware of how the limiting factor concept (as based on Liebig's "law" of the minimum, Shelford's "law" of tolerance and the subsidary principles) can affect the structure and survival of Chesapeake Bay communities.

ENVIRONMENTAL FACTORS AFFECTING CHESAPEAKE BAY

The major concern of this section of the report is to discuss the environmental parameters (biological, chemical and physical) that affect the biota of the Chesapeake Bay. It is these parameters which act as "limiting factors". *Estuarine managers* must appreciate the interactions of these parameters in order to make knowledgeable decisions.

The Chesapeake Bay is considered an estuary which is defined by Pritchard (1967) as "a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted by fresh water from land drainage". In other words, it is an unique system, being neither a fresh water nor a marine ecosystem.

Pritchard (1955, 1967) classified estuaries into four types: A, B, C and D. Chesapeake Bay fits his classification of a Type B estuary; i.e., circulation is aided by tidal mixing of two water layers, causing an increase in the net volume of water flow. The two water layers consist of an upper, lower salinity, seaward flowing layer and a bottom, higher salinity layer flowing toward the head of the estuary. Thus, the Chesapeake Bay is considered a moderately stratified estuary (Bumpus, Lynde and Shaw, 1973).

The geographical shape of an estuary is important because it directly affects the actions of the physical factors within the bay. Figure 4 is Day's plan of an ideal estuary.

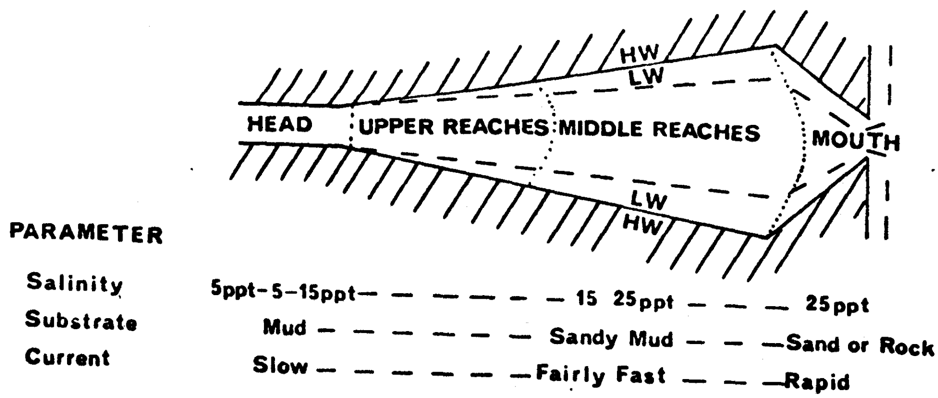

Figure 4. Plan of an ideal estuary. Modified from Day (1951).

Figure 4. Plan of an ideal estuary. Modified from Day (1951).

The original shape and depth of the Chesapeake basin has been modified by sedimentation brought down by the rivers, by tides as they range up the Bay, and by wave action. These physical factors, individually and in combined action, affect the fauna and flora and, therefore, the communities. For example, the shape of the mouth partially determines the distribution of seawater which entered the bay with the tide. The distribution of the biota thus depends upon their salinity tolerance. The depth of a bay mouth may also affect the constitution of bay biota since it partically restricts the ability of organisms to enter and leave the mouth (Day, 1951). According to Boesch (personal communication) depth of the Chesapeake Bay mouth is not known to prevent faunal movement.

Physico-Chemical Factors

Sedimentation

Estuarine sediments are unique; they are of marine and terrigenous affinities and yet retain their own integrity (Nelson, 1962). Inorganic sediments originate from a variety of sources, including the rivers, bordering sea cliffs, adjacent sea floor, and reworking of the marshes (Emery and Stevenson, 1957b). Organic sediments are contributed by rivers, the estuary itself, and/or the ocean. Emery and Stevenson (1957b) considered organic sediment a "burial assemblage" since it is comprised of dead plankton, pieces of plants, decayed organisms, etc. Organic sediments are also formed by fecal and pseudofecal pellets excreted by benthic organisms (Moore, 1955) and by sedimentary particles cast off by burrowing animals in their search for shelter and food (Carriker, 1967).

The bulk of the sediments comes from the rivers. When freshwater with its suspended sediments enters an estuary, it flows on top of the more saline water because of the lighter density of the former. Generally, coarsest particles are deposited before finer particles (Carriker, 1967). The silt, making up the majority of the suspended material, is deposited as soft mud in low salinity zones (Emery and Stevenson, 1957a). If deposition is slow, a mud community may result; however, an increase in the deposition rate may smother the inhabitants (Day, 1951). The clay portion of the suspended sediment differs from silt in that it possesses a charge and attracts other particles, resulting in flocculation (Emery and Stevenson, 1957b).

Bader (1962) demonstrated the absorption of dissolved organic materials by clay minerals to form clay-organic complexes. The composition of these complexes is controlled primarily by the "crystallographic structure of the mineral, its molecular weight, functional group, and structure and the molecular weight, functional group, and structure of the organic compound" (Carriker, 1967). These macroscopical organic-inorganic complexes are often called detritus. Detritus, an important food source for many estuarine organisms, occurs in suspension as a loosely aggregrated, flaky mixture of organic molecules, including "vitamins, organic colloids and organic fragments intermixed with various proportions of clay, silt, fine sand and living microbiota" (Carriker, 1967). Since the specific gravity of these organic-inorganic complexes is near that of estuarine water, they can be held in suspension a long time, but eventually this flocculated material falls to the deeper floors of an estuary.

Sedimentation results from the "reworking" of shallow tidal beds and tidal channels. Waves and currents keep a bay in a state of dynamic flux. One of the best examples of "reworking" was done by Hunter (1912) in the Chesapeake near the mouth of the Choptank River. He compared maps made in 1848, 1900 and 1910 and found that erosion on low-cliffed shores of clay and marsh amounted to as much as 110 ft/yr. Three islands were removed by this erosion and at 30-ft depths the bottom was deepened or shoaled by as much as 6 ft (Emery and Stevenson, 1957b).

The sedimentation rate in the Chesapeake is determined by the force of gravity, the vertical turbulence created by the water, and by the supply of sediments (Carriker, 1967). Deposition of materials is greater at ebb tide, when current velocities are slow and flow duration is greater, and also during neap tides when lower tidal amplitudes and correspondingly lower current velocities are present.

Macrophytes can change the sedimentation rate by serving as traps to prevent sediment movement. Wilson (1949) described the changes in sedimentation rate in the Plymouth District, U.K., caused by the loss of eelgrass (Zostera). Before its loss, the eelgrass had trapped suspended materials to such an extent that a channel had to be dredged periodically to allow boat passage. Apparently, this dredging was no longer necessary after the eelgrass loss since the sediments were not retained, but quickly washed on out to sea. Dexter (1944) described changes in the benthic organisms comprising the eelgrass community at Cape Ann when loss of the plant allowed the sediments to spread unchecked.

Substratum

Estuarine substrata are formed by sedimentation. Emery and Stevenson (1957b) considered estuaries as areas with low topographic gradients, active sedimentation and bottoms composed of muds and sand in various combinations. In general, mud is found at the head of an estuary, whereas abundance of sand increases near its mouth. In the Chesapeake Bay, fine silts are found in the deeper waters whereas finer sediments are found in the channels except where scouring action is heavy. The eastern shore of the Bay is sandier than the western because of the greater river inflow into the western portion of the Bay (Boesch and Wass, personal communication).

Carriker (1967) considered the best known substrate areas as those regions in the upper reaches and quiet lateral areas of an estuary. These substrates consist of clays, silts and organic materials. The areas of the inlets, the wave exposed shallows, the intertidal zones and the bottom areas consist of admixtures of sands and coarser particles because of the presence of wave action and/or strong currents (Day, 1951). Hard surfaces such as rocky substrates, oyster reefs and shell deposits nearly always are covered by some form of sedimentation except where strong water action keeps them clean (Percival, 1929; Day, 1951). The flat portions of the floors of estuaries deeper than three fathoms are often covered by a sediment blanket. The particles forming this blanket become increasingly finer as depth increases. This ideal distribution of sediments is possible in Chesapeake Bay only because of the relatively flat bottom and the mild wave and current conditions (Emery and Stevenson, 1957a).

Substrate has long been regarded as a limiting factor, but little research has been accomplished on the association of the distribution of organisms with the bottom type. Brett (1963), McNulty, Work, and Moore (1962), Sanders (1956, 1958, 1960) and Sanders, Goudsmit, Mills and Hampton (1962) are among the few researchers performing detailed investigations of this association. A summary of some of their results follows since it will be useful for comparison with studies of community structure in the Chesapeake Bay.

In Sanders' (1956, 1958) studies he demonstrated quantitatively that, for both Buzzards Bay and Long Island Sound, deposit feeders dominate the mud whereas filter feeders dominate the sandy sediments. On the basis of these findings, Sanders suggested that the quantity of clay in a particular system be used as a method for determining the distribution of deposit feeders. These organisms utilize the complexes formed by clay and organic material as a primary food source (Grim, 1953; Bader, 1962). Detritus, as these clay-organic complexes are called, tends to accumulate on muddy sediments. If its concentration is increased, it will cause a reduction in the oxygen content of the water, creating anaerobic conditions. Those organisms which cannot function as a result of this reduction will die. For example, a greater than 3% concentration of organic material causes a decline in the population density of infaunal bivalves (Bader, 1954). Sanders (1958) concluded that hydrodynamic processes control the distribution of filter feeders in fine sandy sediments. The densest concentration of organisms was found in a weak, steady current, which provided a stable environment and a constant food supply. Sanders (1960) showed that there was a continuum of benthic species associated with gradual changes in sediment composition.

In contrast to the above studies, intertidal deposit feeders were found as dominant organisms in both mud and sand in Barnstable Harbor, Massachusetts (Sanders, et al., 1962). Since the substrate in these habitats is stable, dense concentrations of diatoms and dinoflagellates are present and utilized as a food source. Sanders concluded that sediment should be used as the indicator of the food source and not the factor determining the distribution of feeding types.

McNulty, et al. (1962) demonstrated that in Biscayne Bay, Florida, detrital feeders were more abundant in the fine sediments whereas deposit and filter feeders were more abundant in the intermediate grades. The results of this investigation indicated that as particle size increased, so did the body size of deposit feeders (not detrital or filter feeders) except in the coarse sediments, which did not support any type of large population.

Brett (1963) working in Bogue Sound, North Carolina, found that feeding habits of animals are related to the hydrodynamic characteristics of the environment. Basically, he found detrital feeders in the areas of slow currents with sediments having a 0.09 mm mean diameter, whereas the largest populations of filter feeders were in the area where the mean grain size exceeded 0.09 mm (0.12-0.14 mm).

It must be emphasized that the same research methodology was not used in the studies described above, but generalizations of the research results can still be made. A close relationship between the faunal feeding habits, the amount of organic content and the physical nature of sediments appears to exist. All three studies indicated the importance of movement of the overlying waters and the important role of sediment as a food source for benthic organisms. The questions that can arise from the results of these studies are numerous and point out the definite need for a great deal more study. The above generalizations were based mostly on macrobenthos (large organisms). The relationships of meiofauna (small organisms) and the substrate are even less well known.

The interrelationships of limiting factors are further demonstrated by the tendency of the muddy bottom of estuaries to retain a higher salinity than the overlying water even though the tide is receding. The marine infauna are therefore allowed to penetrate farther up an estuary than the marine epifauna which are restricted by their tolerance of the salinity fo the overlying water (Figure 5). According

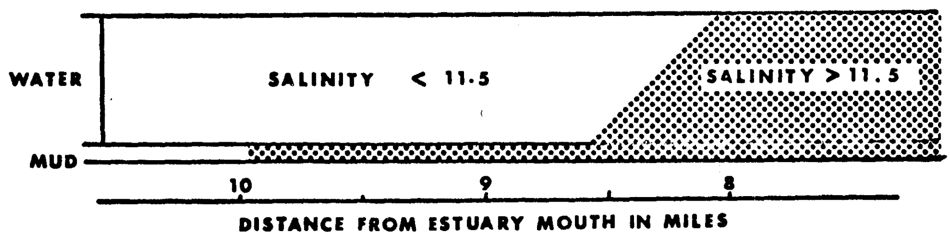

Figure 5. Diagram illustrating the distribution of salinity at low water in the water and muddy foreshore of an estuary (Emery and Stevenson, 1957a).

to Boesch (personal communication) this factor is important for "fluctuating" estuaries, not generally for the Chesapeake Bay which is a gradient estuary.

Nelson (1962) pointed out that estuarine sediments and substrata are important in maintaining the chemical conditions necessary for the survival of the benthos. In order to fully appreciate an estuarine ecosystem, *managers* must realize that "the chemical complex consists of the interdependent factors of texture and structure, organic content, pure water chemistry, ion exchange equilibrium, gas equilibrium and microbiological activity" (Carriker, 1967). The structure and texture of sediment *in situ* establishes the framework within which chemical and biotic processes operate.

Wave Action

The effects of waves on sediments and substrata has already been mentioned but will be described here in more detail. The decrease in wave action is probably one of the most obvious differences between an estuary and the open sea (Day, 1951). This decrease is caused partially by the shorter distance for waves to traverse in an estuary as compared to the ocean, its relatively shallow bottom (Emery and Stevenson, 1957a) and the shape of the mouth (Day, 1951). Moore (1958) stated that waves are ecologically important to the intertidal zone of an estuary although they are felt to a reduced extent on the bottom in deeper waters. Furthermore, they do not affect light penetration in estuaries as much as they do in the ocean, but they do influence aeration and mixing to a moderate depth.

Day (1951) demonstrated that wave action affects estuarine fauna and flora. The geographic makeup of a South African estuary made it possible for him to separate the effects of wave action from the effects of salinity and temperature on the biota. By observation of the fauna and flora of this estuary, and of a nearby shore with moderate wave action, Day demonstrated that they had few organisms in common. It is doubtful, however, that waves have as much influence on the biota of the Chesapeake Bay, as they do in the South African estuary, except possibly at the Bay mouth.

In the Chesapeake, the wave action which wets the upper zones of the shore with spray is beneficial to some species. In sheltered waters the mixing of water by wave action is extremely important for the prevention of excessively high temperatures and salinity stratification.

Ecologically, minimum wave action may be important in an estuary in maintaining wet conditions in the intertidal zone, in providing sufficient oxygen for respiration, and in keeping detrital particles in suspension as a food source.

Tides, Currents and Circulation

Waves and currents both move water particles, but their effects on an estuarine ecosystem vary considerably. Waves directly affect light penetration to some degree whereas currents do not. Currents however do carry suspended sediments which reduce transparency and hence inhibit light penetration. Currents do not form splash zones nor do they cause damage to organisms by impact, but in conjunction with particles suspended in the water, they can harm delicate organisms by their abrasive activity. Currents are relatively stable except when affected by the tidal cycle. If a current is strong and causes substrate shifting, impoverishment of fauna and flora occurs in that area (Moore, 1958). On the other hand, if a current does not cause the substrata to shift, the biota may be rich in both abundance and in number of species.

The effects of tides on organisms need to be considered only in relation to exposure and immersion. The duration of exposure and immersion controls the severity of such adverse factors as desiccation, insolation and exposure to high or low air temperatures as well as of the availability of time for feeding and for larval release (Moore, 1958).

Both currents and the tidal cycle are biologically significant in other ways. They provide mixing, transportation and deposition of inorganic and organic nutrients. "Net circulation" aids in the retention of pelagic larvae for repopulation of existing estuarine communities (Carriker, 1967). Other biological aspects affected by water movement are in "mingling and dispersing gametes, spores, larvae and minute older stages; in removal of metabolic products from and bringing food and oxygen to fixed benthos; and in flushing from the sediment metabolic products of benthic microbiological activity" (Carriker, 1967). Currents are often overlooked aids to distribution. They circulate chemical "clues" which help predators locate their prey, distribute benthic organisms that have floated off the substratum and invertebrates which crawl under the surface film, and guide current-oriented organisms (Nelson, 1928; Carriker, 1957).

Without circulation, as at the bottom of deep estuaries, stagnation can cause a "desert" area. Depth as a limiting factor in the provision of oxygen and food to the bottom of an estuary should be considered only when circulation is absent and insofar as it affects salinity and temperature.

Salainity

Salinity is affected by tidal circulation. In the Chesapeake Bay, salinity increases from near 0 ppt at the head to near that of sea water (approximately 30 ppt) at the Virginia Capes (Bumpus, et al., 1973). An overview of the Bay shows an oblique distribution of salinity isohalines, i.e., a higher salinity is found on the eastern shore than on a comparable area on the western shore. Figure 6 shows typical isohalines of the Chesapeake Bay as drawn by Prichard (1952).

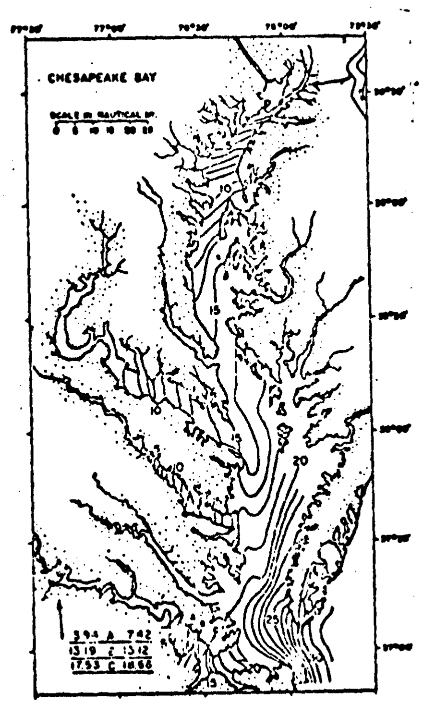

Figure 6. Typical surface salinity pattern in Chesapeake Bay and tributary estuaries (Pritchard, 1952).

The obliqueness of the isohalines is caused by the greater river inflow on the western shore and by the earth's rotation. The river inflow is also responsible for the lateral slope of the salinity wedge that can be observed by facing the mouth; the right side is deeper than the left.

Estuarine waters are essentially brackish* with variable salt concentrations and dissolved salt compositions similar to that of sea water (Day, 1951). Estuaries are therefore more saline than freshwater but less saline than marine. It is important to distinguish the difference between fresh and estuarine water. Pritchard (1967) indicated that in the Chesapeake Bay the "estuary proper extends up the drowned river valley only so far as there is a measurable amount of sea salt". Some dissolved solids (i.e., salts) are present in freshwater, but since salts derived from land differ from those of sea water, the upper limit of the estuary is sharply delineated by the difference in the major constituents of river and sea water. Prichard (1967) utilized the ratio of the chloride ion to total dissolved solids of sea water which is about 1:1.8 for sea water compared to a ratio of 1:10 to 1:20 for freshwater.

It is generally known that estuarine waters contain fewer species than either fresh or marine waters, but it is interesting to note that the placement of the lowest number of species is closer to freshwater than to marine water. The reactions of animals to salinity dilution or increase varies. Remane and Schleiper (1971) described certain generalized reactions of ecological significance: that "on reduction of salinity the marine macrofauna decreases more rapidly than the microfauna", that "reductions of species in groups forming a calcareous skeleton is greater than in their relations lacking such a skeleton", that "groups which have invaded the saline areas from freshwater

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* According to Hedgpeth (1957), the term brackish includes a connotation of relatively stable conditions whereas the term estuarine refers to the waters that are subject to tidal and seasonal variations. Many investigators disagree with this meaning; however, as yet they have not published their definitions.

and have developed distinct species in brackish waters and in the sea, display the usual reduction of species where the brackish region starts; but there is no minimum of species in brackish water or else it is only slightly indicated", and that in "some groups there is a complete gap in the mesohalinikum, that is they exist in high and in low salinities, but not in intermediate ones". It is still an open question as to why a reduction and poverty of species occurs, but undoubtedly a partial explanation is that any change in an ecological factor (e.g., salinity) disrupts the stability of an ecosystem, which in turn limits the inhabiting organisms to ones tolerant of changing environmental conditions. Figure 7 illustrates the distribution of species in relation to salinity.

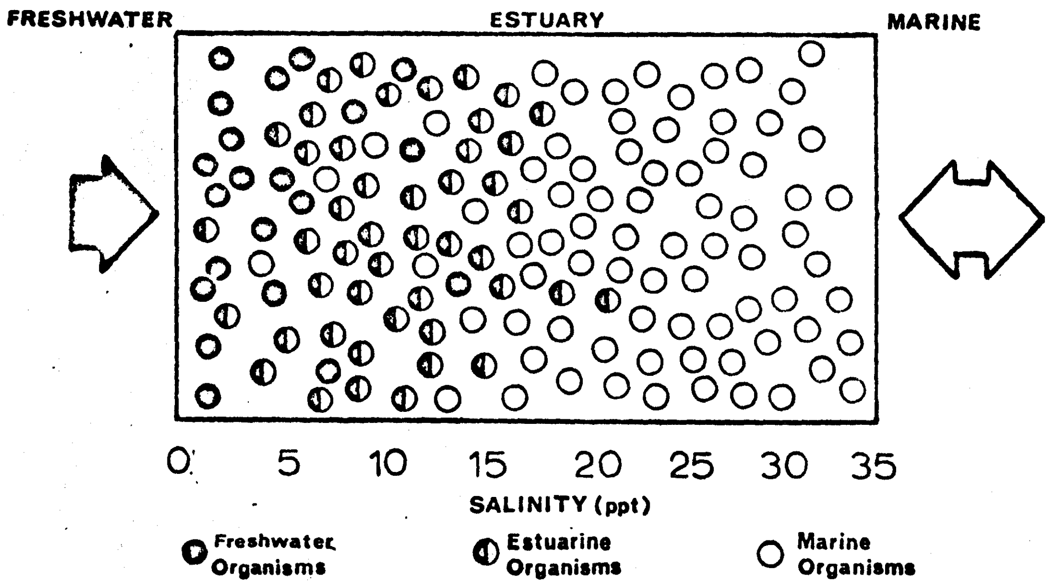

Figure 7. A generalized concept of numbers of species in relation to salinity.

Water movement in a bay constantly changes salinity levels. Inhabiting organisms therefore must have efficient osmoregulatory mechanisms. Euryhaline organisms, which tolerate a wide range of salinity, constitute the majority of total estuarine taxa (Day, 1951; Carriker, 1967). Some stenohaline organisms which tolerate salinity change only to a limited extent are also present. The osmoregulatory ability of individual species will not be described here; this ability is mentioned to point out that salinity changes cause stress situations which can upset community homeostasis, i.e., equilibrium between organisms and their environment.

Some organisms are able to adjust to gradual shifts up and down the salinity gradient although sudden changes may cause irrevocable damage. *Managers* must consider this possibility when they are faced with a situation that can cause a sudden shift in the salinity gradient. The effects of ionic fluctuations (salinity) on the behavior and distribution of estuarine benthos and on community structure have not been reported in any detail (Carriker, 1967).

Light and Turbidity

Suspended material, more than any other physical factor, determines the distance light will penetrate in an estuary (Day, 1951). The quantity of light that reaches the bottom is highly variable because of its dependence upon the discharge of muddy streams and rivers, variations in plankton blooms and changes in solar radiation striking the estuary (Carriker, 1967). This variability is often related to seasonal changes. In 1938 Cooper and Milne stated: "In water, therefore, the region of optimum transmission will result from two opposing factors - absorption by suspended matter cutting out the blue and green, and absorption by the molecules of water and the dissolved salts cutting out infrared and much of the visible red".

It is extremely difficult to individually consider the factors of light penetration and turbidity in an estuary. Turbidity, caused by the river water discharges, reduces the amount of light penetration. Wave action, current and tides all aid in the transportation of this suspended material throughout an estuary, thus maintaining the turbid conditions. Since estuarine waters are more turbid than marine waters, their bottoms consequently receive less light than the sea bottoms (Day, 1951; Carriker, 1967). This absence of light may be beneficial to photonegative benthic organisms since they can come out during daylight hours and feed. In contrast, turbid conditions are hazardous for light-sensitive organisms that use shadows cast by predators as a warning to withdraw into areas of safety.

It has been suggested by several investigators (Nelson, 1916 and 1926; Thorson, 1957, Carriker, 1961; Haskins, 1964) that light plays an important role in the behavior and distribution of the pelagic larvae of benthic organisms, depending on their degree of light sensitivity (Carriker, 1967). Little information is available on the specific effects of light on organisms and the portion of the spectrum effectively useful to these organisms. Haskin (1964) discovered that oyster larvae respond to salinity changes only under light with a maximum transmission of 575 u and passage through a yellow-grain filter.

Light is necessary for photosynthesis. However, the harmful effects of light, especially in the violet and ultraviolet parts of the spectrum, must be recognized (Moore, 1958). They include the rapid breakdown of certain vitamins and the restriction of plankton during the daytime to a depth considerably below the water surface (Moore, 1958). Some of the planktonic crustaceans are restricted by a diurnal vertical behavioral pattern, i.e., the migration of organisms to the surface at night and to deeper depths at midday. This phenomenon is influenced both by illumination and by temperature, but it is still not completely understood (Moore, 1958; Reid, 1961).

Turbidity limits the depth at which photosynthesis can occur (Day, 1951). If turbidity is great, then the distribution of plant life is limited because of the restriction of photosynthetic activity. This restriction of plant life (especially plankton in the open estuary), will reduce the benthic and zooplankton populations which in turn will reduce the amount of fish productivity.

Natural turbidities should be determined for the Chesapeake Bay in order to predict the potential annual productivity of the Bay. *Managers* should not allow any effluent to enter the Bay which affects the aquatic biota in a detrimental manner by the changes it causes in turburdity and/or color.

Oxygen

In the presence of light and carbon dioxide, plants produce oxygen, and animals take in oxygen and give off carbon dioxide as they respire. At night, both plants and animals give off carbon dioxide in their respiratory activities; therefore, the oxygen concentration of an estuary is at its minimum at night and at its maximum during the day. The reverse situation is true for carbon dioxide. The oxygen content of an arm of the Chesapeake Bay showed 85% oxygen saturation before daylight and 115% saturation in the late afternoon (Newcombe, Horne and Shepard, 1939).

Another source of oxygen in addition to its production as a byproduct of photosynthesis is the atmosphere. Oxygen diffuses across the water-air interface. It then is tranported throughout an estuary by turbulence, sometimes caused by wind, and convection currents (Day, 1951). Benthic and planktonic organisms are responsible for the removal of some oxygen from the water. Another source of oxygen removal is the bacterial decomposition of large quantities of organic matter present in suspension and/or on the bottom of estuaries (Day, 1951). This decomposition of organic matter can cause anaerobic conditions which can result in death for many aquatic inhabitants.

Oxygen appears to be a limiting factor in respiratory activities of estuarine organisms when it reaches a low of 1.0 to 2.0 ml/liter although some organisms survive at concentrations as low as 0.1 ml/liter (Emery and Stevenson, 1957a). The distribution of dissolved oxygen at a depth of 10 ft in the Chesapeake Bay is illustrated in Figure 8 (Kester and Courant, 1973). Newcombe, et al.(1939) found that the deeper waters of the Chesapeake contain 2 ml/liter during the summer months when the stratification of the water inhibits turbulent mixing of oxygen to the bottom (Emery and Stevenson, 1957a). This figure is not accurate for the summer of 1973, especially in the upper estuary close to Baltimore, for two reasons: an extremely long heat spell and chemical dumping. "In industrial areas the situation can be further aggravated by the dumping of chemically reduced wastes that take up oxygen from the bottom water during their oxidation" (Olson, Brust and Tressler, 1941; Tully, 1949). The phenomenon of low dissolved oxygen is typical in the Severn, Potomac, and Eastern Bay in the summer. In the main portion of the Bay, anoxic conditions* have not yet been observed (Kester and Courant, 1973).

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* Kester and Courant (1973) defined anoxic conditions as "undetectable oxygen concentrations and the presence of sulfide".

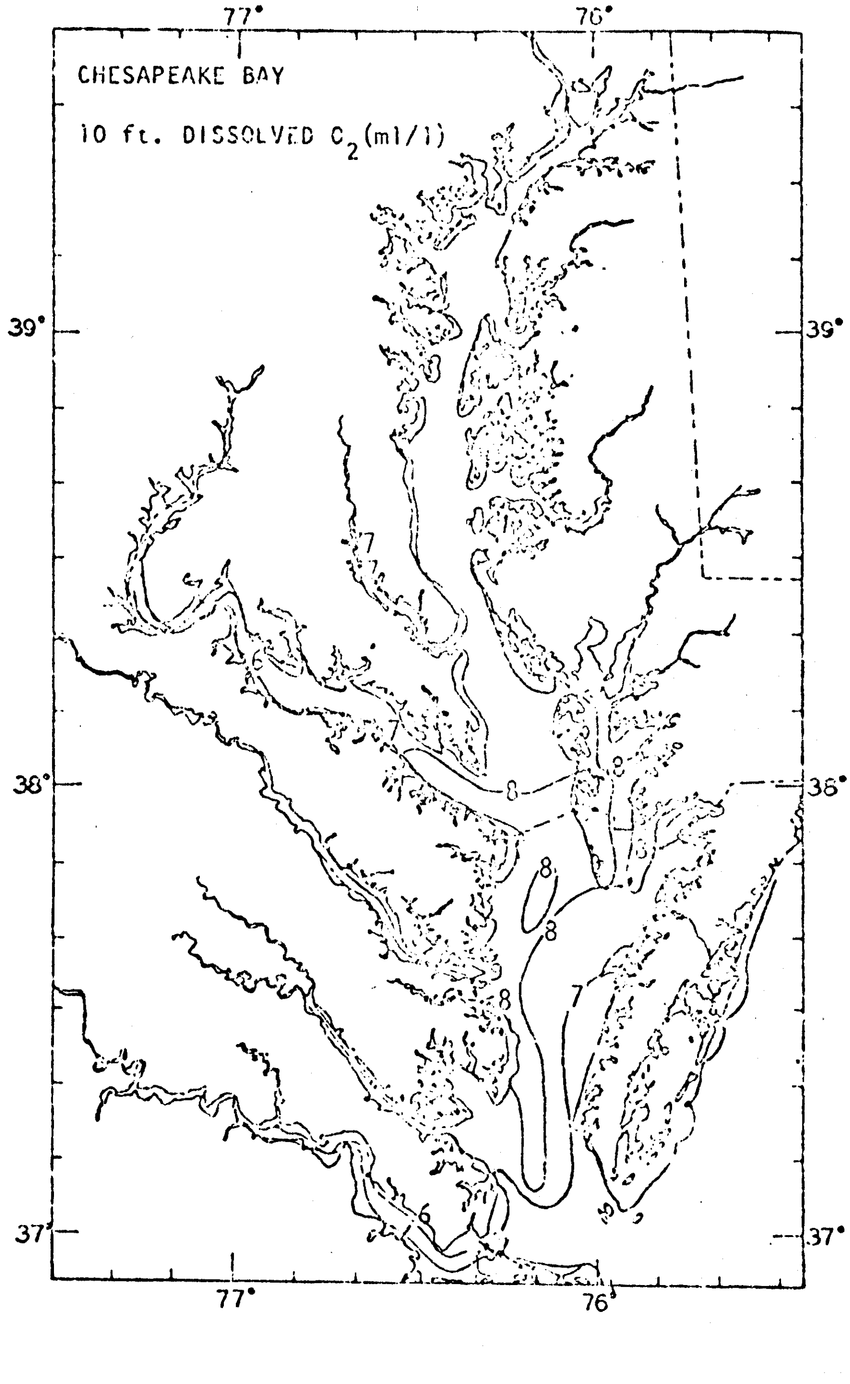

Figure 8. Distribution of dissolved oxygen at a depth of 10 feet in Chesapeake Bay (Kester and Courant, 1973).

Oxygen concentration varies inversely to water temperature. This knowledge has caused much of the concern regarding the discharge of heated effluent from power plants. This heat, if not strictly controlled, can cause deleterious effects on communities. Nature herself creates unfavorable environmental conditions, such as high temperatures. The heat spell at the end of August, 1973, in the Potomac and Rappahannock Rivers resulted in low oxygen concentrations in their bottom waters, causing oyster kills at a depth below 17 ft (Wass, personal communication). Sewage pollution also causes the reduction of oxygen concentration in the water. Some organisms are able to tolerate low oxygen concentrations. For example, Mya arenaria can survive an absence of oxygen for a period of eight days. As a result, however, it suffers a decrease in glycogen content and a poor growth rate (Ricketts and Calvin, 1948; Moore, 1958).

Managers should note that the higher the water temperature, the greater the respiration rate of inhabiting organisms. They should also realize that water retains more oxygen at lower than at higher temperatures. Animals can therefore tolerate lower oxygen concentrations longer at lower temperatures. *Managers* must not forget that in an estuary they also must concern themselves with varying salinities. The higher the salinity, the lower the oxygen saturation level and the greater the respiration rate. It is obvious therefore that a decision based on conditions in the upper regions of an estuary cannot necessarily be applied to a problem at its mouth. It is true that oxygen is less affected by.changes in salinity than by changes in temperature, but their combined action can reduce oxygen concentration to such an extent that a disaster will occur (Moore, 1958).

Carbon Dioxide and pH

Harvey (1945) discovered that sea water contains more alkaline radicals than strong acid radicals. This base excess is important because it retains a carbon dioxide reserve, in the form of bicarbonate and carbonate, for use in photosynthesis. With this reserve a faster photosynthetic rate is possible and more food and oxygen are released for animal consumption (Day, 1951). This excess base also acts in a buffering capacity in estuarine waters to prevent pH changes caused by the addition of acids or bases (Reid, 1961).

The pH of surface sea water ranges between 8.1 and 8.3 and is very stable (Reid, 1961). The pH of the mouth of an estuary is within this range, but more variation exists in the upper reaches of an estuary where the river systems enter. The water of a river transporting large quantities of humic material in colloidal suspension is slightly acidic in nature. As this water enters the estuary and contacts higher salinities, the colloidal particles flocculate, causing the pH range to shift toward that of normal sea water (Reid, 1961). Flocculation *per se* was described in the discussion on sedimentation.

Generalities regarding the interrelationships of carbon dioxide (CO_2), pH and oxygen are that the distributional pattern of CO_2 is expected to be the reverse of oxygen and that pH is expected to vary inversely to free CO_2 content and directly to dissolved oxygen concentration (Day, 1951; Reid, 1961). Low pH is found in the areas of abundant organic matter because bacterial decomposition of this material releases carbon dioxide. High pH is found in areas where plants are abundant because of oxygen production (Reid, 1961).

Moore (1958) did not consider pH as an important limiting factor. However, his examples were restricted to individual species studied in the laboratory. Again it must be emphasized that limiting factors rarely ever act alone. Their combined effects on biological communities have been researched only to a limited extent.

Temperature, Seasonality, and Latitude

The effects of temperature, latitude and seasonality on estuarine biota are interrelated to such an extent that they are extremely difficult to separate. For this reason, these physical factors will be considered together.

Estuaries are covered by a relatively thin layer of water in comparison to the ocean and therefore are affected more by atmospheric temperature variations (Emery and Stevenson, 1957a). Because the mouth of an estuary is close to the sea, it has a relative stable temperature as compared with the upper reaches of an estuary, which are considerably affected by meteorological conditions and somewhat affected by the temperatures of the rivers draining into it.

Some heat is required by all organisms for the functioning of metabolic processes (Kinne, 1970). These processes are restricted, however, to a particular temperature range. Kinne (1970) stated "with regard to life on earth temperature is - next to light - the most important environmental component". Temperature affects living organisms in three basic ways: (1) "It determines the rate and mode of chemical reactions and hence biological processes, (2) it affects the state of water, the basic life-supporting medium, and (3) it modifies basic properties of living matter" (Kinne, 1970).

Investigations have shown that the total number of marine invertebrate species increases from the polar region to the tropics; the species with pelagic larvae increase up to 85% (Thorson, 1957). A seasonal effect associated with upper latitudes is that the benthic intertidal organisms may freeze or ice may scour them away. It has been shown that the metabolic rates for a particular species found in both the northern and southern latitudes is about the same (Thorson, 1950; Bullock, 1955; Dehnel, 1955). These studies have also demonstrated that if comparison is made of organisms from southern and northern latitudes retained at the same temperature in the laboratory, then the more northern organism will have a higher metabolic rate.

Dehnel (1955) studied growth in a shallow-water euhaline gastropod in areas separated latitudinally by 1900 miles. His investigation revealed that the growth rate of encapsulated embryos and larvae was two to three times greater in the northern latitude than that of the southern populations at comparable temperatures. Carriker (1967) implied that this increased growth rate might have been a latitudinal effect, but Dehnel (1955) speculated growth effects (e.g., better yolk quality) in the northern sphere of the study.

In the Chesapeake Bay the annual temperature range is from about 0°C to approximately 29°C (Bumpus, et al. 1973). Schubel (1972) demonstrated that temperatures in the Virginia region of the Bay avarage about 0.5°C warmer than in the Maryland region.

A large volume of literature is available on temperature effects on individual marine and brackish water organisms, but extensive literature on the effects of temperature on the supra-organismal level (e.g., ecosystem or community) does not exist. One exception to this statement is that some information on microbial "communities" is known, but corresponding information on the individual bacteria comprising these colonies is not known.

Certain generalities regarding the effects of temperature on biota have been determined. For example, at summer temperatures in the temperate latitudes, certain mollusks have higher mortality rates when the salinity level decreases. However, if the temperature is low and the salinity remains low, they can survive for a longer period of time (Carriker, 1967). In contrast, some transient crabs and shrimps can survive at low salinities when the temperature level is high (Pearse and Gunter, 1951; Kinne, 1964).

Within the last year the Chesapeake Bay softshell clam industry suffered considerably from the salinity decrease caused by Tropical Storm AGNES. The situation grew worse at the onset of a heat spell. The clams were therefore stressed by both low salinities and high temperatures. Their respiration rates increased, forcing them to pump water even though normally they could cease pumping, thereby avoiding adverse environmental conditions. All of these examples display the interaction of salinity and temperature.

Temperature causes a variation in water density, resulting in changes in stratification and the circulation rate in a two-layered estuarine system such as the Chesapeake Bay. Since the surface layer of the water is alternately warmed and cooled throughout the year, several vertical temperature structures are possible. Seitz (1971) postulated four, and observed three, temperature-salinity structures for the Bay: "From March to August warm-fresh water overlies colder-saltier water. From September to December cold-fresh water overlies warm-saltier water. During January and February cold-fresh water overlies cold-saltier water. The fourth possibility of warm-fresh water overlying warm-saltier water may be a temporary condition near the end of August or early September" (Bumpus, et al. 1973).

Although some information on the hydrodynamics of non-tidal water circulation is known, no attempt has been made to relate it to the spawning of benthos in late spring and early summer in the temperate and boreal regions (Carriker, 1967). Neither has the relationship between seasonal change in the temperature of an estuary and the migration of animals to and from the sea been studied. The movement into and out of an estuary is related to feeding and spawning requirements of the migrant organisms.

The migration of some fishes and decapod crustaceans appears to be related to both temperature and salinity factors; salinity tolerance is greater at higher temperatures (Day, 1951). Broekema (1941) demonstrated that Crangon crangon (a shrimp) is more efficient in its osmotic regulation at higher than at lower temperatures. This animal can therefore maintain, at higher temperatures, a greater difference between its internal salt concentration and that of the surrounding water (Day, 1951).

Nutrients

Moore (1958) believes that most of the elements required by estuarine organisms are present in sufficient enough quantity that they need not be considered as limiting factors. Concentrations of trace elements are probably more significant than concentrations of nitrogen, phosphorus or silica. Lund (1969) stated that phosphorus and nitrogen deficiencies in lakes may not be as important as excess quantities of these elements. Excesses may cause eutrophication. Although eutrophication can be beneficial, if enrichment occurs too quickly, the body of water involved may suffer. "Artificial" eutrophication sometimes eliminates desirable species, encourages the growth of obnoxious algae and causes anoxic conditions from the decay of introduced material and of dead organisms (See p. 35 for a more detailed discussion).

Phosphorus is present in an estuary only as a phosphate compound (Kinne, 1970). In living tissue (e.g., phytoplankton) this element is mainly found in organic compounds. It is released back into the water in particulate or soluble form either by excretion or by decay of the organism after death (Moore, 1958). Figure 9 illustrates a highly simplified model of the phosphate cycle.

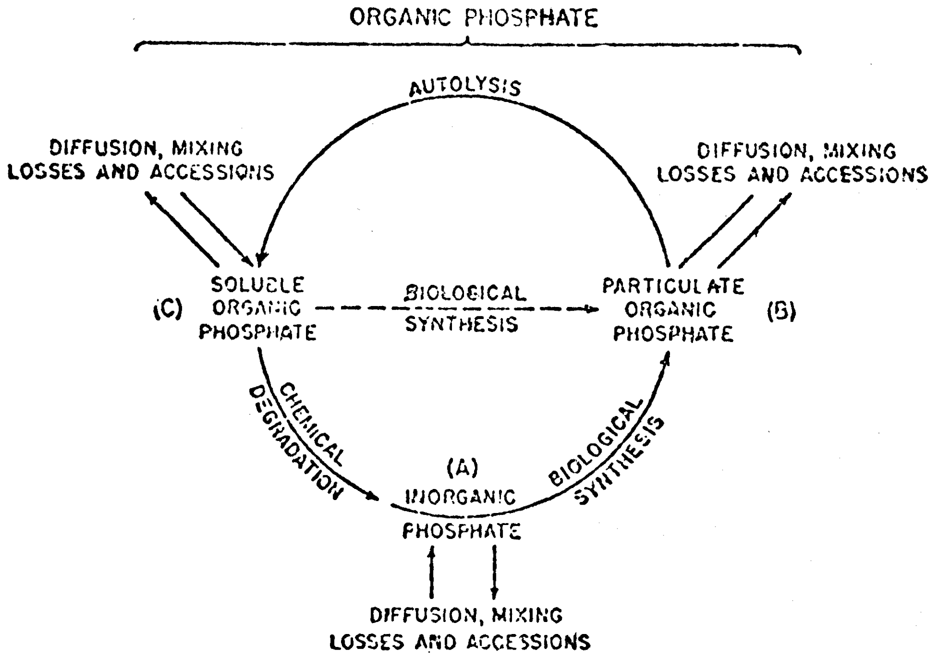

Figure 9. Simplified cycle of phosphorus transformation within a relatively isolated water mass (Emery and Stevenson, 1957a).

Rochford (1951a, 1951b) reported that in deep waters where there is not sufficient light for growth or oxygen for animal respiration, phosphorus concentrations tend to increase (Emery and Stevenson, 1957a). This increase is partially caused by the release of phosphate from the sediment after anaerobic bacterial decomposition of the organic material (Stevenson, 1951). Phosphate concentrations also tend to increase from the mouth of an estuary to its head because rivers discharge high concentrations of phosphorus into a bay.

In general nitrogen, like phosphorus, increases with depth (Collier, 1970). Four processes occur in the utilization of nitrogen: nitrogen fixation, nitrification, denitrification and ammonification. Details of these cycles are well known for terrestrial regimes, but little is known about them in aquatic systems (Collier, 1970). A great deal of research on specific organisms and their biochemistry is needed in order to fully understand all the nitrogen pathways in an estuary. A generalized scheme of the nitrogen cycle in the ocean is illustrated in Figure 10 (Collier, 1970). It is important to recognize that an estuary can receive both elemental nitrogen and nitrate from the atmosphere (Moore, 1958). Different sources of nitrogen can be utilized by different organisms, but many prefer nitrate. Nitrogen and phosphorus may act as limiting factors in freshwater tidal marshes. It has been discovered recently that nitrogen is more likely than phosphorus to limit growth of phytoplankton in coastal waters (Flemer, 1972).

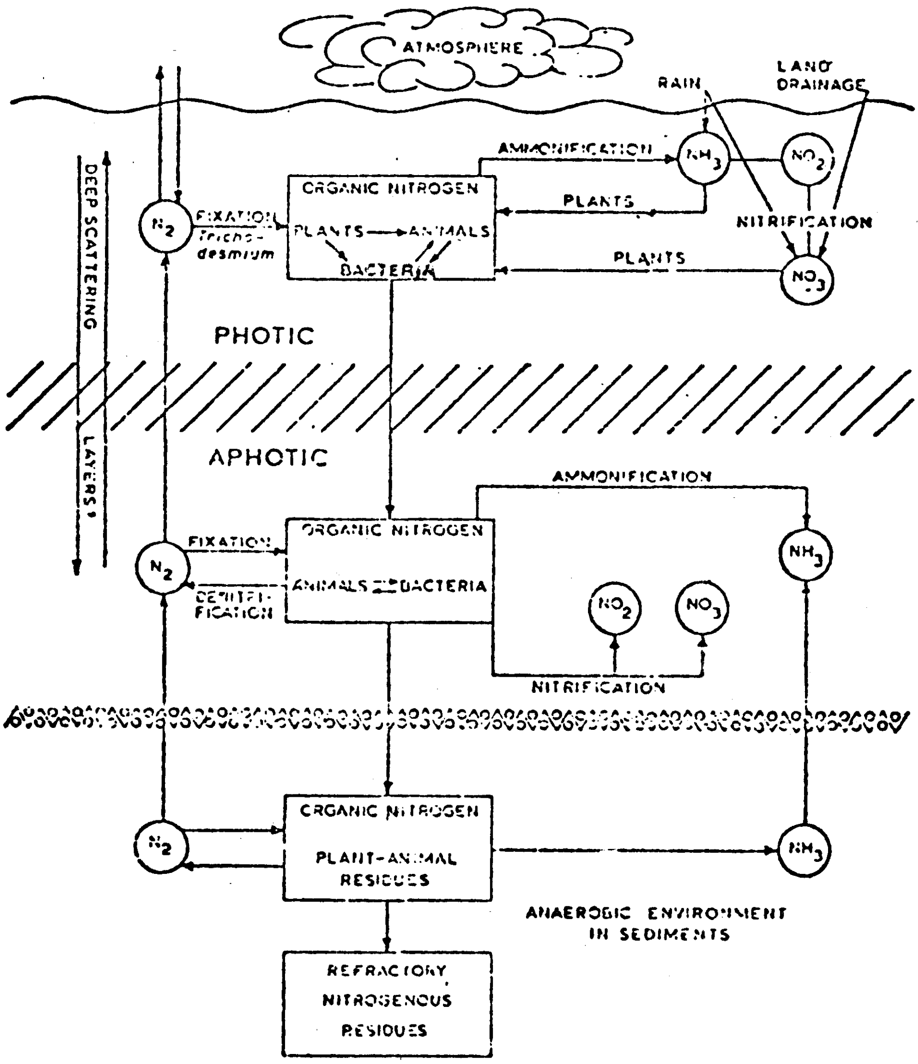

Figure 10. A generalized scheme showing the sources of nitrogen and its organic circulation in the ocean (Collier, 1970).

Silica, in the form of silicate, has been found in higher concentrations in Chesapeake Bay than in the surface water of the ocean (Emery and Stevenson, 1957a). Diatoms utilize silica to build their frustules. If the concentration of silica is limited, they possess thinner walls (Moore, 1958). Little else is known about the effect of low concentrations of silica on organisms.

Other nutrients apparently important to the survival of organisms are iron, manganese, potassium, bromine, vanadium, and beryllium. The effects of these elements as limiting factors have not been studied intensely, but *managers* should recognize their importance.

Environmental Quality Problems

Mankind has always tended to congregate near some form of water because it supplies him with food and drink, is utilized as a means of transportation and serves as a place for disposal of his waste material. This waste either sinks to the bottom near its source or is carried farther downstream. In the past, the typical attitude has been "out of sight, out of mind". This attitude is still prevalent, but the majority of society has now been made aware of the rapid deterioration of water quality. Since World War II technology has made gigantic strides in advancing the standard of living, but along with these advances, "novel abuses" of the environment have been made. Society has always failed to concern itself with a deleterious situation until it interferes with the desired standard of living. The waste problem that society once "dumped" in the water is now being "dumped" back on society.

Estuaries have enormous significance for man, both ecologically and economically. They are areas of great amounts of primary and secondary productivity. Cronin and Mansueti (1971) stated "... they are organic factories, traps for sediments, reservoirs for nutrients and other chemicals, and the productive and essential habitat for a large number of invertebrates, fish, reptiles, birds and mammals. Annual plant growth and decay, providing continuous large quantities of organic detritus, is one of the major components of the cycling of nutrients in estuaries". McHugh (1967) reported that the annual harvest of fish, both sport and commercial, in the Chesapeake Bay amounts to 125 lb/acre with a potential of 600 lb/acre. He also estimated that nearly two-thirds of the commercial catch of fish off the Atlantic coast are estuarine-dependent (McHugh, 1966). Oysters, clams, and blue crabs are other important economical resources of the Bay.

Chesapeake Bay is also important because it serves as a wintering area for Canada geese, ducks, whistling swans and many shore birds (Massmann, 1971). It is also an important recreational area. Its value in terms of the pleasure derived from sailing, fishing and swimming cannot be overestimated.

It must be recognized that "pollution"* was not invented by man. Society has merely accelerated processes that have always occurred in nature (Williamson, 1972). This acceleration can be observed by the layman in fish kills, algal blooms, the restriction of municipal beaches because of microbiological contamination and the decreased abundance of shellfish resulting in increased cost.

The Chesapeake Bay therefore faces attacks on its integrity from nature as well as society. Three natural forces that may affect the Bay deleteriously are wind, flooding and storm surges. The problems caused by Tropical Storm AGNES are still being felt around the region. The tremendous quantity of freshwater dumped into the Bay by AGNES caused a salinity reduction. Freshwater runoff carried huge quantities of sediment, debris and untreated sewage into the estuary. Because of the decreased salinity, added sedimentation and the heat wave following the storm, the oxygen concentration was decreased, resulting in benthic organism mortalities. Swift currents and salinity reductions displaced larval, juvenile and adult fish from their normal feeding, spawning and nursery grounds. Blue crabs were also redistributed from their normal habitats.

The Research Planning Committee of the Chesapeake Research Consortium prepared two tables listing the causes of biological problems in the Chesapeake Bay and the geographical areas of particular concern for

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* Wass (1967) defined pollution as an "environmental alteration detrimental to most indigenous life".

solution of biological problems (Tables 2 and 3) (Williamson, 1972). The localities of major concern are illustrated in Figure 11. The committee also recommended certain areas for additional study in the near future: (1) nutrient loading (2) addition of hazardous substances (3) sedimentation (4) effects of engineering activities (e.g., dredging) (5) extraction of living resources (6) problems resulting from alterations and destruction of wetlands and (7) impact of regional population growth and destruction (Williamson, 1972).

Nutrient enrichment of an estuary results mainly from human waste or its degradation products. This enrichment often results in artificial or cultural eutrophication*, which may deleteriously affect the ecosystem. Eutrophication is not always undesirable; it is a form of pollution only when its effects prevent the use of a body of water or associated products (Frazier, 1972). Frazier (1972) listed some of its harmful effects: (1) certain species and/or certain groups of organisms may flourish at the expense of others (e.g., algal blooms), (2) municipal wastes may cause a lowering of the oxygen content of the water since they often contain much phosphorus resulting in fish and shellfish kills (Discussion of the effects of oxygen as a limiting factor is given on p. 23.), (3) clogging power plant intake structure with plant growth, (4) reduction of freshwater flow in an estuary and (5) aesthetic effects - smells of decay.

Cronin (1967) reported that through a tidal cycle the release plume of a sewage outfall will be transported both up and downstream, covering the exact discharge site continuously or a minimum of two times during the cycle. At the site of a sewage outfall macroinvertebrates are absent from the sludge and soft mud. At zones of increasing distance from this site macroinvertebrates will begin to appear, but many will obviously still be harmfully affected by the effluent (e.g., the growth of a clam may be inhibited). At a greater distance, a great abundance of mollusks, worms, diatoms and other species will be present and eventually normal communities will be formed.

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* Eutrophication is identified as a natural increase in nutrient supply (Frazier, 1972). Artificial or cultural eutrophication is enrichment as a result of man's activities and is usually a greatly accelerated condition compared to natural conditions.

Table 2. Causes of biological problems in the Chesapeake Bay (Williamson, 1972)

MATERIAL	PRIMARY SOURCES/CAUSES
EMISSIONS AND ADDITIONS TO THE BAY	
Nutrients	Municipal and domestic wastes, agriculture
Sediments	Agriculture, urbanization, road building
Biocides	Agriculture, pest control
Metals	Industry, biocides, mining
Petroleum	Boats, municipal and suburban runoff
Radionuclides	Nuclear power plants
Leachates	Land fills
Other Chemicals	Industry, power plants
Heat	Thermal discharges
Exotic species	Introductions, deliberate or accidental
DELETIONS FROM THE BAY	
Process or products	
Freshwater diversion	Dams, consumptive use, Chesapeake & Delaware Canal
Fishery products	Exploitation, poor fishing techniques
ALTERATIONS OF WETLANDS, SHORELINES AND SHALLOWS	
Process	
Shoreline erosion	Natural processes, wetlands destruction
Habitat destruction	Dredging, dumping, filling
Loss of productivity	Dredging, dumping, filling
Flooding, sedimentation	Dredging, dumping, filling

CUMULATIVE EFFECTS OF MULTIPLE ENGINEERING CHANGES

Process		
Erosion	Filling	Bulkheading
Sedimentation	Dredging	Piling placement
Habitat destruction	Groin construction	Construction
Loss of productivity	Spoil deposition	

Table 3. Geographical areas of the Chesapeake Bay of particular concern for solution of biological problems (Williamson, 1972).

Area	Reason for concern	Immediacy of problems (if this is reason for concern)
	Maryland- Western Shore	
Susquehanna River	Nutrients, modification of fresh water flow, sediments, energy, fisheries	Freshwater flow–immediate; others–chronic
Bush River	Proposed thermal addition	Near term
Back River	Municipal waste, nutrients	Immediate
Patapsco River	Municipal and industrial wastes, dredging, spoil disposal, all hazardous materials	Chronic
Magothy, Severn and South Rivers	Residential wastes, agricultural runoff (nutrients), recreation	Chronic
West and Rhode Rivers	Protected area of low stress for baseline data and experimental study	
Calvert Cliffs	Thermal addition, radionuclides, political problems	Immediate
Cove Point	Proposed liquid natural gas terminal, dredging, spoil disposal	Immediate
Patuxent River	Thermal addition, nutrients, area of immediate stress	immediate
	Maryland–Eastern Shore	
Chesapeake & Delaware Canal	Modification of freshwater flow, dredging and spoil disposal, shipping, oil spills	Immediate
Chester River	Heavy metals, biocides	Long range
Choptank River	Nutrients, sedimentation	Near term
Dorchester County	Shoreline erosion	Chronic
Maryland & Virginia		
Upper Tidal Potomac River	Urbanization, municipal wastes (nutrients), sediments, legal and institutional problems	Chronic
Lower Tidal Potomac River	Oil spills, dredging, fisheries	Near term
Lower eastern shore	Economy, agricultural wastes, wetlands, fisheries, erosion, access to water, industrial development	Immediate
	Virginia	
Rappahannock River	Freshwater flow modification, industrial wastes, area of relatively low stress, nutrients	Freshwater flow–immediate; others–chronic
Upper York River	Industrial wastes, freshwater flow modification wetlands, fisheries	Freshwater flow–immediate; others–chronic
Lower York River	Thermal addition, oil transport, dredging, spoil disposal, wetland alteration, fisheries, residential wastes, VIMS	Immediate
Upper Tidal James River (above Jamestown)	Industrial and municipal wastes, dredging, heavy metals, human health (bacterial counts)	Immediate
Lower Tidal James River (below Jamestown)	Industrial and municipal wastes, transportation (water & vehicular), spoil disposal, dredging, thermal addition, fisheries, heavy metals	Immediate and chronic
Hampton Roads	Transportation (water & vehicular), ship waste, spoil disposal, recreation	Immediate and chronic
Nansemond, Elizabeth and LaFayette Rivers	Heavy metals, municipal wastes, fisheries, urbanization, oil handling and transport, shipping, shoreline modifications	Immediate
Lynhaven system	Residential development, nutrients, shoreline modifications	Chronic
Bay-mouth area	Only exit from system to sea; sedimentation, fisheries (crab spawning area)	Near term

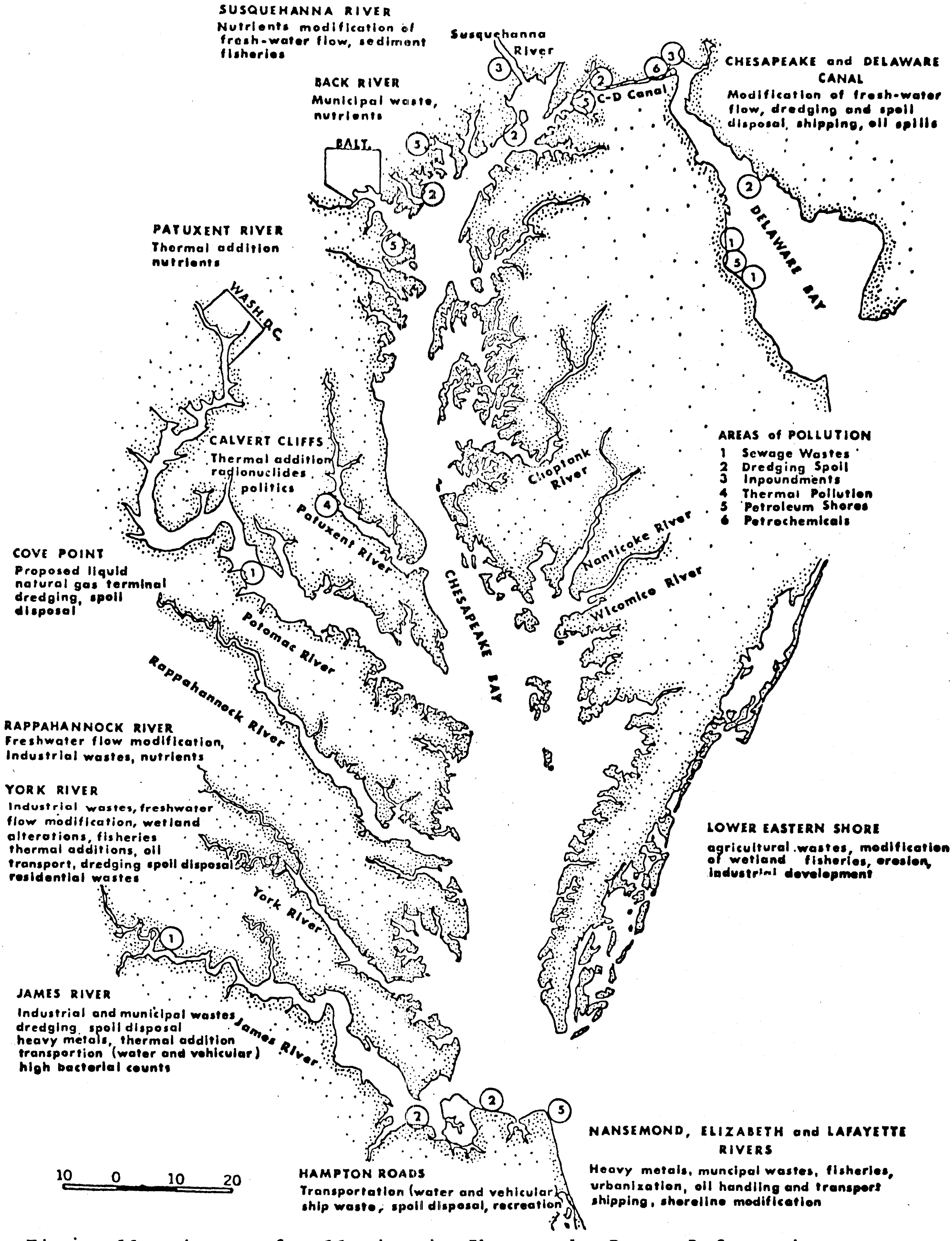

Figure 11. Areas of pollution in Chesapeake Bay. Information modified from Odum and Copeland (1974) and Mastrangelo (1972)

Up to the present time the Chesapeake Bay has been able to withstand nutrient enrichment, but Frazier (1972) believes that it faces a serious threat to its stability if this enrichment is allowed to continue at an accelerated rate. The solution to the nutrient pollution problem by dilution is obviously limited. However, no alternate solution to this problem has been ascertained.

Pesticides, heavy metals, fecal pathogens and radioactive materials are examples of hazardous additions to the Chesapeake Bay. They may cause fish kills and/or the restriction of shellfish consumption.

Little is known about the effects of pesticides on the biota of Chesapeake Bay. Only in a few cases have mortalities been attributed directly to pesticides. More than likely, any detrimental effects caused by pesticides in the Bay are subtle rather than immediate (Munson and Huggett, 1972). In other words the effects of a particular contaminant will not necessarily be noticed until there is a continuous numerical decrease of organisms (e.g., soft-shell clams) over a period of time (months or years). Pesticides have been shown to be highly concentrated by Chesapeake Bay mollusks (Williamson, 1972), but the present levels in the Bay do not appear to be critical. However, pesticide levels require continuous monitoring in order to prevent levels great enough to cause mortalities and food contamination (e.g., blue crabs and shoftshell clams) (Williamson, 1972).

Examples of heavy metals of immediate concern for the Chesapeake Bay are mercury, arsenic, cadmium, lead, chromium and nickel (Schubel, 1972). Bivalves are known to absorb and store copper, mercury, lead and arsenic (Galtsoff, 1960). Oysters, clams and scallops concentrate zinc 100,000 times that of surrounding water (Cronin, 1967). It should be realized that the presence of heavy metals in Chesapeake Bay is not unusual; they occur there naturally. They result from weathering and erosion and are absorbed by fine sediment particles. Man has, however, increased the concentrations of these heavy metals (e.g., in the molecular makeup of pesticides) and hence has accelerated their harmful biological effects. It must be remembered that these materials are "non-biodegradable" and thus have a long lifetime and that physical, chemical and biological processes may have a combined effect of concentrating these metals making them potentially dangerous pollutants (Frazier, 1972). The concentrations of heavy metals in the Susquehanna River are associated with suspended sediments

(Schubel, 1972) and with vegetation (Williamson, 1972). Concentration in the Bay are greatest at the head of the estuary (Williamson, 1972); it is here that the shellfish grounds are closed periodically.

Few reports regarding radioactive waste in the Chesapeake have been made, but it is known to be entering the Bay in increasing quantities (Cronin, 1967). Radioactive chemicals with a short half life (the time required for half of a radioactive particle to decay) may not be critical, but the presence of ones prossessing a long half life probably have some effect on the biota. As they pass through the various trophic levels of a biological system, these chemicals, as well as heavy metals and pesticides, become more and more concentrated. They may be cycled and recycled, but eventually enter human food supplies in significant enough quantities to be a health hazard (Cronin. 1967). Their presence is especially dangerous because they are capable of altering genetic structure.

The process of sedimentation also can affect the biota. (Some of these effects were mentioned previously: see p. 12). Dredging, an activity necessary to keep ship channels open, causes deposition of spoil which can cause smothering of benthic organisms. Other engineering activities such as filling for parks, industry, housing and airports, shoreline construction, dynamiting, cutting of waterways and canals and some specialized fishing operations, e.g., hydraulic dredging for softshell clams, all contribute to sedimentation problems if they are not controlled (Cronin, 1967a). Other biological effects caused by sediments listed by Sherk (1972) are: (1) they can reduce light penetration, thereby reducing photosynthetic activity, (2) the resuspension of sediments can harmfully affect the biota if the oxygen demand is critical since the suspended particles exert an oxygen demand eight times greater than bottom deposits and (3) the suspended particles will also stimulate community respiration probably by organic matter accompanying inorganic turbidity. The organic matter is absorbed by inorganic particles or mud and concentrated to 100,000 times its dissolved value. These inorganic-organic complexes provide a substrate for bacteria by concentrating substances from the water that attract bacteria and retarding the diffusion of enzymes.

As mentioned earlier in this section, wetlands are sediment depositories. The inorganic sediment from the rivers and the organic sediment originating in the are transported via the marsh drainage system to the estuary. The channels that flood and drain these areas are "critical transport links in delivering detritus and nutrients to the estuarine food chain" (Williamson, 1972). Figure 12 clearly demonstrates nutrient exchange between the marsh and the estuary. It is now apparent to many state and Federal agencies that a wetland is one of the most important production units in a bay.

One form of pollution that often makes the headlines in our environmentally awakening society is that of thermal pollution. For years the American society has taken power for granted, but now because of the "energy crisis", everyone is aware of a power shortage. At the same time that power companies are trying to expand to produce more power, environmentalists are trying to hinder expansion because of alleged deleterious environmental effects. Opinions regarding the "harm" of heated effluents from power plants are controversial. It is known that thermal additions can and do cause algal blooms out of season and block fish migration. Young and Gibson (1973) reported the death of juvenile menhaden due to thermal shock. Few reports of menhaden kills have been made. However, Young and Gibson pointed out that the type of fish kill where the dead fish sink rather than float often goes unnoticed. In this particular case, the detrimental effect was observed only because scuba divers happened to be at the right place at the right time. The question arises as to how often the effects of thermal additions have previously not been reported simply because of the veil of water covering a bay bottom.

A form of environmental alteration often overlooked is biological pollution, e.g., the introduction of exotic species. A review of the literature indicates that "transportation of oysters, oyster shell, and seed has probably modified the distribution of more aquatic species than any other human activity" (Cronin, 1967). For example, the introduction of the American oyster into the English Channel resulted in the spread of Urosalpinx cinerea, an oyster drill. In the Chesapeake Bay the introduction of Eurasian milfoil (previous distribution restricted to Europe, Asia and Africa) has blocked navigation, prevented boating and swimming, and interfered with seafood harvests.

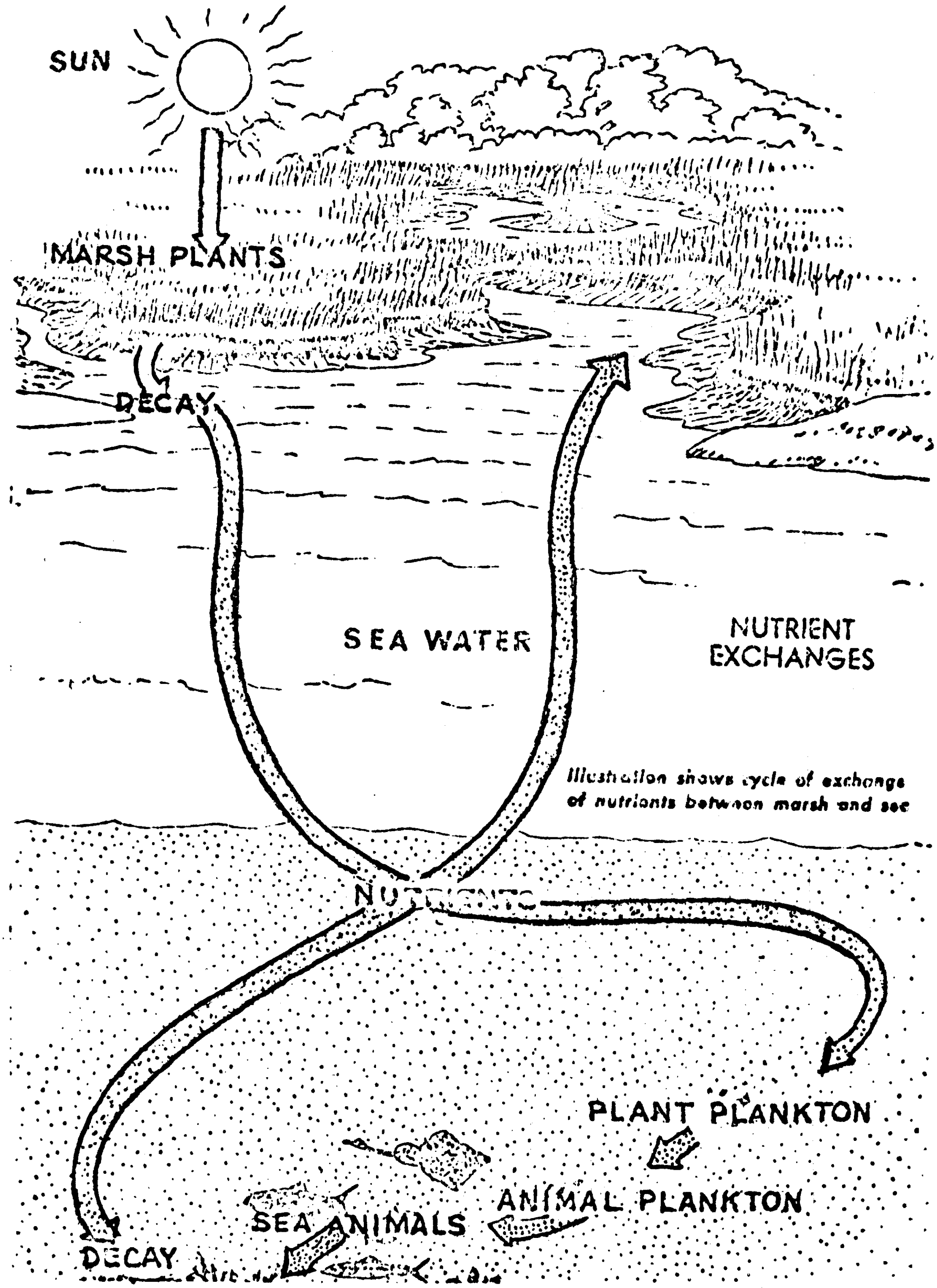

Figure 12. Exchange of nutrients between marsh and sea (Odum and Copeland, 1974).

Cronin (1967) reported on the factors that provide the Chesapeake Bay with resiliency, but at the accelerating rate of pollution, it will be difficult for the Bay to continue its cleansing process. *Water managers* will be responsible for protecting the environmental quality of the Bay. Failure can result from several sources of error or insufficiencies. Cronin (1971) listed these as:

1. "Incorrect population prediction."

2. "Erroneous estimates of the quality or nature of industrial activity."

3. "Continuation of the existing philosophy of the right to use public water for waste disposal."

4. "Inadequate knowledge of the assimilation and biological effects of unknown new compounds."

5. "Erroneous engineering data or calculation."

6. "Insufficient understanding of the biological system and population affected."

7. "Deficiency of funds."

8. "Mechanical break-down in equipment."

9. "Operational error.".

10. "Inadequate enforcement."

11. "Weakness in legislation."

12. "Political pressure."

Management has a massive job ahead of itself if it is going to prevent the Bay from reaching a point of no return. Cronin (1971) listed the capabilities of technology to control various pollutants (Table 4), but he also pointed out "the levels of results which are 'generally acceptable' are rapidly changing and generally rising".

Biological Factors

Up to this point limiting factors have been discussed mainly in the physico-chemical sense. Now attention is

Table 4. Capabilities of technology for control of various pollutants (Cronin, 1971)

Pollutant	Technological Capability
I. Suspended solids	
(a) Settleable	adequate
(b) Colloidal	adequate
II. Dissolved solids	
(a) Inorganic	
1. Total dissolved solids	available*
2. Nitrogen compounds	inadequate
3. Phosphates	available*
4. Trace metals	inadequate
5. Heavy metals	adequate
6. Acidity	adequate
7. Alkalinity	adequate
8. Radioactive elements	adequate
(b) Organic	
1. Biochemical oxygen demand	adequate
2. Refractory materials	
(i) Detergents	adequate
(ii) Pesticides	inadequate
(iii) Residues	inadequate
(iv) Industrial	inadequate
III. Thermal pollution	adequate
IV. Living organisms	
(a) Infectious agents	
1. Bacteria	adequate
2. Viruses	inadequate
(b) Plants	
1. Attached	available*
2. Algae	adequate
(c) Slimes	inadequate

* Economically limited.

being turned to biological "limiting factors". This discussion will involve topics in most biological science subdivisions (e.g., physiology, ecology, biochemistry). It is inherent that biological factors are intimately associated with physicochemical factors. Limiting biological factors will be discussed mainly in regard to the concept of trophic relations, i.e., in community metabolism. When various ecological concepts were discussed earlier, the various trophic levels of producers, consumers and decomposers were mentioned; they will form the basis of this discussion.

Food webs and/or food chains indicate the organisms involved and the energy flow sequence in a particular biological system. Water flow, invisible pathways of physical and chemical elements, and various organizational mechanisms which interrelate the parts are all involved (Copeland, 1970). Material flow is cyclic whereas energy flow is linear: it flows from the green plants through the various levels of consumers to the bacteria, fungi, and other microorganisms (Figure 13). An ecosystem (or major community) is dependent upon only one outside energy source, solar energy. Vertically, then, an ecosystem is divided into two major zones dependent upon the light energy entering the system. In the upper zone, the dominant process is photosynthesis whereas in the lower, more shaded zone, food consumption and consequently mineral and carbon dioxide release are the dominant processes (Copeland, 1970).

It is necessary to understand primary productivity, community production and respiration in order to understand the functioning of energy flow in an ecosystem. Primary productivity is the energy fixed by photosynthesis and chemosynthesis as organic material. The existence of all other organisms is dependent upon the production of this material. Respiration is used here in its broadest definition, i.e., the respiratory consumption of food and oxygen which measures the magnitude of work involved in self maintenance (loss of energy) (Copeland, 1970). Community production, including both primary and secondary productivity, under stabilized conditions equals community (i.e., both plants and animals) respiration. If community production (P) exceeds community respiration (R), then organic material accumulates in an estuary. If R exceeds P, then energy is lost from the system (Swartz, 1972). If a community is in an early stage of development or is disrupted in some manner, (e.g., addition of pollutant)

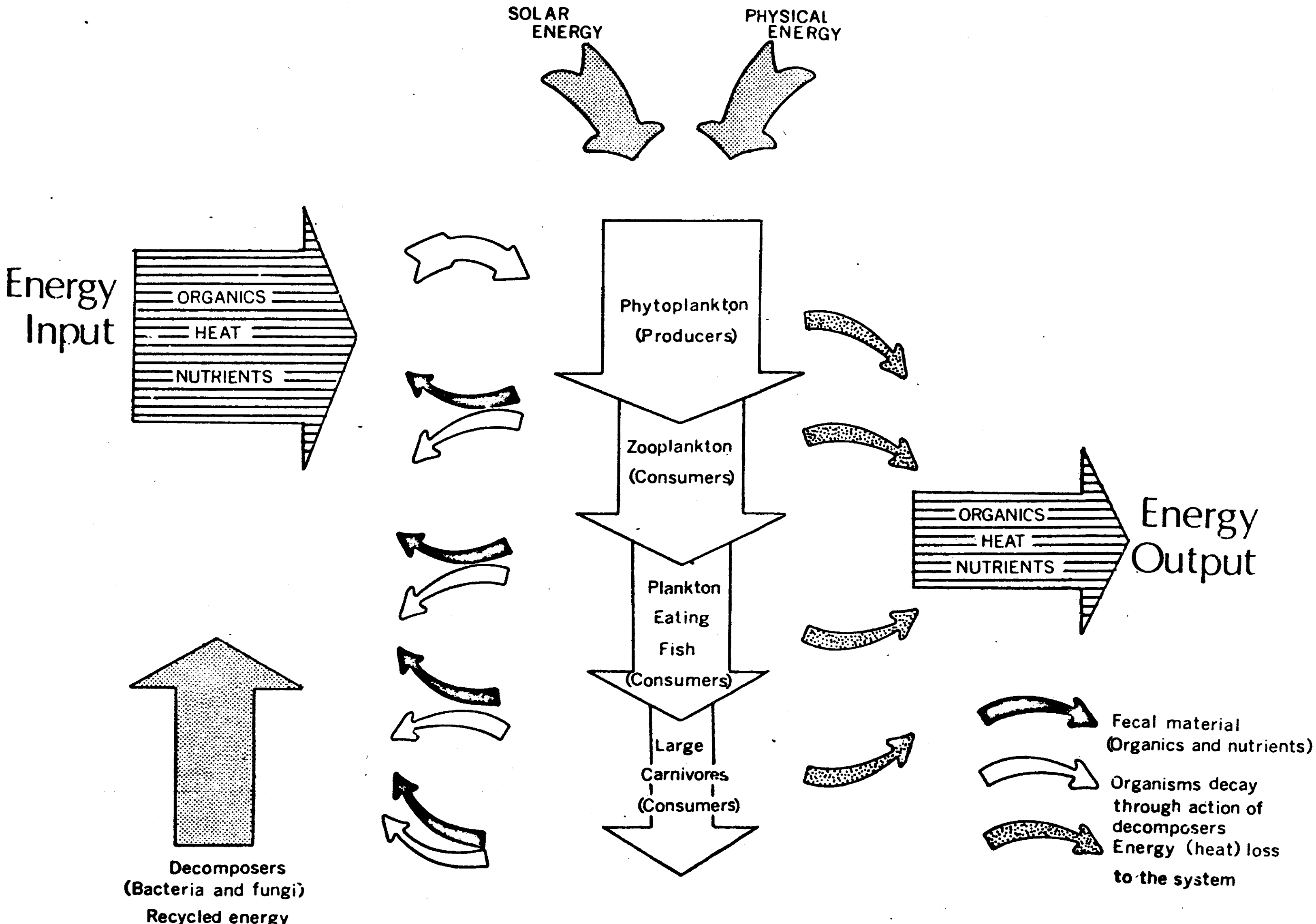

Figure 13. Energy flow through an aquatic ecosystem.

then the P/R ratio is less than or greater than unity. The most efficient energy pathways are, therefore, not being used. Measurement of these two factors, production and respiration, and determination of their inequality can provide valuable evidence of environmental change (Odum, 1969; Swartz, 1972).

Vascular plants (e.g., eelgrass, marsh grass) are a major source of primary productivity in an estuary. This plant material decomposes and enters the water as organic detritus. Decomposition occurs slowly enough that a continuous supply of food is available. Useful nutrition is provided mostly by the bacteria, fungi, protozoa, micro-algae, etc., adsorbed onto this detritus. Diatoms and filamentous green algae are known to provide 10 to 20% of the diet of many detrital feeders. For this reason, Odum (1970) feels that these feeders should be called "detritus-algal consumers". Amphipods, isopods, mysids, small crabs, insect larvae, caridean shrimp and some fishes use detritus and absorbed microorganisms as their principal source of energy. In addition, this material serves as an emergency food supply for other organisms when their normal food source is not available. A predator often can consume detritus and survive, but its growth rate will be hampered (Odum, 1970).

Phytoplankton form the base of an important estuarine food chain (Figure 14). Some juvenile estuarine fish, spawned at sea, feed on zooplankton. As they migrate into an estuary, they continue to use zooplankton (which feed on phytoplankton) as their primary food source. They gradually shift their feeding habits to benthic organisms, plants and detritus (Odum and Copeland, in press; Odum, 1970). This example illustrates another important principle of energy flow. An effective ecosystem circulates the products of one trophic level to another, either by taking advantage of naturally occurring circulation patterns or by organism movement (Copeland, 1970).

It should be recognized that energy is naturally lost as unavailable heat during each biochemical reaction. In addition, potential energy is lost when commercial species are harvested, when migratory forms move out of the estuary, and when organic matter is buried and removed permanently from participating in the chemical reaction of the system. If man interrupts an established energy flow, he may cause additional energy losses as well as other detrimental

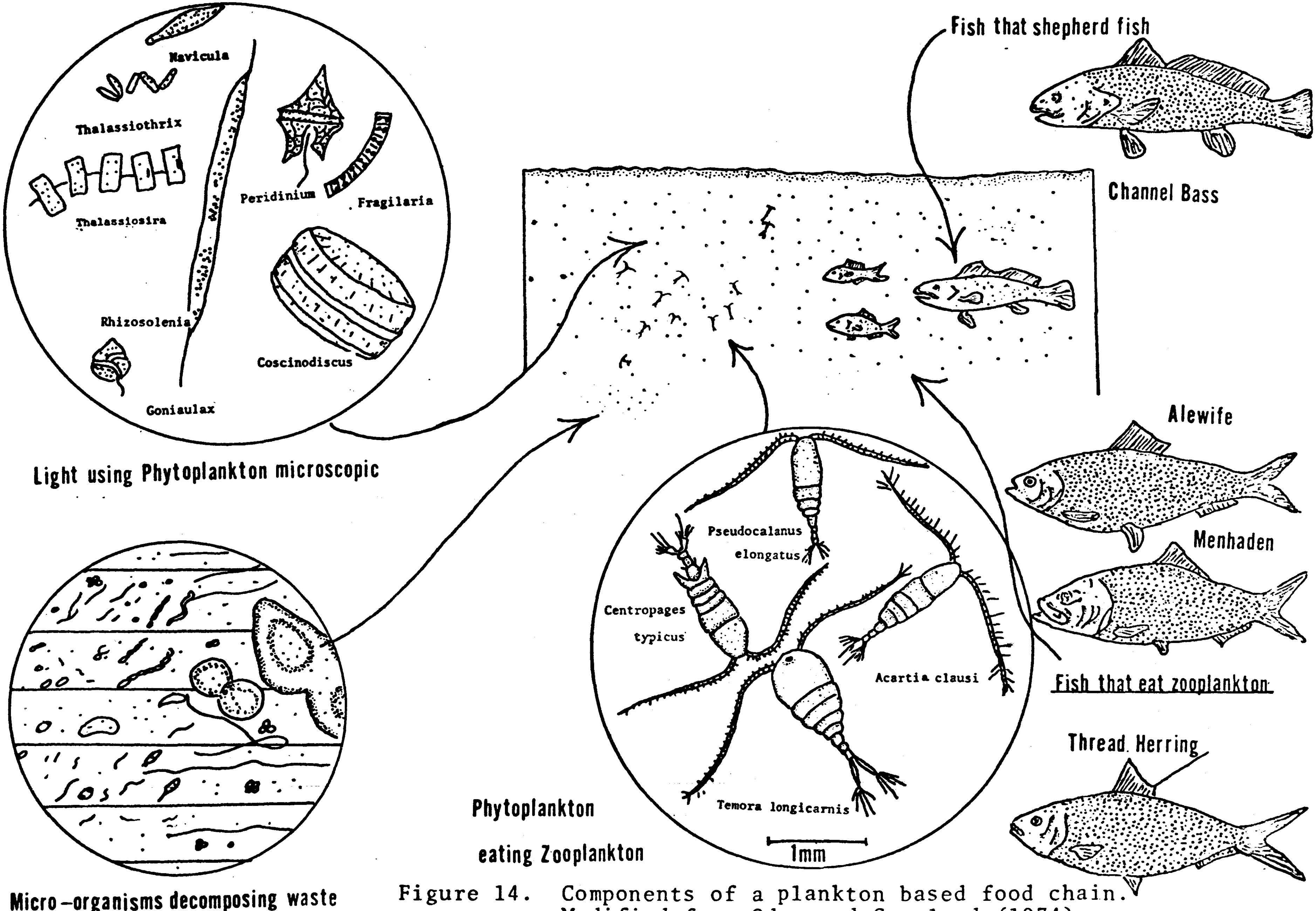

Figure 14. Components of a plankton based food chain. Modified from Odum and Copeland (1974).

biological effects. The decline or demise of a desirable species may occur, or its niche may be claimed by a less desirable species as a result. Man's activities may cause the loss of a marsh area and/or detritus-producing area, resulting in a decline of the organisms which primarily feed on detritus. A loss of this nature directly affects the next higher trophic level, thereby starting a chain reaction throughout the food web (Odum, 1970).

Estuarine food chains are vulnerable to interruption apparently because they are basically short and simple (refer back to Figure 14) (Odum, 1970). Generally, in estuaries, there is a great deal of dependence of larger organisms on a few key smaller organisms that utilize detritus and micro-algae for food.

A classic example of the effects of man on a food chain is demonstrated in "The Great South Bay Duck Farm Incident" (Ryther, 1954). Duck farms were established on the tributaries of the Great South Bay in Long Island Sound, New York. As a consequence, a great amount of duck manure was flushed into the Bay. Low circulation allowed it to accumulate, causing artificial eutrophication and consequently, algal blooms. The type of producers present shifted. Prior to the establishment of the duck farms, the phytoplankton consisted of mixed diatoms, green flagellates and dinoflagellates. These dominant organisms were replaced by small green flagellates of the genera <u>Nannochloris</u> and <u>Stichococcus</u>. Because they could not utilize these flagellates as food, oysters which had lived in the Bay for years began to decline in abundance.

Trophic relationships represent only one aspect of species interactions occurring in an estuary. Species interaction refers to the sum total of all interspecific and intraspecific relationships of the biota, including food procuring, mating and reproducing, spacing between organisms, shelter seeking and physiologically adapting to surrounding physico-chemical parameters. All of these processes are significant at some stage in the ecological life history of an organism.

The changes as a result of successful artificial introduction of species into an established estuarine system are dependent primarily upon species interactions. Although these introduction may be beneficial, they have also harmfully affected existing communities. For example, <u>Gryphea</u>

(Crassostrea) angulata, the Portuguese oyster, was transplanted into English waters, but inadvertently introduced at the same time was Urosalpinx cinerea, an oyster drill now recognized as an extensive predator. A present threat to the James and Delaware Rivers is the Chinese clam, Corbicula manilensis, which clogs industrial intake pipes and causes significant pollution problems by periodic mass die-offs and decay (Boesch, personal communication).

Extensive research on the interactions of organisms is definitely needed. Some interesting information has already been learned, e.g., that chemicals released into the water by some species attract their own kind. It has been postulated that this chemical release provides the basis for the development of oyster bars. On the contrary, some species repel by various methods settling of their own kind. Thorson (1957) noted that Spisula larvae are attracted to clean sand. Once settled, their feces accumulate and act as an inhibitor to the settling of other Spisula larvae (Carriker, 1967). It is known that many planktonic larvae "explore" the bottom in order to find one suitable for metamorphosis (Carriker, 1967). The environmental clues detected by an organism indicate whether or not the bottom is a suitable one on which to settle. Additional research is needed to thoroughly understand this mechanism. *Managers* should recognize that survival time of larvae is limited. If they are unable to find a suitable substratum on which to develop futher, they will die. The greater the number of unsuitable habitats in the Chesapeake Bay, the greater the reduction in kinds and numbers of individuals, and consequently in communities.

LITERATURE CITED

Literature cited for Section I is located at the end of Section 3 (p. 3-107 - 3-127).

SECTION 2

SUMMARIES OF THE BIOLOGY OF THE MOST SIGNIFICANT BAY ORGANISMS

BY

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INTRODUCTION

The need for a systematic compilation of more detailed information on selected species of the Bay has been pointed out by Kohlenstein (1972). It will be of value, he wrote, "to scientists seeking information on species unfamiliar to them, to modelers attempting to pull together a broader understanding of the function of an ecosystem, to scientists, engineers, and resource managers attempting to assess the impact of a proposed change affecting the Bay." He proposed an outline to be followed for compiling descriptive ecological information on biological entities (see Chesapeake Sci. 13, Suppl., 1972). It was the opinion of those completing the outline that much modification was needed since it was not suitable for all phyletic groups. It is doubtful if any one outline, with sufficient detail to be of any value, can fit all of these groups.

The species summaries prepared for this report follow the general outline as proposed by Kohlenstein. Although category numbers have been omitted to save space, the order is the same. The specialists preparing the summaries were given liberty to modify the form to fit the entity with which they were working.

The task of selecting the important species is formidable when one considers the biological complexities of the Chesapeake Bay system. Individual species and their relationships with each other, their associations with unrelated species, their direct value to man, and the effect they have on the environmental community are but a few of the more perceptible considerations which must be weighed. The state of our knowledge on any one of these aspects is not complete, and much research remains to be done before our understanding of the interrelationships and importance of individual species is final.

With these facts in mind, we have attempted to complete a list of those species in the Bay system which, so far as our knowledge exists, are important for water resource management purposes. Assistance in selecting these species was sought by questionnaires sent to scientists who were familiar with a particular group or groups of Chesapeake Bay fauna. A copy of the questionnaire and accompanying letter is included in this report. Several species were listed on the form for consideration when it was sent to the respective authorities and they were requested to add and evaluate other species which they believed important.

Upon return of the questionnaire each species was carefully examined for its inclusion in the faunal list. An attempt was made at first to assign a numerical value to each of the 15 criteria on the questionnaire and to use this method as a means of selecting important species. This was later rejected for several reasons. The relatively few criteria, purposely kept at a minimum to get maximum response, and the decision to include any species if it qualified for one of several criteria, made an empirical evaluation probably just as valid. For example, a species would qualify as an "important species" if it were either a commercial species, a species pursued for sport, a prominent species important for energy transfer to a higher trophic level, a mammal or bird protected by Federal Law, or if it exerted a deleterious influence on other species important to man.

In addition to these criteria, many others entered into the selection process. Several species were eruptive in their reproduction and thus of great ecological significance; others were tolerant of pollution or nutrient enrichment to the point of being a nuisance. Many, particularly fishes and birds, are migratory and thus their significance is felt only seasonally. Zoogeography of the estuary was considered in attempting to find species representative of as many areas and habitats as possible, including freshwater tidal reaches. Some species were listed because they were introduced or had recently undergone a rapid increase. Some have been chosen for significance in certain communities, particularly the wetlands and eelgrass communities.

The interim report outlined 124 important species of the Chesapeake Bay representing 12 phyla. Biological summaries for the following eight species were completed in the Sample Inventory of the Bay Organisms section of the first report on the existing conditions of the biota of Chesapeake Bay (Chesapeake Sci. 13, Suppl., 1972): *Corollospora pulchellus* (ascomycete fungus), *Ruppia maritima* (ditch-grass); *Myriophyllum spicatum* (Eurasian watermilfoil); *Acartia tonsa* (copepod); *Chrysaora quinquecirrha* (stinging nettle); *Mya arenaria* (soft-shell clam); *Sagitta elegans* (arrow worm); and *Hyla cinerea* (green tree frog). An additional 24 species were selected from the important species list and completed for this report by persons who were familiar and had worked with that particular species or group. Summaries of the biology of these species were taken from the literature, either published or unpublished, and from the knowledge of the person writing the inventory. Included are a genus of diatoms, 9 invertebrates, 5 fish, 2 turtles and 7 birds.

The completion of these biological summaries of several important Bay organisms contributes to our pool of readily accessible information which may be used by scientists, engineers, or laymen. Now that a fourth of the 124 species defined as most important in the Chesapeake Bay have been summarized, it is hoped that the rest may be similarly treated in the near future.

Sincere appreciation is extended to the 11 individuals, in addition to the author, who contributed much professional and personal time to complete the summaries of many of these species. Any future reference to these summaries should be made to the individual author so that he may receive proper recognition for his willing efforts.

LITERATURE CITED

Kohlenstein, L. C. 1972. Systems for storage, retrieval and analysis of data. Chesapeake Sci. 13 (Suppl.): 157-168.

Questionnaires were sent to 42 scientists who were conducting, or had in the past, conducted research on Chesapeake Bay fauna. The compiler wishes to acknowledge and thank the following 31 colleagues who completed and returned the questionnaires.

Dr. Richard Anderson	American University, Wwashington, D.C.
Dr. Jay Andrews	Virginia Institute of Marine Science Gloucester Point, Virginia
Dr. John Bishop	University of Richmond, Richmond, Virginia
Dr. Donald Boesch	Virginia Institute of Marine Science Gloucester Point, Virginia
Dr. T. E. Bowman	Smithsonian Institution, Washington, D.C.
Dr. Robert Burchard	University of Maryland, Baltimore, Maryland
Dr. Victor Burrnell	Dept. of Wildlife, Charleston, South Carolina
Dr. Martin Buzas	Smithsonian Institution, Washington, D.C.
Mr. David Cargo	Chesapeake Biological Laboratory, Solomons, Maryland
Dr. Rita Colwell	University of Maryland, College Park, Maryland
Dr. George Grant	Virginia Institute of Marine Science Gloucester Point, Virginia
Dr. Donald Heinle	Chesapeake Biological Laboratory, Solomons, Md.
Dr. Harold H. Humm	University of South Florida, Tampa, Florida
Dr. H. P. Jefferies	University of Rhode Island, Kingston, Rhode Island
Dr. Frederick Kazama	Virginia Institute of Marine Science Gloucester Point, Virginia
Mr. James Kerwin	Patuxent Wildlife Center, Laurel, Maryland
Dr. Donald Lear	Environmental Protection Agency, Annapolis, Maryland
Mr. Robert Lippson	National Marine Fisheries Service, Oxford, Maryland
Dr. Frank Maturo	University of Florida, Gainesville, Florida
Ms. Patricia Orris	University of Maryland, College Park, Maryland
Dr. Franklyn Ott	Virginia Institute of Marine Science Gloucester Point, Virginia
Mr. Charles Rawls	Chesapeake Biological Laboratory, Solomons, Maryalnd

Dr. Colin Rees	University of Maryland, College Park, Maryland
Mr. William Shaw	National Marine Fisheries Service, Oxford, Maryland
Dr. Eugene Small	University of Maryland, College Park, Maryland
Dr. Victor Sprague	Chesapeake Biological Laboratory, Solomons, Maryland
Dr. Stephen Sulkin	Chesapeake Biological Laboraotry, Solomons, Maryland
Dr. Frank Schwartz	University of North Carolina, Morehead City, N. C.
Mr. W. Van Engel	Virginia Institute of Marine Science Gloucester Point, Virginia
Dr. Marvin Wass	Virginia Institute of Marine Science Gloucester Point, Virginia
Dr. Austin Williams	Smithsonian Institution, Commerce Department, Washington, D.C.

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The Chesapeake Research Consortium is attempting to further summarize knowledge on the condition of the biota of the Chesapeake Bay by continuing the program under the sponsorship of the U. S. Army Corps of Engineers. You may recall, and probably participated in the first comprehensive efforts which were published in a special supplemental issue of Chesapeake Science.

As a further aid to future resource management programs of the Bay, we are presently attempting to compile a list of "important" species as far as our present knowledge will permit. Realizing that such a list in many instances is a result of subjective opinions, we would like to gain the benefit of your expertise on a particular group of organisms.

The enclosed form lists species from a particular phylum or group of organisms with which we think you are quite familiar. These are species we believed should be considered as important. If in your opinion they do not meet the criteria for importance within the Bay system, then eliminate them from the list. If other species should be considered, then please add them in the spaces provided.

Included on the form is a list of 15 very general criteria, some of which are prerequisites for "importance" while others were included to gain the benefit of your knowledge of the species. Would you please evaluate the species on the list, and any species you might add, according to these characteristics? Many of these categories do not apply to your particular group since we have tried to use one form for all groups of organisms. We hope that evaluation according to the brief key shown on the form will not require an undue amount of time.

Any assistance you may be able to give us on this undertaking will be appreciated, and you will receive proper acknowledgment in all forthcoming reports. Thank you for the benefit of your experience and the valuable time you are able to afford us for this request. If for some reason you are not able to complete the form, would you please pass it on to one of your colleagues whom you feel would be similarly qualified?

Sincerely,

Hayes T. Pfitzenmeyer
Research Associate

enc.

IMPORTANT BAY SPECIES

Compiled by ______________________ Phylum or group ______________________

______________________ ______________________

______________________ ______________________

Key:

+ = Yes

- = No

0 = No info available

1.	Commercial species										
2.	A sport species										
3.	Predator of a commercial or sport species										
4.	Food for a commercial or sport species										
5.	Damaging to human interests or activities										
6.	Indicator of presence of pollutants										
7.	Human influence detrimental										
8.	A significant biomass at some trophic level										
9.	Critical link in energy flow in food chain										
10.	Seasonal in ecological significance										
11.	An eruptive species										
12.	Wide geographic distribution										
13.	Narrowly defined habitat										
14.	Migratory										
15.	Can be cultured in controlled environment										

IMPORTANT CHESAPEAKE BAY SPECIES

Common Name	Scientific Name	Importance
	Algae	
Blue-green alga	*Anacystis* spp.	Nuisance
Diatom	*Skeletonema costatum*	Food chain
Diatom	*Rhizosolenia* spp.	Food chain
Diatom	*Nitzschia* spp.	Food chain
Diatom	*Chaetoceras* spp.	Food chain
Dinoflagellate	*Polykrikos kofoidi*	Toxic
Dinoflagellate	*Cochlodinium heterolobatum*	Toxic
Dinoflagellate	*Gymnodinium splendens*	Toxic
Sea lettuce	*Ulva lactuca*	Nuisance
Green alga	*Enteromorpha* spp.	Nuisance
Red alga	*Agardhiella tenera*	Cover
	Vascular Plants (Marsh and aquatic)	
Widgeongrass	*Ruppia maritima*	Food chain
Cordgrass	*Spartina alterniflora*	Food chain
Eelgrass	*Zostera marina*	Food chain
Horned pondweed	*Zannichellia palustris*	Food chain
Wild rice	*Zizania aquatica*	Food chain
Cattails	*Typha* spp.	Cover
Pondweeds	*Potamogeton* spp.	Food chain
Arrow-arum	*Peltandra virginica*	Food chain
Wild celery	*Vallisneria spiralis*	Food chain
	Cnidaria	
Stinging nettle	*Chrysaora quinquecirrha*	Nuisance
Hydroid	*Sertularia argentea*	Nuisance
	Ctenophora (comb jellies)	
Comb jelly	*Mnemiopsis leidyi*	Predator
Comb jelly	*Beroe ovata*	Predator

Common Name	Scientific Name	Importance
	Platyhelminthes (flatworms)	
Flatworm	Stylochus ellipticus	Predator
	Annelida (Worms)	
Bloodworm	Glycera spp.	Food chain
Polychaete worm	Nephtys spp.	Detrital breakdown
Clam worm	Nereis succinea	Food chain
Polychaete worm	Paraprionospio pinnata	Detrital breakdown
Polychaete worm	Scolecolepides viridis	Food chain
Polychaete worm	Polydora ligni	Nuisance
Oligochaete worm	Limnodrilus spp.	Detrital breakdown
	Mollusca (Shellfish)	
Eelgrass snail	Bittium varium	Food chain
Oyster drill	Urosalpinx cinerea	Predator
Marsh periwinkle	Littorina irrorata	Food chain
Hooked mussel	Brachidontes recurvus	Food chain
Ribbed mussel	Modiolus demissus	Food chain
Oyster	Crassostrea virginica	Commercial
Hard shell clam	Mercenaria mercenaria	Commercial
Coot clam	Mulinia lateralis	Food chain
Brackish water clam	Rangia cuneata	Food chain
Balthic macoma	Macoma balthica	Food chain
Stout razor clam	Tagelus plebius	Food chain
Razor clam	Ensis directus	Food chain
Soft shell clam	Mya arenaria	Commercial
Asiatic clam	Corbicula manilensis	Nuisance
	Arthropoda (Crabs, shrimp, and other crustaceans)	
Barnacle	Balanus eburneus	Nuisance
Copepod	Eurytemora affinis	Food chain
Copepod	Acartia spp.	Food chain
Opposum shrimp	Neomysis americana	Food chain
Cumacean	Leucon americanus	Food chain

Common Name	Scientific Name	Importance
	Arthropoda (Continued)	
Isopod	*Cyathura polita*	Food chain
Isopod	*Paracerceis caudatum*	Food chain
Amphipod	*Ampithoe longimana*	Food chain
Amphipod	*Ampelisca* spp.	Food chain
Amphipod	*Corophium* spp.	Food chain
Amphipod	*Leptocheirus plumulosus*	Food chain
Amphipod	*Gammarus* spp.	Food chain
Sand flea	*Talorchestia longicornis*	Detrital breakdown
Grass shrimp	*Palaemonetes pugio*	Food chain
Sand shrimp	*Crangon septemspinosa*	Food chain
Xanthid crab	*Neopanope sayi*	Scavenger
Xanthid crab	*Rhithropanopeus harrisii*	Scavenger
Blue crab	*Callinectes sapidus*	Commercial
	Urochordata	
Sea squirt	*Molgula manhattensis*	Nuisance
	Pisces (Fish)	
Cownose ray	*Rhinoptera bonasus*	Predator
Eel	*Anguilla rostrata*	Commercial
Shad, herring	*Alosa* spp.	Commercial
Menhaden	*Brevoortia tyrannus*	Commercial
Anchovy	*Anchoa mitchilli*	Food chain
Variegated minnow	*Cyprinodon variegatus*	Food chain
Catfish, bullheads	*Ictalurus* spp.	Commercial
Hogchoker	*Trinectes maculatus*	Predator
Killifish	*Fundulus* spp.	Food chain
Silverside	*Menidia menidia*	Food chain
White perch	*Morone americana*	Commercial
Striped bass	*Morone saxatilis*	Commercial
Black sea bass	*Centropristis striata*	Commercial
Weakfish	*Cynoscion regalis*	Commercial
Spot	*Leiostomus xanthurus*	Commercial
Blenny	*Chasmodes bosquianus*	Food chain
Goby	*Gobiosoma* spp.	Food chain
Harvestfish	*Peprilus paru*	Predator

Common Name	Scientific Name	Importance
	Pisces (Fish) (Continued)	
Flounder	*Paralichthys dentatus*	Commercial
Northern puffer	*Sphoeroides maculatus*	Commercial
Oyster toadfish	*Opsanus tau*	Predator
	Reptiles	
Snapping turtle	*Chelydra s. serpentina*	Commercial
Diamond-backed terrapin	*Malaclemys t. terrapin*	Commercial
	Aves (Birds)	
Horned grebe	*Podiceps auritus*	Protected
Cattle egret	*Bubulcus ibis*	Protected
Great blue heron	*Ardea herodias*	Protected
Glossy ibis	*Plegadis falcinellus*	Protected
Whistling swan	*Olor columbianus*	Protected
Canada goose	*Branta canadensis*	Game
Wood duck	*Aix sponsa*	Game
Black duck	*Anas acuta*	Game
Canvasback	*Aythya valisineria*	Game
Lesser scaup	*Aythya affinis*	Game
Bufflehead	*Bucephala albeola*	Game
Osprey	*Pandion haliaetus*	Protected
Clapper rail	*Rallus longirostris*	Game
Virginia rail	*Rallus limicola*	Game
American coot	*Fulica americana*	Game
American woodcock	*Philohela minor*	Game
Common snipe	*Capella gallinago*	Game
Semipalmated sandpiper	*Ereunetes pusillus*	Protected
Laughing gull	*Larus atricilla*	Protected
Herring gull	*Larus argentatus*	Protected
Great black-backed gull	*Larus marinus*	Protected
Forster's tern	*Sterna forsteri*	Protected
Least tern	*Sterna albifrons*	Protected

Common Name	Scientific Name	Importance
	Mammalia (Mammals)	
Beaver	Castor canadensis	Commercial
Muskrat	Ondatra zibethicus	Commercial
Mink	Mustela vison mink	Commercial
Otter	Lutra canadensis	Commercial
Raccoon	Procyon lotor	Commercial
White-tailed deer	Odocoileus virginianus	Game

Endangered species

Shortnose sturgeon Acipenser brevirostrum. Potomac River.

Atlantic sturgeon Acipenser oxyrhynchus. Anadromous, juveniles estuarine all year.

Maryland darter Etheostoma sellare. Endemic to Swan Creek, near Havre de Grace.

Southern bald eagle Haliaetus leucocephalus leucocephalus. Generally decreasing.

American peregrine falcon Falco peregrinus anatum. Decreasing, extirpated as a breeding bird in Eastern U. S.

Ipswich sparrow Ammodramus sandwichensis princeps. Rare dune nester; winters in Virginia.

Delmarva fox squirrel Sciurus niger cinereus. Occurs only on Eastern Shore of Maryland, mostly in counties bordering Chesapeake Bay. Endangered by development.

Category: Lower Plants

*In order to save space, numbers are used for citations in this summary - Editor

Common Name: Diatom

Inventory Prepared by:

Daniel E. Terlizzi
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Solomons, Maryland

Classification

Phylum: Chrysophyta
Class: Bacillariophyceae
Order: Centrales
Family: Chaetoceraceae
Genus: Chaetocerus (Ehrenberg, 1844)
Species: Griffith (2) described 23 species.
Present review of literature indicates 43 species (Table 1)

Distribution

Known range: Cosmopolitan
Distribution in Chesapeake Bay: Poole's Island to mouth of Bay extending over Continental Shelf.

Population

Reproduction (see generic description)

Life Stages

Physical appearance: Cells with oval section to almost or rarely completely circular in valve view; in broad girdle view quandrangular with straight sides and concave, flat, or slightly convex ends. Valve with a more or less flat end surface or valve surface and a cylindrical part or valve mantle which are bound together without a seam. A long thick or thin seta, bristle or awn, at each end of the long or apical axis of the valve on the corners. The opposite setae of neighboring cells touch one another near their origin, usually directly or sometimes by a bridge, and fuse firmly at a point near their base holding the cells in chains, usually with large or small apertures or foramina between the cells. Basal portion of the setae parallel to the pervalvar axis, or directed diagonally outward with the outer portion frequently perpendicular to the axis of the chain. In most species, the length of the chain is limited by the formation of special end cells, terminal setae, usually shorter and thicker and more nearly parallel to the chain axis than the others. In relatively few species are cells solitary.

Table 1. Literature summary of <u>Chaetocerós</u> sp. in Chesapeake Bay, showing species, distribution, and month of observation.

Species	Locality	Source	MONTHS											
			J	F	M	A	M	J	J	A	S	O	N	D
C. aequatorialis	Lower Bay	7				x								
C. affinis	Lower Bay	7	x	x	x		x	x	x	x	x	x	x	
	Patuxent R.	8	Rare											
	Lower Bay	9			x		x		x	x				
	Lower Bay	5			x			x	x	x	x	x	x	
	Calvert Cliffs	5							x	x	x	x	x	
	Mouth of Bay	10		x					x	x	x	x	x	x
	Calvert Cliffs to Lower Bay	11	Not available											
C. atlanticus	Lower Bay	5			x	x				x		x	x	
	Mouth of Bay	10			x							x	x	
C. borealis	Lower Bay	5			x	x			x	x				
	Mouth of Bay	10		x	x								x	
C. brevis	Patuxent R.	8	Rare											
	Lower Bay	6	Not available											
C. ceratosporus	Lower Bay	8	Rare											

Table 1 (Continued)

Species	Locality	Source	MONTHS											
			J	F	M	A	M	J	J	A	S	O	N	D
C. ceratosporus	Lower Bay	7	x											
C. coarctatus	Lower Bay	5										x		
	Lower Bay	5										x		
	Mouth of Bay	10										x		
C. compressus	Lower Bay	7	x	x	x	x			x	x	x	x	x	x
	Lower Bay	9	x			x	x	x	x	x	x	x	x	x
	Lower Bay	6	Not available											
	Lower Bay	5			x	x		x	x	x	x	x	x	
	Calvert Cliffs	5		x			x	x			x	x		
	Mouth of Bay	10	x	x								x	x	x
C. concavicornis	Lower Bay	5							x	x			x	
	Mouth of Bay	10	x	x										
C. constrictus	Patuxent R.	8	Rare											
	Lower Bay	7									x	x		
	Lower Bay	9						x						

Table 1 (Continued)

Species	Locality	Source	J	F	M	A	M	J	J	A	S	O	N	D
			MONTHS											
C. convolutus	Patuxent R.	8	Summer											
	Lower Bay	5				x						x		
	Mouth of Bay	10										x		
C. curvisetus	Lower Bay	7	x	x		x				x			x	
	Lower Bay	9						x						
		12	Not available											
	Mouth of Bay	10	x											
C. dadayi	Lower Bay	9							x					
C. danicus	Patuxent R.	8	Rare											
	Lower Bay	7	x			x		x	x			x	x	x
	Lower Bay	9	x	x	x		x	x	x		x	x	x	
	Mouth of Bay	10		x	x							x	x	
C. debilis	Patuxent R.	8	Rare											
	Lower Bay	9											x	x
	Lower Bay	5				x								
	Mouth of Bay	10				x								

Table 1 (Continued)

Species	Locality	Source	MONTHS J	F	M	A	M	J	J	A	S	O	N	D
C. decipiens	Patuxent R.	8	Autumn											
	Lower Bay	7	x		x	x				x		x		
	Lower Bay	9			x	x				x	x			
	Lower Bay	6	x											
	Lower Bay	5			x	x		x	x	x	x	x	x	
	Calvert Cliffs	5		x				x	x	x		x	x	
		12	Not available											
	Mouth of Bay	10	x	x	x							x	x	x
	Calvert Cliffs to mouth of Bay	11	Not available											
		12												
C. densus	Lower Bay	7	x							x				
	Lower Bay	5			x	x			x		x		x	
	Calvert Cliffs	7			x						x	x	x	x
	Mouth of Bay	10	x		x						x	x	x	
C. didymus	Patuxent R.	8	Rare											
	Lower Bay	7	x			x		x	x	x	x	x	x	

Table 1 (Continued)

Species	Locality	Source	J	F	M	A	M	J	J	A	S	O	N	D
			MONTHS											
C. didymus	Lower Bay	9	x	x	x	x						x		
	Lower Bay	5				x	x		x		x		x	
	Mouth of Bay	10	x	x	x							x	x	x
C. eibenii	Patuxent R.	8	Rare											
	Lower Bay	5			x			x		x	x		x	
	Mouth of Bay	10										x	x	x
C. filiformis	Lower Bay	7								x		x		
C. fragilis	Lower Bay	9	x							x				
C. gracilis	Patuxent R.	8	Spring											
	Lower Bay	7	x	x	x	x							x	
C. laciniosus	Lower Bay	9						x	x					
	Lower Bay	5			x				x	x		x		
	Calvert Cliffs	5		x	x									
	Mouth of Bay	10			x							x	x	
C. lorenzianus	Lower Bay	7				x		x	x	x	x	x	x	x
	Lower Bay	9						x	x	x	x			

Table 1 (Continued)

Species	Locality	Source	J	F	M	A	M	J	J	A	S	O	N	D
			MONTHS											
C. lorenzianus	Lower Bay	5											x	
	Calvert Cliffs	5			x							x	x	
C. messanensis	Mouth of Bay	10										x	x	
C. mitra	Mouth of Bay	10		x										
C. peruvianus	Lower Bay	7	x	x	x	x	x	x		x	x	x	x	x
	Lower Bay	9	x	x	x		x	x	x		x	x	x	
	Lower Bay	6	Not available											
	Lower Bay	5								x			x	
	Calvert Cliffs	5		x	x		x	x	x	x	x	x	x	x
	Mouth of Bay	10	x	x					x			x	x	
		12	Not available											
C. pseudocurvisetus	Lower Bay	9		x	x							x		
	Mouth of Bay	10										x	x	
	Lower Bay	5									x		x	
C. pseudocrinitus	Patuxent R.	8	Rare											
C. pendulus		12	Not available											

Table 1 (Continued)

Species	Locality	Source	J	F	M	A	M	J	J	A	S	O	N	D
			MONTHS											
C. pendulus	Pooles Island to mouth of Bay	11	Not available											
C. radicans	Lower Bay	5				x								
	Mouth of Bay	10			x							x		
C. ralfsii		12	Not available											
C. rostratus	Lower Bay	6								x	x		x	
	Mouth of Bay	10							x			x	x	x
C. septentrionalis	Patuxent R.	8	Rare											
	Lower Bay	7	x		x	x								
C. similis	Lower Bay	7	x	x	x								x	x
	Lower Bay	9				x								
	Lower Bay	5			x									
	Calvert Cliffs	5		x	x		x							
	Mouth of Bay	10	x		x									
C. simplex	Calvert Cliffs	5										x		
C. socialis	Patuxent R.	8									Autumn			
	Lower Bay	7	x			x								

Table 1 (Continued)

Species	Locality	Source	J	F	M	A	M	J	J	A	S	O	N	D
			MONTHS											
C. socialis	Calvert Cliffs	5										x	x	x
C. subsecundis	Lower Bay	9						x			?			
C. subtilis	Patuxent R.	8	Rare											
	Lower Bay	7	x					x	x	x	x	x	x	
	Lower Bay	9	x				x	x	x		x	x	x	x
	Lower Bay	6	Not available											
	Lower Bay	5			x				x	x		x		
	Calvert Cliffs	5		x	x			x	x	x	x			
C. seiracanthus		1	Not available											
C. teres	Patuxent R.	8	Rare											
	Lower Bay	9							x					
		12	Not available											
	Mouth of Bay	10										x		
C. wighami	Patuxent R.	8	Rare											
		1	Not available											

Cell wall formed of two valves and one or two girdle bands. Two frequently unequally developed girdle bands always present in most species. Intercalary bands present in some species, usually difficult to see without special preparations.

Cytoplasm either forms a thin layer along the cell wall or fills the greater part of the cell. Nucleus against the cell wall or central. Chromatophores vary greatly in number, size, form, and position in different species; may be one to several, small or large, but are constant for a given species and consequently indispensable for species demarcation. In many species, pyrenoids are distinctly visible.

Resting spores formed in most neritic species. Only one spore formed in a vegetative cell, usually in cylindrical part near the girdle band of the mother cell, in some species near the cell end. Free ends of spores often armed with spines or spicules. Each spore with two valves, but only primary valve provided with a valve mantle. Younger resting spores often smooth. If spore lies near end of cell, one valve may be in common with that of mother cell, with valve mantle rudimentary and setae shorter and thicker than in vegetative cells. Such spores always in pairs; formed in adjacent cells simultaneously.

Auxospores known in only a few species. Contents of cell empty laterally and form a large globule or bladder within which the new daughter cell is formed.

Microspores known in several species. Formed by repeated divisions of nucleus and cytoplast. Contain organized chromatophores. Locomotion observed in some species.

Great variations may be observed in chains of the same species from different localities and at different times of the year, Cupp (1943).

Ecology

Habitat (physical/chemical)

Salinity range: No entirely freshwater species known (Cupp, 1943). Cosmopolitan distribution in oceans and estuaries indicates tolerance of euryhaline conditions at least for some species.

Temperature range: Variable within genus. Mulford (1972) observed _C. socialis_ as an autumn-winter species. _C. subtilis_ was observed during the warmer months, and _C. affinis_ was observed from May to December.

Importance

Size: Although Van Valkenburg and Flemer (In press) have reported nannoplankton to be responsible for the bulk of carbon fixation in the Bay, the genus Chaetoceros is often reported as a dominant in the "net phytoplankton," (Mulford 1972; Mulford and Norcross 1971; Marshall 1967). Its contribution is therefore significant.

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Category: Invertebrates

Common Name: Silver hydroid (edit. suggestion), "grass" by watermen; "white weed" in England.

Inventory Prepared by: D. G. Cargo
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Solomons, Maryland

Classification:

Phylum: Cnidaria
Class: Hydrozoa
Order: Leptomedusae
Family: Sertulariidae
Species: *Sertularia argentea* L.

Distribution

Known range: Arctic Ocean to North Carolina and Louisiana (Calder, 1971).

Distribution: Lower Bay and tributaries (Clark, 1882; Fraser, 1944).

Occurrence elsewhere: Extends into mid and upper Bay areas (personal observation).

Population

Abundance: Abundant on a variety of substrates, shells, rocks, crustaceans, annelid tubes, barnacle shells (Calder, 1971).

Affecting factors: Temperature - annual

Reproduction:

Method: Separate ♂ and ♀ colonies exist. Sexual breeding in summer produces planulae. Hydroids 70 mm and larger were able to breed.

Seasons: gonophores - Nov. to May (Calder, 1971)
gonangia - in summer, June-August (Hancock et al., 1956)

Fecundity: 100% of colonies breed in peak summer spawning (Hancock et al., 1956)

Life Stages

Early stages

Early stages (Continued)

Physical features: Planulae .5 mm long, blunt anterior end (Hancock et al., 1956)

Development: Settled planulae reached polyp stage in 12 days. Growth: .3-1.3 mm/day in quite young colonies in summer. .2-mm/day for older colonies in winter (Hancock et al., 1956).

Survival: Regeneration possible at all levels in hydrothecae (Hancock et al., 1956)

Behavior: Planulae do not swim near surface - swim near bottom. Swim 2-3 days.

Adult stage

Physical appearance: Calder (1971) gives an explicit description: "Colony consisting of a monosiphonic hydrocaulus reaching 35 cm or more high, branches arising from all sides in a regular arrangement. Branches dichotomous with a hydrotheca in each axil. Hydrotheca sessile, alternate quite distant, fusiform, being widest in the middle somewhat less than half of the adcauline wall; free, distal portion curved gradually outward, but hydrothecae facing upward. Operculum of two valves, 2 prominent teeth, abcauline caecum present. Gonophores fixed, gonothecae arising from the upper surface of the branches near the base of the hydrothecae; arrow shaped with one or two prominent shoulder spines distally and a short collar bordering the terminal opening."

Survival: Temperature - regresses in summer, resurges when temperature drops to 20°C and below from old growth. Growth rapid (Calder, 1971).

Ecology

Habitat

Physical/chemical

Substrate: Sandy or shelly bottom

Salinity range: Meso-polyhaline (Wass, 1972)

Associated communities: Serpulid polychaetes, sand dollars, sea urchins (Calder, 1971)

Food Requirements

Food: Minute animal material; protozoans, dinoflagellates, planktonic organisms.

Consumers

Natural predators: Hancock, et al (1956) observed *Idulia* on *Sertularia* in England, but did not see it feeding on the hydroid. However, Browne (1907) observed *Tergipes* grazing on *Syncoryne*.

Man: "White weed" industry prominent in Thames estuary of England. Hydroid is processed and dyed to use decoratively, mainly in the United States. Fishery concentrated in Thames estuary (Hancock, et al., 1956).

Non-nutritional Roles

Competition: *Membranipora* encrusts fronds. Other hydroids may attach to it. Peritrichous ciliates are abundant on it. Developing bivalve larvae find it a haven (Hancock et al., 1956).

Protection: Furnishes cover and food for gastropods and crustacea.

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Category: Invertebrates

Common Name: Green anemone (editor)

Inventory Prepared by:

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Department of Biology
Florida State University
Tallahassee, Florida

Classification: Original description with subsequent revisions according to taxonomic review in Hand (1955).

Phylum:	Cnidaria
Class:	Anthozoa
Order:	Actinaria
Suborder:	Nynantheae
Tribe:	Thenaria
Subtribe:	Acontiaria
Family:	Diadumenidae
Species:	*Diadumene leucolena* (Verrill, 1866)

Distribution

Known range: Cape Cod Bay to Beaufort, N. C.; San Francisco Bay area

Distribution: In Chesapeake Bay; generally abundant in the poly- and mesohaline regions of the Chesapeake Bay, extending from the mouth of the bay north to the Severn River area, salinity patterns permitting.

Population

Density: Population densities vary seasonally; peak densities can be as high as 2000 individuals per square meter (Minasian, unpublished).

Dynamics

Trends and fluctuations: Peak settlement of these anemones occurs during the summer in the Patuxent River estuary (Cory, 1967). Population abundance may peak during the autumn months prior to a precipitious decline in temperature (Minasian, unpublished).

Affecting factors: Population abundances are dependent upon seasonal trends in temperature and salinity.

Reproduction

Method: Dioecious; fertilization is internal, although external fertilization may also occur. Planulae are sometimes visible within the maternal coelenteron

Method (Continued)

(Mecca, 1969). Asexual reproduction is by budding and longitudinal fission, according to Mecca (1969).

Seasons: Sexual reproduction in the Chesapeake Bay occurs during the summer months. If a group of anemones is kept in the laboratory at this time, individual females may release clutches of eggs, usually already fertilized, within a day or two (Minasian, unpublished). Cory's (1967) project also showed settlement of _D. leucolena_ larvae to be heaviest during the summer season.

Fecundity: Individual females may release several hundred eggs.

Life Stages

Early stages: Eggs show cleavage patterns soon, if not immediately, after being released. A coeloblastula results, which invaginates to form a gastrula. The planula stage is reached in about two days. The planulae of this anemone swim actively by means of cilia, and possess an obvious apical tuft of very long cilia (flagella?) at the aboral end, which contacts the substratum in settlement. The planula has a well developed stomodeum and gut, but is not known to feed during its brief existence in the plankton.

Adult stage: Mature adults may vary in size, but large individuals are 20 - 25 mm in length, with a diameter of 8 - 12 mm. When expanded, the length of the column may be four to six times its diameter (Hand, 1955). Cinclides, holes in the body wall through which the acontia are extruded, are present on the upper part of the column. There are usually four to six cycles of tentacles, numbering over 200 in larger animals. Individual tentacles are filiform, and as long as 2 cm. Inner tentacles are longer than outer ones (Hand, 1955). A single "catch tentacle", about 4 cm long, is present on a few individuals. About 8% of the specimens of _D. leucolena_ at Solomons Is., Md. possess this catch tentacle (Mecca, 1969). These anemones vary in color from a vary pale pink to various shades of green. The green color is due to the presence of a gastrodermal algal endosymbiont.

During the winter months, these anemones are quiescent, fully contracted, and covered by a secreted mucous film and surface growth (Mecca, 1969). This dormant condition is described as "encystment" by Sassaman and Mangum (1970).

Ecology

Physical/chemical

Classification: *D. leucolena* is a brackish-water form, and is most abundant at estuarine salinities. It is epifaunal, the most typical substrate being oyster shells.

Salinity range: *D. leucolena* shows at least 50% survival in salinities ranging from 6 - 33‰ (Pierce and Minasian, 1974).

Temperature range: Sassaman and Mangum (1970) found that exposure to a water temperature of 40°C for more than 2 hours is lethal for this species. At the opposite extreme, *D. leucolena* withstands low water temperatures near the freezing point.

Dissolved oxygen range: *D. leucolena* is sensitive to low O_2 concentrations, which are lethal in less than 24 hours. According to Sassaman and Mangum (1973), this anemone consumes all available O_2 in solution, and then shuts down its O_2 uptake when the environmental O_2 concentration falls to 2 ppm. Beattie (1971) found no metabolic adjustments in *D. leucolena* which could indicate anaerobic function.

Associated communities: This anemone is one of the primary organisms which exists as part of the oyster (*C. virginica*) community in the Chesapeake Bay.

Food Requirements

Food: *D. leucolena* is known to prey upon any organisms of suitable size, ranging from zooplankters to polychaetes. Thus, it is a consumer, showing several possible trophic relationships.

Feeding: *D. leucolena* feeds in the typical manner of all coelenterate predators: by seizing the prey with specialized microscopic organelles called nematocysts. Nematocysts entangle, adhere to, and puncture the prey tissues while injecting a toxin. Subsequent tentacular movement and ciliary currents function in ingestion. *D. leucolena* has three different nematocyst types, with two additional, different nematocyst types on the catch tentacle, if present (Hand, 1955).

Consumers

Natural predators: The most probable predators of *D. leucolena* are fish which graze on epifauna of the oyster

Natural predators (Continued)
community, and certain predaceous gastropods (e.g. Epitoniidae, Pyramidellidae).

Non-nutritional Role

Competition: *D. leucolena* is in competition for space with certain other epifaunal species, especially hydroids and bryozoans.

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Category: Invertebrates

Common Names: Bloodworm, beakthrower, bloods

Inventory Prepared by: Hayes T. Pfitzenmeyer
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Solomons, Maryland

Classification

Phylum:	Annelida
Class:	Polychaeta
Order:	Eunicida
Family:	Glyceridae
Species:	*Glycera dibranchiata* Ehlers
Other species:	*G. capitata*, *G. americana* and *G. robusta*

Distribution

Known range: Gulf of St. Lawrence to Florida, Gulf of Mexico (Florida, Texas); central California to Lower California and Mexico (Pettibone 1963).

Distribution in Chesapeake Bay: Probably limited to saline areas 13 to 15 o/oo. Species disappeared in mid-bay areas after salinity decline as a result of hurricane in June 1972.

Population

Structure: Female to male ratio, 1.24:1 (Creaser 1973)

Density: Variable, 18-220/m^2 (Wass 1972).

Dynamics

Trends and fluctuations: Very variable, may be long-term or short-term, year to year fluctuations.

Affecting factors: Changes in physical characteristics of mud flats in Canada. Populations in Chesapeake Bay are very variable. Yearly fluctuations appear related to changes in salinity pattern.

Reproduction

Method: Sexually mature worms, epitokes, emerge from sediment and swim to water surface. Males emit sperm from posterior end while swimming at surface. Body wall of females ruptured near the posterior one third of worm and eggs liberated. All worms probably die after spawning. Remaining cuticle and atrophical organs called "ghost worm."

Reproduction (Continued)

Seasons and conditions: Spawning begins in June at 13-14°C, and is completed by August in Maine. Began 2 hrs before high water and continued during high tide. Possibly two breeding seasons per year in Maryland - June-July, and again in November-December (Simpson 1962).

Fecundity: Worm 22-24 cm may contain 1.5-2.0 million eggs (Canada), whereas in Maine it would contain 3.0-3.5 million. Become sexually mature and spawn as 3-yr olds (Klawe and Dickie 1957).

Life Stages

Early stages

Physical appearance: Swimming blastulae develop after about 22 hrs, and at 32 hrs the trochlear ring is formed. At this stage, the larvae alternate short periods of rest on bottom with vigorous swimming. Pelagic larvae soon elongate and the buccal aperature becomes strongly ciliated (Klawe and Dickie 1957).

Development: Smallest specimens found in Canada were 3 cm long and suggest these were probably 1 yr of age. Late larval and post larval stages were not found. Three-yr olds are 21 to 29 cm, 4-yr olds average 31 cm.

Survival: Changes in habitat, especially bottom types, affect commercial abundance.

Behavior: Larvae believed not pelagic in all stages since none were collected in plankton tows (Klawe and Dickie 1957).

Adult stage

Physical appearance: Length up to 370 mm. Width up to 11 mm. Segments up to 300. Parapodia with 2 sharply conical presetal lobes throughout the length of the body. Two shorter, bluntly conical postsetal lobes in the anterior region, the upper being shorter and rounded; the lower one longer and bluntly conical; in the middle region the 2 postsetal lobes are both bluntly conical, the upper one shorter than the lower one. In the posterior parapodia there may be a single rounded postsetal lobe with a conical tip. Branchiae 2, digitiform to ligulate, nonretractile; the upper one occurs between the dorsal cirrus and notopodium; the lower one occurs anterior to the ventral cirrus; they are thin

Physical appearance (Continued)

walled and contractile, with a thin layer of spiral muscle fibers. Proboscis with proboscidial organs are similar, small, conical, flattened, with a central core and surface marked with oblique furrows.(Pettibone 1963). Vascular system lacking, but have corpuscles containing hemoglobin in the coelomic (body cavity) fluid.

Development: Mean lengths of potential male and female spawners between 32 and 36 cm. (3-4 yrs) (Maine); spawning worm length is 14-20 cm in Maryland.

Survival: Maximum age - 5 yrs in Maine. Growth apparently does not occur during June to August.

Behavior: Perform lateral movement in sediments. Apparently emerge from sediments only during period of spawning activity.

Ecology

Habitat (Physical/chemical)

Substrate: Typical flat consists of soft dark mud about 12 inches in deep over hard, dark gray, mud-sand mixture (Canada).

Salinity range: Lower limit probably 10 o/oo

Temperature range: Summer temperatures probably critical since no growth takes place.

Depth/pressure: Near high tide line on beach to 100 fathoms.

Associated communities: Common in eelgrass communities (Wass 1972), and sand bottom communities.

Food Requirements: Organic detritus feeders. Rarely found in clear, sandy soils.

Consumers

Natural predators: Herring gulls and striped bass consume large numbers when the worms are pelagic during spawning.

Man: Bait-worm industry in Maine and Canada. In 1954 and 1955 annual landings of 4 million worms were valued at $40,000 to Canadian diggers. The 1970 production in Maine amounted to 808,186 lbs, valed at $1,381,676.

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Category: Invertebrates

Common Name: Coot clam, dwarf surf clam

Inventory Prepared by: Hayes T. Pfitzenmeyer
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Classification

Phylum: Mollusca
Class: Pelecypoda
Order: Eulamellibranchia
Family: Mactridae
Species: *Mulinia lateralis* (Say)

Distribution

Known range: Maine to northern Florida, south to Texas and Mexico.

Distribution in Chesapeake Bay

Areas of greatest density: Upper meso- and polyhaline (above 8 o/oo). Peak populations in silt areas but low reservoir populations apparently in nearshore sand (Wass, 1972).

Occurrence in other areas: Also found where salinity is less than 8 o/oo but populations are temporary.

Population

Structure: Sex ratio 50:50; maximum longevity appears to be 2 years.

Densities: In Tangier Sound 22,000/sq. m. (Wass, 1972)

Dynamics

Trends and fluctuations: Opportunistic species with highly variable densities.

Affecting factors: Ubiquitous set in sand and mud sediments of Pamlico River but adverse dissolved oxygen levels prevented permanent establishment in mud (Tenore, 1970).

Reproduction

Method: Sexes separate, eggs and sperm expelled into water mass where fertilization takes place at 16 to 20°C.

Behavior: Since it is a shallow burrowing species, it is subject to wind-wave action which oftentimes washes tremendous numbers in windrow along beaches.

Ecology

Habitat (Physical/chemical)

Substrate: Probably prefers sand bottoms but large numbers may be found in silt/clay sediments.

Salinity range: Usually above 8 o/oo but has been found as low as 5 o/oo.

Temperature range: No significant mortality at 21 to 27°C in early developmental stages; 90% of sensitive cleavage stages would be eliminated in 4 min. in water at 26 to 38°C (Kennedy *et al.*, 1974).

pH range: 7.25 to 8.25 (Calabrese and Davis, 1970).

Dissolved oxygen range: Tolerances unknown but mass mortalities in channel areas attributed to summer oxygen deficiencies.

Food Requirements

Food: A primary consumer which probably feeds on phytoplankton and detrital matter.

Feeding: Filter feeder which extends its siphon to water-sediment interface and pumps large quantities of water from which it extracts its food.

Consumers

Natural predators and parasites: Highly infested with digenetic trematode cercaria and metacercaria, *Cercaria imbecilla* and *granosa* (Gymnophallinae) Holliman (1961). Provides food for fish, starfish, oyster drills, and waterfowl (Calabrese, 1970).

Man: No direct value to man

Influence of Toxic Substances

Thermal shock: LC_{50} between 30 and 33°C for specimens acclimated between 2 and 25°C (Kennedy, 1971).

Other toxins: No information available in published literature on the influence of toxic substances. However, Pfitzenmeyer (1971) did not find *Mulinia* in a biological study of Baltimore Harbor, whereas they were abundant in the Chester River. It is believed that this species is sensitive to man-induced pollutants.

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Wass, M. L. et al. 1972. A checklist of the biota of lower Chesapeake Bay. Virginia Inst. Mar. Sci. Spec. Sci. Rept. No. 65, 290 p.

Category: Invertebrates

Common Name: Brackish-water clam (other proposed names have been marsh clam, Gulf clam and wedge clam - editor).

Inventory Prepared by: Hayes T. Pfitzenmeyer
Natural Resources Institute
University of Maryland
Solomons, Maryland

Classification

Phylum: Mollusca
Class: Pelecypoda
Order: Eulamellibranchia
Family: Mactridae
Species: *Rangia cuneata* Gray

Distribution

Known range: Pleistocene - New Jersey to northern South America; recent - Maryland to Mexico.

Distribution in Chesapeake Bay

Greatest density: Areas of most dense populations were first found in upper Potomac River in 1964 (Pfitzenmeyer and Drobeck). Large specimens taken in oligohaline part of James River in 1963; introduced in Rappahannock River later.

Occurrence elsewhere: Small populations are found in most major tributaries of Chesapeake Bay. Since low salinity conditions associated with storm AGNES in June 1972 were correlated with spawning season, populations may be found over a wide area. No established populations found in Patuxent or York rivers.

Population

Structure: Populations quite often made up of single year-class. Healthy populations should include several year-classes.

North Carolina and Maryland. (Average lengths).
1 yr. - 15 mm, 2 yrs. - 30 mm, 3 yrs. - 40 mm, 4 yrs. - 45 mm, 5 yrs. - 50 mm (Wolfe and Petteway, 1968).
Louisiana - 1 yr. - 15 mm, 2 yrs. - 20 mm, 3 yrs. - 24 mm.
Texas - 1 yr. - 19 mm, 2 yrs. - 31 mm, 3 yrs. - 41 mm, 4 yrs. - 48 mm, 5 yrs. - 51 mm.
Clams 5 to 7-year-old are up to 63-64 mm in length.

Reproduction (Continued)

Seasons and conditions: Spawning completed by end of Sept. or early Oct. in Long Island Sound. Some ripe clams found at all seasons, but gametogenesis most active mid-July through August (Calabrese, 1970). Shaw (1965) reported setting throughout summer (May to Nov.) in Maryland. Fall set in Pamlico River (Tenore, 1970).

Fecundity: Three to 4 million eggs produced at one spawning.

Life Stages

Early stages

Physical appearance: Larvae usually slightly pale or light. No apical flagellum or pigmented eyespots. Hinge undifferentiated except for faint irregularity at either end. Posterior ligament appears at about 200 u. Rounded umbos at 80-100 u; becoming higher and angular at 130-160 u; anterior end longer, slightly more pointed than posterior. Metamorphosis from 185 to 240 u (Chanley and Andrews, 1971).

Development: Larvae grew satisfactorily within salinity range from 20 to 30 or 32.5 o/oo; 25 o/oo optimum. Temperature range of satisfactory growth was from 20 to 30^{o}C; 27.5^{o}C optimum (Calabrese, 1969).

Survival: Maximum development of fertilized eggs to straight hinge larvae and maximum growth of larvae occur at 20 and 27^{o}C, respectively (Calabrese, 1969).

Adult stage

Physical appearance: Up to 20 mm in shell length. Beaks quite prominent and near the center of the shell and pointing toward each other. Exterior whitish to cream and smoothish except for a fairly distinct, radial ridge near the posterior end (Abbott, 1954).

Development: Life-span appears to be about 2 years. Overcrowding probably affects growth rate. Generation period approximately 60 days (Calabrese, 1969).

Survival: Large numbers of set can be found in soft bottoms of deep water (>25 ft) of Chesapeake Bay. These usually die-off following summer during oxygen depletion in these deep areas. Trematodes in various stages must have some effect since infections up to 100% have been observed.

Population (Continued)

Densities: Variable; maximum reported in upper Chesapeake Bay averaged 1,200 m^2. This was single year-class averaging 23 mm in shell length. Multi-aged populations average up to 600/m^2. Maximum length about 52 mm.

Dynamics

Trends and fluctuations: Spawning and setting not successful every year due to adverse environmental conditions. Prolonged salinities near 0 or above 15 o/oo are also detrimental. Winter kill is also a factor in northern range.

Affecting factors: Adult populations made up of single age-classes may be found in areas where salinities are between 1 and 15 o/oo. These may not all be breeding populations but were set and survived during periods when conditions were more optimal. A change in salinity, either up from near 0 or down from 15 o/oo is necessary to induce spawning (Cain, 1972).

Reproduction

Method: Sexes separate. Eggs and sperm expelled into water where fertilization takes place. Eggs 69 microns in diameter. Develop into veligers in 24 hrs., 75 to 130 microns long (Chanley, 1965).

Seasons and conditions: Spawning takes place in summer months when ambient temperature probably above 22°C. Spawning can be induced artificially by raising temperature a few degrees and/or raising the salinity up from near 1 o/oo or down from near 15 o/oo.

Fecundity: James River clams in 14-20 mm length group (1 yr.) had recognizable sex products (Cain, 1972). Adult may produce 1 to 3 million eggs.

Life Stages

Early stages

Physical appearance: Hinge teeth lacking; umbo round, inconspicuous. Straight-hinge line 55-60 u long. Height 5-10 u less than length. Umbo develops at 120-130 u. Larvae dark yellow, with a conspicuous apical flagellum in all pelagic stages. Larvae develop a foot and metamorphose at 160-175 u (Chanley, 1965). Set wider (20-30 u less than length) than all other species (Cain, 1972).

Early stages (Continued)

Development: Straight-hinge larvae stage is reached after 24 hours (75-175 u). Set occurs after 6 to 7 days as veliger larva (ave. 300 u). Rangia set are tolerant to temperature and salinity changes and grow at same rate up to 41 days (Hopkins et al., 1973).

Survival: Embryos and early larvae can survive best in salinities between 5 and 10 o/oo, and 20, 25, and 30°C (Cain, 1972).

Behavior: Recruitment of clams into marginal non-reproductive areas is by selective swimming or by passive transport of larvae in a water mass.

Adult stage

Physical appearance: Shell highly variable in size, 20 mm in length and depth to about 70 mm in length and 60 mm in depth, obliquely ovate, very thick and heavy. Exterior whitish but covered with a strong, smoothish, gray-brown periostracum. Interior glossy, white and with blue-gray tinge. Pallial sinus small, but moderately deep and distinct (Abbott, 1964).

Development: Maximum length of about 74 mm reached in approximately 10 years (Wolfe and Petteway, 1968). Largest size attained in lower salinities. Sand is more favorable substrate than clay-silt. High phosphate and high organic concentrations gave greater growth in sand (Tenore et al., 1968).

Survival: High densities of single year-classes often found. However, mass mortalities often occur as population exceeds food supply or encounters adverse seasonal factors.

Behavior: Natural position in bottom is with anterior-end pointing downward, siphon-end vertical with its tip just above sediment surface so umbones, lunule, and most of shell buried. No lateral movement, only vertical in sediment for purposes of burial (Fairbanks, 1963).

Ecology

Habitat (Physical/chemical)

Substrate: Greatest percentage found in sand, clay, and silt, in that order. High concentrations of organic matter and phosphates beneficial in sand but harmful in silt-clay (Tenore et al., 1968).

Salinity range: 1 o/oo to 15 o/oo, mainly oligohaline

Temperature range: 0.5 - 31.3°C - Maryland
2 - 40°C - Louisiana
4 - 35°C - Texas
30 - 35°C is critical range

Dissolved oxygen range: Consumption highest at 5 and 10 o/oo (Hopkins, 1973). Found in 5.36 to 13.22 mg/l (Cain, 1972).

Benthic composition:
Scolecolepides viridis
Cyathura polita
Corophium lacustre
Gammarus sp.
Macoma mitchelli
Brachidontes recurvus
Congeria leucophaeta
Chironomid larvae
Leptocheirus plumulosus
Nereis succinea

Turbidity/light: Commonly found in highly turbid environment.

Fluctuations effects: Short-term changes in salinity as a result of increases or decreases in freshwater inflow determine the success of recruitment.

Associated communities: Occupies the low salinity brackish-water zone which overlaps the typical freshwater community upstream and slightly overlaps the oyster bar community towards the seaward border (Hopkins *et al.*, 1973).

Food Requirements

Food: A filter-feeder which also utilizes detritus. Larvae grow well on mixture of unicellular algae, probably *Isochrysis* and *Monochrysis* (Chanley, 1965). *Dunaliella peircei* used as food in controlled experiments.

Consumers

Natural predators and parasites: Food for fishes, shrimps, crabs, and waterfowl. Trematode sporocysts and *cercaria* in gonads (Fairbanks, 1963), probably Fellodistomatidae and Bucephalidae.

Man: Shells utilized in place of gravel for roadbeds (Gooch, 1971). Also calcium carbonate in manufacturing of water purification apparatus. Meat used for food in North Carolina (Hopkins *et al.*, 1973).

Influence of Toxins

Heavy metals: Mercury, copper, and chromium are toxic to *Rangia* at all salinities. Copper was most toxic ion in freshwater and chromium a close second (Olson and Harrel, 1973).

Radionuclides: Concentrations of caesium-137 variable depending on rainfall and amount of potassium in water (Wolfe, 1967).

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Category: Invertebrates

Common Name: Copepod

Inventory Prepared by: Rogers Huff
Natural Resources Institute
University of Maryland
Solomons, Maryland

Classification

Phylum: Arthropoda
Class: Crustacea
Order: Copepoda
Suborder: Calanoida
Family: Temoridae
Species: Eurytemora affinis (Poppe, 1880)

Distribution

Known range: Northern Hemisphere. Coastal and estuarine waters of Eastern North America from the Gulf of St. Lawrence to the Florida Keys; the Baltic, North, and Caspian Seas, freshwater lakes in Central Asia and Eastern North America, and rivers and estuaries of the Gulf of Mexico.

Distribution in Chesapeake Bay: Entire Bay into freshwater tributaries. Present year-round in upper regions of brackish tributaries. In higher salinities (up to 20 o/oo) it occurs in significant numbers from January to May.

Population

Structure: Adult population usually predominantly male; up to 5:1 ratio. Age-group structure changes from overwintering adults and copepodites to predominantly naupliar stages in the late spring and summer.

Densities: Density ranges from 1,000 up to 3 x 10^6 per m^3, with highest populations recorded in sediment trap regions during March and April.

Dynamics: Numbers highest in late winter and early spring. Highest densities in tributaries and upper Bay.

Trends and fluctuations: Large, high-salinity winter population in years when Acartia clausi populations are low. Spring population peaks in low salinity succeeded rapidly with emergence of Acartia tonsa. Controlling factors are probably competition with, and possible predation by, Acartia spp., and predation by finfish and Neomysis americana in the spring months.

Reproduction

Method: Reproduction sexual. Male attaches spermatophore to urosome of female. Female carries eggs in a clutch until they hatch. Female requires fertilization before each clutch of eggs.

Seasons and conditions: Capable of reproduction from 2 to 26°C and at salinities ranging from 0 to 35 o/oo.

Fecundity: Egg clutches vary from 10 to over 100 eggs. Egg development time ranges from 12.5 days at 5°C to 1 day at 25°C. New clutch of eggs is immediately ready to be laid upon hatching or release of the previous clutch.

Life Stages

Stages of life cycle: Life stages 13, egg, six naupliar, and six copepodite. The final copepodite is the adult.

Early stages

Physical appearance: /See Davis (1943) - Larval stages of the calanoid copepod Eurytemora hirundoides./

Naupliar stage: Usual calanoid form. Approximately 2:1 length:width ratio. Living nauplii nearly colorless except for blue-red eye spot. Preserved specimens usually opaque. Distinguished by unequal development of caudal spines in Stages II through VI. Size range approximately .1 mm (Stage I) to .375 mm (Stage VI).

Copepodite stage: Division into cephalosome, metasome, and urosome; generally resembles adult form. Sexes separable by Stage IV. Length .475 mm to 1.275 mm to 1.275 mm (Stage V female).

Development: Duration of developmental stages equal at constant temperature. Stage I nauplius molts to Stage II within six hours at 20°C. Growth rates (days per stage) range from approximately 6 days at 5 C to 1 day at 25°C. Length and length-weight relation is dependent on food concentration.

Survival: Assumed to be nearly 100% in the absence of predation.

Behavior: Nauplii hatched free-swimming and independent of mother. Feeding begins with the development of mouth in the Stage II nauplii. Vertical migration data unavailable.

Adult stage (see Davis, 1943)

Physical appearance: Male 1.4-1.65 mm. Females 1.5-1.8 mm. Female with nine segments; male eleven. Adult has two sets of antennae, mandible, two sets of maxillae, maxilliped, four pairs of swimming legs, and sexually dimorphic fifth legs. Right first antennae modified for grasping in the male. Fifth legs asymmetrical and longer in the male. Fifth thoracic segment modified into pointed "wings" in the female and the first urosomal segment (genital) is swollen on the female.

Development: Little or no growth as adult. Animals maturing at higher rate due to higher temperature are smaller and of lower weight at all stages.

Survival: Mean survival time at 2°C over 3 months for females, 80 days for males. Decreases with increasing temperature. At 23.5°C adults live for 10-16 days. Mortality largely due to predation.

Behavior: Swim by several different techniques, using swimming legs, antennae and urosome for propulsion. Considered planktonic, but adults, particularly females, may be concentrated, clinging to litter and aquatic plants on the bottom. This behavior may partially account for the preponderance of males in plankton tows.

Ecology

Habitat

Physical/chemical habitat

Classification: Planktonic, true estuarine species.

Salinity range: Tolerates 0-35 o/oo.

Temperature range: Tolerates 1-30°C.

Dissolved oxygen range: Resistant to very low dissolved oxygen concentrations--as low as .04 ug/l.

Turbidity/light: Occurs under lighted and turbid conditions.

Depth/pressure: Essentially a shallow water species, but occurs at all depths in the Chesapeake Bay.

Effects of fluctuations: Range expands seaward with lowered salinity/temperature in winter and retreats with increasing temperature and salinity in spring. Reproduces most successfully at 5-15 o/oo salinity and up to 20°C. Growth rate higher than _Acartia tonsa_ below 12-15°C.

Food Requirements

Food: Herbivorous, grazing on phytoplankton. Large early spring blooms could not be supported by the existing phytoplankton populations. Animals are therefore acting as detritovores or feeding on protozoan and bacterial communities associated with detritus. Utilizes particles from 2-63 um. Feeding efficiency lower than in marine copepods.

Feeding: Probably feeds continuously throughout the day on an intermittent basis. Filter-feeder, selective in its ingestion. Filtering rates and selectivity under study.

Consumers

Natural predators and parasites: Consumed by larval stages of most estuarine fish and by adult zooplankters, both filter and individually selective feeders, including ctenophores, medusae, and many other invertebrates. Quantitative data on predation does not exist. Parasites include *Zoothamnium* and other protozoans.

Non-nutritional Role

Competition: Competes with other estuarine filter-feeding herbivores and detritovores.

Non-nutritional Role of Other Species

Competition: Other filter feeders compete.

Protection: In presence of *Acartia tonsa* and predators, *Eurytemora* concentrates on the bottom, using vegetation or litter for protection.

Influence of Toxic Substances

Biocides: Pesticides under study, also effects of chlorine in secondarily-treated sewage.

Thermal shock: Exposure to a temperature of 30°C for 24 hrs killed all animals acclimated at 25°C. *Eurytemora* adults acclimated at lower temperatures, 5, 10, 15, and 20°C, showed higher tolerance for thermal shock, with maximum survival at 10-15°C.

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Category: Invertebrates

Common Name: Grass, or glass, shrimp (collectively with others of this genus)

Inventory Prepared by: D. G. Cargo
Natural Resources Institute
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Solomons, Maryland

Classification

Phylum: Arthropoda
Class: Crustacea
Order: Decapoda
Family: Palaemonidae
Species: *Palaemonetes pugio* (often confused with *P. intermedius* where ranges overlap.

Distribution

Known range: Massachusetts to Port Aransas, Texas (Williams 1965)

Distribution in Chesapeake Bay: Bay-wide, especially in vegetation.

Population

Structure: Sexes even, life span annual.

Density: Abundant in quiet, weedy areas.

Affecting factors: Abundance of vegetation, especially *Zostera* and *Ruppia*.

Reproduction

Method: Sexual by copulation, eggs carried by female.

Seasons: May through September

Fecundity: 200-300 - personal estimate

Life Stages

Stages of life cycle: Zoea, post larvae, adult

Early stages:

Physical appearance: Elongate zoea unarmored except for rostrum. Prezoeal molt occurs prior to hatching. Approx. 2.6 mm long. Abdomen of 6 somites, telson with

Early stages (Continued)

Physical appearance (continued)

16 spines. Nine more zoeal stages. Tenth 6.3 mm; post larval 6.3 mm. Similar to P. vulgaris in many respects. Abdominal somite 2 has a pair of chromatophores, lacking in vulgaris (Broad 1957a, 1957b).

Development: Developmental rates variable, depending on larval diet (Broad 1957a).

Survival: With no food or unicellular algae, 2 molts - 100% mortality. Survival past 7 molts with Artemia nauplii, <20% mortality (Broad 1957b).

Behavior: Very seasonal in Chesapeake Bay. Young numerous in late spring.

Adult stage

Physical appearance: Lobster like, small chelae on 1st and 2nd walking legs.

Development: With adequate diet, 7th inter-molt yielded post larvae at 18 days after hatch (Broad 1957b).

Behavior: Adults abundant in late summer, especially in beds of vegetation; hibernation appears to be initiated at about 10°C.

Ecology

Habitat (Physical /chemical)

Substrate: Estuarine - weedy areas.

Salinity range: Oligo-polyhaline (Wass 1972). 5.4 o/oo to approx. 30 o/oo.

Temperature range: 30-30°C, hibernates at 10°C and below.

pH range: 7-8.5

Benthic composition: Weeds, muddy sand

Effects of fluctuations: Presence or absence of weed beds appears to have a major effect upon local abundance.

Associated communities: Shallow Zostera and Ruppia.

Food Requirements

Plant and animal, scavenges, eats detritus algae and plant food alone is inadequate (Broad 1957b).

Consumers

Natural predators and parasites: Fish and jellyfish, parasitized by *Probopyrus pandalicola*.

Man: Small local fisheries in Chesapeake Bay for sport fish bait in recent past; minor use now.

Non-nutritional Role

Protection: Rostrum, telson spines and armored periopods.

Influence of Toxins

Biocides: Probably very susceptible to insecticides.

Heavy metals: Cadmium chloride (0.42 mg/l), lethal to 50% of *P. vulgaris* (Eisler, 1971).

Thermal shock: LD50-(24 hr)-32-37.5^{o}C depending on acclimation temp. (Mihursky, et al., 1971).

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Category: Invertebrates

Common Name: Sand shrimp, salt and pepper shrimp

Inventory Prepared by: David G. Cargo
Natural Resources Institute
University of Maryland
Solomons, Maryland

Classification

Phylum: Arthropoda
Class: Crustacea
Order: Decapoda
Family: Crangonidae
Species: *Crangon septemspinosa* (Say), *Crago septemspinosus* (old name) was changed by Holthuis, 1951.

Distribution

Known range: Baffin Bay to eastern Florida, Alaska and Japan (Whiteley, 1948).

Distribution in Chesapeake Bay

Areas of active reproduction: Tributaries and Bay proper from Swan Pt. to outside Bay mouth; more abundant in lower Bay (Wass, 1972); 4.0-31.5 o/oo.

Occurrence in other areas: Farthest upriver in summer

Population

Structure: Sexes even; spawn at 1 year (Whiteley, 1948; Price, 1962); may live to age 3.

Dynamics

Trends and fluctuations: Size varies - seasonally

Reproduction

Method: Sexual

Seasons: Ovigers found at all seasons; in deeper waters in winter. Most abundant in summer (Price, 1962).

Fecundity: At 70 mm length, 3-4 thousand eggs/season.

Life Stages

Early life stages

Early life stages (Continued)

Physical appearance: At least 2 zoeal stages, reaches 2nd zoeal stage at 5 days after hatching.

Development: Hatching time 6-7 days at 21°C, 30 days at 16°C and 90 days at 5°C

Adult stage

Physical appearance: Lobster-like, no chelae

Development: Time of hatching and embryonic development controlled by temperature.

Survival: Boreal, not present in N. C. in summer.

Behavior: Surface swarming of juveniles has been observed in spring (Solomons, 1974, Cargo).

<u>Ecology</u>

Habitat (Physical/chemical)

Substrate: Marine to mesohaline - sandy bottoms and hydroids, not confined to benthos.

Salinity range: 4-31.5 o/oo

Temperature range: 0-26°C

Depth/pressure: Shoal to 180'

<u>Food Requirements</u>

Food: Detritus, crustaceans, molluscs, invertebrate eggs, also scavengers.

<u>Consumers</u>

Natural predators and parasites: Fish, skates (*Raja*) and rays (Price, 1962), (Fitz, 1956).

<u>Non-nutritional Role</u>

Competition: Probably competes with xanthid crabs, portunid crabs and other decapods for living space and food.

<u>Influence of Toxins</u>

Biocides

Chlorinated/hydrocarbons: Very susceptible to malathion and methoxychlor in amounts of 33-83 ppb (Eisler & Weinstein, 1967).

Heavy metals: Sensitive to cadmium and mercury at .32 mg/1 much more so after long exposure.

Thermal shock: More sensitive than other local decapods to high temps., 31C max. even under high temperature acclimation (Mihursky et al., 1971).

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Category: Invertebrates

Common Name: Mud crab (Miner, 1950)

Inventory Prepared by:

Robert E. Miller
Natural Resources Institute
University of Maryland
Solomons, Maryland

Classification

Phylum:	Arthropoda
Class:	Crustacea
Division:	Eucarida
Order:	Decapoda
Suborder:	Reptantia
Tribe:	Brachyura
Subtribe:	Brachygnatha
Superfamily:	Brachyrhyncha
Family:	Xanthidae
Species:	*Rhithropanopeus harrisii* (Gould)

Distribution

Known range: Netherlands; Schleswig-Holstein, West Germany; Copenhagen, Denmark; Vistula mouth and adjacent waters, Poland; northwestern France; southwestern France (once); Black Sea, Sea of Azov; Caspian Sea; W. Coast of Atlantic, in estuaries from Nova Scotia to Mexico; northeastern Brazil; W. coast of America in San Francisco Bay and in Coos Bay, Oregon (Christiansen, 1969 and Williams, 1965).

Distribution in Chesapeake Bay: Primarily in the upper Bay and in tributaries of the lower Bay in depths of 0 to 10 meters. Specimens have been found in waters ranging from fresh to 18.6 o/oo. Larvae have been found in water from 4 to no higher than 28.5 o/oo salinity. Surface to 15 meters (Christiansen, 1969; Williams, 1965; and Ryan, 1956).

Population: During the years 1945 to 1951, approximately 1,000 specimens were collected at 113 stations in Chesapeake Bay (Ryan, 1956).

Reproduction

Method: Sexual

Seasons and conditions: Ovigerous females are taken from May through September. Copulation occurs at temperatures between 14°C and 32°C. Molting immediately before copulation is not required for this species as it is for many other hard shell crabs (Turoboyski, 1973).

Reproduction (Continued)

Fecundity: Females taken in the Dead Vistula had between 1,280 and 4,800 eggs. These females averaged 3.51 mm wider in carapace width than those in the Chesapeake Bay. The egg mass varied with the size of the females.

Life Stages

Stages of life cycle: Four zoeal stages and one megalopa.

Early life stages

Physical appearance: Typical xanthid zoea. A very long rostral spine and second antennal spines serve as distinguishing features. The number of setae on the exopodite of the first and second maxillipeds increases as molting into successive stages occurs (Connolly, 1925 and Hood, 1962).

Development: The normal rate of development for the larval stages of R. harrisii from hatching to crab stage is about 18 days at 25 C and 25 o/oo of salinity (Costlow, Bookhout, and Monroe, 1966). The initial portion of this period is marked by four zoeal stages, each about 72 hours duration.

Eyestalk removal affects the rate of development in R. harrisii (Kalber and Costlow, 1966).

The removal of eyestalks also causes production of one or two supernumerary zoeal stages. Injection of a variety of extracts had little effect on normal larvae (Costlow, 1965).

Survival: Under laboratory conditions, the rate of survival for R. harrisii is very good (Costlow, 1965). Bousfield (1955) found good retention of zoea in the Miramichi Estuary but little other work has been done on survival rates.

Behavior: Retention of crab larvae in an estuary is effected by the vertical distribution of the larvae. This vertical movement is the result of behavioral responses which place the larvae in water currents beneficial to estuarine retention (Bousfield, 1955).

Adult stage

Physical appearance: Two transverse lines of granules on each protogastric region, one on mesogastric region interrupted at middle, two branchial, one of which is opposite the tip of the posterior lateral tooth. Front

Adult stage (Continued)

Physical appearance (continued)

little produced, edge nearly straight, channeled, upper and lower margins granulate; median notch triangular. Lateral teeth not prominent; a sinus in coalesced tooth; third and fourth teeth pointing obliquely forward; last tooth smaller. Outer orbital hiatus a nearly closed fissure opening on a broad shallow notch. No subhepatic tubercle.

In old crabs the chelipeds are nearly smooth. In small specimens the wrist is rough with lines and bunches of granules, distal groove deep; two granulate ridges on upper margin of palm; upper edge of fingers granulate. Fingers slender, prehensile edges evenly dentate. Legs long, slender, compressed.

The third segment of the male abdomen does not touch the coxae of the last pair of legs; terminal segment subquadrate.

Color: Brownish, paler below; fingers white. Yellow with red spots (Rathbun, 1930).

Development: Ryan (1956) summarized life history data for R. harrisii in the Chesapeake Bay area. Ovigerous females were collected from June to September (also in April in Louisiana and Brazil). Though juveniles were found in all months of the year, they occurred most frequently in samples taken from July to October. Immature forms of undetermined sex ranged from 2.2 to 2.6 mm in width. Immature males ranged from 3.2 to 5.0 mm and similar females ranged from 3.3 to 5.7 mm in width. Ryan considered maturity to be reached the following summer at a carapace width of 4.5 mm for males and 4.4 to 5.5 mm in females.

Adults continue to grow and molt after maturity is reached, and males finally attain a larger size than females (up to 14.6 and 12.6 mm wide, respectively). No concrete data on number of instars throughout life are available but it is estimated that there may be four instars between attainment of the 5 and 10 mm carapace widths (Williams, 1965).

Ecology

Habitat (Physical/chemical)

Substrate: Ryan (1956) found this species in some kind of shelter - oyster bars, living and decaying vegetation, old cans, and other debris.

Habitat (Continued)

Salinity range: Fresh to 18.6 o/oo (Ryan, 1956 and Pinschmidt, 1963). Bousfield (1955) found larvae from 4 to 25.5 o/oo.

Temperature range: 0 to 34.1°C.

Benthic composition: Shelter of some type, oysters, cans or vegetation needed.

Turbidity/light: It has been suggested that *R. harrisii* larvae exhibit a reversed pattern of diurnal vertical migration dependent on a persistent internal rhythm modified by lighting conditions (Forward, In press).

Water flow: Bousfield (1955) concluded that current flow was utilized by *R. harrisii* zoeae to maintain their horizontal distribution within the estuary.

Associate biological communities: *R. harrisii* are often found in oyster bar communities.

Food Requirements

Food: Probably dead organic matter of animal origin and several aquatic plants in the detritus stage (Turoboyski, 1973).

Consumers

Natural predators and parasites: The oyster toad is a natural predator. *R. harrisii* is cannibalistic when finding a soft-shell crab, personal observation in ten-gallon aquariums. Eaten by several diving ducks.

A common parasite in the Chesapeake Bay is the sacculinid barnacle, *Loxothylacus panopaei*.

Non-nutritional Role

Concentration of toxic substances: Not applicable; work done on several other species of xanthid crabs but not *R. harrisii*.

Non-nutritional Role of Other Species

Fertilization: *Loxothylacus* castrates the sexual organs.

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Williams, A. B. 1965. Marine decapod crustaceans of the Carolinas. Fish. Bull. 65(1):298.

Category: Fish

Common Name: Blue-backed herring

Inventory Prepared by: Linda L. Hudson and Jerry D. Hardy, Jr.
Department of Natural Resources
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Solomons, Maryland

Classification

Class: Osteichthyes (bony fishes)
Order: Clupeiformes
Family: Clupeidae
Species: *Alosa aestivalis* (Mitchill)
Subspecies: None currently recognized
Synonyms: *Clupea aestivalis* Mitchill, 1815
Alosa cyanonoton Storer, 1857
Pomolobus aestivalis (Mitchill) Jordan & Everman, 1896-1900
Pomolobus cyanonoton Storer, Dean, 1903

Other common names: Menhaden, glut herring, blueback, summer herring, blackbelly, kyack.

Distribution

Known range: New Brunswick and Nova Scotia, Canada to St. Johns River, Florida (Hildebrand, 1963; Scott and Crossmann, 1973).

Distribution in Chesapeake Bay: Occurs throughout the region (Hildebrand and Schroeder, 1928).

Area of active reproduction: Spawns in both fresh and brackish water in rivers and ponds (Davis, 1973; Hildebrand, 1963; Raney and Massmann, 1953). Chittenden (1972) reported spawning 105 kilometers above the tide in the Delaware River.

Occurrence in other areas: Outside the spawning season occurs in a narrow band of coastal water offshore at the bottom (Hildebrand, 1963; Hildebrand and Schroeder, 1928; Bigelow and Schroeder, 1957).

Population

Dynamics

Affecting factors: Hildebrand (1963) has noted that overfishing, pollution, and impassable dams have diminished the abundance of "alewives."

Population (Continued)

Reproduction

Method: External fertilization.

Seasons and conditions: Late April through early May in Potomac River (Hildebrand, 1963). Spawning takes place at temperatures of 14 to 25°C. Streams used for spawning typically have relatively deep ingresses, swift currents, and rocky substrates (Bigelow and Schroeder, 1953; Loesch, 1970).

Fecundity: Probably an average of 100,000 (Smith, 1907).

Life Stages

Stages of life cycle: Egg, larva, juvenile, adult.

Physical appearance: Eggs demersal; adhesive; stick to sticks, stones, gravel and other objects with which they come in contact (Scott and Crossman, 1937); average diameter about 1.0 mm; yellowish, semi-transparent; perivitelline space about ¼th egg radius; capsule finely corrugated; yolk granular; oil globules very small, scattered. Hatching length about 3.5 mm. Body of larva long, slender; anus about 5/6th of body length from snout; pectorals absent at hatching, conspicuous at 4.0 mm; dorsal finfold never extended to head; chromatophores over yolk mass, along intestine and, toward end of stage, at base of ventral finfold posterior to vent. At 5.2 mm, yolk absorbed, mouth open, auditory vesicles greatly enlarged. In juveniles between lengths of 20.5 to 25.0 mm, the body depth increases markedly and pigment develops on the head, dorsum, and upper sides. Scales develop at about 45 mm, and in specimens of this size, the tongue is pigmented laterally and the peritoneum is usually dark (Hildebrand, 1963; Kuntz and Radcliff, 1917; Mansueti and Hardy, 1967).

Development: Hatching occurs in about 2 to 3 days at temperatures of 22.2 to 23.9°C (Scott and Crossman, 1973). When reared at "laboratory temperatures", eggs develop as follows: early blastomeres large, spherical: three somites visible just prior to closure of blastopore (16 hrs after fertilization); at 24- to 26-somite stage embryo about 2/3rds around yolk, optic and auditory vesicles developed; just prior to hatching, embryo longer than yolk circumference, relatively opaque, slightly pigmented (Kuntz and Radcliff, 1917). Young may reach a length of 30 to 50 mm in 1 month (Scott and Crossman, 1973). Hildebrand and Schroeder

Development (Continued)

(1928) presented the following growth data for the Potomac River: In June, 30 to 37 mm; in July, 30 to 59 mm; in August, 34 to 64 mm; in September, 40 to 69 mm; in October, 40 to 74 mm; in November, 50 to 74. Hildebrand recorded lengths of 65 to 120 mm at 1 year.

Behavior: In the Chesapeake Bay area, the young remain in upstream "nursery areas" until late summer or fall (Hildebrand, 1963; Hildebrand and Schroeder, 1928; Bigelow and Schroeder, 1957). Davis et al. (1967), working in North Carolina, found that the seaward migration is associated with increased water level and decreased temperature. Some young may remain in lower Chesapeake Bay during their first or possibly their second winter (Hildebrand and Schroeder, 1928). North of Chesapeake Bay, the movement to sea apparently occurs much earlier: Scott and Crossman (1973) found a rapid downstream movement when the young were 30-to 50-mm long. Perlmutter et al. (1967) and Chittenden (1972) found "young" in brackish water in summer. Warrinner and Miller (1970) have presented detailed data on the distribution of young in the Potomac River.

Adult stage

Physical appearance: Dorsal 15 to 20, anal 16 to 21, ventral 10 to 11, pectoral 14 to 18. Body elongate, laterally compressed; depth 22.1 to 25.2% of total length; lower jaw extended beyond upper jaw; maxillary to below middle of eye; scales large, deciduous; lateral line not developed; ventral scutes well developed; prepelvic scutes 18 to 21; postpelvic scutes 12 to 16. Back grayish, bluish-green or dark blue; sides and belly silvery; rows of scales on back and upper sides with distinct dark lines; shoulder with a dark spot usually followed by several other discrete, dark spots; fins greenish or yellowish. Maximum length 380 mm. (Scott and Crossman, 1973; Hildebrand, 1963; Mansueti and Hardy, 1967).

Development: Marcy (1969) found that 47% of the males first spawn at age group III, 50% at age group IV; 75% of the females mature at age group III. Hildebrand (1963) stated that maturity occurred at 205 mm or less.

Behavior: A schooling species. In Chesapeake Bay region, move up to spawning areas during first half of April (or when temperatures reach 70 F), remain until June 1st or later, return to sea after spawning (Bigelow and Schroeder, 1953; Hildebrand, 1963).

Behavior (Continued)

There is some evidence that this species may overwinter near the bottom (Scott and Crossman, 1973).

Ecology

Habitat (Physical/chemical)

Classification: Fresh, brackish, and marine waters.

Salinity: Fresh to full-strength sea water. Chittenden (1972) found this species to be highly tolerant to abrupt changes in salinity.

Temperature: Minimum reported, 6 to 7°C (Recksick and McCleave, 1973). Gift and Westman (1971) have discussed responses to increasing thermal gradients.

Dissolved oxygen: Mortalities in excess of 35% occurred when test animals were held at O_2 concentrations of 2 to 3.0 mg/liter for 16 hours (Dorfman and Westman, 1970).

Food Requirements

Food: Mostly crustaceans and crustacean eggs; also copepods, cladocerans, ostracods, amphipods, hydracarina, dipterans (and presumably other insects), insect eggs, fish eggs and larvae (Davis et al., 1967; Scott and Crossman, 1967). Brooks and Dodson (1965) have studied feeding habits in a fresh-water population and list various fresh-water zooplankters including *Cyclops* and *Daphnia*.

Consumers

Predators and parasites: *Alosa aestivalis* is preyed upon by predatory fish inhabiting fresh, brackish, and marine waters; this appears to be especially true of the weakfish, *Cynoscion regalis* (Hildebrand, 1963). Parasites include the acanthocephalan, *Echinorhynchus acus*, the nematode, *Heterakis foreolata*, and the copepod, *Ergasilus clupeidarum*. The species may also be infested with the colonial hydroid, *Obelia commensuralis* (Gudger, 1937; Sumner et al., 1913; Johnson and Rogers, 1972).

Man: Utilized by man, but generally not distinguished from alewife, *Alosa pseudoharengus*, and therefore exact catch statistics not available (Hildebrand and Schroeder, 1928).

Influence of Toxins

Other: Jensen (1969) points out that some blueback eggs and larvae are lost through power-plant intakes.

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Category: Fish

Common Name: Mummichog

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Classification

Class: Osteichthyes (bony fishes)
Order: Atheriniformes
Family: Cyprinodontidae
Species: *Fundulus heteroclitus* (Linnaeus) 1766
Subspecies: Several subspecies have been proposed (*fonticola*, *bermudae*, *macrolepidotus*, *grandis*, and *badius*). Of these, only *bermudae* of Bermuda is recognized.
Synonyms: *Cobitus heteroclita* Linnaeus, 1766
Cobitus macrolepidota Walbaum, 1792
Cobitus killifish Walbaum, 1792
Esox pisciculus Mitchill, 1815
Esox pisculentus Mitchill, 1815
Hydrargyra nigrofasciatus LeSueur, 1817
Hydrargyra ornata LeSueur, 1817
Hydrargyra swampina Lacepede, 1803
Poecilia caenicola Bloch and Schneider, 1801
Zygonectes funduloides Evermann, 1891
Fundulus bermudae Gunther, 1874
Fundulus rhizophorae Goode, 1877
Fundulus viridescens DeKay, 1842
Fundulus zebra DeKay, 1842
Fundulus floridensis Girard, 1859
Fundulus mudfish Lacepede, 1803
Fundulus nisorius Cope, 1870
Fundulus heteroclitus macrolepidotus (Walbaum)
Fundulus heteroclitus badius Garman, 1895
Other common names: Common mummichog, common killifish, salt-water minnow, mummy, minnow, pike minnow, mud-minnow, mud-dabbler, cobbler.

Distribution

Known range: Newfoundland and Nova Scotia to Mantanzas River, Florida; Bermuda (Briggs, 1958; Collette, 1962; Livingstone, 1951; Miller, 1955; Scott and Crossmann, 1964). Introduced into Ohio River drainage in western Pennsylvania (Raney, 1938).

Distribution in Chesapeake Bay: Found throughout the Chesapeake Bay region (Hildebrand and Schroeder, 1928).

Distribution in Chesapeake Bay (Continued)

Area of active reproduction: Spawns in salt, brackish, and fresh water in ponds, shallow pools, rivers, and "pure" sea water.

Occurrence in other areas: All salinities from fresh to salt water. In inshore areas, recorded from large rivers, fresh-water streams and creeks, lakes, salt marshes, barrier beach ponds, and ditches. Detailed descriptions of the habitat are available in the following papers: Brown (1957), Carr and Goin (1955), Chidester (1920), Fisher (1920), Fowler (1912, 1952), Greeley (1935), Heilner (1920), Hildebrand and Schroeder (1928), Hoedeman (1954), Livingstone (1951), Moore (1922), Newman (1914), Raney (1950), Scherzinger (1915), Seal (1908), Tracy (1910).

Population

Structure: Schmelz (1964) observed a sex ratio of 0.985 females to one male.

Densities: Munro (1973) found that Fundulus heteroclitus comprised 81.5% of the total fish fauna in her study area. The density appeared to vary considerably with the tide.

Reproduction

Method: External fertilization.

Season and conditions: April to August. Peak activity variously reported: late May or late June (Chidester, 1916; Fowler, 1916; Hildebrand and Schroeder, 1928; Newman, 1919; Schwartz, 1967). Spawning takes place in shaded areas over gravel or hard bottom having sparse to dense vegetation; also among emergent vegetation so close inshore that eggs may be stranded by tide (Fanara, 1964; Fowler, 1906; Moore, 1922; Newman, 1907; Nichols and Breder, 1927; Pearcy and Richards, 1962).

Fecundity: Estimates of the number of mature eggs vary from 4 to 800 (Hildebrand and Schroeder, 1928; Kagan, 1935; Moenkhaus, 1904; Munro, 1973; Schwartz, 1967). Munro estimates 4 to 215 mature eggs in specimens from the Patuxent River, Maryland. Ehnle (1910) pointed out that a maximum of 30 eggs are deposited during one spawning.

Life Stages

Stages of life cycle: Egg, larva, juvenile, adult.

Early stages

Physical appearance: The eggs are demersal, sometimes attached to plant stems and to one another; sometimes under algal mats and exposed to air; and sometimes buried in mud (Battle, 1949; Bigelow and Schroeder, 1953; Breder, 1917; Brinley, 1938; Carranza and Winn, 1954; Chidester, 1916; Newman, 1918; Ryder, 1886; Schwartz, 1967; Pearcy and Richards, 1962; Solberg, 1938; Stockard, 1921; Tracy, 1910). Eggs spherical; diameter 1.5 to 2.5 mm; yellowish, amber, or almost colorless, essentially transparent; chorion heavy, firm, adhesive in newly deposited eggs, and with or without (depending on geographic location) a thick mat of attachment filaments; oil globules opaque, unequal, small, numerous (Armstrong and Child, 1965; Battle, 1944; Bigelow and Schroeder, 1953; Brinley, 1938; Brummett, 1966; Kuntz, 1918; Nelson, 1953; Newman, 1908, 1915, 1918; Nichols and Breder, 1927, 1929; Ryder, 1886; Stockard, 1915a, 1915b, 1915c, 1921; Solberg, 1938; Tracy, 1910). Hatching length 4.0 mm or less to 7.3 mm (larger individuals may hatch without yolk). Total myomeres, about 35. In yolked hatchlings, head flexed over yolk; oil globules still evident; pectoral rays developed; origin of dorsal finfold over midpoint of body; urostyle oblique; a double line of melanophores mid-dorsally and mid-ventrally, and a series of red chromatophores mid-laterally; yolk sac pigmented. In more advanced larvae, a triangle of chromatophores on head and scattered chromatophores along mid-dorsal ridge. Towards end of larval stage (up to 20 or 25 mm), 6 to 8 vertical pigment bars on flanks. Juvenile males olive above, yellow below; young females paler than males. This composite, brief description is based on information presented by Agassiz, 1882; Armstrong and Child, 1965; Bancroft, 1912; Bigelow and Schroeder, 1953; Carpenter and Siegler, 1947; Chidester, 1916; Cooke, 1965; Denny, 1937; Evermann, 1901; Gabriel, 1942; Gilson, 1926; Hildebrand and Schroeder, 1928; Jordan and Gilbert, 1883; Newman, 1900; Oppenheimer, 1937; Richards and McBean, 1966; Smith, 1892; Solberg, 1938a, 1938b; Stockard, 1907a, 1907b, 1907c; Truitt et al., 1929. In our own recent laboratory studies, we have not observed the mid-lateral red chromatophores described by earlier workers. We have noted, in very recent hatchlings, the presence of large white chromatophores on the body and at the base of the pectoral fin, and a mass of yellow spots on the body just behind the anus.

Early stages (Continued)

Development: A number of authors have presented detailed developmental sequences or have commented on certain aspects of development (Bancroft, 1912; Gilson, 1926; Hyman, 1921; Jones, 1939; Kagan, 1935; Manery et al., 1933; Milkman, 1954; Moenkhaus, 1904, 1911; Newman, 1908, 1914; Oppenheimer, 1936a, 1936b, 1936c, 1937; Solberg, 1938; Stockard, 1915, 1921; Richards and Porter, 1935; Rogers, 1952; Wyman, 1924). The following condensed description is based on the Solberg series (1938). Rearing temperature was 25°C. 1 hour - blastodisc formed; 2 hours - 4-cell stage; 4 hours - 64-cell stage; 10 to 14 hours - blastula flattened into yolk; 17 hours - embryonic shield formed; 24 hours - eye and brain divisions evident; 26 hours - blastopore closed; 28 hours - 4 somites formed; 33 hours - auditory placodes formed; 38 hours - optic lobes formed; 40 hours - pigment on yolk; 42 hours - pigment on embryo; 44 hours - heart pulsating; 46 hours - circulation established; 60 hours - otoliths developed; 72 hours - 35 somites; 78 hours - pectoral buds evident; 84 hours - eye pigmented; 90 hours - liver evident; 102 hours - pectorals rounded; 114 hours - peritoneum pigmented; 126 hours - caudal rays formed; 144 hours - gas bladder formed; 168 hours - vertebrae well-differentiated; 192 hours - head noticeably more straightened than in earlier stages; 240 hours - mouth open; 264 hours - hatching. Incubation varies with temperature as follows: At 25°C, 11 days (Solberg, 1938); at 24.5°C, 9 to 20 days (Gabriel, 1942); at 19.4 to 21.4 C, average 17 days (Scott and Kellicott, 1917); at 13 to 17°C, about 24 days (Ryder, 1886). The maximum incubation period is 40 days, but no temperature was specified (Scott and Kellicott, 1917). Nothing is known concerning the growth of the young fish.

Behavior: Newly hatched larvae are phototropic and remain off bottom. More advanced larvae swim at the surface, but will occasionally make forays to the bottom. Juveniles have been recorded from eelgrass along sandy beaches; in warm, shallow pools; and in ditches associated with salt marshes (Armstrong and Child, 1965; Bean, 1903; Fisher, 1920; Moore, 1922; Richards and McBean, 1966; Stockard, 1907).

Adult stage

Physical appearance: Dorsal 10 to 14; anal 9 to 12; caudal 17 to 20; pectoral 16 to 20; ventral 6 to 7. Body robust, deep, short. Teeth pointed and in villiform bands. Dorsal origin somewhat anterior to

Physical appearance (Continued)

anal origin. Typically olivaceous to dark green above, pale to yellow-orange below, but color highly variable. Scales sometimes with white spots arranged in vertical, longitudinal, or diagonal stripes; dorsal fin sometimes with a dark ocellus; sides of females with 13 to 15 crossbands (Bigelow and Schroeder, 1953; Brown, 1954; Carpenter and Siegler, 1947; Carr and Goin, 1955; Chidester, 1916; Garman, 1895; Hildebrand and Schroeder, 1928; Hubbs, 1926; Parker, 1925; Schwartz, 1961; Scott and Crossmann, 1973; Smith, 1892, 1907; Truitt et al., 1929).

Development: "Yearlings" may possible spawn in late August, otherwise probably mature during 2nd winter. Females mature at a minimum of 28 mm SL; males at a minimum of about 32 mm TL (Chidester, 1916; Hildebrand and Schroeder, 1928; Schmelz, 1964; Tracy, 1910).

Behavior: Typically a schooling species. Apparently ubiquitous in some areas, but showing marked preference for muddy water and muddy bottom in some areas. Sometimes moves overland or buries in mud when stranded by tide; can remain out of water for up to 4 hours. Sometimes found in extremely foul water. Migratory, moving into marshes and fresh-water creeks when spring temperatures reach 15 C (sometimes as early as March). Peak migrations in mid-April. Run in and out with the tide. Hibernate in deep holes near mouths of rivers or bury 6 to 8 inches in mud in salt marshes or sheltered lagoons in winter. Seldom more than 100 yards from shore or in water deeper than "a couple of fathoms" (Bean, 1902; Bigelow and Schroeder, 1953; Butner and Brattstrom, 1960; Carranza and Winn, 1954; Chidester, 1916, 1920, 1922; deSylva et al., 1962; Fowler; 1914; Hildebrand and Schroeder, 1928; Moore, 1922; Newman, 1908, 1918; Nichols and Breder, 1927; Radcliff, 1915; Schwartz, 1961; Smith, 1907).

Ecology

Habitat (Physical/chemical)

Classification: Fresh, brackish, and marine waters.

Salinity: Loeb (1900) found that newly hatched larvae could survive in distilled water, but died in sodium chloride solutions equal in strength to seawater. Maximum salinity, 35 o/oo (deSylva et al., 1962). Burden (1956) has shown that Fundulus heteroclitus can withstand abrupt salinity changes.

Temperature: Eggs can be reared at 26 to 27^{o}C with only 2% mortality (Solberg, 1938). Advanced eggs can survive temperatures as low as 0 to 2^{o}C for rather long periods, but early eggs are killed or develop abnormally at reduced temperatures (Kellicott, 1916; Loeb, 1915). Garside and Jordon (1968) found an upper lethal temperature for adults of 33.9 C (at a salinity of 14 o/oo). Umminger (1969, 1970a, 1970b, 1970c, 1971) and Benziger and Umminger (1973) studied physiology and biochemistry at temperatures near freezing (minimum acclimation temperature minus 1.5^{o}C). Pickford et al. (1971) noted that mummichogs become comatose when adapted at 20^{o}C and immersed for 3 minutes at 1^{o}C. McNabb and Pickford (1970) studied thyroid function as it is affected by high and low temperatures. Gift and Westman (1971) studied responses to increasing thermal gradients.

Dissolved oxygen: Bigelow and Schroeder (1953) noted that this species is resistant to "a lack of oxygen." Voyer and Hennekey (1972) found that dissolved O_2 concentrations of 0.74 to 0.89 were lethal to 50% of their experimental adult animals. They presented similar data for eggs.

Food Requirements

Food: Diatoms, foraminifers, amphipods, and other crustaceans, mollusks, insect larvae, fish eggs, small fishes, and vegetation. Mud is sometimes ingested, but this is probably by accident (Scott and Crossmann, 1973; Linton, 1901; Schmelz, 1964).

Consumers

Natural predators and parasites: Predators include bluefish (Grant, 1962), chain pickerel (Meyers and Muncy, 1962), white perch (Schmelz, 1964), brook trout, bullfrogs, otter, mink, and kingfishers (White, 1953; White et al., 1965). Hoffman (1967) found that mummichogs were infested with protozoans, trematodes, nematodes, acanthocephalids, and crustaceans. Stromberg and Crites (1972) recorded the cucullonid, *Dichelyne bullocki*, from the species, and two parasites, *Distomum* sp. and *Gyrodactylus* sp. were recorded by Stafford (1907) and Gowanlock (1927), respectively. More recently, Lawler (1967) described a new parasitic dinoflagellate, *Oodinium cyprinodontum*, which occurs on the gills of *heteroclitus*.

Man: While this species is not consumed by man, it is sometimes harvested in large numbers for bait (Richards and Castagna, 1970).

Influence of Toxins

Biocides: Eisler (1970a, 1970b) and Eisler and Weinstein (1967) studied the effects of several insecticides on *Fundulus heteroclitus* under a variety of experimental conditions.

Heavy metals: Data on the toxicity of beryllium, cadmium, copper, lead, mercury, and zinc has been presented by Eisler (1968, 1971), Eisler and Gardner (1973), Eisler et al. (1972), Gardner and LaRoche (1973), Garside and Yevich (1970), Jackim, (1973), Jackim et al. (1970) and White (1912). Gardner and Yevich (1970) found pathological changes in the intestinal tract, kidneys, and gills after exposure to 50 ppm of cadmium. Gardner and LaRoche (1973) found that hatchlings of *Fundulus heteroclitus* were much more sensitive to copper toxicity than were adults. Fletcher et al. (1971) studied the effects of yellow phosphorus waste production on the species.

Radionuclides: Angelovic et al. (1969) studied the effects of cobalt-60 and sodium-22, and pointed out that mummichogs become more sensitive to radiation as temperature or salinity increases.

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Category: Fish

Common Name: White perch

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Classification

Class: Osteichthyes
Order: Perciformes
Family: Percichthyidae
Species: *Morone americana* (Gmelin)
Subspecies: None currently recognized.
Synonyms: *Perca americana* Gmelin, 1789
Perca immaculata Walbaum, 1792
Morone rufa Mitchill, 1814
Morone pallida Mitchill, 1814
Roccus americanus (Gmelin)
Other common names: White perch, silver perch, sea perch, blue-nosed perch, gray perch, black perch.

Distribution

Known range: New Brunswick, Nova Scotia, and Prince Edwards Island to Georgia (records from Florida and the Gulf Coast are questioned). Introduced into the Great Lakes, into freshwater lakes and ponds in New England, and into lakes and rivers in Nebraska (Mansueti, 1964; Woolcott, 1962; Webster, 1942; Thoits and Mullan, 1958; Raney, 1965; Dence, 1952; Larsen, 1954; Scott and Christie, 1963; Hergenrader and Bliss, 1971).

Distribution in Chesapeake Bay: Found throughout the region (Hildebrand and Schroeder, 1928).

Area of active reproduction: In Chesapeake Bay region in tidal fresh or slightly brackish water, mostly in lower parts of large rivers on sand and gravel bars, on rocky ledges, or under banks or debris (Mansueti, 1961, 1964; Woolcott, 1962; Webster, 1942; Smith, 1971; Hildebrand and Schroeder, 1928. Raney (1965) suggested that spawning takes place at the surface, while Mansueti (1961) felt that it occurred under shelters beneath the surface.

Occurrence in other areas: Bays, estuaries, brackish and fresh-water ponds, lakes, unprotected coastal waters, creeks, and streams (Woolcott, 1962; Raney, 1965; Radcliff and Welsh, 1917; Whitworth et al., 1968; Miller, 1963). Congregates around piers, timbers, bridges, and water lilies. Hibernates in deep water or bays (Goode et al., 1884; Smith, 1971).

Population

Structure: Reported sex ratios vary from 0.76 to 0.89 males to 1 female (Cooper, 1941; Thoits and Mullan, 1958).

Densities and totals: A total of 13,259 pounds of white perch were recovered from a 185-acre lake. This represented 51% of the total weight of fish recovered (Thoits and Mullan, 1958). In other ponds, white perch accounted for less than 1.0% of the total fish population (Stroud and Bitzer, 1955).

Dynamics

Trends and fluctuations: The white perch tends to become over-populated when stocked. This results in conspicuously stunted growth (Everhart, 1950; Stroud, 1955a; Thorpe, 1942).

Factors affecting density: Biological and physical conditions of the environment, fishing pressure, spawning success, and predation may all influence population densities (Stroud, 1952, 1955b).

Reproduction:

Method: External fertilization.

Season and conditions: Over entire range, late March (Mansueti, 1961; Dovel, 1971; Conover, 1958) to late July (Mansueti, 1964). In Chesapeake Bay region late March (Mansueti, 1961), but in some years, eggs not evident in upper Bay until early April (Radcliff and Welsh, 1917; Rinaldo, 1971; Johnson, 1972). Winter spawning in lower Chesapeake Bay has been suggested (Hildebrand and Schroeder, 1928), but Mansueti (1961, 1964) has questioned this. Estuarine populations generally spawn in April and May and fresh-water populations in May, June, and July (Raney, 1965; Richards, 1960; Lagler, 1961). Spawning takes place during daylight hours or at dusk (Mansueti, 1961; Raney, 1965). Spawning congregations typically occur in lower reaches of large coastal rivers in estuarine populations (Woolcott, 1962); also in fresh-water spillpools of larger creeks (Smith, 1971). Spawning usually occurs over fine sand or gravel, but has also been observed over pulverized snail shell, and over predominantly clay bottom (Webster, 1942; Thoits and Mullan, 1958; Richards, 1960). Spawning temperatures vary from 10 to 19°C (Mansueti, 1961, 1964; Smith, 1971); in York River, Virginia, peak activity was observed at 11 to 16°C (Rinaldo, 1971). The maximum

Seasons and conditions (Continued)

salinity in which spawning has been observed is 4.2 o/oo (Smith, 1971). A report of spawning in oceanic water (Schwartz, 1960) is questioned.

Life Stages

Stages of life cycle: Egg, larva, juvenile, adult.

Early stages

Physical appearance: Eggs demersal, usually attached to grass, rocks, and debris, either singly or in small clumps or thin layers (sometimes, however, not attached and float from point of deposition). Eggs spherical; diameter 0.65 to 1.09 mm; chorion thick, tough, yellowish-brown to brownish-grey, rarely transparent, occasionally opaque; eggs initially adhesive but with adhesiveness varying greatly during development; yolk usually with a single large amber oil globule 0.20 to 0.44 mm in diameter; sometimes several to many additional smaller oil globules; perivitelline space about 24% egg diameter (Schwartz, 1960; Mansueti, 1964; AuClair, 1958, 1960; Everhart, 1958; Dovel, 1971; Wong, 1971). Hatching length 1.7 to 3.0 mm. Total myomeres 11 to 14, posterior myomeres 10 to 12. Body tadpole-like, mouth and pectoral buds lacking at hatching. Yolk sac not projected beyond head. At hatching, virtually without pigment. At about 2.8 to 3.0 mm (age 1 day) larvae transparent with orange and brown chromatophores; pigment concentrated on head, anterior region of oil globule, posterior part of yolk sac, ventral edges of hind gut and trunk, and sparsely on dorsal edge of trunk. Yolk absorbed by 3.4 mm. At 3.4 to 19.0 mm, anus 55% of body length. At 12.0 to 14.0 mm, pigment very sparse. Juveniles at 20.0 mm have small chromatophores scattered on snout, head, operculum, dorsolateral part of body, entire posterior part of trunk, on spinous and soft dorsal, anal, and caudal, and along lateral line. At ca. 25 to 75 mm, 5 to 7 dusky vertical bars on sides and, sometimes, faint horizontal stripes. Young-of-the-year have dark brown horizontal stripes on sides which are lost by age group I. "Young" less than 100 to 125 mm long are usually silvery-grey and lack blue pigment on the head (Mansueti, 1964; Webster, 1942; Raney, 1965; Taub, 1966; Hildebrand and Schroeder, 1928).

Development: A typical developmental sequence follows, based on a temperature of 65°F. About 10 minutes - perivitelline space developing. About 20 minutes - one- and 2-cell stages. About 45 minutes - two- and

Development (Continued)

4-cell stages; 1 hour - 4- to 16-cell stages; 2 hours - some approaching 32-cell stage; 3 hours - blastoderm berry-like, up to 64 cells; 6 hours - morula stage; 10 hours - blastoderm over ½ yolk; 14 hours - blastopore closed; 18 hours - embryo surrounds 3/4th of yolk; 24 hours - embryo pigmented, somites visible; 30 hours - tail free; 36 hours - pigment increased, tail longer; 44 hours - prehatching embryo, about 25 somites; 44-50 hours - hatching (based on Mansueti, 1964). The incubation period varies greatly with temperature as follows: At 45°F, "little-development" (Thoits and Mullan, 1958). At 52°F, about 6 days (Conover, 1958). At 58°F, about 3 to 4½ days (Thoits and Mullan, 1958; AuClair, 1956; Richards, 1960; Foster, 1919). At 60°F, variously reported: 24 to 30 hours (AuClair, 1956); 48 to 52 hours (Titcomb, 1910); 72 hours (Schwartz, 1960). At ca. 63°F, about 48 hours (Raney, 1965). At 65°F, 44 to 50 hours (Raney, 1965). At ca. 65°F, 44 to 54 hours (Mansueti, 1964). At 68°F, 24 to 30 hours (Foster, 1919; Richards, 1960; Thoits and Mullan, 1958). At 68 to 77°F, 20 to 42 hours (Taub, 1966). Hatchlings grow rapidly and the yolk is absorbed in 4 to 13 days (Rinaldo, 1971; Mansueti and Mansueti, 1955) and the young reach lengths of about 37 to 62 mm by July and August (Thoits and Mullan, 1958). By the end of the first year of growth, the average length is about 80 to 85 mm (Wallace, 1971).

Survival: At temperatures of 50°F or lower, few eggs survive. At normal temperatures, a sudden drop of 4 or 5°F may destroy the eggs (Auclair, 1956, 1960; Rinaldo, 1971). Egg mortality can also result from siltation (Morgan, Rasin, and Noe, 1973). In some areas, "young" white perch are preyed upon by various species of gamefish (Cooper, 1941).

Behavior: Yolk-sac larvae settle to bottom and lie on their sides. Larvae remain in the spawning area. Specimens 8 to 13-mm long over mud bottom; also recorded from quiet water in shore zone and on current-swept sand and gravel bars. Maximum depth for larvae, 12 feet. As larval development proceeds, there is a general downstream movement (Mansueti, 1964; Mansueti and Mansueti, 1955; Raney, 1965; Webster, 1942; Rinaldo, 1971). Juveniles remain in the nursery areas to at least 20 or 30 mm, or sometimes apparently to an age of one year. Generally found along shore line in shallow sluggish water over silt and mud bottom or among plants; also sometimes along sandy shoals and beaches, particularly at evening. Juveniles may form large schools. Estuarine populations remain in schools

Behavior (Continued)

during summer months, but move toward brackish water between August and late November, at which time the schools break up. Juveniles up to 75-mm long move inshore in evening and when water is rough or turbid (Mansueti, 1964; Woolcott, 1962; Webster, 1942; AuClair, 1956, 1958; Raney, 1965; Brice, 1898; Goode, 1888; Abbott, 1876; Dovel, 1971; Rinaldo, 1971; Richards, 1960; Smith, 1971).

Adult stage

Physical appearance: First dorsal with 8 to 11 spines; 2nd dorsal with 1 spine and 11 to 13 rays; anal 8 to 10 rays; pectoral 10 to 18 rays; ventral 1 spine and 5 rays. Body oblong, ovate, compressed; back moderately elevated. Teeth small, pointed. Two dorsal fins barely connected. Silvery, greenish, greyish or almost black above, sometimes brassy. Large individuals with bluish lustre on head. Sides paler and sometimes with indistinct lateral stripes. Belly silvery-white, immaculate. Melanophores on rays and membranes of all fins. Anal and ventrals sometimes rosy at base (Woolcott, 1962; Hildebrand and Schroeder, 1928; Thoits and Mullan, 1958; King, 1947; Whitworth et al., 1968; Richards, 1960; Scott and Christie, 1963; Raney, 1965). Maximum length 485 mm (Taub, 1966).

Development: Size at maturity varies greatly. The minimum size at maturity is 72 mm for males and 98 mm for females (Miller, 1963). Mansueti (1961), working with Chesapeake Bay material, found 50% of the males mature at 100.3 mm SL and 50% of the females mature at 105.5 mm SL. In Lake Ontario, the smallest male was 140 mm FL and the smallest female 172 mm FL (Sheri and Power, 1968). Maturity occurs in age groups II to IV (Mansueti, 1961, 1964; Thoits and Mullan, 1958; North Carolina Wildlife Resources Commission, 1962).

Survival: Meyers (1967) reported on an extensive kill of white perch. He attributed this to the bacteria Pasteurella sp.

Behavior: A schooling species usually found in summer at depths of 15 to 30 feet during daylight hours and at 3 to 4 feet at night; and, in winter, at depths of 40 to 60 feet. Maximum depth - 138 feet. Maximum distance from shore, 10 miles. Anadromous or semi-anadromous in some areas but not in others (in Patuxent River, may move up to 60 miles during spawning run).

Adult stage (Continued)

Behavior (continued)

Marine and estuarine populations move shoreward and generally upstream in spring, entering tidal creeks and fresh-water areas. Summer movements are generally local and random, although adults may move inshore at night when water is rough or turbid. Apparently congregate in large numbers to spawn. Hibernate in deep waters of Chesapeake Bay (Thoits and Mullan, 1958; Schwartz, 1960; King, 1947; AuClair, 1956; Richards, 1960; Miller, 1963; Hildebrand and Schroeder, 1928; Woolcott, 1962; Raney, 1965; Goode et al., 1884; Smith, 1971; Lagler, 1961; Mansueti, 1961; Webster, 1942; Anonymous, 1953).

Ecology

Habitat (Physical/chemical)

Classification: Fresh, brackish, and marine waters.

Salinity: Larvae usually at less than 1.5 o/oo (Rinaldo, 1971), experimental upper limit 8 o/oo (Mansueti, 1964). "Young" (larvae or juveniles?) collected at 13 o/oo (Dovel, 1971). Juveniles mostly at less than 3 o/oo (Rinaldo, 1971). Adults at maximum salinity of at least 30 o/oo (Smith, 1971).

Temperature: 2.0 to 32.5°C, but optimum highly variable. In some areas seldom above 15.5°C, in other areas seldom below about 27°C. In still other populations, mortality results from temperatures close to about 27°C, if sustained for several days (Smith, 1971; Richards, 1960; AuClair, 1956). On the other hand, Dorfman and Westman (1970) were able to hold white perch at temperatures up to 87°F, and found that they could survive brief exposures (2 minutes) to 100°F. Meldrin and Gift (1971) noted that avoidance responses to temperature increases ranged from 44 F to 95°F, depending on time of year and acclimation temperature. Avoidance responses to decreased temperatures occurred at 3 to 5°F below ambient acclimation temperature. McErlean and Brinkley have correlated temperature tolerance and thyroid activity.

Dissolved oxygen: Prefer O_2 content of over 3 ppm (Thoits and Mullan, 1958), but experience 50% mortality in O_2 concentrations of 0.5 to 1.0 mg/liter; growth is impaired when diurnal fluctuations of oxygen average less than 3.8 mg/liter (Dorfman and Westman, 1970).

pH range: 6 to 9 (Richards, 1960).

Benthic composition: Larvae sometimes over sand and gravel bars; juveniles over silt, mud, sand, or vegetation (Woolcott, 1962; Raney, 1965; Goode, 1888; Richards, 1960; Smith, 1971).

Turbidity/light: Schubel and Wang (1973) found that concentrations of suspended sediment up to 500 mg/liter did not influence hatching success. Morgan, Rasin, and Noe (1973) found that suspended sediment levels as high as 5,250 ppm did not effect hatching success, but that levels above 1,500 ppm did increase the incubation period.

Depth: Maximum depth for larvae, 8 to 12 feet (Webster, 1942), for adults, 138 feet (Hildebrand and Schroeder, 1928).

Water flow: Morgan, Ulanowicz, Rasin, Noe, and Gray (1973) have presented data on the effects of water movement on eggs and larvae of this species.

Associated biological communities: Found in close association with all species of fish with which it shares its environment (Anonymous, 1917; Thorpe, 1942).

Food Requirements

Food: "Fry" feed on plankton (Hover, 1948; Stroud, 1955b). Adults primarily insectivorous: mayfly nymphs, caddisfly larvae, dragonfly nymphs, midge larvae. Also eat fish (smelt, yellow perch, white perch, young eels), fish eggs, crabs, crayfish, fresh-water shrimp, and small amounts of vegetation (Cooper, 1941; McCabe, 1944-45; Thorpe, 1942; Goode, 1888; Alsop and Forney, 1962; Reid, 1972; Linton, 1901).

Feeding: Appear to feed mainly during evening (Webster, 1942).

Consumers

Natural predators and parasites: In some areas, young of the white perch are preyed upon by game fish (Cooper, 1941). The following parasites have been recorded from the white perch: *Ergasilus* sp., *Lernaeca cruciata*, *Glochidia* sp., *Piscicolaria* sp., *Leptorhynchoides thecatus*, *Neoechinorhynchus cylindratus*, *Crepidostomum cornutum*, *Crepidostomum cooperi*, *Bunodera sacculata*, *Bunodera lucioperca*, *Clinostomum marginatum*, *Diplostomulum scheuringi*, *Posthodiplostomum minimum*, *Azygia angusticauda*, *Poteocephalus ambloplitis*, *Abothrium crassum*, *Spinitectus gracilis*, *Spinitectus carolini*, *Metabronema* sp., *Camallanus truncatus*, *Dichylene cotylophora*, Natural predators and parasites (Continued)

Dichylene robusta. This list is based on the works of DeRoth (1953), Hunter (1942), McCabe (1953), Meyer (1954), and Thorp (1942), as well as the review table by Thoits and Mullan (1958).

Man: Widely utilized by man as sport and food fish. Total Chesapeake Bay catches for 1953 amounted to 1,364,000 pounds (Anderson and Power, 1956).

Influence of Toxins

Biocides: Morgan, Fleming, Rasin, and Heinle (1973) documented sublethal changes in blood morphology and biochemistry in white perch from Baltimore Harbor water which contained, among other pollutants, the insecticide dieldrin.

Heavy metals: Morgan, Rasin, Noe, and Gray (1973) and Morgan, Fleming, Rasin, and Heinle (1973) discuss mortality rates and sublethal changes in blood morphology and biochemistry resulting from water from various sources known to contain cadmium, chromium, copper, iron, mercury, and zinc. Rehwoldt et al (1971) presented data on the toxicity of copper, nickel, and zinc. Zitko et al (1971) recorded 0.75 to 1.07 ppm (wet weight) of methyl-mercury in muscle tissue of white perch.

Petroleum: Mortalities of white perch in Baltimore Harbor resulted from the effects of a combination of pollutants, one of which may have been petroleum waste (Morgan, Rasin, Noe, and Gray, 1973).

Other: Tsai (1970) commented that spawning runs of white perch in the Patuxent River were probably blocked by the outflow of chlorinated sewage effluents.

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Category: Fish

Common Name: Spot

Inventory Prepared by: Linda L. Hudson and Jerry D. Hardy, Jr.
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Classification

Class: Osteichthyes
Order: Perciformes
Family: Sciaenidae
Species: *Leiostomus xanthurus* (Lacepede)
Subspecies: None currently recognized.
Synonyms: *Mugil obliquus* Mitchill, 1815
Sciaena multofasciata Le Sueur, 1821
Leiostomus humeralis Cuvier and Valenciennes, 1830

Other common names: Spot, Norfolk spot, flat croaker, silver gudgeon, goody, Lafayette, chub, roach, jimmy, spot croaker, oldwife (Dawson, 1958).

Distribution

Known range: Coastal waters from Massachusetts Bay to Bay of Campeche, Mexico (Bigelow and Schroeder, 1953; Springer and Bullis, 1956).

Distribution in Chesapeake Bay: Found throughout the area (Hildebrand and Schroeder, 1928).

Areas of active reproduction: Moderately deep offshore oceanic waters (Hildebrand and Schroeder, 1928; Dawson, 1958).

Occurrence in other areas: Inshore when not actively spawning.

Population

Structure: A sex ratio of 50 females to 61 males has been reported (Thomas, 1971).

Densities: Large yearly fluctuations apparently occur in population densities (Thomas, 1971).

Reproduction

Method: External fertilization.

Reproduction (Continued)

Season and conditions: In Chesapeake Bay region November to February, but mainly December and January (Hildebrand and Cable, 1931); in South Carolina October to March, peak December and January (Dawson, 1958); on Gulf Coast October through March (Gunter, 1945; Pearson, 1928).

Fecundity: 70,000 to 90,000 (Dawson, 1958), with several sizes of ova present in the ovary simultaneously (Hildebrand and Cable, 1931).

Life Stages

Stages of life cycle: Egg, larva, juvenile, adult.

Early stages:

Physical appearance: Eggs undescribed. Hatching length unknown. Smallest specimen described 1.5 mm. In larvae of this size, yolk absorbed; mouth well developed, very oblique; peritoneum dark; sometimes a row of dark chromatophores along venter posterior to anus, and another mid-laterally; few scattered chromatophores on head. At 4.0 mm, urostyle usually oblique, caudal rays developing, finfold still prominent. At 7.0 mm, dorsal and anal rays developing, pectoral and ventral fins forming, dark peritoneum still visible, a dark chromatophore slightly in advance of anal origin, and pigment spots in row mid-ventrally. At 15 mm, dark peritoneum no longer visible. In juveniles at 20 mm, dorsal outline convex, margin of caudal concave. At 25 mm, body proportionately deeper, pigmentation noticeably increased. At 30 mm, preopercular spines absent; lateral line and scales well developed; lower parts silvery; body with dark chromatophores which extend onto fins; sides usually with row of dark blotches; back sometimes with faint saddlelike blotches. At 50 mm, form and color adultlike (Hildebrand and Cable, 1931). Sundararaj (1960) has described juveniles in which the scales are visible at ca 22 mm.

Development: Growth rate varies considerably. For example, Welsh and Breder (1923) recorded a total length of 80 - 100 mm at 1 year, 170 - 220 mm at 2 years, and 240 - 290 mm at 3 years. Pacheco (1957) obtained an average of ca 196 mm at the end of the first year and 247.9 mm at the end of the 2nd year.

Behavior: "Fry" (larvae?) found throughout the water column, but are most abundant on the bottom; from February to April, schools of young occur along shore,

Behavior (Continued)

particularly in protected coves and around breakwaters and jetties; later on, fish about 25 mm long and longer are abundant in vegetation; "young" ascend brackish-water ditches to fresh water in spring and early summer; immature fish remain in channels in shallow water or, sometimes, over shallow-water grass flats throughout winter, except during extremely severe cold snaps. Apparently only immature fish move northward as far as Massachusetts (the northern limit of the range), making the trip in fall (Hildebrand and Cable, 1931; Daiber and Smith, 1970).

Adult stage

Physical appearance: First dorsal triangular and with 10 spines, 2nd dorsal with 1 spine and 30 to 34 rays. Caudal concave. Pectorals pointed. Body bluish-grey with golden reflections above, silvery below, and with 12 to 15 oblique yellowish cross bars. A conspicuous black spot behind upper corner of each gill opening. Fins yellowish or dusky (Bigelow and Schroeder, 1953). Maximum length 330 mm (Sundararaj, 1960).

Development: Spot apparently reach maturity in two years. In the Chesapeake Bay region, the minimum size at maturity is about 214 mm; on the Gulf Coast, 170 mm (Hildebrand and Schroeder, 1928; Pearson, 1929).

Behavior: A schooling species. In late September and October, migrate from Chesapeake Bay to North Carolina to spawn (Hildebrand and Cable, 1931; Pacheco, 1962a).

Ecology

Habitat (Physical/chemical)

Classification: Estuarine, marine, and fresh-water.

Salinity range: 0 to 60 o/oo (Massmann, 1954; Tagatz, 1968; Hedgpeth, 1967).

Temperature: 5 to 36.7°C (Dawson, 1958; Hildebrand and Cable, 1931).

Dissolved oxygen: Thus far, recorded in a range of 3.8 to 10.8 ppm (Thomas, 1971).

Benthic composition: "Young" in low salinity water over bottom of thick loose mud (Reid, 1955).

Food Requirements

Food: A benthic feeder (Thomas, 1971). Worms, crustaceans, ostracods, copepods, mysids, amphipods, isopods, decapods, shrimp, mollusks, echinoderms, fish, mites, insect larvae, and plants (Dawson, 1958). Roelofs (1954) found that, in "young", the diet consisted of 50% copepods and 25% annelids. Hildebrand and Cable (1931) found that, up to a size of 25 mm, the food consists wholly of small crustaceans (principally copepods), but that, beyond that size, young ingested plant fragments and sand. Plant material may constitute up to 70% (by volume) of the stomach content; generally about 30% of the volume of the stomach content consists of copepods (Thomas, 1971).

Consumers

Natural predators and parasites: Predators include sharks (Dawson, 1958) and striped bass (Hollis, 1952), as well as, to a very slight degree, other game fish (Knapp, 1950). Worms occur in the gut (Hargis, 1957; Huizinga and Haley, 1962; Korathe, 1955a, 1955b) and parasitic copepods on the gills (Dawson, 1958).

Man: Man consumes large quantities of spot, for example, up to 8,000,000 pounds per year in Virginia (Pacheco, 1962b).

Influence of Toxins

Biocides: Lowe (1964, 1967) has studied the effects of sublethal concentrations of toxaphene and prolonged exposure to Sevin.

Radionuclides: Baptist (1966) studied the uptake of mixed fission products on spot.

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Category: Fish

Common Name: Northern puffer

Inventory Prepared by: Linda L. Hudson and Jerry D. Hardy, Jr.
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Classification

Class: Osteichthyes
Order: Tetraodontiformes
Family: Tetraodontidae
Species: *Sphoeroides maculatus* (Bloch and Schneider)
Subspecies: None currently recognized
Synonyms: *Tetraodon hispidis* var. *maculatus*, Bloch and Schneider, 1801
Tetraodon turgidis, Mitchill, 1815
Sphaeroides maculatus, Fraser-Brunner, 1943

Other common names: Puffer, swellfish, swell toad, sea squab, balloonfish, bellowfish, globefish.

Distribution

Known range: Atlantic coast of North America from Bay of Fundy, Canada, to Flagler County, Florida (Bigelow and Schroeder, 1953; Shipp and Yerger, 1969a).

Distribution in Chesapeake Bay: North at least to Love Point, Maryland (Hildebrand and Schroeder, 1928).

Areas of active reproduction: Shoal waters close inshore (Bigelow and Schroeder, 1953).

Occurrence in other areas: A typically inshore species, usually not found in water over 20 meters deep or more than a mile or two from land. May run up into nearly fresh water (Hildebrand and Schroeder, 1928; Shipp and Yerger, 1969a).

Population

Reproduction

Method: External fertilization.

Seasons and conditions: Spawning begins in mid-May in Chesapeake Bay. In Massachusetts, it begins somewhat later (early June) and continues through summer (Bigelow and Schroeder, 1953).

Reproduction (Continued)

Fecundity: In a 268-mm specimen, about 176,000 eggs (Bigelow and Schroeder, 1953).

Life Stages

Stages of life cycle: Egg, larva, juvenile, adult.

Early stages

Physical appearance: Eggs demersal, adhesive, transparent, spherical; diameter 0.85 to 0.91 mm (average 0.874 mm); chorion finely reticulated; perivitelline space narrow; yolk with numerous oil globules forming clusters 0.34-mm wide. Hatching length, about 2.4 mm. At hatching, pectorals formed; minute tubercles over most of body; red, orange, yellow and black chromatophores scattered over body; iris and anterior part of yolk sac with purple chromatophores. By age of one day, red chromatophores reduced, orange and yellow more prominent. Mouth open at two days. At this age, green pigment forming, especially in iris; a prominant chrome-yellow spot on tail; dorsal pigment limited to a few black chromatophores on head. At 7.35 to 7.80 mm fins formed, young essentially adult-like in appearance (Welsh and Breder, 1922; Bigelow and Schroeder, 1953; Hildebrand and Schroeder, 1928).

Development: Incubation takes about 112 hrs at 19.5°C (Welsh and Breder, 1922); 3½ to 5 days at about 20°C (Bigelow and Schroeder, 1928).

Adult stage

Physical appearance: Dorsal 8, anal 7, pectoral 15-17. Body heavy anteriorly, tapering to a noticeably slender caudal peduncle; depth 3 times in length. Mouth small and lacking teeth. Eyes near top of head. No ventral fins, caudal fin weakly rounded, but with angular corners. Parts of body covered with small close-set prickles. Dark green, ashy, or dusky above; sides with 6 to 8 vertical bars posterior to pectorals; belly white; in mature specimens, dorsal and lateral surfaces with tiny jet-black spots. Maximum length about 356 mm. (Bigelow and Schroeder, 1953; Shipp and Yerger, 1969b).

Development: Welsh and Breder (1922) noted that a 140-mm male was mature. Shipp and Yerger (1969b) mention "mature specimens" 70-mm long.

Adult stage (Continued)

Behavior: Sometimes runs into estuaries having low salinity; may make seasonal inshore-offshore movements in areas north of Chesapeake Bay (Bigelow and Schroeder, 1953).

Ecology

Habitat (Physical/chemical)

Classification: Estuarine, coastal marine.

Depth: Not much beyond 20 meters (Bigelow and Schroeder, 1953).

Food Requirements

Food: Primarily crabs, shrimp, isopods, and amphipods; also mollusks, annelids, barnacles, sea urchins, and seaweed. Young feed on copepods as well as crustacean and molluscan larvae (Bigelow and Schroeder, 1953; Welsh and Breder, 1922; Linton, 1901).

Consumers

Natural predators and parasites: No natural predators are known. Linton (1901) listed the following kinds of parasites: Acanthocephala, cestodes and trematodes.

Man: The puffer is consumed by man, but only in limited numbers. Popular in Virginia.

Influence of Toxins

Biocides: Eisler and Edmunds (1966) studied the effects of endrin on blood and biochemistry of puffers. Johnson (1968) reported a lethal concentration of 0.0031 ppm based on 96 hrs exposure. Eisler and Weinstein (1967) and Eisler (1967, 1970) commented on mortalities and physiological and behavioral changes resulting from exposure to methoxychlor and methyl parathion, and presented toxicity levels on seven organochlorine and six organophosphorus insecticides. Endrin was found to be most toxic, methyl parathion least toxic.

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Category: Reptile

Common Name: Snapping Turtle

Inventory Prepared by: Herbert S. Harris, Jr. and Jerry D. Hardy, Jr.
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Classification

Class: Reptilia
Order: Chelonia
Family: Chelydridae
Subfamily: Chelydrinae
Species: *Chelydra serpentina serpentina* Linnaeus
Subspecies: *serpentina* (North America and Mexico)
osceola (Peninsular Florida)
rossignoni (Guatemala to Costa Rica)
acutirostris (Panama to Ecuador)
Synonyms: *Chelydra lacertina* Schweigger, 1812
Testudo longicauda Shaw, 1831
Chelydra emarginata Agassiz, 1857
Other common names: Common snapping turtle

Distribution

Known range: Southern Canada to Ecuador. Range of the subspecies *serpentina* southern Canada through Mexico (Conant, 1958; Carr, 1952).

Distribution in Chesapeake Bay: Found in appropriate habitats throughout the region (McCauley, 1945; Harris, 1969).

Areas of active reproduction: Mating takes place in bays, tributaries, ponds, creeks, and ditches. Eggs are deposited on land at various distances from water (Carr, 1952).

Occurrence in other areas: Found in almost any aquatic situation, but prefer habitats with soft muddy bottom (Carr, 1952).

Population

Structure: The sex ratio is approximately 1:1. In two different studies ratios of males to females were 27 to 28 and 74 to 77 (Mosiman and Bider, 1960; Lagler and Applegate, 1943).

Population (Continued)

Densities and totals: Lagler (1943a) estimated approximately 2 snapping turtles per acre of surface in a Michigan lake. Hammer (1969) estimated a total of 2,415 adult turtles in a South Dakota marsh, with an average of 1 turtle per 2 acre area. The species congregates in large numbers to hibernate (Carr, 1952).

Reproduction

Method: Internal fertilization (Carr, 1952).

Season and conditions: Mating may take place from late April to November, but eggs are apparently deposited only between May and October. Deposition occurs on land (Carr, 1952).

Fecundity: Eleven to 87 eggs with averages reported as 25 and 37 (Carr, 1952; Hammer, 1969; Yntema, 1970). Bleakney (1957) reported that a 362 mm specimen contained 83 eggs. Larger females apparently produce larger eggs (Yntema, 1970).

Life Stages

Stages of life cycle: Eggs, juveniles, adults.

Early life stages

Physical appearance: The eggs are round and vary from 23 to 32 mm in diameter with an average of 26.8 mm (Yntema, 1970). Juveniles approximately 30 mm long at hatching and similar to adults (Conant, 1958).

Development: Incubation period normally about 60 to 90 days. The young usually remain in the nest no more than 10 to 15 days, although both eggs and juveniles have been known to overwinter in the nest (Carr, 1952; Ernst, 1966; Hammer, 1969; Toner, 1933; Yntema, 1960).

Survival: Gibbons (1970) reported an average growth rate of 32 mm per year through the first 6 years. Survival of young is affected by predators and climate. In a marsh in South Dakota, 59% of the nests were destroyed by skunks, minks, and raccoons. In the same area, hatchlings emerged from less than 20% of the undisturbed nests (Hammer, 1969). Ernst (1966) pointed out that severe drought conditions may hamper hatchling success. Yntema (1970) found that snapping turtle embryos did not survive sustained temperatures of 34°C or more.

Adult stage

Physical appearance: A large dark-brown or black turtle with a long tail. The shell has three keels and is serrate posteriorly. The plastron is very small and cross-shaped (Conant, 1958). Yntema (1970) and Lagler and Applegate (1943) give average lengths of about 265 mm.

Development: Sexual maturity is attained at a carapace length of about 200 mm (Mosiman and Bider, 1960).

Behavior: The snapping turtle is primarily restricted to the aquatic environment, although Gibbons (1970) collected a number of individuals on land using pitfall traps. Klimstra (1951) reported a maximum distance from water of 610 yards. Hammer (1969) reported that there was "little movement" in this species; but recorded a movement of 3.75 miles in 3 years in one specimen, and pointed out that one female moved 2.11 miles in ten days. Carr (1952) mentioned that snapping turtles congregate in large numbers to hibernate. Langlois (1964) found hibernating individuals beneath damp soil. Breeding behavior has been described by Hamilton (1940) and Pell (1941). McBride (1963) reported on apparent defense behavior in a large male.

Ecology

Habitat (Physical/chemical)

Classification: Fresh and brackish water, also terrestrial.

Salinity range: Fresh to "brackish" water (Neill, 1958).

Temperature range: Upper lethal temperature 38 to 41°C (Baldwin, 1925; Boyer, 1965).

Food Requirements

Food: Omnivorous: principal food - fish and aquatic plants (Lagler, 1943a; Alexander, 1943). Other animal food includes other reptiles (snakes and young alligators), frogs, tadpoles, salamanders, birds, small mammals, and a variety of invertebrates, as well as carrion. Plant food includes algae, duckweed, waterlilies, and skunk cabbage (Carr, 1952; Lagler, 1943b; Brown, 1969). Bush (1959) recorded a population which consumed 75% (by weight) of crayfish (*Cambarus* sp.) and 25% (by weight) of tree frogs (*Hyla versicolor*). He pointed out that the amount of plant material eaten varied from 36.2 to 80.2%. Pell (1941) believed the species was carnivorous in spring and largely herbivorous in summer. Coulter (1957) found that snapping turtles destroyed 10 to 13% of the duckling population in a South Dakota marsh.

Food Requirements (Continued)

Feeding: Opportunistic (Conant, 1958).

Consumers

Natural predators and parasites: Predators include bullfrogs, fish, reptiles, crows, hawks, skunks, minks, and raccoons (Brown, 1969; Conant, 1958; Korschgen and Baskett, 1963). The snapping turtle is parasitized by nematodes, trematodes, and leeches (Ernst et al., 1969; Brown, 1969).

Man: Both the eggs and flesh are consumed by man (Brown, 1969; Conant, 1958).

Non-nutritional Role

The shell is utilized by various species of algae (Dixon, 1961).

Influence of Toxins

Meeks (1968) reported high accumulations of DDT in the fat, liver, and testes of snapping turtles 15 months after application.

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Category: Reptile

Common Name: Diamondback terrapin

Inventory Prepared by: Herbert S. Harris, Jr., and Jerry D. Hardy, Jr.
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Classification

Class: Reptilia
Order: Chelonia
Family: Testudinidae
Subfamily: Enydinae
Species: *Malaclemys terrapin terrapin* Schoepff
Subspecies: *terrapin* (Cape Cod to Cape Hatteras)
centrata (Cape Hatteras to northern Florida)
tequesta (east coast of Florida)
rhizophorarum (the Florida Keys)
macrospilota (west coast of Florida)
pileata (Florida and Louisiana)
littoralis (Texas and possibly Mexico)
Synonyms: *Malaclemys terrapin terrapin* Lindholm, 1929
Testudo concentrica Shaw, 1802
Testudo ocellata Link, 1807
Emys macrocephala Gray, 1844
Malaclemys tuberculifora Gray, 1844
Other common names: Northern diamondback terrapin

Distribution

Known range: Cape Cod, Massachusetts to Mexico. The subspecies *terrapin* ranges from Cape Cod to Cape Hatteras, North Carolina (Conant, 1958).

Distribution in Chesapeake Bay: Found throughout the region (McCauley, 1945; Harris, 1969).

Area of active reproduction: Copulation takes place in the water (Carr, 1952).

Occurrence in other areas: Coastal marshes, tide flats, coves, estuaries, along inner edges of barrier beaches; generally any sheltered and unpolluted body of salt or brackish water (Conant, 1958), also probably in tidal-fresh water (Warden, 1920).

Population

Structure: Hildebrand (1932) reported a sex ratio of 1 male to 5.9 females in a captive breeding population.

Structure (Continued)

He also stated that a ratio of 1 male to 8 females would ensure fertility in his captive breeding program.

Dynamics

Trends and fluctuations: Overexploitation has caused serious fluctuations in population density. In 1891, the total Maryland catch was estimated at 89,150 pounds; in 1920, the total catch was 823 pounds and the species was apparently close to extinction in the area (McCauley, 1945).

Affecting factors: Diamond-back terrapins are killed by man and several other predators. Pollution and destruction of the wetlands habitat are serious threats to the species.

Reproduction

Method: Internal fertilization, promiscuous; females produce fertile eggs for three or four years from a single mating (Hay, 1907; Hildebrand and Hatsel, 1926).

Season and conditions: Mating takes place in spring; eggs are deposited on sandy beaches from May to August (Hay, 1904; Hildebrand and Hatsel, 1926; Schwartz, 1967).

Fecundity: 5 to 18 (Hay, 1904; Truitt, 1939).

Life Stages

Stages of life cycle: Egg, juvenile, adult.

Early stages

Physical appearance: Eggs oblong; average size 31.1 x 21.2 mm; pinkish-white when deposited; shell fragile, easily dented. Hatchlings are about 30 mm long and similar to adults (McCauley, 1945).

Development: Hatching occurs (in various subspecies) in 61-90 days (Cunningham, 1939; Hay, 1904; Reid, 1960). Allen and Littleford (1955) observed a growth rate of 31.28 mm in the first year and 27.70 mm in the second year. Hay (1904) stated that the young grow an inch a year during the first 5 years.

Survival: Hay (1904) states that the hatchlings spend the first winter buried in marshes. When they emerge, they are especially vulnerable to predation.

Adult stage

Physical appearance: Body color light-grey on brown; plastron yellow to greenish-grey. Carapace with a central keel; concentric grooves and ridges on all large dorsal scutes (Conant, 1958; Schwartz, 1967). Maximum length of Chesapeake Bay female, plastron 8.1 in. (206 mm); male about 2/3 size of female (Carr, 1952).

Development: Maturity is reached at an age of 5 years (Hildebrand and Hatsel, 1926).

Survival: Both Hildebrand and Hatsel (1926) and Truitt (1939) point out that adult diamondbacks have no important enemies except man. Crab traps cause death of many in Va. (Editor).

Behavior: An aquatic species which frequently bask out of water. In winter, hibernates at bottoms of ponds and rivers (Hay, 1904; Reid, 1960; Schwartz, 1967).

<u>Ecology</u>

Habitat (Physical/chemical)

Classification: Salt, brackish, or, rarely, tidal-fresh water (Conant, 1958; Worden, 1920).

Salinity range: Possibly fresh water (Worden, 1920) to full-strength sea water (Neill, 1958).

Temperature range: Upper lethal temperature for eggs 95°F; development of eggs temporarily stopped at 55°F (Cunningham, 1959).

<u>Food Requirements</u>

Food: Omnivorous (Reid, 1960). Primarily crustaceans and molluscs, also insects and plant material; in captivity eat cut-up fish (Carr, 1952).

Time: Feed most actively while the tide is in (Truitt, 1939).

<u>Consumers</u>

Natural predators: Fish, birds, rats, muskrats, skunks, raccoons (Hildebrand and Hatsel, 1926; Schwartz, 1967; Truitt, 1939).

Man: During the early part of the 20th century, the diamondback terrapin was heavily exploited by man; since that time, it has been less actively sought and the species is now making a strong comeback (Conant, 1958; Reid, 1960).

Man (Continued)

A number of authors have described culture methods for the diamondback terrapin (Hildebrand and Hatsel, 1926; Hildebrand, 1929, 1932; Truitt, 1939; Hildebrand and Prytherch, 1947).

Influence of Toxins

In 1960, the senior author observed a number of diamondback terrapins in Baltimore Harbor which were dying after being heavily coated with oil and grease.

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Common Name: Whistling Swan Scientific Name: *Olor columbianus*

Prepared by: Marvin L. Wass
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Seasonality:

Fall migration: Oct. 15-25 to Nov. 20-30, with peak falling between Oct. 25 and Nov. 20. Spring migration: Mar. 1-10 to Apr. 20-30; with peak falling between Mar. 10 and Apr. 5 (Stewart, 1962). Usually migrates in flocks of 5 to 200 or more.

Preferred Habitat

Generally restricted to fairly extensive areas of open estuarine waters not more than 5 ft. deep; locally will occasionally inhabit saltwater estuarine bays.

The 1955-58 Fish & Wildl. Serv. average ecological distribution of wintering population reads as follows: brackish estuarine bays - 76%, salt estuarine bays - 9%, fresh estuarine bays - 8%, slightly brackish estuarine bays - 6%, coastal impoundment-bay complex - 1%, fresh & brackish estuarine bay marshes - t%.

Fall & spring migration: occur regularly in open shallow tidewater areas of fresh & slightly brackish estuarine bays (Stewart, 1962).

Nesting

Large bulky mass of sticks, moss, grass, rubbish and other materials, lined lightly with feathers or down, placed on ground near water; usually on a small island in a secluded area or a bank marsh close to pond (Bailey, 1913).

Food Habits

Rarely dives but obtains food by extending head under water and sieving.

Primarily aquatic plants, also: grasses, sedges, eelgrass, wild celery and foxtail grass (the latter 3 being preferred during winter at Back Bay, Va.); grain, tadpoles, frogs, small fish, worms, insects and shellfish (Bailey, 1913). Recently began feeding in wheat fields in Md. and Va.

Reproduction

Mate for life when 3 years old, begins nesting at ages 4 to 6 (Banko and Mackay, 1964).

Season: Late May and early June; incubation period about 32 days.

Clutch Size: 4-7, usually 4; 1 brood per season (Banko and Smith, 1964).

Fledging Period: 50 to 60 days (Reilly, 1968).

Reproductive Success: Between 2 and 3 survive to fly (Banko and Mackay, 1964).

Growth Rate

Age at maturity: 4-6 years (Banko and Mackay, 1964).

Longevity: Swans live long lives, some living as long as 70 years in captivity (Brooks, 1922). Record in nature 19 years.

Mortality

Predation: Coyote.

Natural: Storms destructive to nests and young: early winter storms "ground" large numbers. Aquatic vegetation apparently much reduced in estuaries in recent decades.

Man-made: Many hunters still cannot withstand temptation to kill such large, beautiful birds.

Mortality rate: Unknown, probably under 30% after age 1.

Competition

Ducks and geese also eat aquatic vegetation.

Abundance

In area: Large numbers migrate through, and winter in, upper Ches. Bay region - F.&W.S. 1953-58 wintering populations given as 17,000 in 1958 to 71,600 in 1955. Atlantic Flyway population in 1974 was 64,200, up 12% from 1973 (Ferguson and Smith, 1974).

Over total range: Breed in Arctic islands or ponds north of Arctic Circle from n. Alaska to Baffin Is., s. to barren grounds of Canada, Alaskan Peninsula and St. Lawrence Islands. Maximum density ca. 1 pr./sq. m. Winters - mainly Ches. Bay, Back Bay and Currituck Sound N.C., Del. Texas and in n. Calif., Nev. and Utah (Banko and Mackay, 1964).

Known reasons for decline or increases: Protected by law (except Arctic natives allowed to take them. This has resulted in steady increases. All-time high Christmas Bird Count was 37,670 set at Sacramento, Calif. in 1973 (Monroe, 1973).

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Common Name: Canada Goose Scientific Name: *Branta canadensis*

Prepared by: Marvin L. Wass
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Seasonality

Migrate Feb. - Apr. with peak Mar. 10 to Apr. 10; Sept. - Dec. with peak Oct. 15 to Nov. 5 (Stewart, 1962).

Preferred Habitat

Water shallow enough to allow easy feeding. Also deeper water near open fields where grasses & other vegetation offer sufficient food.

Nesting

Variety of situations: usually hollow in ground or mound of grasses, reeds, etc. lined with feathers, occasionally high on cliffs, rarely in old crow and eagle nests. Now frequently on artificial platforms in United States. Nest usually well-made structure, well-hidden.

Food Habits

Great variety of aquatic plants & roots, grain and grasses; also small vertebrates and invertebrates, including frogs, toads, fish, worms, crustaceans and mollusks. Feed either on shore or bring food up from bottom by thrusting head and neck under water. Probably most of winter feeding is now in grain fields.

Reproduction

Pair for life, young usually mate before migration.

Season: Apr. - June.

Clutch: 4 to 10, usually 5 or 6; 1 brood/season (Bent, 1925).

Incubation: 28 to 30 days by female only (Bent, 1925).

Fledging Period: Young leave nest shortly after hatching, unable to fly for 50 days or more (Reilly, 1968).

Reproductive success: Nests 64% successful in southern end of range, up to 87% in Arctic (Hansen and Nelson, 1964).

Growth Rate

Age at maturity: Mate in 2nd to 4th year.

Longevity: Up to 33 years (Kortright, 1943).

Mortality

Predation: Crows, raccoons and skunks in southern end of range; jaegers, gulls and foxes in Arctic. Predation little in Arctic except when lemmings are low (Hansen and Nelson, 1964).

Natural: Parasitic diseases, botulism, storms, over-crowded nesting grounds.

Man-caused: Shooting, unstable levels in impoundments; spills and lead poisoning.

Mortality rate: Unknown, likely under 30% after first year.

Competition

Competes with other geese, including brant and swans, also plant-eating ducks and coots.

Abundance

In area: Some bred in captivity in Ches. Bay area, esp. at Patuxent Refuge. Has also bred at Chincoteague NWR.

Over total range: Most widely distributed of water-fowl; from Atlantic to Pacific Oceans, and from Gulf of Mexico to Arctic Coast. Formerly bred from n. North America south to c. Calif., Mont., se. Canada; now breeds south to St. Marks, Fla. Although all-time CBC high was set in 1950 at Sacramento, Calif., species is still increasing. Winter survey in 1974 showed Canada Goose up to 19.3% over 10-yr. average in Atlantic Flyway (Ferguson and Smith, 1974).

Known reasons for increase: Benefits have come from increased numbers of refuges, expansion of breeding grounds, greater food supplies from farm fields and lessened hunting pressure - the latter partly due to sagacity of this mostly widely distributed North American waterfowl.

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Common Name: Black Duck Scientific Name: *Anas rubripes*

Prepared by: Marvin L. Wass
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Seasonality

Sept. 10-20 to Dec. 1-10, peak around Oct. 20 - Nov. 25; Feb. 15-25 to Apr. 15-25, peak around Feb. 25 - Mar. 25. Breeds throughout area in suitable salt marshes (Stewart, 1962).

Preferred Habitat

Bottomlands freshwater impoundments of coastal plain, estuarine and coastal bays and marshes with submerged aquatics.

Nesting

Nearly 60% in wooded areas, 18% on duck blinds, 16% in marshes and 5% in cultivated areas and borders.

Food Habits

Consumes about 3 times as much animal food as the mallard does. Examination of 390 stomachs showed plants 76%, animals 24%. Plants (%) included pondweeds 32, grasses 11, sedges 11, smartweed 5, seeds of burr reed, watershield, water lilies and coontail 9, miscellaneous 13. Animal percentages were molluscs 12, crustaceans 8, insects 2, fishes 1, miscellaneous 1. During summer and autumn, food is 90% vegetable (Kortright, 1942).

Reproduction

Season: Breeding: Mar. - mid-Aug. Apr. - June peak; usual egg dates: last Apr. - first May, hatching mainly May - June.

Clutch: In Kent I., Md. study, average clutch (360 clutches) declined from 10.9 early in season to 7.5 near end; max. 14.

Incubation: Average 26.2 days (51 clutches).

Fledging Period: Unknown, probably about 45 days.

Reproductive success: Of 574 nests, 38% hatched one or more eggs, 11.5% were deserted and 50% were destroyed (34% by crows). In Md., 5.1 young were produced per nest.

Growth Rate

Age at maturity: One year, but not all breed during first year.

Longevity: Up to 10 yrs. (Kortright, 1942).

Mortality

Predation: Mainly on eggs by fish crow in Md.; less by common crow and raccoon.

Natural: Storms, botulism, parasitic diseases. Tidal flooding caused 30% of nest desertion in Md. (Stotts and Davis, 1960).

Man-caused: Hunting and lead poisoning; loss of nesting habitat probably most important. Humans collected eggs in 1955 in Md. (Stotts and Davis, 1960).

Mortality rate: From hatching to flying, 9.2%; of adult females 50%, few surviving to age 4 or 5 (Stotts and Davis, 1960).

Competition

With Canvasback, Mallard and other waterfowl for aquatic plants.

Abundance

In area: Breeds s. to se. Va. and upper James. Up to 21 pairs per acre on some islands in Eastern Bay, Md. (Addy, 1964).

Over total range: Breeds from Hudson Bay east to n. Lab. & Nfld. s. to Great Lakes & e. N.C.

Winters from Ont., Quebec, Prince Edward I. and Nfld., south to Gulf coast and Fla. Atlantic Flyway population now at lowest point in 20 years (Ferguson and Smith, 1974). All-time CBC high was 36,000 at Oceanville, N.J. in 1966; 3.5 times the 1974 high.

Known reasons for increase or decline: Species is now one of the 70-point ducks, which allows only 2 per day to be taken. However, numbers in Atlantic Flyway were down 10.5% (to 246,700) from 1973 population, which still made it second in duck numbers, but only a third of the Canada Goose population.

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Stotts, V. D. and D. E. Davis. 1960. The black duck in the Chesapeake Bay of Maryland: Breeding behavior and biology. Chesapeake Sci. 1:127-154.

Common Name: Bufflehead   Scientific Name: Bucephala albeola

Prepared by: Marvin L. Wass
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Gloucester Point, Virginia

Seasonality

Fall migration: Oct. 20-30 to Dec. 10-20; peak: Nov. 1-30.

Spring migration: Mar. 10-20 to Apr. 20-30; peak: Mar. 25-Apr. 15 (Stewart, 1962).

Late migrant both fall and spring; usually travels in flocks of 20 to 50 during peaks of migration (Reilly, 1968).

Preferred Habitat

Ponds, lakes and rivers; estuarine and inshore marine waters in winter, and Great Lakes.

Nesting

Almost entirely dependent on holes made by flickers in poplars, cottonwoods and Douglas fir in the boreal-montane coniferous forest biome. Use of nest boxes is increasing (Erskine, 1971).

Food Habits

Mainly insects on freshwater, crustaceans on saltwater. Plant material may predominate in autumn (Erskine, 1971). Overall - 80% animal, 20% vegetable (Cottam, 1939).

Reproduction

Season: Late April through July.

Clutch Size: 5-17, usually 5-11; 9 being most common (dump-nesting possible in large clutches). Clutches started Apr. 23 - May 31 in B.C. Largest clutches laid first week in May. Late clutches may be renestings (Erskine, 1171).

Incubation Period: 28-33 days after last egg hatched, usually between 29-31 days (Erskine, 1971).

Fledging Period: 50-55 days (Erskine, 1971).

Reproductive success: Nest success averages 75-80%, much higher than for ground-nesting ducks. Hatching in successful nests was 90% in B.C. Probably only 50% or less of young survive to flight age (Erskine, 1971).

Growth Rate

Age at maturity: Breed at age 2, although less successfully than older birds do (Erskine, 1971).

Longevity: 4 banded at Kent I., Md. lived from 11½ to 13½ yrs.

Mortality

Predation: Once preyed on by Peregrine Falcon (Kortright, 1942).

Natural: Summer storms may cause loss of young.

Man-caused: Some shooting, grouped with ducks valued at 25 points, thus only 4 may be legally shot in one day. Cutting of nest trees possibly most detrimental.

Mortality rate: 72% first year, 53% thereafter, calculated from banding data. Annual adult mortality probably only about 30% (Erskine, 1971).

Competition

Competes with goldeneyes and scaups for food in summer and winter; with starlings, tree swallows, squirrels, and goldeneyes for nests in parts of range (Erskine, 1971).

In area: Migrant and wintering flocks common in upper Chesapeake region (Stewart, 1962). Population holding better than any other duck, being 34.8% above 10-yr. average in Atlantic Flyway (Ferguson and Smith, 1974).

Over total range: Breeding: from Hudson Bay to Alaska & B.C., s. to Calif. (Reilly, 1968); probably 2/3 of total population breeds in the interior of B.C. and Alberta (Erskine, 1971).

Winter: Gulf Coast and Calif.; north to British Columbia, Ontario and Nova Scotia.

Known reasons for increase or decline: Recent increase likely due to less hunting and natural predation. It is also largely unaffected by drouths. Coastal refuges and inland reservoirs also help it. Permanent decline since 19th century largely due to loss of 100 x 800 mile "parklands" in w. Canada.

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Common Name: Oldsquaw   Scientific Name: *Clangula hyemalis*

Prepared by: Marvin L. Wass
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Seasonality

Oct. 20-30 to Dec. 10-20; peak: Nov. 5-Dec. 5.
Mar. 1-10 to Apr. 20-30; peak: Mar. 15-Apr. 15.
(Stewart, 1962).

Preferred Habitat

Ponds on tundra in summer; Great Lakes, estuaries and coastal waters in winter.

Nesting

Hollow lined with down from breast of female, located on ground of tundra of sub-Arctic regions (Bent, 1925).

Food Habits

In examination of 227 stomachs: crustaceans - 48%, mollusks - 16%, insects - 11%, fishes - 10%, miscellaneous animal food - 3%; grasses - 3.5%, pondweeds - 1.5%, miscellaneous plant food - 7% (Cottam, 1939). Able to dive to depths of 200 feet.

Reproduction

Season: May to July, occasionally as late as Aug.

Clutch size: As many as 17, usually 5 to 7; 1 brood/season, with as many as 2 replacement sets (Bent, 1925).

Incubation period: 3½ weeks, by female alone; male stays close by until hatched.

Fledging period: Age at first flight unknown (Reilly, 1968).

Reproductive success: Unknown, apparently low recently, down 29% on Atlantic Flyway in 1974 from 1973.

Growth rate

Age at maturity: Around 2 years (Kortright, 1942).

Longevity: Unknown, possibly 15 years.

Mortality

Predation: Dogs, foxes, jaegers, gulls and coyotes destroy eggs and young (Bent, 1925).

Natural: Storms during breeding season.

Man-caused: Although not very tasty, many are still hunted during duck season because of their quick flight which presents a challenge. Bag limit is 10 per day (since this is a 10-pt. duck), and season is over 3 months long.

Mortality: Unknown, probably currently high.

Competition

Competes with scoters, goldeneye and bufflehead for food. Large blue crab population possibly detrimental.

Abundance

In area: Common transient and winter resident along coast and throughout brackish/salt estuarine bays of Chesapeake region (Stewart, 1962).

Over total range: Circumpolar; breeds on all Arctic tundras from Atlantic to Pacific s. along mountains into extreme n. B.C.; winters s. to Calif. and Fla. (rarely), also Great Lakes. All-time CBC high of 35,500 set on Lake Michigan in 1956. Atlantic Flyway count was 7,900 in Jan., 1974; down 29% from 1973 (Ferguson and Smith, 1974).

Reasons for increase or decline: Early decline due to large kills by gill nets in Great Lakes. Dead hen found in Ware R., Va., 1972 had 6 lead shot in gizzard; 4 would probably kill this species.

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Common Name: Ruddy Duck Scientific Name: Oxyura jamaicensis

Prepared by: Marvin L. Wass
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Gloucester Point, Virginia

Seasonality

Sept. 15-25 to Dec. 5-15; peak: Oct. 25-Nov. 30.
Mar. 1-10 to May 10-20; peak: Mar. 15-Apr. 10.
(Stewart, 1962).

Preferred Habitat

Freshwater ponds, lakes, marshes; enters marine waters in winter (Reilly, 1968).

Nesting

Nests near prairie sloughs wherever vegetation provides a thick cover; forms a basket-like structure of materials from surrounding vegetation, cleverly matching it with environment; built about 8 inches above water level and attached firmly to reeds (Kortright, 1942).

Food Habits

Diet mostly vegetation, for which it dives to bottom. Examination of 181 stomachs yielded: pondweeds - 30%, sedges - 18%, muskgrass - 4%, wildcelery - 2.5%, smartweeds - 1.5%, watermilfoils - 1%, grasses - 1%, miscellaneous plants and gravel - 13%; animal content: insects - 22%, mollusks - 3%, crustaceans - 1.5%, miscellaneous - .5% (Cottam, 1939).

Reproduction

Season: Apr. - Aug.

Clutch size: As many as 19 or 20, usually 6 to 9 or 10; eggs are very large; 2 broods may be raised per season (Bent, 1925).

Incubation period: Unknown, probably around 30 days by female alone, but contrary to other ducks, male remains near until young are fully grown.(Bent, 1925).

Fledgling period: Age at first flight around 52-66 days (Reilly, 1968).

Reproductive success: Unknown, probably near 6 per nest.

Growth rate

Age at maturity: 1 year (?) (Kortright, 1942).

Longevity: May live up to 20 years (Kortright, 1942).

Mortality

Predation: Foxes, dogs, coyotes, raccoons, mink; probably higher than for hole and Arctic nesting species.

Natural: Storms

Man-caused: Lead poisoning, chemicals, destruction of wet lands, sport kill likely less than for most other ducks.

Mortality rate: Unknown

Competition

Apparently not great, food similar to that of Bufflehead, but containing more plant material.

Abundance

In area: Migrant and winter resident along Ches. region; common in many areas.

Total range: Breeds mainly in prairie states and provinces from Nebr. to n. Sask. and from B.C. to Minn., rarely on e. coast. Winters from B.C. to Guatemala, incl. most of Mexico; and from N.J. to s. Fla.

Reasons for decline or increase: Increasing, only common duck setting an all time high on a Christmas Bird Count in the United States since 1968 (in 1971 and again in 1974). Atlantic Flyway population 28% above 10-yr. average in Jan., 1974 (Ferguson and Smith, 1974).

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Stewart, R. E. 1962. Waterfowl Populations in the Upper Chesapeake Region. Fish & Wildl. Serv., Spec. Sci. Rep. - Wildl. No. 65.

Common Name: Osprey Scientific Name: Pandion haliaetus

Prepared by: Donald W. Meritt
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Seasonality

In the Chesapeake Bay area, birds occur from March through November (Stewart and Robbins, 1958). Main migration occurs late March through early April, and mid-September through early October. Some immatures start south as early as late August (Henny and Van Velzen, 1972).

Preferred habitat

Along the Coast in bays, rivers, and estuaries. Inland near lakes or rivers.

Nesting

Formerly in trees (Reese, 1969), but adapt well to available man-made structures (duckblinds, channel markers, telephone poles); occasionally on the ground. Chesapeake site selections are broken down as follows: trees (31.7%); duck blinds (28.7%); channel markers (21.8%); other man-made structures (17.8%) (Henny et al., 1974); often nesting in loose colonies.

Food habits

Diet made up almost entirely of fish: menhaden, eels, killifish, hogchoker, and toadfish. Seldom, if ever, feeds upon dead fish.

Reproduction

Season: Late March through late August (peak, late April through early July) (Stewart and Robbins, 1958).

Clutch size: 2-4; 1 clutch normally laid; relaying may occur if eggs are removed or destroyed early in the season (Reese, 1970).

Incubation period: Bent (1938) and Ames (1964) give incubation periods of 28-33 days. Garber and Koplin (1972) report California ospreys incubating as long as 38-43 days. Thirty-eight day incubation periods have also been recorded in Chesapeake populations (Reese, pers. comm.). Both sexes are known to incubate (Garber and Koplin, 1972; Reese, pers. comm.) with the male incubating about 30% of the time (Garber and Koplin, 1972).

Fledging period: About 55 days (Reese, pers. comm.).

Reproductive success: Number of birds fledged per active accessible nest; .64 to 1.16 (527 nests, Talbot Co., Md., 1963-69) (Reese, 1970); .87 to 1.43 (422 nests, Talbot Co., Md. 1970-73) (Reese, pers. comm.); .43 to .81 (88 nests, Queen Annes Co., Md. 1966-69) (Reese, 1970); .87 (20 nests, Queen Annes Co., Md. 1973) (Reese, pers. comm.); .73 to 1.25 (86 nests, Choptank River Md. 1968-71) (Reese, 1972); 1.43 (28 nests, Choptank River, Md. 1973) (Reese, pers. comm.); .45 to .98 (104 nests, Potomac River, Md. 1963, 1967-68) (Reese, 1970); .70 (46 nests, Potomac River, Md. 1970) (Wiemeyer, 1971); 1.6 (46 nests, Smith's Pt., Va. 1934 (Tyrrell, 1936).

Production rates required to maintain a stable population are estimated at 1.22 - 1.30 young per active nest. Maryland osprey populations are currently declining 2-3% annually (Henny and Ogden, 1970). Preliminary 1974 data indicate Va. nests increased to near 600; fledge rate near 1.2 (vs. .75 in 1972). Several nests fledged 4 young in 1974 whereas none did so before 1972. However, James R. had no nests in 1974, following 5 years of complete hatching failure. Nest on navigation aids are twice as successful as other nests.

Growth rate

Age at maturity: At least 3 years. Although some birds return to the nesting grounds and build nests as 2-yr olds, no eggs are laid (Henny and Van Velzen, 1972).

Longevity: Band recoveries indicate ospreys live at least 18 years (Henny and Wight, 1969).

Mortality

Predation: Adults have few problems with predators; eggs and young are more vulnerable, crows and rats have been seen in the act of egg robbing, and raccoons, otters, snakes, muskrats, diamond-backed terrapins, gulls, herons, owls, and foxes are probable or potential predators (Reese, 1970).

Natural: Violent summer storms with heavy rain, high winds and tides take a major toll of eggs and young (Reese, 1970); exposure to the sun is also known to cause nestling mortality (Tyrrell, 1936).

Man-caused: The U.S. Coast Guard, through maintenance to navigational aids, has caused substantial egg and nestling losses (Reese, 1970); water-oriented recreational activities disturb nesting ospreys and reduce egg hatchability and nestling survival (Reese, 1970; Ames and Mersereau, 1964).

Mortality Rate: 53.3% for the 1st year; 19.6% for 2nd through 15th, for 29.6% overall (Henny and Wight, 1969).

Competition

Bald Eagles rob ospreys of fish but this is not a major factor due to the small population of eagles in the Chesapeake system.

Abundance

In area: 1450 ± 30 pairs estimated in Chesapeake Bay area (Henny et al., 1974).

Over total range: Cosmopolitan; American subspecies *P. h. carolinensis* breeds from N. Alaska to Baja California and Sonora, east to S. Labrador, Newfoundland, and south to Florida. Winters from southern United States to South America (Bureau of Sport Fisheries & Wildlife, 1973). Population declining over most of the United States at a rate of 2-14% annually with the exception of the Florida Bay population, which is stable (Henny and Ogden, 1970).

Known reasons for increase or decline: Major reason for population declines in the U.S. is egg failure (Reese, 1970; Ames and Mersereau, 1964; Kury, 1966); chlorinated hydrocarbons have been shown to cause thinning in eggshells which could account for eggs being broken (Hickey and Anderson, 1968; Porter and Wiemeyer, 1969; Wiemeyer and Porter, 1970). Maryland osprey eggs have been shown to contain chlorinated hydrocarbon concentrations of 3.0 microgrammes per milliliter of total egg volume (Ames, 1966).

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SECTION 3

CHESAPEAKE BAY COMMUNITIES: GENERAL ECOLOGICAL DESCRIPTIONS AND SELECTION OF SEVERAL COMMUNITIES FOR MORE DETAILED STUDY

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INTRODUCTION

Delineation of the various types of Chesapeake Bay communities is a formidable task because an overall, concrete community concept does not exist. It is not unusual for one investigator to designate a group of organisms living together as a community, whereas another investigator will consider this same group as either several distinct communities or merely as a subdivision of an even larger community. Scarcity of literature on estuarine community structure is another obstacle. A few studies on Chesapeake Bay community structure have been conducted (e.g., Stone, 1963; Marsh, 1970; Boesch, 1971; Orth, 1971 and Richardson, 1971), but they deal with communities found only in limited Bay regions, whereas information on other Bay localities and other Bay communities is practically nonexistant. A few more inclusive works on general estuarine community structure and on detailed descriptions of particular communities exist (e.g., Allee, 1934; Day, 1951; Thorson, 1957; Carriker, 1967; Sanders, 1968: Remane and Schlieper, 1971). Some information included in these publications can be directly applied to Chesapeake Bay communities, therby increasing the knowledge base. The purpose of this review is to provide *water resource managers* with a foundation for their decisions regarding human activities which influence community stability.

An attempt will be made in this report to describe in detail the interactions between organisms that compose the community and the interactions between the community and its environment. A correspondant of H. T. Odum, B. J. Copeland and E. A. McMahan (1974) expressed the problems associated with a study such as this when he stated:

> "What needs emphasis is that we have almost none of the hard, detailed information which is needed to intelligently manage most of our shore areas. Written material like this is likely to give would-be managers the illusion that they know a whole lot, and can now proceed with safely predictable results. It seems to me this could lead to great damage. What these managers really need is a brochure setting out the complexity of the problems to be faced, and pointing out the necessity of making detailed local studies of each particular situation before making drastic changes therein!"

This section attempts to demonstrate the complexity of the problem for *water managers*. The *Zostera marina* community and the *Crassostrea virginica* community will be discussed in detail. The fish, bottom and plankton communities will be reported in more generalized terms. Choice of the communities studied in detail was not solely because of economical importance but also for their economical significance, trophic relationships, vulnerability to stress and/or spatial distribution.

Although two communities are discussed rather thoroughly in this section of the report it must be emphasized that much of the information utilized in their preparation was not from research concerned with the Chesapeake Bay. Therefore a *water manager* must not accept statements verbatim but must conduct his own investigation in the locality where a decision has to be made or obtain assistance from a scientist who has already studied the area. Often a *manager's* decision will be nothing more than an educated guess, but if he attempts to utilize all channels of available information then the chances of an unfavorable decision are greatly diminished.

CHESAPEAKE BAY COMMUNITY STRUCTURE

In Section 1 of this report the concepts of community and "limiting factors" and the environmental parameters that act as "limiting factors" were reviewed. It is these basic ideas and parameters that are the foundation of this report. Hopefully, it is understood that one cannot designate the boundaries of a Bay community as one would a community of people. If a person says he is from Baltimore, a specific geographical region is brought to mind. However, mention of a specific Bay community, e.g. the Nepthys-Ogyrides-Retusa community, may provide a different picture in the mind of a Maryland investigator who usually thinks only in terms of upper Bay communities than in the mind of a Virginia researcher who usually considers only lower Bay communities. In other words, *managers* must recognize that community boundaries are not only indistict, but often form a continuum and also that "one" community can be distributed in many localities throughout the Bay.

This section will present the major ecological communities found in the Chesapeake Bay. The basis of classification for these communities was given in the discussion of the community concept, i.e., by physical habitat or by a dominant structural feature. The use of energy flow, as a means of classification, was not attempted at this time. Copeland (1970) used this method for generalized separation of estuarine system types. He based this separation on the major energy source factors of each system. For example, the major energy source(s), of a grass bottom is light, of a clam flat is circulation, and of a marsh is (are) light and land runoff.

The criteria necessary for the Chesapeake Bay classification scheme are demonstrated in Table 5. This system is based on the division of the estuary into geographical divisions. Four of these divisions were first designated by Day (1951) in his discussion of an ideal estuary. Carriker (1967) added one other division: the lower reaches of the estuary. Both investigators based their division on salinity, water movement and substrate. It must be emphasized that neither Carriker nor Day intended these divisions to be precise boundaries, but rather rough approximations. Carriker (1967) caracterized the central regions of these divisions thusly:

> 1. "Head of estuary - where fresh water enters the estuary from streams, and salinity during high spring tides may reach a maximum of 5 ppt. Currents and substrate vary broadly and are dependent on the physiography of the region."

Table 5. Classification of Approximate Geographic Divisions, Salinity Ranges, Types, and Distribution of Organisms in Estuaries (Carriker, 1967).

Venice system				Ecological classification				
Divisions of estuary	Salinity ranges ‰	Zones		Types of organisms and approximate range of distribution in estuary, relative to divisions and salinities				
River	0.5	limnetic		limnetic				
Head	0.5 - 5	oligohaline		oligohaline				
Upper Reaches	5 - 18	mesohaline	mixohaline					
Middle Reaches	18 - 25	polyhaline				true estuarine		
Lower Reaches	25 - 30	polyhaline						
Mouth	30— 40	euhaline			stenohaline marine		euryhaline marine	migrants

2. "Upper reaches of estuary - muddy bottoms, slow movement of water, and salinities from 5 to 18 ppt."

3. "Middle reaches of estuary - sandy mud bottoms, fairly fast movement of water, with salinities from 18 to 25 ppt."

4. "Lower reaches of estuary - sandy mud to clear sand or gravel bottoms, fast movement of water, and salinities from 25 to 30 ppt."

5. "Mouth or inlet of estuary - clean sand, gravel, or rock bottom, very rapid flow of water, with salinities above 30 ppt and depending on the salinity of neritic water outside."

In addition to delineating geographical divisions, zones and salinity ranges of organisms in estuaries, Carriker (1967) also demonstrated the approximate range of distribution of types of estuarine organisms in relation to these criteria. The terminology Carriker used in classifying estuarine organisms has been applied in this review to Chesapeake Bay organisms. For example, an oligohaline organism is one that generally does not survive a salinity content greater than 5 ppt, whereas a true estuarine organism can survive in a range of about 0.5 ppt to 30 ppt. "True" estuarine species have marine affinities, but do not occur in the sea or in freshwater. They have adapted to the estuarine environment and require its conditions for their survival. Euryhaline organisms, by definition, tolerate a wide range of salinities, i.e., they can live in seawater and in salinities sometimes as low as 5 ppt. On the contrary, stenohaline organisms do not tolerate a wide salinity range, e.g., stenohaline marine organisms are limited in their penetration into estuaries by a salinity content no lower than 25 ppt. Migrant organisms are characterized as those organisms that move in and out of a community and/or which only spend a portion of their life in a bay. Distribution of salinity zones in Chesapeake Bay is illustrated in Figure 15. This scheme is arbitrary and subject to change. Using these definitions, salinity zones and divisions, an attempt has been made to classify Chesapeake Bay communities.

It is not the intention of this report to present a rigid classification of Chesapeake Bay communities because it is not unusual for different communities to overlap and form ecotone* communities. Instead, a

* An ecotone is the area of overlap between two more or less diverse communities (Odum, 1959)

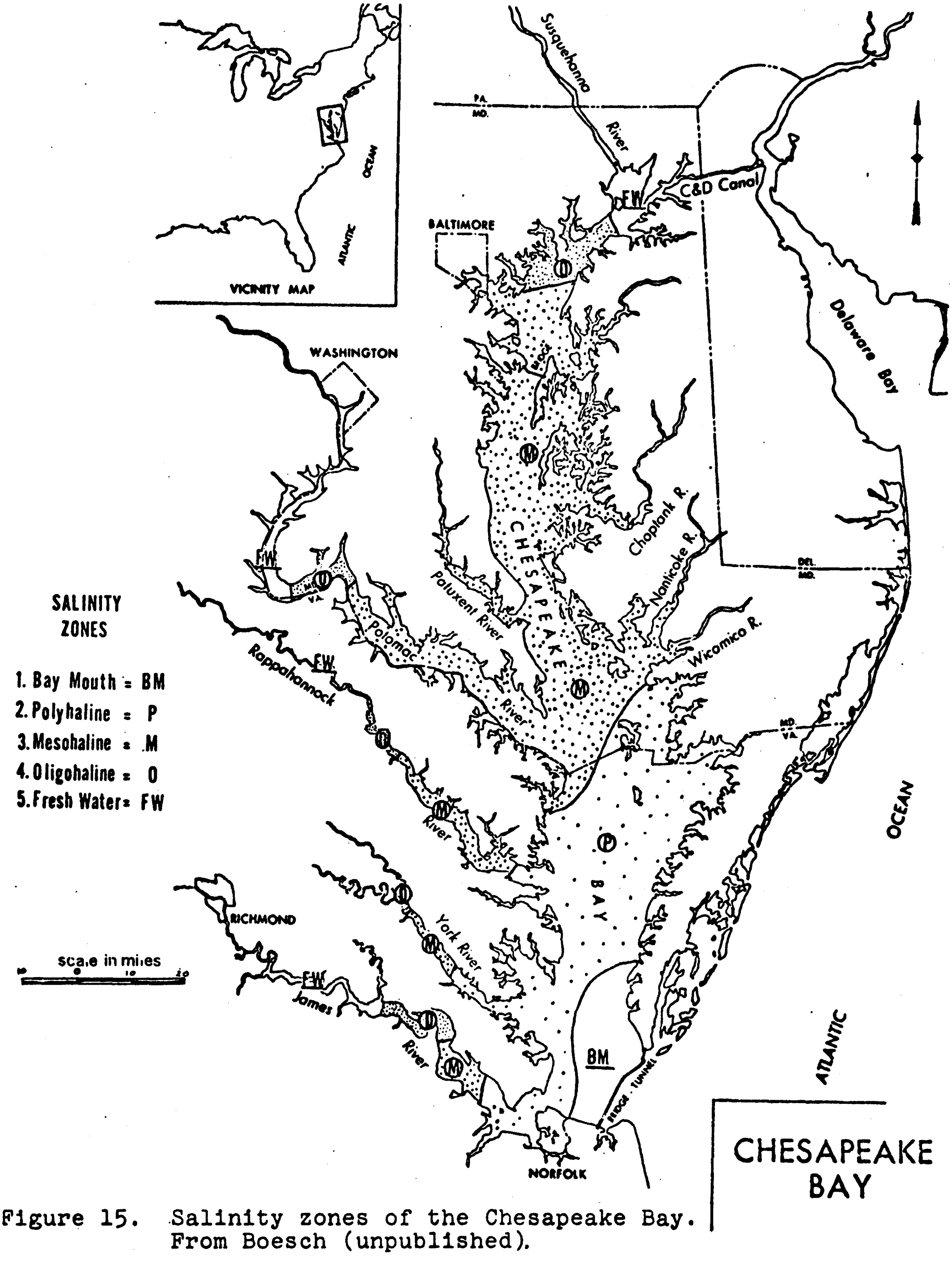


Figure 15. Salinity zones of the Chesapeake Bay. From Boesch (unpublished).

generalized scheme of community delineation by means of salinity zones is given (Table 6).

The decision by which communities were chosen for investigation was arbitrary. It may appear that a particular community was not important since it was not initially chosen for further study. On the contrary, all Bay communities are important because of the complex interactions between inhabiting organisms of a community and between one community and another. It is our purpose to present as complete a picture of certain Chesapeake Bay communities as possible to enable an *estuarine manager* to make pertinent and timely decisions.

Zostera Community

The Zostera community derives its name from the dominant species of a distinct assemblage of organisms. Remember that the dominant species is one way of naming a community (p. 4-6). In this case, Zostera (eelgrass) is the dominant species. It is also the comptroller of the energy flow among the species living in the community. A *water manager*, therefore, must understand the natural history of eelgrass in order to appreciate the intricacies of community relations.

One question a *water manager* will ask when he is faced with a decision that could result in the removal of a Zostera bed is: "Why is eelgrass important?" Orth (1971) listed several reasons, both physico-chemical and biological:

(1) It provides a habitat for a wide variety of microorganisms.

(2) It provides a substrate for epifauna.

(3) It is utilized as a nursery ground by fish.

(4) It is a food source for ducks and brant.

(5) The organic detritus formed by Zostera, plus the microorganisms absorbed on it, represent the main energy source for animals living in the Zostera community and for animals outside the community to which detritus is transported.

(6) The plant physically acts as a stabilizing factor for bottom sediments, which allows greater faunal diversity.

(7) It plays a role in reducing turbidity and

Table 6. Community structure of the Chesapeake Bay.

MOUTH	MIDDLE and LOWER REACHES	UPPER REACHES	HEAD	RIVER
EUHALINE	POLYHALINE ZONE	MESOHALINE ZONE	OLIGOHALINE ZONE	LIMNETIC ZONE
Benthic	Aquatic plants, e.g. *Zostera*	Aquatic plants, e.g. *Ruppia*	Aquatic plants, e.g. *Ruppia*, *Zannichellia*	Aquatic plants, e.g. *Potomogeton* *Myriophyllum*, *Zannichellia*
Intertidal (beach)	Benthic Sand Mud Sand-mud combinations	Benthic Sand, Mud Sand-mud combinations	Benthic Sand Mud Sand-mud combinations	Benthic
Epifauna	Epifauna-on or upon solid substrata, e.g. rocks, jetties, piers	Epifauna-on or upon solid substrata, e.g. rocks, jetties, piers	Epifauna-on or upon solid substrata, e.g. rocks, jetties, piers	Epifauna
Plankton Phytoplankton Zooplankton Meroplankton	Plankton Phytoplankton Zooplankton Meroplankton	Plankton Phytoplankton Zooplankton Meroplankton	Plankton Phytoplankton Zooplankton Meroplankton	Plankton Phytoplankton Zooplankton Meroplankton
Migratory Component Fish Blue crabs (females)	Migratory Component Fish Blue crabs	Migratory Components Fish Blue crabs	Migratory Components Fish Blue crabs	Migratory Components Fish Blue crabs
		Oyster bar		
	Salt marsh Plants, e.g., *Spartina alterniflora*, *S. patens*, *Juncus* Invertebrates Reptiles and amphibians Birds Mammals	Brackish marsh Plants, e.g. *Spartina alterniflora*, *S. cynosuroides* Invertebrates Reptiles and amphibians Birds Mammals	Oligohaline Marsh Plants Invertebrates Reptiles and amphibians Birds Mammals	Fresh-water marsh and swamp Plants Invertebrates Reptiles and amphibians Birds Mammals

erosion in coastal bays.

Geographic Distribution

Hedgpeth (1957) stated that Zostera is widespread in the cooler temperate regions of the northern and southern hemispheres and is present in the warm latitudes. On the east coast of North America, Zostera has been observed from Hudson Bay to Cape Hatteras, North Carolina (Phillips, 1969). Cottam and Addy (1947) reported the distribution of eelgrass from Maine to North Carolina. Their report was written after Zostera started recovering from the "wasting disease".

Ostenfeld (1918) observed eelgrass as far as 65°N during his investigations for the Danish Biological Station. In general, eelgrass is distributed along Denmark's east coast and extends into the Baltic Sea (Ostenfeld, 1908). Apparently growth is not as luxuriant in the Baltic (a brackish environment) as in the true marine environment. Segerstrole (1957) reported Zostera in the Baltic and Black Seas. The Zostera beds along the French Atlantic coast have been investigated by Blois, Francax, Gaudichon and LeBris (1961) and Ledoyer (1964). Aleem and Petit (1952) reported eelgrass in the Canet Marshes of Southern France. Casper (1957) and Zenkevich (1957) investigated Zostera from the Mediterranean, Black, Caspian, and Aral Seas. Casper (1957) reported extensive beds of Zostera marina and Zostera nana in the northewestern part of the Black Sea on sandy-clay bottoms. Zostera is widely distributed in the Caspian, especially along the Eastern shore.

Millard and Harrison (1952), Scott, Harrison and Macnae (1952), Day, Millard and Harrison (1952) and Day (1967) have observed Zostera in South African estuaries, such as the Knysna, Richards Bay and the Klien River Estuary.

Many excellent studies on the community structure of Zostera have been conducted in Japan. Kikuchi (1966) investigated Z. marina in Tomioka Bay, southwest Japan. Sando (1964) worked in Aomori Bay at the northern end of Honshu, whereas Fuse (1962), Kita and Harada (1962), Kitamori, Nagata and Kobayashi (1959), Nagata (1960) and Azumo and Harada (1968) conducted research in the Seto Inland Sea.

The saline water habitat of Z. marina provides it with a ready "vehicle" for passive dispersion. Detached eelgrass may be carried by currents into a new, suitable locality (Tutin, 1938). Setchell (1929) observed that Zostera bed formation can be initiated by floating rhizomes settling in a locality suitable for growth, but not conducive to seed production. Therefore, to keep the bed thriving, a continuous supply of live plants from an outside source is necessary. McRoy (1968) observed that the reproduction stem of *Zostera*, on which the seeds are found, can become detached, along with several leaves. The entire unit is capable of floating, thereby providing a means of transporting seeds to a new site. This structure (stem, leaves and seeds) has been observed in turtle grass several hundred miles from the coast (Menzies, Zaneveld, and Pratt, 1967). Another form of passive dispersion is by ducks eating *Zostera* and ingesting the seeds. Arasaki (1950) recovered seeds that had passed through duck alimentary tracts and found that a high percentage of germination could be obtained. Likewise, marine animals have been observed to be seed carriers (Ostenfeld, 1914).

McRoy (1968) believed that *Zostera marina* originated in the western Pacific and reached the Atlantic by one of two routes. One theory, less accepted by McRoy, is that eelgrass was dispersed from the Pacific through the Indian Ocean to both sides of the Atlantic in early Tertiary times when the Tethys Sea covered much of the Eurasian continent. A second theory is that eelgrass migrated through the Arctic region when the climate was milder. McRoy holds to the latter theory because relict populations exist in the White Sea, the Barents Sea, the Kara Sea and Hudson Bay. This theory is also aided by the location of its fossil ancestors and because some marine invertebrates have a similar dispersal pattern (McRoy, 1968).

Within the Chesapeake Bay, *Zostera marina* is found in the polyhaline zone of the lower and middle reaches of the Bay. Its distribution in the lower Bay can be described with some accuracy. In the summer and fall of 1973, Robert Orth (personal communication) observed and reported the destruction of *Zostera* beds by cownose rays. Personnel at the Virginia Institute of Marine Science, concerned over the destruction, conducted aerial flights and ground observations to determine the extent of the loss. These observations were compared with high altitude photographs taken by NASA in October 1971. Dr. M. Wass, using the NASA photographs, results of the aerial and ground observations and his own extensive knowledge of the Bay, provided a description of eelgrass distribution before and after the destruction of the beds by the rays.

Before October 1973, eelgrass beds were generally dense around the Guinea Marshes; the north side of the York River up to Clay Bank, areas of Ellen and Mumfort Islands, south side of the York around the VEPCO plant; and along Goodwin Neck and Goodwin Islands. By October, little eelgrass was present in the York, and it was quite sparse in the Guinea Marshes.

In 1971, Zostera was present along the Severn, Ware, North and East Rivers and within Mobjack Bay. By October 1973, it was sparse on the south side of Mobjack Bay and around the Ware and North Rivers. However, there are some fairly dense beds in Brown's bay.

Zostera was not sighted in the Piankatank River or the Rappahannock River in October 1973. In 1971, it was abundant around Gwynn's Island, along the north and south shore of the Piankatank River up to Ginny Point. In the Rappahannock, it was present up to Whiting Creek on the north side and to Monaskon on the south side.

Between the Back River and Tue Marsh there are sparse patches in the vicinity of the Drum Island flats and the Poquoson flats. In October of 1973, Zostera beds were densest along the eastern shore of the Bay, in particular from the south side of Pocomoke Sound to Cherrystone Inlet.

The above-mentioned distribution cannot be taken at face value because Zostera dies off in October and November; therefore, some of the sparse areas may be more representative of normal die-off conditions rather than cownose ray activity. A survey will have to be made when Zostera is at its growth peak (i.e., in May or June 1974) to determine the true extent of damage caused by the rays.

In Figure 16, the black circles ( ) represent appropriate locations of eelgrass beds in the lower Bay as of fall 1973. The symbols do not represent abundance. This information was made available by the Virginia Institute of Marine Science. Also in Figure 16 are circles enclosing numbers. These symbols are representative of locations where eelgrass beds were observed between 1971 and 1973. This information was made available through the courtesy of J. Kerwin and R. Munro of the Migratory Bird and Habitat Research Laboratory of the Department of the Interior. Table 7 correlates the numbers with the location of the bed within the Bay. The frequency percentage for 1971, 1972 and 1973 also is reported as well as the number of samples taken at each station. The only exception is location number 24 in the Potomac. Neither Kerwin and Munro nor the Virginia Institute of Marine Science reported any beds in the Potomac River; however, one bed has been observed in the Potomac (May, personal communication).

Scientists cannot always keep abreast of the development and decline of eelgrass beds. Therefore, it is imperative that sites of "development" be checked for the organisms present. Just because an organism has not been observed at a specific site, does not necessarily mean it has not settled in the location.

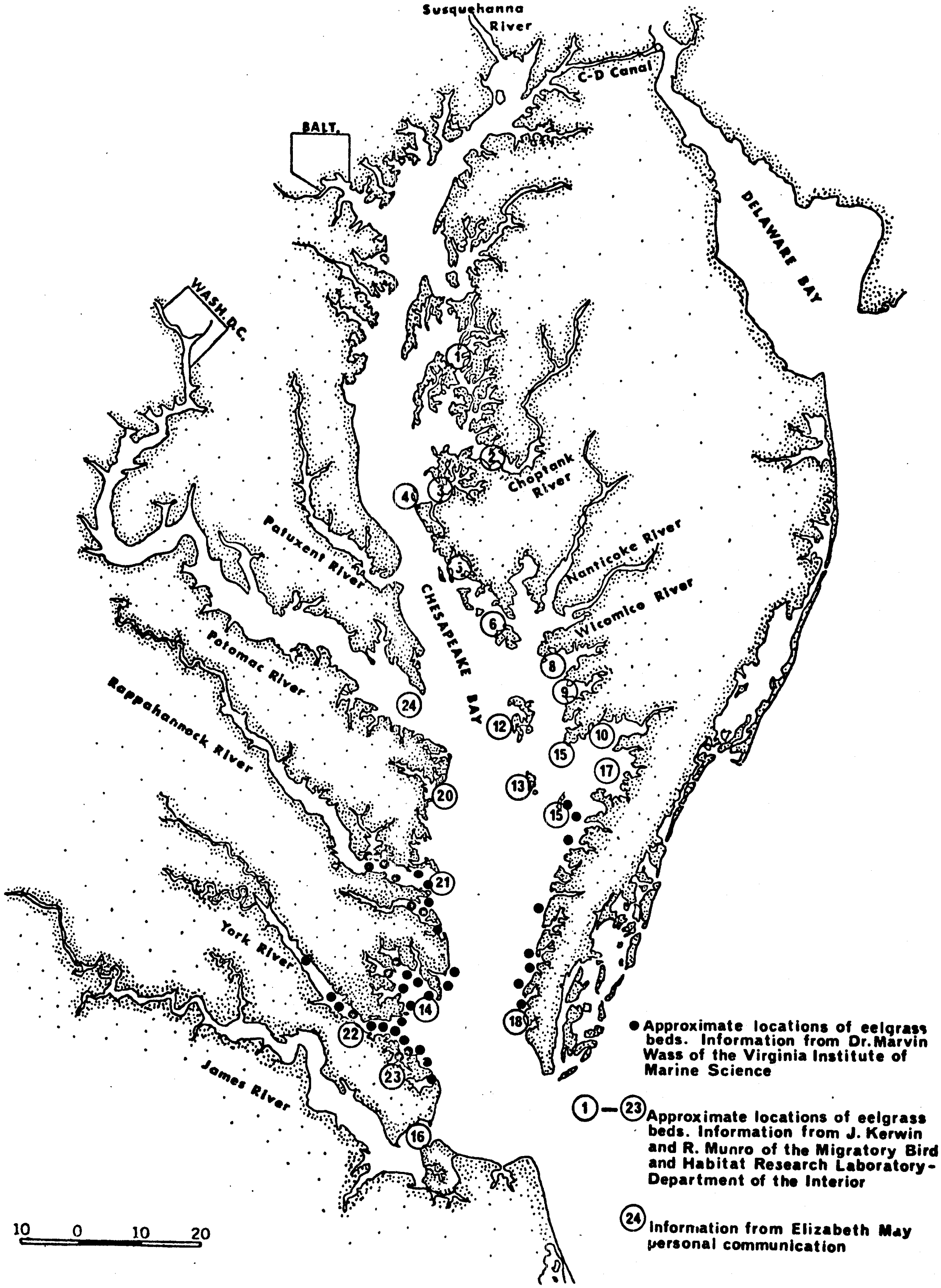


Figure 16. Distribution of eelgrass in the Chesapeake Bay (From M. Wass, J. Kerwin and R. Munro, personal communication).

Location	Frequency 1971	1972	1973	Number of Sampling Stations 1971	1972	1973
1. Eastern Bay	4.26	11.63	0.00	47	43	47
2. Choptank River	5.00	5.17	0.00	60	58	57
3. Little Choptank River	5.26	0.00	0.00	19	19	19
4. James Island-Honga River	41.18	2.94	0.00	34	34	34
5. Honga River	26.67	16.67	0.00	30	30	30
6. Bloodsworth Island	20.00	15.91	2.17	40	44	46
7. Fishing Bay	4.00	4.00	0.00	25	25	25
8. Manokin River	33.33	40.00	13.33	15	15	15
9. Big and Little Annemessex Rivers	60.00	50.00	15.00	20	20	20
10. Pocomoke Sound	18.18	10.00	4.76	22	20	21
11. Patuxent River	2.00	0.00	0.00	50	47	50
12. Smith Island	29.41	45.45	0.00	17	11	12
13. Smith Island-Tangier Island (VA)		52.00			25	
14. Mobjack Bay		20.00			30	
15. Clump Island and Watts Island		20.00			20	
16. Hampton Roads		9.09			22	
17. Pocomoke Sound (VA)		16.92			[illegible]	
18. Cape Charles		30.77			[illegible]	
19. Mattawoman Cr. and Matchotank Cr.		24.14			29	
20. Great Wicomico-Rappahannock Rivers		3.85			26	
21. Rappahannock River		1.25			80	
22. York River		11.63			43	
23. Poquoson and Black River (VA)		68.18			22	
24. Potomoc River	Elisabeth May - personel [illegible]mmunication					

Table 7. Eelgrass Frequency Distribution (1971, 1972, 1973) From J. Kerwin and R. Munro of the Migratory Bird & Habitat Research Laboratory, Laurel, Md.

Depth

There is not a "clear cut" range of depths where eelgrass is found. Tutin (1938) observed the lowest depth limit of growth in England to be 4 meters below the low spring tide. Moffit (1941) reported eelgrass at a depth of 10 meters. Along areas of the Pacific coast, eelgrass has been reported at depths greater than 10 meters: 20 meters in the Black Sea (Caspers, 1957) and 30 meters on the slope of La Jolla Submarine Canyon in California (Cottam and Munro, 1954). Ostenfeld (1908) found that eelgrass grew in the coastal waters of Denmark at a maximum depth of 11 meters in clear water and 5.4 meters in turbid water. In Puget Sound, Phillips (1969) observed that eelgrass was limited to the same maximum depth at high tide that Ostenfeld observed for clear waters (11 meters). This water level is equivalent to 6.6 meters below mean lower-low water. To some extent, the depth of occurrence appears to depend on light penetration and substrate.

Apparently a correlation can be made between leaf size and depth. (In the next discussion, on substrate, it will appear that a similar correlation can be made between leaf size and substrate.) In a study by Phillip and Grant (1965) it was reported that there is a change in leaf characteristics with tidal zones. Narrow-leaved plants were found in the intertidal zone and wide-leaved plants in the sublittoral zone. They conducted field transplanting experiments and found that intertidal narrow-leaved plants would grow wide leaves when placed in the sublittoral zone and vice-versa. McRoy (1966), also, found a correlation between leaf width and plant density with depth. Subtidal depths illustrated wide leaves of intermediate characteristics. McRoy stated that gradient in the physical environment determines the charactersitics of the eelgrass beds.

In Puget Sound, the upper limit of Zostera is the mean lower-low water (Phillips, 1969). Arasaki (1950) found the upper limit in Japan to be 10 cm below low tide. Keller and Harris (1966) determined that the upper limit of eelgrass occurrence depended on the length of exposure of the plant to air. To survive and grow, it could not be exposed to air any longer than 15% of the time. For optimum growth, Zostera should not be exposed longer than 5% of the time. Keller and Harris (1966) stated that in those areas where growth is most luxuriant, eelgrass stranded during low tide is capable of retarding the water drainage, thereby preventing its own dessication. They believe the area of optimum depth for eelgrass to be -1.0m below mean lower-low tide

During their study, Keller and Harris (1966) calculated an eelgrass resource index. They determined for South Humboldt Bay that 90% of the total biomass of eelgrass and about 60-67% of the eelgrass-producing acreage occurred below mean lower-low tide. Therefore, they contended that "in any management program designed to sustain eelgrass stocks for waterfowl or other reasons, it would be imperative that at least those portions of the bay below mean lower-low tide should be preserved in an undisturbed state". The validity of this statement needs to be determined for Chesapeake Bay.

Marsh (1970) determined in Chesapeake Bay that although most of the epibiotic species were common to all stations, there were differences in their relative abundance at each station in relation to depth. An average of 70 species was collected from station A (0.7 m at mean low water); 76 from B (1.2 m at mean low water) and 88 from C (1.6 m at mean low water). (Note: Marsh collected all his samples at Mumfort Island, which is site 3 in Figure 21). These data plus the average number of organisms/g of Zostera (A=96.8 organisms/g; B=114.3 organisms/g and C=192.4 organisms/g) suggests that depth either directly or indirectly influences the composition of the eelgrass community. It must be pointed out that, statistically, station B did not differ from station A (Marsh, personal communication). More detailed work will have to be completed before the generality Marsh observed can be applied over the entire Bay area where Zostera is found.

Substrate

Tutin (1938) conceived the typical substratum for Zostera to be firm, muddy sand, often covered with a layer of coarse sand. Caspers (1957) found Zostera exclusively in the sandy-clay substrate of the northwestern part of the Black Sea. Ostenfeld (1908) found eelgrass in firm sand and soft mud substrates. Contrarily, Phillips (1969) never observed eelgrass in pure sand substrate. Both Marsh (1970) and Orth (1971) found that fine sands or very fine sands were an integral part of the total substrate composition in the areas where they sampled in the Chesapeake Bay and York River. Orth (1973) noted that dense beds of eelgrass can increase the amount of finer sediments in the substrate by hindering wave action and trapping fine grain fractions.

It was reported on page 2-63 that there appears to be a correlation between leaf size and depth. Ostenfeld (1908) discovered that a correlation also exists between leaf size and the nature of the substrate. On wave-exposed coasts, he found a narrow-leaved plant in the firm sand as deep as six fathoms. Conversely, in the sheltered areas, he found a narrow-leaved form in a mixed sand and mud substrate and a wide-leaved plant in the deeper waters where mud was the dominant substratum.

As simply a note of interest, Phillips (1969) always noted an odor resembling hydrogen sulfide 5-6 cm below the surface of the substrate. Boysen-Jensen (1914) almost always found ferrous sulfide in the muddy substrate of eelgrass. Wood (1959 a and b) believes that Zostera sp. is normally found in reducing conditions, which are conducive to the acceleration of sulfate reduction by Microspira (sulfur bacteria). Phillips (1969) stated that "eelgrass conditions the substrate and is also an integral interacting part of it. Careless treatment (e.g. additions of pollutants, etc.) of the marine soil may render it unfit for colonization by seagrasses."

Salinity

Orth (1973) observed eelgrass in the York River at a salinity as low as 13 ppt and in the Bay as high as 26.5 ppt. Figures 15 and 16 present the relationship of salinity and Zostera distribution. Figure 16 is not representative of total Zostera distribution. Ostenfeld (1908) considered 10-30 ppt to be the optimum growth range. Arasaki (1950) determined that eelgrass grows best in the salinity range of 23.5-30.7 ppt. The growth rate was poor at 18.0 ppt and non-existent at 9.1 ppt although death did not occur (Arasaki, 1950). Salinities as high as 42 ppt were tolerated in an English bay, and in the laboratory the plants have tolerated fresh water for two days (Tutin, 1938). Martin and Uhler (1939) found eelgrass extending upstream in estuaries with salinities of 8.5 ppt. Osterhout (1917) at Mount Desert Island, Maine, found eelgrass distributed in a locality where there was an alternate change of fresh and sea water every six hours. The peculiarity of the environment led him to propose the possibility of physiological types of Zostera. That is, there might be a type of Zostera that cannot survive when exposed to fresh water, whereas another type can. His experiments revealed that the protoplasts of the leaf cells from marine waters were affected detrimentally by freshwater, whereas those from the mouths of streams withstood freshwater for several hours. Root cells from either area were killed after exposure to freshwater for just a few minutes. Different reactions to different salinities by the various structural parts of eelgrass were also observed by Arasaki (1950).

Biehl and McRoy (1971), when investigating eelgrass taken from Izembek Lagoon, discovered that the osmotic resistance of eelgrass over a 24-hour period ranged from distilled water to seawater three times that of normal seawater (normal seawater for the experiment = 31 ppt). When the salinity went above three times normal seawater (93 ppt), the leaves were completely dead within 24 hours. Biehl and McRoy (1971) also observed that within the salinity limit of 93 ppt for 24 hours, photosynthesis decreased in distilled water, reached its maximum in normal seawater (31 ppt) and then decreased again as the salinity concentration became greater.

Once again, "hard and fast" limits cannot be established for an environmental factor. To make decisions in regard to the Chesapeake Bay and the role of salinity in Zostera production, *water managers* will either have to (1) conduct investigations themselves, (2) talk to scientists that have worked directly upon the Bay and not published their results or (3) make value judgements from available literature.

Temperature

Setchell (1922) proposed that the normal distribution range for Zostera marina is in the North Temperate zone where waters average summer temperatures from 15° to 20°C. Any extension northward is possible because of insolation of shallow enclosed waters, and any extension southward is possible because of seasonal temperature lowering during winter and spring. According to Setchell (1922, 1929), a temperature range of 15° to 20°C is necessary because it is required for reproductive growth. He divided seasonal succession into 5° increments:

1. Cold rigor period - lowest temperature experienced-below or to 10°C

2. Vegetative period - 10° to 15°C

3. Reproductive period - 15° to 20°C

4. Heat rigor period - 20° to the highest temperature experienced

5. Recrudescent rigor period - 20° to 10°C

Setchell was emphatic in his belief that the various stages of growth and reproduction are dependent on temperatures, not on a particular length of illumination. On the other hand, Phillips (1969) disputed Setchell's hypothesis on the grounds that not enough emphasis has been placed on illumination and its relationship to the flowering eelgrass plant. In Puget Sound, Phillips observed flowers when the temperature was well below Setchell's 15°C; flowering was initiated during April and May, months of increasing day length. Apparently, there was no correlation between plant activity and water temperature. However, in Izembek Lagoon, Alaska which is still farther north and where one would expect the water to be even colder than Puget Sound, McRoy (1966) observed that tidal pool plants flowered after the pool warmed about 15°C. He credited the warming to isolation of shallow water areas instead of illumination. On this basis, McRoy accepted Setchell's temperature regimes. In Newburyport Harbor, Ispwich River, Barnstable Harbor and to some extent Cape Cod Bay, flowering and fruiting were observed occurring at temperatures of 24-25°C in July and August (Addy and Aylward, 1944). This observation again does not fully agree with Setchell's hypothesis; therefore, some doubt exists as to the usefulness of Setchell's temperature regimes in all localities. Investigations will have to be conducted in the Chesapeake Bay to determine the validity of Setchell's regimes.

Zostera marina is an eurythermal plant. Biehl and McRoy (1971) observed eelgrass experimentally survived temperatures from a low of -6°C (12 hours) to 34°C (12 hours). However, extended periods of exposure at either temperature extreme can result in death. A point of interest arising from Biehl and McRoy's investigation is that tidepool *Zostera* and subtidal *Zostera* exhibit different survival rates. Another interesting aspect is that other environmental factors also can affect the rate of survival, because of temperature fluctuations. For example, Biehl and McRoy (1971) observed that an increase in salinity allows a slightly higher resistance of tidepool eelgrass to increased temperatures. Among other temperature observations, McRoy (1969) found live eelgrass under ice 100 cm thick with an additional 50 cm of snow on top. In the Chesapeake Bay, Marsh (1970) and Orth (1971) observed live eelgrass in the winter when the water temperature was at 0.0°C and a thin layer of ice formed on the surface, and at 31°C during late summer at low slack water. An investigation similar to that of Biehl and McRoy (1971) needs to be done for the Chesapeake Bay to determine both the maximum and minimum temperatures that can be withstood by *Zostera* and the duration of survival.

Oxygen

In Holland, eelgrass beds were observed to become anoxic for several hours at night (Broekhuysen, 1935). The anoxic condition did not seem to affect the plants in a detrimental manner. McRoy (1969) reported that eelgrass in Safety Lagoon, Alaska tolerates anoxic conditions for several weeks or months. As already mentioned, eelgrass has been observed under 150 cm of snow and ice. McRoy (1966) determined that *Zostera* is capable of active anaerobic respiration (fermentation). During anoxic conditions, this metabolic pathway may be important for plant survival. McRoy (1969) believes that some slow photosynthesis may occur when the plant is under ice and snow, but it will be very slow. The photosynthesic rate is dependent upon varying temperature and light. Relief from anaerobic conditions may occur from the oxygen produced and stored in the leaves' lacunal system from which oxygen can be recycled in respiration during anoxic conditions.

When McRoy (1969) investigated anoxic conditions under ice, he also took a few bottom samples from which he recovered a gastropod, a bivalve, a polychaete and a filamentous alga. How these organisms lived in anoxic waters is an intriguing question.

pH

Shelford and Fowler (1925) observed a diurnal pH range of 8.8 to 7.7 for eelgrass in the San Juan channel and adjacent areas of Washington. In general, the pH of the water bathing eelgrass is more basic during the day because of photosynthesis (Cameron and Mounce, 1922). Cameron and Mounce (1922) almost always found that the water covering an eelgrass bed was higher in pH than the water outside the bed. Allee (1923 a) concluded that pH has a greater effect than dissolved oxygen on the occurrence and behavior of organisms living in an eelgrass bed. His investigations indicated a vertical pH gradient in the bed in the mid-afternoon. From bottom to top of the bed, the pH ranged from 7.3 (substrate level) to 8.5 (24 inches off the bottom) to 9.0 (30 inches off the bottom). A similar gradient was observed at low tide, but only in the absence of a moving tide. McRoy (1969) observed a pH of 7.09 in the eelgrass bed buried under 150 cm of ice and snow. This pH is low for the marine environment; it reflects the anoxic conditions present in the bed when McRoy made his observations. Apparently, the effects of pH as an environmental factor have been considered less in Zostera research than salinity and temperature factors.

Wave, Surge and Current

One of the prerequisites that Ostenfeld (1908) reported as necessary for the growth of Zostera was shelter. Where the waves beat heavily, eelgrass is not found because the water motion prohibits the establishment of a substrate stable enough for the plant to become established. Ostenfeld observed plants in regions of strong wave action, but the leaves were narrow and short, the root-stock was strong and the flowering shoots were not observed as often as in sheltered bays. Phillips (1969) agreed with Ostenfeld that persistent shock will uproot and destroy the plants, but he also observed luxuriant growths of eelgrass in areas where there is a moderate current (up to 3.5 knots).

Nutrients

The Zostera community plays an important role in the cycling of nutrients. When nutrients enter the community, they become "caught up" in what Reid (1961) describes as a cycle of "biological assimilation, decomposition and inorganic processes". Figure 17 illustrates the basic principles of nutrient cycling in the Zostera community. Nutrient X enters the community from a "reservoir pool". This "reservoir pool" is defined by Odum (1971) as a large, slow-moving, generally nonbiological component of nutrient cycling (biogeochemical cycles). Examples of nutrient sources within a reservoir pool in Figure 17 are terrestrial runoff, weathering, wastes and evaporation. In a broad sense, it is physico-chemical reactions that move nutrients from a point a to a point b. Once a nutrient is assimilated, it becomes part of an "exchange or cycling pool", another descriptive component of nutrient cycling designated by Odum (1971). It is a smaller, more intense cycle, represented in Figure 17 by the solid black circle. Within this cycle, a nutrient is actively exchanged between organisms and the environment. The efficiency of the system is proportional to the loss of the nutrient into the "reservoir pool".

At the International Seagrass Workshop in Leiden, the Netherlands, Fenchel (1973) chaired a group of scientists who concerned themselves primarily with nutrient cycling. They believe that the sediments associated with eelgrass are important sites of nutrient regeneration and that the anoxic layer (reducing zone) of the sediments might act as a nitrogen sink. Depicted in Figure 18 is a model conception based on the one Fenchel's group proposed. It depicts how the sediments interrelate to seagrass and the water column. The sediments receive nitrogen as either organic nitrogen in detritus or as dissolved organic nitrogen from the water column. This organic nitrogen (amino acids, polypeptides and/or proteins) is returned to the ecosystem via decomposition and as nitrogenous animal waste. Decomposition results in oxidation of nitrogen to ammonia in both the oxic layer (layer where oxygen is available) and anoxic layer (layer where oxygen is not available. Ammonia can diffuse into the water column, be further oxidized into nitrate or nitrite, adsorbed onto sediment particles, thereby being retained in the interstitial waters, or bound to metals present in the sediments. Nitrate and nitrite can be further denitrified to molecular nitrogen. Part of the N_2 can, in turn, by nitrogen fixation, become ammonia. In fact, several aquatic macrophytes and algae are capable of nitrogen fixation. McRoy (1973) tested a theory that epiphytes living on the leaves and bacteria associated with the roots, might supply

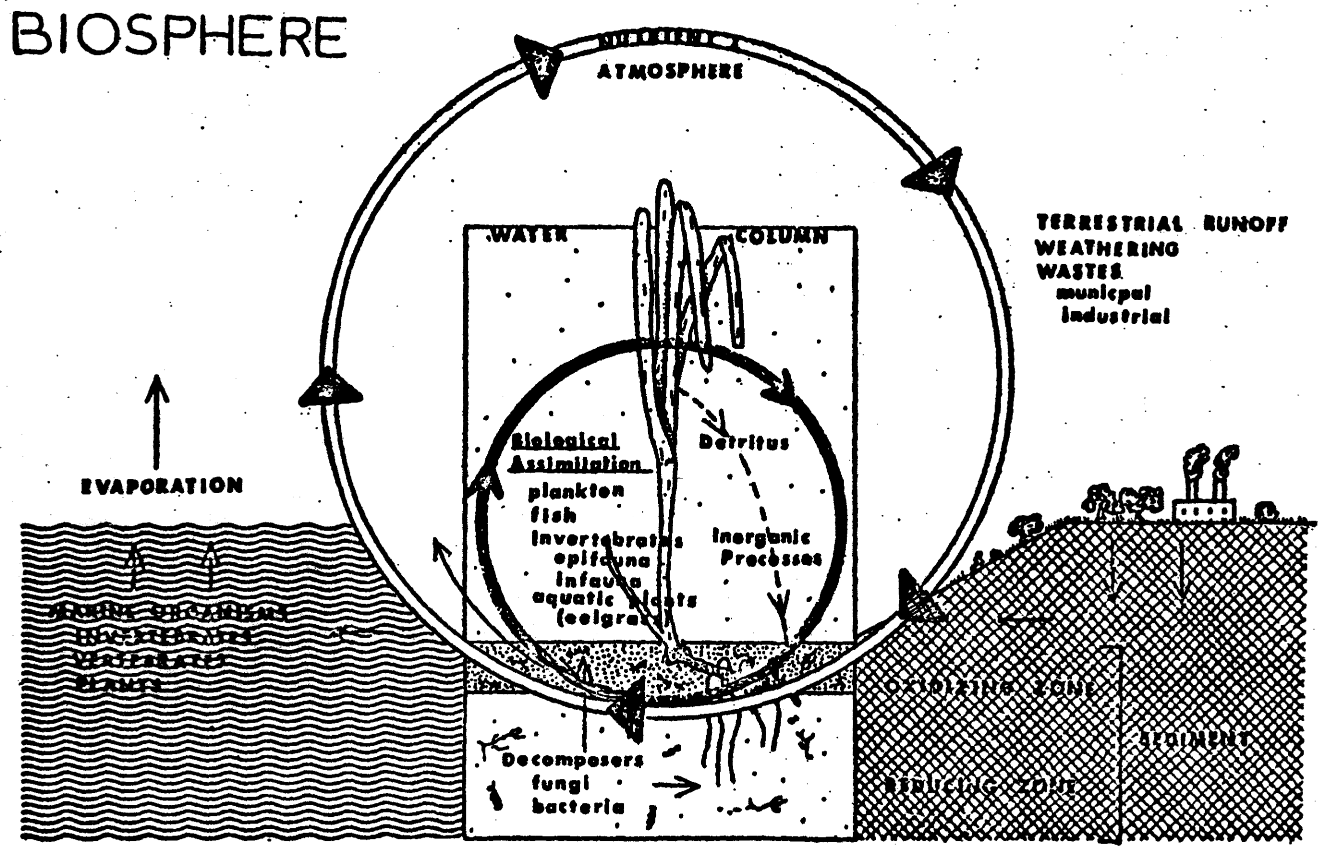


Figure 17. The biogeochemical cycle of nutrient X. The large circle represents the general cycle of the nutrient in the biosphere; whereas the smaller circle represents the intensive recycling of the nutrient in an ecosystem. In this case, the eelgrass community is the represented ecosystem.

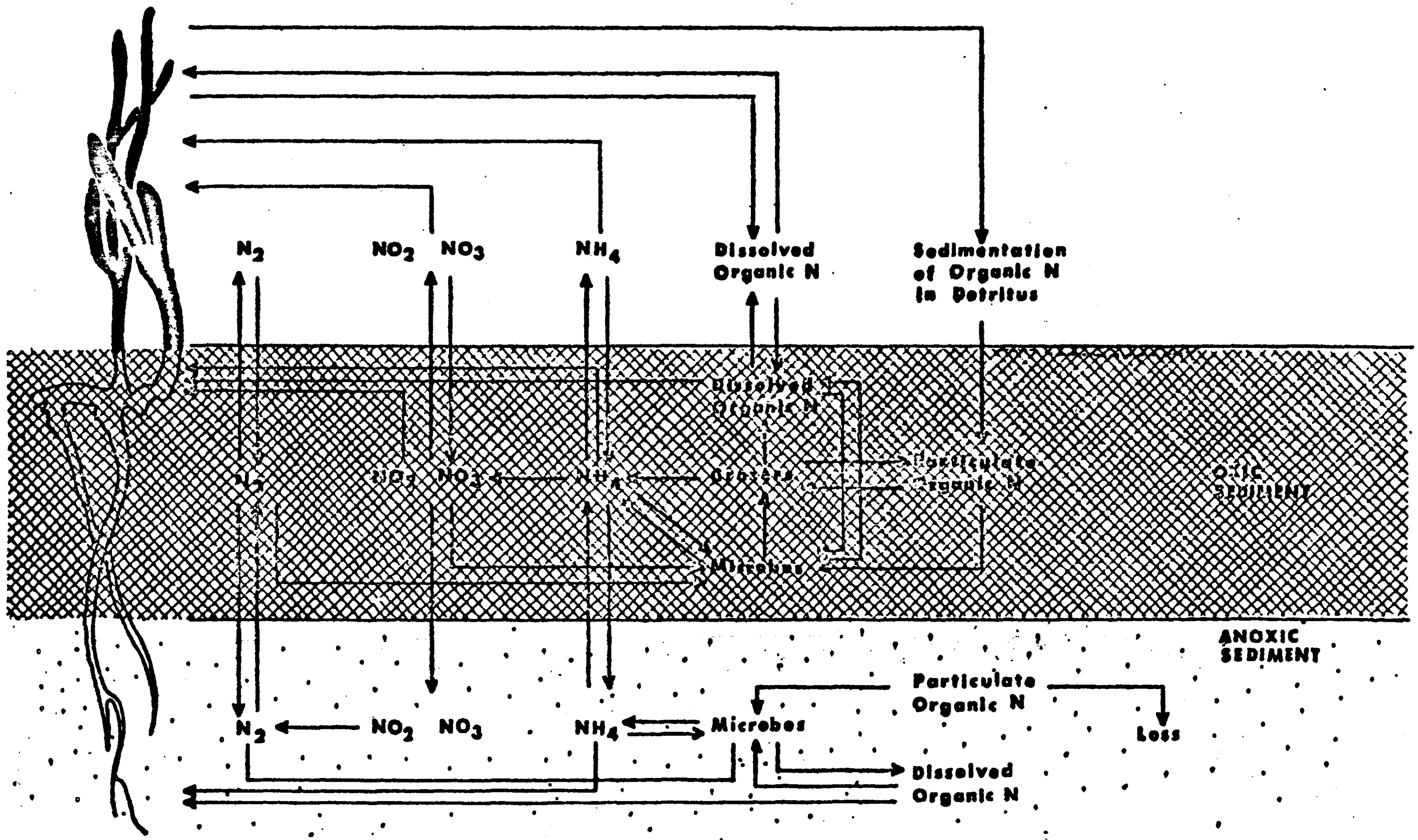


Figure 18. Circulation of nitrogen in Seagrass Ecosystem (From Seagrass Ecosystems, 1973)

seagrasses with a nitrogen supply by nitrogen fixation. His results did not reveal any measurable nitrogen fixation associated with Z. marina. Zostera can utilize nitrate, nitrite, ammonia and/or dissolved organic nitrogen for plant growth.

A *water manager* may say "Yes, this is very interesting, but what does it mean to me?" Boysen-Jensen (1914) was able to show that Zostera is a primary contributor of nitrogen to the sea bottom in the sheltered waters of fjords. His analysis revealed that the nitrogen content of Zostera was about 3%. A similar investigation should be conducted in the Chesapeake Bay to determine if nitrogen is made available to the areas outside the bed as was observed in Boysen-Jensen's (1914) study.

When conducting a study of sulphate reduction in Zostera mud flats, Woods (1953) found that autoclaved Zostera, placed in autoclaved sand and seawater, yields ferrous sulphide. Further investigations showed that living Zostera could cause the reduction to occur. Zostera is partially comprised of a nitrogenous base and a sulphur compound, responsible for Zostera's reduction capability. Wood (1953) believed that these two substances were of "great importance in Zostera muds in two ways: they may produce ferrous sulphide directly, and may also bring about reducing conditions that greatly accelerate sulphate reduction by Microspira" (a bacteria). Wood's investigation was a "break through" into understanding the process of sulphur cycling in eelgrass beds, although it does not explain the complete cycle.

Zostera roots are normally in the reducing environment of the anoxic sediment layer. In fact, its root hairs are often in actual contact with hydrotolite (FeSH(OH)) particles (Wood, 1959). It is known that certain bacteria (i.e. sulphate reducing bacteria, thiobacteria, purple bacteria and green bacteria) are components of the sulphur cycle. Such algae forms are also important. The specific pathways for the cycling of sulphur are not well known and should be investigated.

The phosphorus cycle is probably the best-known nutrient cycle in the aquatic environment because of the investigations of McRoy and Barsdate (1970), McRoy, Barsdate and Nebert (1972), and Pomeroy (1960), Pomeroy, Johannes, Odum, and Roffman (1969), and Pomeroy, Smith and Grant (1965). Phosphates generally accumulate where there is a great deal of metabolic activity (e.g. an area of cell division). Greatest biomass of benthic plants (including eelgrass) in Great Pond, Massachusetts was correlated with areas of highest phosphate concentration (Conover, 1958). Large standing crops of eelgrass were correlated by Rockford (1951) to high concentrations of phosphates in interstitial waters.

McRoy and Barsdate (1970) determined sites of phosphorus uptake and subsequent transport by the use of radioactive phosphorus (P). Their studies indicated that phosphate absorption occurred in both roots and leaves, the leaves having the greatest absorption rates. There is a tendency for phosphate to accumulate in the roots or the leaf base since these are the areas of the most rapid cell division. McRoy and Barsdate (1970) were able to show that although sediments pool phosphorus, the roots can pick it from the sediment and transport it to the leaves which release it into the water. Therefore, a positive feedback mechanism keeps the phosphorus cycling. It must be pointed out, however, that the direction of transport depends upon the relative concentration of phosphorus in the water column and in the sediments (McRoy, Barsdate and Nebert, 1972).

McRoy, et al. (1972) demonstrated that there was a net movement of phosphorus out of Glazenap Pass from Izembek Lagoon to the Bering Sea. This movement makes phosphorus available for phytoplankton production in the open ocean. Although there is a flux of phosphorus out of the eelgrass, the sedimentation rate is so rapid in the bed that there is also local internal recycling.

Pomeroy, Smith and Grant (1965) demonstrated that phosphate was exchanged between the water and sediments by two processes. The first process, absorption, consists of two steps. The more rapid of the steps is initial absorption, whereas the slower is the reaction of phosphate with the clay lattice work. The second process is a biological process: microorganisms control the exchange between the water column and sediments. Pomeroy, et al. (1965) demonstrated the biological process by poisoning sediment samples. In the poisoned samples, absorption was the only process observed, because it is a physico-chemical process not dependent on microorganisms. In the unpoisoned samples, the microorganisms were involved in the exchange of phosphate between the water column and sediments. Pomeroy, et al. (1965) ascertained that the biologically controlled exchange was trivial because the organisms involved live only in the oxidized zone of the sediment below the surface where they exchange phosphate with the interstitial water, which in turn diffuses slowly into the overlying water. The two mechanisms of exchange are sufficient to provide benthic plants and phytoplankton with enough phosphate for utilization even during periods of great production (e.g., blooms) and increased flushing (e.g., spring tide or runoff). Figure 19 illustrates a conceptual idea of phosphate cycling by Fenchel, et al. (1973).

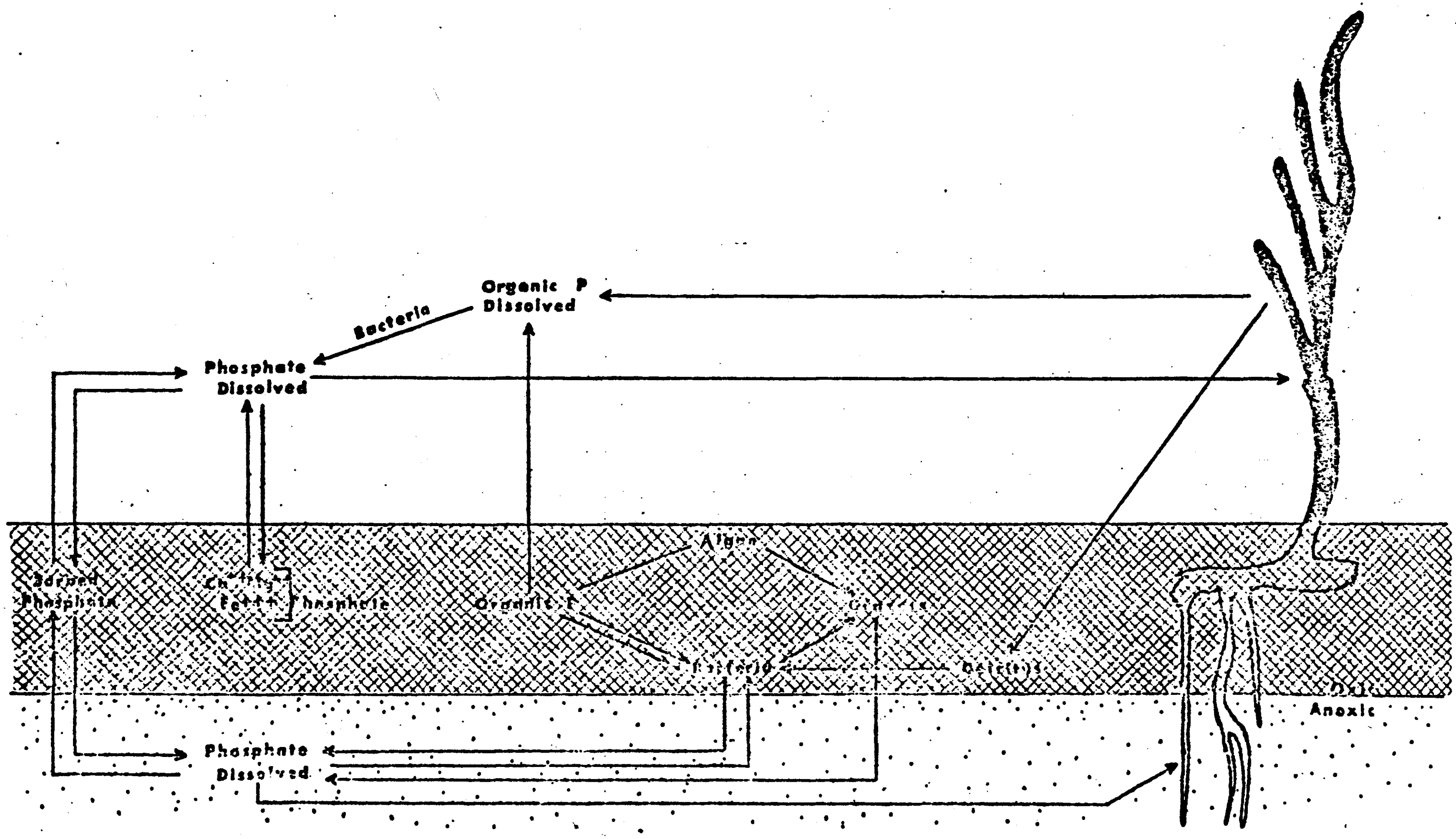


Figure 19. Circulation of phosphorus in seagrass ecosystem. (From Seagrass Ecosystem, 1973.)

McRoy (1970) discussed the elemental composition of eelgrass. Table 8 lists those elements he identified through his own experimentation or through literature research.

Major Elements	Minor Elements	Trace Elements
Oxygen	Sodium	Bromine
Hydrogen	Chlorine	Rubidium
Carbon	Magnesium	Fluorine
Phosphorus	Potassium	Nickel
Nitrogen	Sulphur	Barium
	Calcium	Molybdenum
	Boron	Cadmium
	Silicon	Copper
	Iodine	Cobalt
	Zinc	Beryllium
	Iron	
	Aluminum	
	Manganese	

Table 8. Elemental Composition of Eelgrass (McRoy, 1969)

Seasonal Activity of Zostera marina

Because of the lack of information about the seasonal development of Zostera marina var. typica, which is the variation found along the Atlantic coast, Setchell's (1929) observations on development of var. latifolia, found along the Pacific coast, will be extensively used in this report.

In Paradise Cove, California, Setchell (1920) observed seed germination in February. Phillips (1969) observed seed germination in Puget Sound in June and July, whereas Arasaki (1950) noted it between April and May in Japan. Taylor (1957) observed germination off Prince Edward Island, Canada in May and early June. In Japan, Arasaki (1950) determined that the best germination rate occurred in low salinity waters at a temperature range of 5-10°C (Taylor, 1957). However, continued low salinities checked the growth of seedlings.

When the seed germinates, the ribbed seed covering splits longitudinally, and the embryo protrudes. The caulicle* elongates, carrying up the cotyledon which covers the primary leaf bud (plumule of the embryo). (Figure 20 A) After the sheath ruptures, the plumule expands and projects beyond it. At the same time, two adventitious roots with root hairs grow out from the opposite side of the first node. (Figure 20 B) As growth continues, the first turion (A bundle of 6 to 7 leaves) and two bundles of roots are formed. (Figure 20 C) After formation of the first turion, the first season of growth generally can ge considered closed for var. typica. Figure 21 is a schematic generalization of Setchell's (1929) diagram illustrating progressive development of Zostera through four seasons. From the scale-like, outermost leaves of the first turion will grow a short plant of 6-7 internodes which will later elongate and terminate into either another turion, or develop an erect stem on which the reproductive structures will be produced (Figure 20 D and E).

In var. latifolia, there is no rest period between the first and second stages, but apparently there is in var. typica. Ostenfeld (1908) found seedlings in July and August which were known to be less than a year old because they had not put forth a visible creeping shoot. He expected seed germination to occur the following spring. From Ostenfeld's (1908) information, Setchell (1929) believed var. typica might have a shorter season of growth than latifolia. Therefore, var. typica would go through the first growth stage the first season, then through a period of quiescence with the onset of unfavorable environmental conditions, and finally into the

*Caulicle: The initial area between the radicle (rudimentary root) and the cotyledons of the embryo.

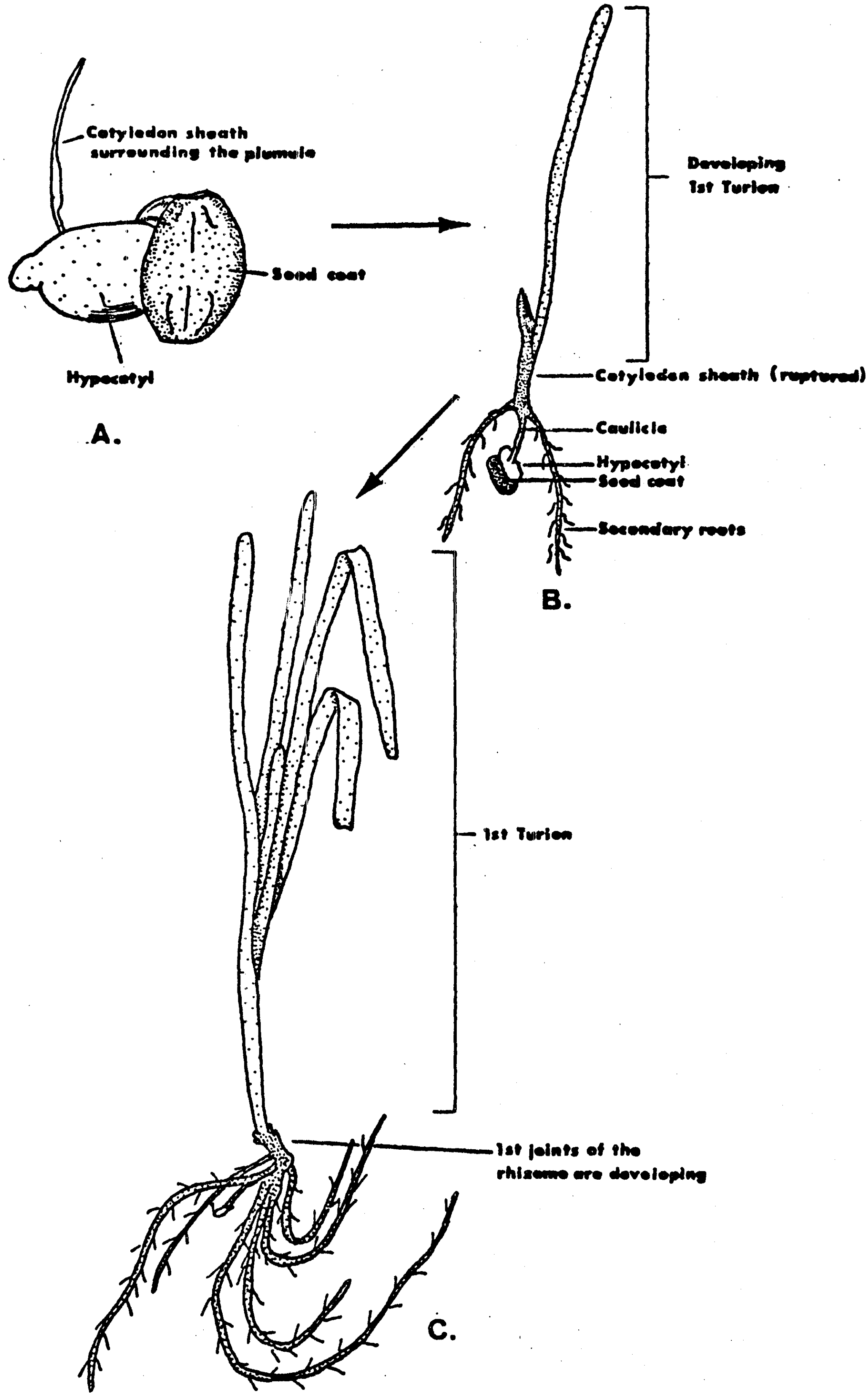


Figure 20. Progressive Development of Zostera marina (modified from Setchell, 1929).

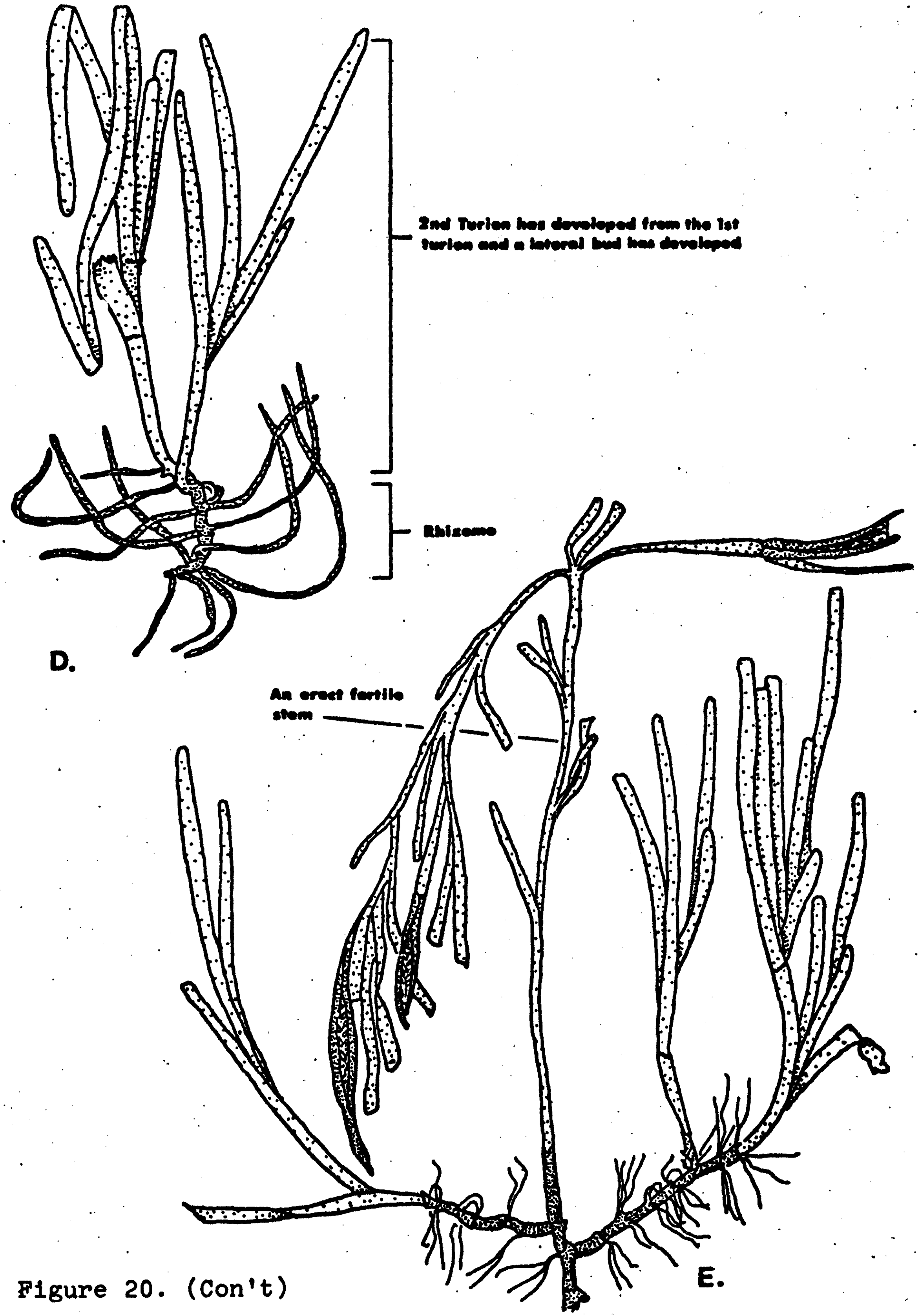


Figure 20. (Con't)

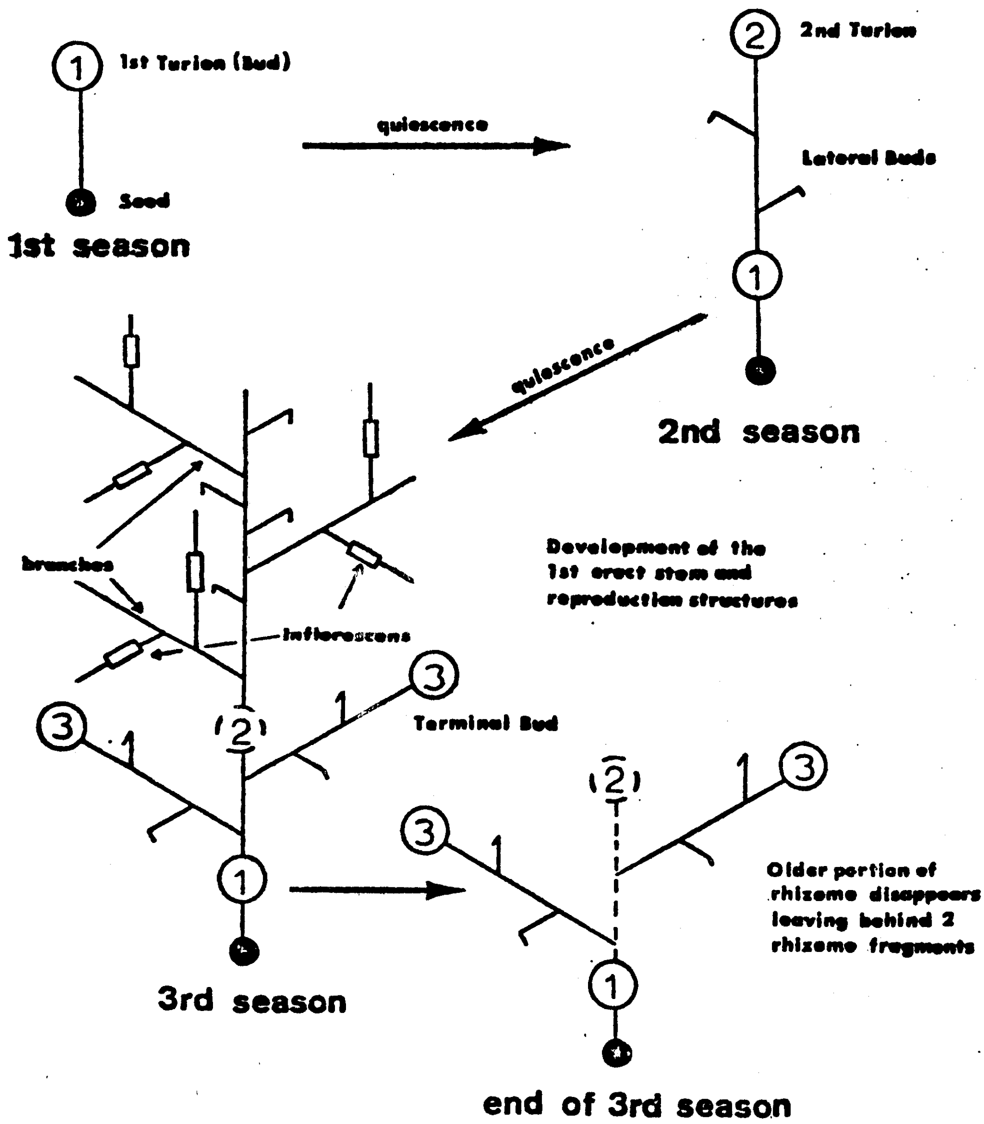
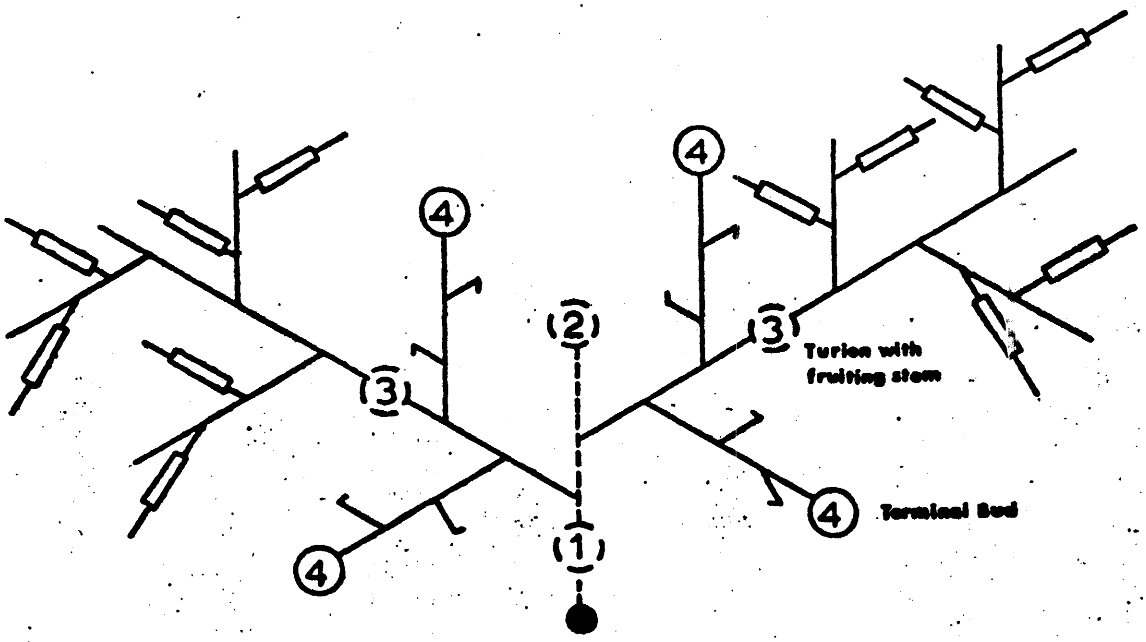
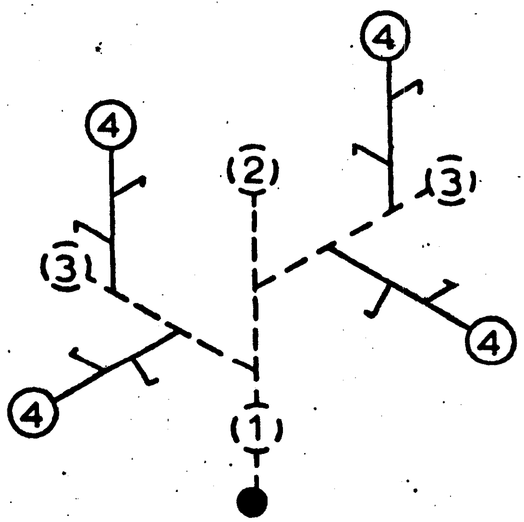


Figure 21. (1st season) The seed germinates and the first turion develops. The plant enters a period of quiescence with the onset of unfavorable conditions (2nd season). The 2nd turion develops with lateral buds. Again, the plant enters a quiescence (3rd season). The 2nd turion gives rise to the erect stem with its productive structures (inflorescens) on alternate branches. The lateral buds of the 2nd season become turions 3 with lateral buds (end of 3rd season). The 2nd turions with erect stem becomes disjunct. The 3rd turion and its rhizomes are left behind. (From Setchell, 1929).



4th season



end of 4th season

Figure 21. (Con't) The terminal bud of the 3rd season (3) becomes the turion with the erect fruiting stem. The two lateral buds of the previous season are now the terminal bud (end of 4th season). Erect fruiting stem and rhizome have become disjunct.

second period the following growing season. Whenever the second period of growth for either variety occurs, it is characterized by elongation of the internodes of the old turion, with a corresponding loss of leaves along the elongated rhizome with at least two lateral turions. Figure 21 (second season) illustrates the formation of the second turion with lateral turions. The new terminal turion may have six to seven leaves; whereas, the laterals have fewer leaves when they develop. Variety typica may produce fewer internodes.

Both var. latifolia and var. typica undergo a period of quiescence. However, var. latifolia and var. typica differ in the degree to which the quiescence is enforced. Variety typica's quiescence is generally enforced by severe conditions of the environment, whereas the conditions that enforce quiescence in var. latifolia are mild in comparison. In Zostera marina, it is during the quiescent period that the earliest produced internodes of the rhizome die. This dying off is represented in Figure 21 by broken lines in the Zostera plant at the end of the third season.

Differentiation occurs with the advent of the third season of growth. As the terminal turion matures, the internodes elongate, resulting in separation of leaves (this event may occur in the second or third season, depending on the variety). Reproductive structures (inflorescence) are produced on alternate lateral branches of the turion (Figure 21, third season). The lateral buds of the plant will become terminal buds which in turn become the terminal turion in the next growth season. Pollination and maturation of the seeds continues as long as environmental conditions remain favorable. Stems of Zostera marina var. typica reach a length of 1-4 feet, with seven internodes and 1-5 branches. When conditions become unfavorable, the plant again enters a period of quiescence. Disjunction of the older portion of the rhizome may occur during the period of growth (particularly when sampled), but the disjunction is increased during the quiescent period. As unfavorable conditions set in, not only do older plants of the rhizomes die and decay, the erect fruiting stem and its associated rhizome also die. As the stem and rhizome die, the plant hold within the substrate is loosened. Often, windrows of Zostera are observed on shore, the result of the reproductive stems floating off after the rhizomes hold on the substrate has been loosened. In the previous discussion of geographic distribution, it was pointed out that these floating reproductive stems of Zostera are one means of dispersion.

When the new season begins, the lateral turions of the previous growing season develop in the same manner as the terminal turion of the previous season. The leaf structures associated with the internode detach themselves, and a terminal turion forms with 6-7 leaves and two smaller lateral turions (Figure 21, fourth season). The erect fruiting stem forms; the reproductive structure matures and pollination occurs. The lateral buds of the new terminal turion become terminal buds. When unfavorable conditions set in, quiescence occurs and disjunct stems and rhizomes float away. The following season, the same cycle will occur. Barring any adverse actions by the environment on the beds, a geometric progression of turions should occur, and the bed will continue to increase ad infinitum.

Community Composition and Trophic Structure

Community composition is the crux of this part of the report on eelgrass. All previous information was presented so that *water managers* would have a grasp of the ecological factors that regularly affect Zostera marina because these same ecological factors impinge on each and every organism found within the Zostera bed. In the final analysis, community structure at a particular time or place depends on the ability of the assembled life stages to adapt physiologically to the prevailing environment.

As mentioned previously, there are two definitive investigations of the Chesapeake Bay region, Marsh, 1970 and Orth, 1971. It is fortuitous that these works complement each other. Marsh studied eelgrass epifauna for 14 months in the lower York River Estuary in the vicinity of big Mumfort Island, whereas Orth collected infauna in the York River Estuary, in Back River and from both sides of the Eastern Shore of Virginia. Figure 22 indicates the approximate areas investigated.

Other studies have been conducted on fauna associated with eelgrass, such as Dodd's (1966) and McKeough's (1968) research on the epiphytes and epizoans of Zostera blades in Great South Bay, Long Island, New York. In Japan, Kikuchi (1966, 1968) conducted excellent research on the ecology of the animals living within the Zostera community located in Tomioka Bay, Kumamoto Prefecture on the west coast of Kyushu. Hatanaka and Iizuka (1962) studied the fishes that utilize Zostera as a habitat. Work on microalgae and small animals of the Zostera community was conducted by Kita and Harada (1962) studied the fishes that utilize Zostera as a habitat. Work on microalgae and small animals of the Zostera community was conducted by Kita and Harada (1962). Japanese scientists have produced several significant works related to Zostera

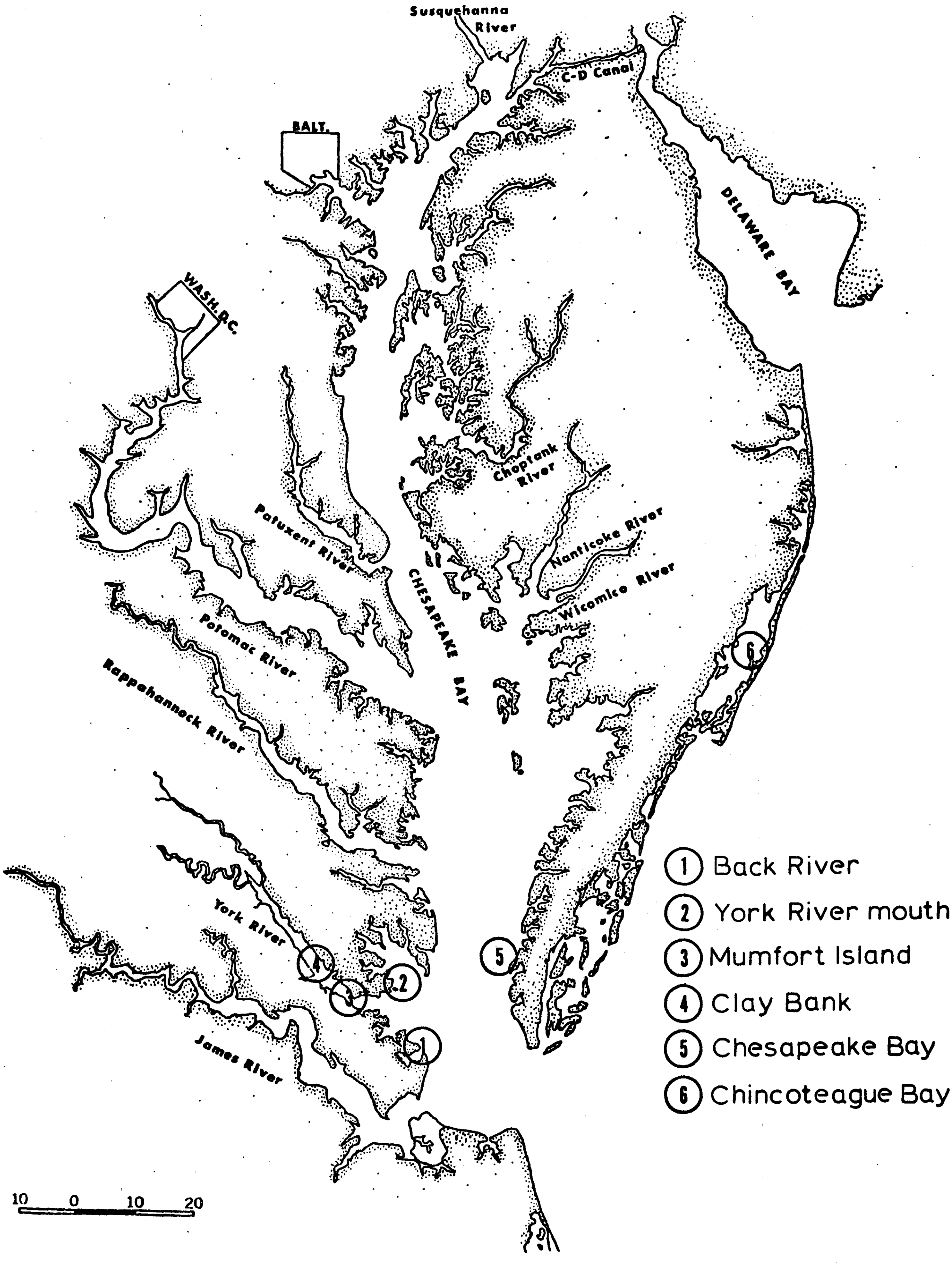


Figure 22. Sites of eelgrass investigations by Marsh (1970) and Orth (1971)

and its associated fauna. This may in part be because of their greater dependence on estuaries and the sea as a protein food source. There has been some work on eelgrass communities in Europe and North Ameican such as Blois, Francax, Gaudichon and LeBris (1961) and Ledoye (1964 a, and 1964 b). Ostenfeld (1908) reported on some of the organisms assoicated with eelgrass on the Danish Coast. However, European and American scientists have not investigated the eelgrass community as extensively as have the Japanese.

Marsh (1970) collected 112 epibiotic invertebrate species plus 28 macroalgal species in the Zostera beds. His collection does not include such organisms as diatoms, nematodes ostracods, copepods, and other small invertebrates which were not retained by a 0.5 mm mesh seive. Orth (1971) collected 117 *infaunal* invertebrate species. Table 9 represents a composite of the organisms observed during the two investigations associated with the eelgrass community. The value of Table 9 to *water managers* is not intended as a "laundry list" of scientific names, but as a revelation of the complexity of the community. However, finding an organism in both the infauna and epifauna, does not necessarily indicate a normal situation. For example, Marsh found a very small Callinectus sapidus (blue crab) one time in the epifauna although its normal habitat is on the bottom. Table 9 is not complete. The fish associated with eelgrass beds are not listed because that information is not available in the literature. Other investigations are necessary to provide a complete list.

The five most abundant epifaunal organisms in Marsh's study were Bittium varium, Paracerceis caudata, Crepidula convexa, Ampithoe longimana and Erichsonella attenuata. These organisms constituted 59% of the total fauna observed. The 22 most abundant epifaunal organisms accounted for 95.5% of the fauna. In terms of dominant taxa 43.2% were Gastropoda, 18.5% Amphipoda, 16.7% Isopoda and 15% Polychaeta. Orth (1973) reported that Polychaeta constituted 36% of the total infaunal population, Amphipoda 16%, Gastropoda 11% and Bivalvia 7%. The remaining percentage belonged to various other taxa. Although most of the epibiotic species of Marsh's study were common at all stations, differences in their relative abundance in relation to depth were evident. An average of 70 species were collected from station A, 26 from B, and 88 from C. This data and the average number of organisms/g of Zostera (A - 96.8 organisms/g, B - 114.3 organisms/g and C - 192.4 organisms/g) suggest that depth either directly or indirectly influences the composition of the eelgrass community. It must be pointed out that statistically Station B did not differ from Station A (Marsh, personal communication).

	Marsh (1970)	Orth (1971)
Porifera		
1. *Microciona prolifera*	x	
2. *Haliclona loosanoffi*	x	
3. *Halichondria bowerbanki*	x	
4. *Mycale sp.*	x	
5. *Prosuberites microsclerus*	x	
Cnidaria		
6. *Edwardsia sp.*		x
7. *Dynamena cornicina*	x	
8. *Halocordyle tiarella*	x	
9. *Hydractinia arge*	x	
10. *Aiptasiomorpha luciae*	x	
11. *Diadumene leucolena*	x	
Platyhelminthes		
12. *Euplana gracilis*	x	
13. *Stylochus ellipticus*	x	
14. *Zygonemertes virescens*	x	x
15. *Tetrastemma elegans*	x	
16. *Amphiporus ochraceus*	x	x
17. *Amphiporus bioculatus*		x
18. *Cerebratulus lacteus*		x
19. *Tetrastemma sp.*		x
20. *Tubulanus pellucidus*		x
21. *Nemerteans* (unidentified)		x
Bryozoa		
22. *Electra crustulenta*	x	
23. *Bowerbankia gracilis*	x	
24. *Membranipora tenuis*	x	
Polychaeta		
25. *Nereis succinea*	x	x
26. *Platynereis dumerilii*	x	x
27. *Sabella microphthalma*	x	x
28. *Polydora ligni*	x	x

Table 9. Composite listing of organisms found within the eelgrass beds of the Chesapeake Bay by Marsh (1970) and Orth (1971).

		Marsh (1970)	Orth (1971)
29.	Brania clavata	x	x
30.	Hydroides hexagona	x	
31.	Podarke obscura	x	x
32.	Nereiphylla fragilis	x	
33.	Exogone dispar	x	x
34.	Pista palmata	x	
35.	Odontosyllis fulgurans	x	x
36.	Lepidonotus variabilis	x	
37.	Amphitrite ornata		x
38.	Asabellides oculata		x
39.	Clymenella torquata		x
40.	Eteone heteropoda		x
41.	E. lactea		x
42.	Diopatra cuprea		x
43.	Phyllodocidae (unidentified)		x
44.	Glycera americana		x
45.	G. dibranchiata		x
46.	Glycinde solitaria		x
47.	Gyptis vittata		x
48.	Heteromastus filiformis		x
49.	Hydroides dianthus		x
50.	Lepidonotus sublevis		x
51.	Loimia medusa		x
52.	Lumbrineris tenuis		x
53.	Melinna maculata		x
54.	Parahesione luteola		x
55.	Paraprionospio pinnata		x
56.	Pectinaria gouldii		x
57.	Phyllodoce fragilis		x
58.	Prionospio heterobranchia		x
59.	Pseudeurythoe paucibranchiata		x
60.	Sabellaria vulgaris		x
61.	Scoloplos acutus		x
62.	Ampharetidae (unidentified)		x
63.	Capitellid A (unidentified)		x
64.	Scoloplos armiger		x
65.	S. fragilis		x
66.	S. robustus		x
67.	S. sp.		x
68.	Spio filicornis		x
69.	S. setosa		x
70.	Spiochaetopterus oculatus		x
71.	Spiophanes bombyx		x
72.	Streblospio benedicti		x
73.	Tharyrx setigera		x
74.	Sphaerosyllis hystrix		x
	Oligochaeta (unidentified)		x

		Marsh (1970)	Orth (1971)
Mollusca			
75.	Bittium varium	x	x
76.	Crepidula convexa	x	
77.	Mitrella lunata	x	x
78.	Triphora nigrocincta	x	
79.	Nassarius obsoletus	x	x
80.	N. vibex	x	x
81.	Odostomia impressa	x	x
82.	O. bisturalis	x	
83.	Elysia catula	x	
84.	Stiliger fuscata	x	
85.	Polycerella conyma	x	
86.	Doridella obscura	x	
87.	Doris verrucosa	x	
88.	Tenellia fuscata	x	
89.	Gemma gemma		x
90.	Cratena pilata	x	
91.	Hermaea cruciata	x	
92.	Anadara transversa	x	x
93.	Mya arenaria	x	x
94.	Ensis directus		x
95.	Laevicardium mortoni		x
96.	Lyonsia hyalina		x
97.	Macoma balthica		x
98.	Mercenaria mercenaria		x
99.	Mulinia lateralis		x
100.	Acteon punctostriatus		x
101.	Eupleura caudata		x
102.	Mangelia plicosa		x
103.	Pyramidella candida		x
104.	Retusa canaliculata		x
105.	Triphora perversa		x
106.	Turbonilla interrupta		x
107.	T. sp.		x
108.	Urosalpinx cinerea	x	x
Arthropoda			
109.	Balanus improvisus	x	
110.	Neomysis americana	x	x
111.	Mysidopsis bigelowi	x	
112.	Paracerceis caudata	x	x
113.	Erichsonella attenuata	x	x
114.	Idotea baltica	x	x
115.	Edotea triloba		x
116.	Cyathura burbancki		x
117.	Ampithoe longimana	x	x

		Marsh (1970)	Orth (1971)
118.	Cymadusa compta	x	
119.	Elasmopus laevis	x	x
120.	Gammarus mucronatus	x	x
121.	Caprella penantis	x	
122.	Batea catharinensis	x	x
123.	Corophium acherusicum	x	x
124.	C. simile	x	x
125.	Melita appendiculata	x	
126.	Colomastix halichondriae	x	
127.	Paracaprella tenuis	x	
128.	Rudilemboides nageli	x	
129.	Ampelisca vadorum	x	x
130.	A. abdita	x	x
131.	A. verrilli		x
132.	Jassa falcata		x
133.	Leptocheirus sp.		x
134.	Listriella barnardi		x
135.	Lysianassa alba		x
136.	Melita appendiculata		x
137.	M. nitida		x
138.	Stenothoe minuta		x
139.	Unciola irrorata		x
140.	Callinectes sapidus	x	x
141.	Crangon septemspinosa	x	x
142.	Lembos smithi		x
143.	Monoculodes edwardsi		x
144.	Heterophoxus sp.		x
145.	Cucumaria pulcherrima		x
146.	Thyone briareus		x
147.	Anoplodactylus parvus		x
148.	Cylindroleberis mariae		x
149.	Sarsiella zostericola		x
150.	S. texana		x
151.	Callipallene brevirostris		x
152.	Cyclaspis varians		x
153.	Oxyurostylis smithi		x
154.	Leptochelia savigny		x
155.	Hippolyte pleuracantha	x	
156.	Palaemontes pugio	x	
157.	P. vulgaris	x	
158.	Neopanopa texana sayi	x	
159.	Libinia dubia	x	
160.	Molgula manhattensis	x	
161.	Botryllus schlosseri	x	
Echinodermata			
162.	Cucumaria pulcherrima		x
163.	Thyone briareus		x

Orth (personal communication) revealed some interesting points on community composition. Comparative data of a bare sand habitat and a _Zostera_ bed indicated an approximate fourfold increase in numbers of organisms within the _Zostera_ bed. He also has determined that the majority of organisms inhabiting _Zostera_ beds are tube dwellers rather than mud dwellers. In _Zostera_, tube dwellers are not subject to the same degree of stress they would be subjected to in bare sand. An organism living in bare sand must burrow rapidly or be enclosed in a long tube to prevent smothering by shifting sand.

Marsh (1970) used Sander's (1960) index of affinity on each collection date to indicate faunal similarity between stations off Mumfort Island (site 3 in Figure 22), and he also used Duncan's multiple range test (Steel & Torrie, 1960) to indicate significant differences in the average faunal affinity between station pairs. He found the affinity between stations A and B averaged 69.9%, between B and C averaged 58.3% and between A and C averaged 46.1%. Station C was distinct because of the appearance of eelgrass, its lower biomass and the abundance of certain algae epiphytes. The affinity values calculated by Marsh were relatively high in comparison to other community studies (Sanders, 1958: McCloskey, 1968) when affinity values were determined. These values establish a distance relationship of continuity between the epifauna.

In describing faunal similarity, Orth (1970) used the dominance affinity index or percentage similarity, Kendall's coefficient of association T and the Wisconsin variant of percentage similarity. All three tests were used to compute values between station pairs, whereas just the percentage similarity index and Kendall's T were used to compute differences between seasonal samples. In general, the mean index for the station pairs within seasons was 39% in March and 41% in July. The similarity of the infauna between seasons was found to be relatively low with a mean of only 31%. The results indicate that a similarity pattern of the infauna of _Zostera_ within the Chesapeake exists, especially between adjacent stations.

The information function of Shannon (Shannon & Weaver, 1933) is a common diversity index which Marsh (1970) used because it is sensitive to the number of forms present and the equitability of their distribution, yet relatively independent of sample size. The equitability component of diversity also was utilized to describe the theoretical distribution of individuals among species. The two computations demonstrated that on a seasonal basis there is not a marked seasonal diversity. Orth (1973) calculated diversity, evenness and species richness. His results appeared quite similar to Marsh's in that there was not a distinct seasonal pattern for diversity (although the species components decreased from stations A to D both seasons).

Thus far, we have been concerned only with the invertebrate epifauna and infauna of the Zostera bed, which comprises only part of the total picture. Zostera provides a substrate for many epiphytes. Table 10 is a list of macroalgal epiphytes found on Zostera leaves by Marsh. Marsh (1970) did observe a distinct seasonality among algal genera. In the winter, Desmotrichum and Elachistia (brown algae) were dominant, whereas Champia, Spyridia and Agardhiella (red algae) were dominant in summer and fall. Depth apparently affected some of the algae because Champia and Fosliella were found at shallow inshore stations, whereas in deep waters Enteromorpha intestinalis and Ceramium rubrum were common. Also during his investigation, Marsh took surface scrapings of the eelgrass blades which revealed great numbers of nematodes, rotifers, diatoms and other microorganisms as well as quantities of detritus and sediments.

Marsh concluded that there are three primary food sources within a Zostera bed:

1. "Detritus and microorganisms found on the plant surfaces"

2. "Suspended particulate organic matter and plankton"

3. "Epiphytic algae"

A fourth food source is the detritus formed from dead Zostera leaves (Kita and Harada, 1962). In our area, live Zostera does not appear to be directly utilized for food except by ducks and geese, such as the Brant, Canada Goose, Scaups and Redheads. Of the three food sources reported by Marsh, 21 of the 22 most abundant species (equivalent to 95% of the total fauna) in the Chesapeake Bay were dependent on at least one of them. The exception, Odostomia impressa, is an ecotoparasite on various invertebrates.

Chlorophyta		Rhodophyta	
1.	_Ulva lactuca_	13.	_Grinnellia americana_
2.	_Bryopsis plumosa_	14.	_Porphyra leucosticta_
3.	_Enteromorpha plumosa_	15.	_Agardhiella tenera_
4.	_E. intestinalis_	16.	_Callithamnion byssoides_
5.	_E. linza_	17.	_Ceramium fastigiatum_
6.	_Cladophora gracilis_	18.	_C. rubrum_
7.	_C. glaucescens_	19.	_C. diaphanum_
8.	_Chaetomorpha linum_	20.	_C. rubriforme_
		21.	_Polysiphonia nigrescens_
Phaeophyta		22.	_P. subtillisima_
9.	_Desmotrichum undulatum_	23.	_P. larveyi_
10.	_Asperococcus siliculosus_	24.	_Dasya pedicellata_
11.	_Elachistia_ sp.	25.	_Champia parvula_
12.	_Scytosiphon lomentaria_	26.	_Spyridia filamentosa_
		27.	_Fosliella lejolisii_

Table 10. Macroalgae observed by Marsh (1970) on _Zostera_ leaves

It has already been mentioned that numerous nematodes, rotifers, diatoms and other microorganisms as well as detritus and sediment are found on Zostera leaves. This material is grazed upon by many mollusks, isopods, amphipods and polychaetes. Sponges, tunicates and bryozoans are some of the common suspension feeders. Other organisms such as caprellid amphipods, mysid shrimp and polychaetes are known to utilize both suspended particles and detrital material as food sources. Other studies have similar relationships, but one of interest that will be discussed here is Nagle's (1968) study on the distribution of epibiota.

Nagle observed that infauna can "spill" over onto the plants, but numbers of organisms decrease with the increasing distance up the stem, whereas suspension-feeding, fouling organisms increase up the stem. Marsh believed that macroalgae are not an important food source, but rather supplement the diet of organisms such as the polychaetes Platynereis dumerili and Nereis succinea. Nagle found a similar situation in both field observations and laboratory experiments. The epiphytes serve as detrital traps, and the grazers clean the epiphytes by utilizing the detritus as a food source. Only in time of distress will the epiphytes be used as food. The epiphytes benefit because they remain strong and healthy.

Another aspect or interest Nagle demonstrated was that the organisms relatively immune to fish predation, such as snails and amphipods of the genus Corophium, demonstrate a peripheral zonation. Those amphipods more susceptible to predation live nearer the center of the stem where there is more protection. A striking resemblance often is discerned between the coloration and bars of diatoms and those of snails.

Nagle also was able to show that some organisms prefer areas of high physical energy, whereas others prefer lower energy areas. Usually this difference is related to the ability of the organism to gather food and is dependent on morphological adaptation. One last point of interest is that interspecific organisms often have staggered reproductive periods. This staggering allows niche coexistence since the adult form of one species and the larval form of another species are present at the same time. The different life stages have different food requirements, and therefore do not compete for the same food. A similar study to Nagle's would be beneficial for the Chesapeake Bay.

Several organisms are predators of the invertebrate fauna, such as Urosalpinx cinerea and Odostomia impressa (Marsh 1970). In summer, fishes such as common silversides (Menidia menidia), the four-spined-stickleback (Apeltes quadracus) and the pipefish (Syngnathus fuscus) utilize amphipods, mysids, other small crustaceans and some polychaetes as food sources. Figure 23, taken from Marsh (1970), demonstrates an apparent trophic relationship of the common epifaunal genera.

Work has been published by the Japanese on the relationship of fish and Zostera. An interesting study was conducted by Kikuchi (1966) on the fish community of Zostera marina in Tomioka Bay. A comparison was attempted for this report to see if parallelism could be demonstrated between the Tomioka (1966) and Chesapeake Bays. For the most part, it could not. However, a similar study for the Chesapeake would be valuable.

Kikuchi (1966) described microhabitats within the Zostera belt:

1. "the surface layer water above the vegetation"

2. "the bottom layer water in the vegetation"

3. "the surface of Zostera blades"

4. "the surface of the substratum"

5. "the inside of the substratum"

He then related the fish to these microhabitats and described their behavior, social relations and feeding rites. Behavior included such activities as swimming slowly or resting on Zostera, whereas social relations included their manner of interacting with others of their species (e.g. did they school or were they solitary?) The rite refers to the microhabitat fish utilize for obtaining food. He carried his investigation one step farther, and described the various fishes as to how long they lived in the Zostera belt. Table 11 generalizes how he accomplished this task.

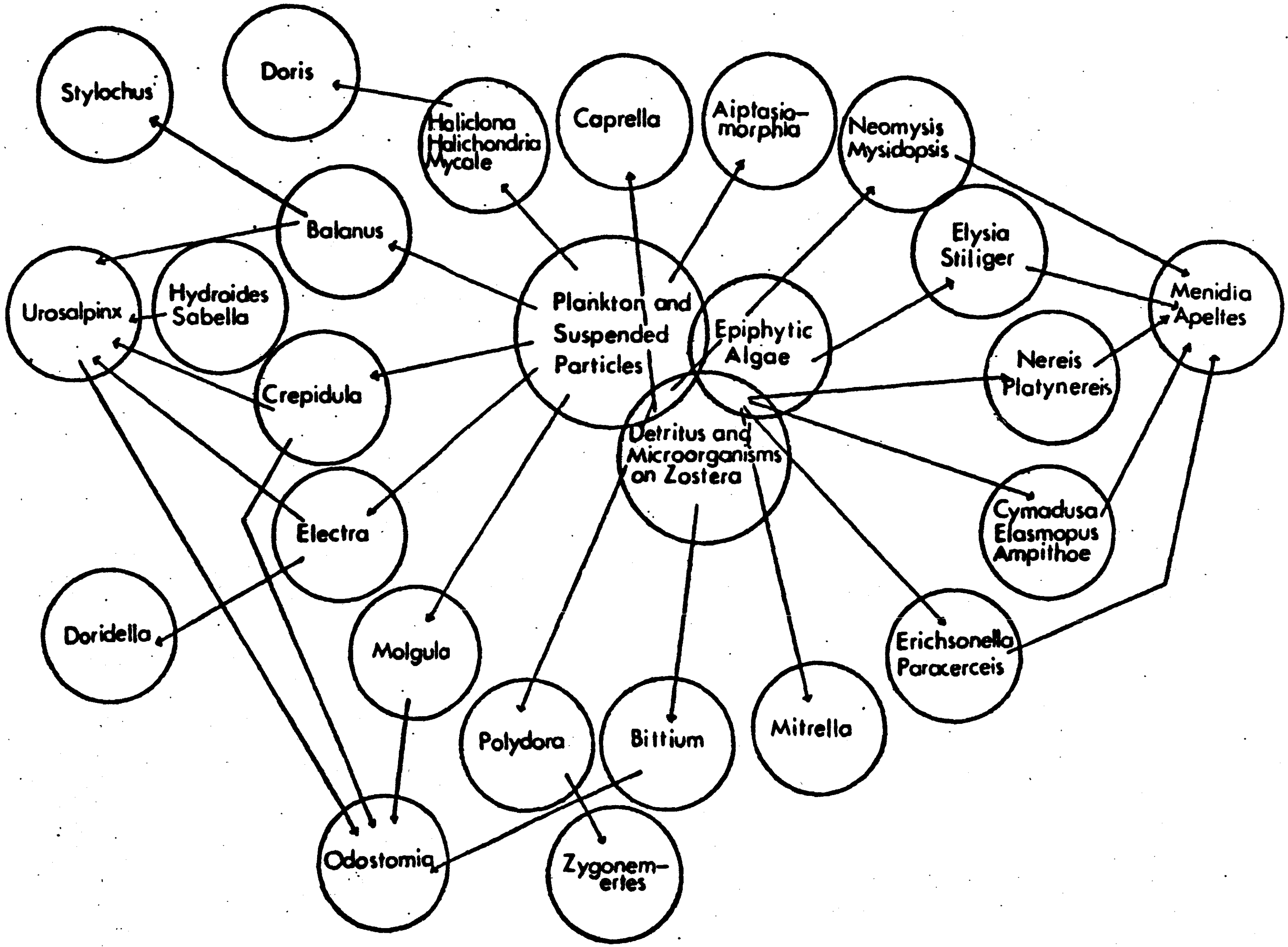


Figure 23. Trophic relationships of some of the epifauna of the Chesapeake Bay (From Marsh, 1970)

1. Residents (fish residing in the Zoastera belt year round).

   a. Fishes which utilize the belt as their only habitat.

   b. Fishes in common with rocky coast.

   c. Fishes in common with muddy or sandy bottoms.

2. Seasonal residents (fishes which spend definite seasons or definite life stages in the Zostera belt).

   a. In spawning season

   b. In juvenile and subadult stages

3. Transients (fishes which forage about a larger area in the bay and come to the Zostera belt as part of their foraging range).

4. Causal species (fishes which casually appear in the Zostera belt).

Table 11. Kikuchi's (1966) classification of fishes associated with Zostera.

Although the method in Table 11 may not be entirely utilized in the Chesapeake Bay, a good part of it is appropriate for the Bay. A generalized statement Kikuchi made that would be worth investigation is that "the year round residents are small in their adult size, large species are transients, and juvenile seasonal inhabitants are of a size similar to those of year-round residents."

Kikuchi (1966) continued his study with investigators of decaped crustaceans. Decapods are important because of their significance as fish food. Crustaceans show nocturnal behavior so they were collected at night, something that has not been done in the Chesapeake Bay to my knowledge. The crustaceans were classified much like the fish in Table 11.

In his study of other invertebrates, Kikuchi (1966) portrayed an organism in its microhabitat similar to the way he did fish except he substituted the mode of life (swimming, creeping or crawling sessile) and mode of feeding (seston, plankton, herbivore, or predator) into the classification. In general, he found that the infauna of the Zostera belt were similar to that of the surrounding bare muddy bottom or muddy sand bottom. The epifauna exists only on the Zostera vegetation and was not observed on bare bottom. He considers a Zostera community relatively independent.

Wasting Disease

Another reason the Zostera community was chosen for additional study in this report was because of its reported decline in 1931 and 1932 which resulted in the death of a dominant organism, Zostera marina, over large areas. By the end of the fall of 1931, about 90% of the eelgrass located along the Atlantic coast had been eliminated by some unknown factor (Moffit, 1941). From 1931 to 1941, Zostera was reported declining in several parts of the globe. Lewis and Taylor (1933) noted its decimation from Nova Scotia to North Carolina, whereas Taylor (1933) noted the decline on the French and Netherlands coast. Blegvad (1935) reported the progressive destruction of eelgrass along the coasts of Portugal, France, and Holland during the early part of 1932 and early 1933. In the Limfjord, he observed the first effects on growing Zostera in deep water on soft bottoms. In 1941, the Danish stock was 1/13th of its former total and was limited to slightly saline water (Lund, 1941). Fischer-Piette, Heim and Lami (1932) reported the disease in France, where they described the symptoms and isolated a gram-negative rod bacterium which they believed might be the causative agent. On the English coast, Atkins (1947) reported a 70-75% loss of Zostera in Guernsey in 1932, and Wilson (1949) reported a decline in Salcombe Harbor and the resultant effects upon the shore. During a ten-year period (1941-1951), Zostera slowly regained its population, but the decimation that struck then could strike again. As late as 1964, a decimation of Zostera was observed in the vicinity of Auckland, New Zealand (Armiger, 1964).

Many theories have arisen as to what caused the destruction of the eelgrass. Tutin (1938) suggested that a lack of sunshine might be the reason, but Atkins (1938) quickly pointed out that Tutin's theory could not be correlated with the meteorological data available from 1897 onward. Butcher (1934), and Duncan (1933) suggested crude oil spillage, but this theory has little support. Cottam (1933), for one did not believe oil pollution could be correlated with the decline. There was a lot of speculation, but the controversy seems to reside in two fungal-like organisms. In Canada, Ophiobolus lamimus was reported by Mouance and Biehl (1934) to be associated with the rhizomes and fertile shoots of Zostera. They also demonstrated its development on the leaves of Zostera kept in seawater in the laboratory. Petersen (1935) believed that in Danish waters the fungus Ophiobolus was the pathogen and not a bacterium or the protozoan Labyrinthula which was first reported by Renn (1934), after a superficial examination, as the causative agent. After a more detailed investigation, Renn (1936) stated that although Ophiobolus lamimus was reported as abundant along the Canadian, Danish and English coasts, it was an infrequent species from Maine southward. He believed that the ameoba-like organism, Labyrinthula with its mycetozoan affinities was the causative agent. By means of histological examinations and inoculation experts, he was able to make a fair assumption that Labyrinthula was the causative agent. Young (1943) gave support to Renn's theory because his work also led him to believe that Labyrinthula was the etiologic agent of the eelgrass "wasting disease." His investigation revealed that the optimum temperature for Labyrinthula was 14° to 20°C, but he also found it active from 0.3°C to 30°C. Salinity appeared to be an inhibitor of the organism's growth; the vegetative stage did not do well in low salinity waters. Cottam and Munro (1954) stated that in both Maryland and Virginia low salinities in the adjacent tributaries of the Chesapeake Bay were conducive to the recovery of eelgrass, whereas along the oceanic coast, it was at the time of their publication still non-existent.

A *water manager's* prime concern should be the effect of disruption on a community if it is disturbed. In regard to Zostera, he can get an excellent idea because as the eelgrass was decimated, a noticeable decline occurred in several marine industries. Milne and Milne (1951) reported the reduction of cod, flounder, shellfish, scallops and crabs. Dexter (1944) stated soft-shelled clams and razor clams, lobsters, and mud crabs declined severely. Mya arenaria, the soft-shell clam, became so scarce that the industry became non-existent. Moffit and Cottam (1941) reported the decline of perch and herring. Stauffer (1937) observed, after Zostera disappeared, a reduction of 1/3 of the total number of species of the Woods Hole area reported by Allee (1932). Table 12 illustrates the relative abundance of characteristic species before and after the disappearance of eelgrass. Moffit and Cottam (1941) reported a decline of 80% of the sea brant along the Atlantic coast. They also pointed out a decline in numbers of Canadian geese, black duck, scaups, and redheads.

However, in one location, the decline of eelgrass helped an industry. In the Niantic River in Connecticut, the scallop population increased (Marshall, 1947). The increase was probably because the currents carried nutrients to the area that had been stifled previously by the Zostera. Not all the organisms associated with Zostera disappeared. Dexter (1944) observed that some members survived by living on algae such as Laminaria. It should be apparent that

I. Animals formerly growing on the plants	Occurrence Before	After
Coelenterata:		
Sagartia luciae	*[4]	
Bryozoa:		
Bugula turrita	***	
Arthropoda:		
Idothea baltica	*	
Mollusca:		
Bittium alternatum	**	
Lacuna vincta	**	
Littorina sp.	***	**
Mitrella lunata	*	
Total number of characteristic epiphytic species	7	1

II. Animals formerly swimming among the plants	Before	After
Annelida:		
Podarke obscura	*	
Arthropoda:		
Crago septemspinosus	*	*

[3]Allee (1923) listed 138 species found in the eelgrass areas from 1915 to 1921.

[4]*Occasional: Before--found in less than 33 per cent of Allee's collection.
After---forming less than 2 per cent of the 1936 population.

**Common: Before--in 33 per cent to 50 per cent of Allee's collections.
After---forming 2 per cent to 5 per cent of total population.

***Abundant: Before--in over 50 per cent of Allee's collections.
After---forming 5 per cent or more of the total population.

Table 12. The relative abundance of characteristic species in N.W. Gutter lagoon before and after the disappearance of the eelgrass[3]. (From Stauffer, 1937)

II. Animals formerly swimming among the plants (con't)	Occurrence Before	After
Gammarus sp.	**	**
Palaemonetes vulgaris	**	**
Virbius zostericola	**	
Mollusca:		
Pecten irradians	**	
Total number of characteristic swimming species	6	3
III. Animals living on the surface of the mud		
Coelenterata:		
Hydractinia echinata	**	**
Arthropoda:		
Carcinides maenas	**	
Libinia dubia	*	
Libinia emarginata	*	*
Pagurus longicarpus	***	***
Pagurus pollicaris	*	*
Neopanope texana sayi	**	**
Limulus polyphemus	**	*
Mollusca:		
Crepidula convexa	**	**
Crepidula fornicata	*	*
Crepidula plana	**	*
Nassa obsoleta	***	**
Nassa trivittata	**	**
Modiolus demissus	***	
Mytilus edulis	**	
Ostraea virginica	*	*
Total number of characteristic mud surface species	16	12
IV. Burrowing Forms		
Nemertea:		
Cerebratulus lactens	*	*
Micrura leidyi	***	

IV. Burrowing Forms (con't)	Occurrence Before	Occurrence After
Echinodermata:		
Leptosynapta inhaerens	***	*
Thyone briareus	***	**
Annelida:		
Amphitrite ornata	**	*
Arabella opalina	**	**
Cistenides gouldi	**	**
Clymenella torquata	**	***
Diopatra cuprea	*	
Glycera sp.	***	*
Lumbrinereis tenuis	*	***
Maldane urceolata	*	*
Nereis virens	***	
Scoloplos fragilis	***	***
Spio setosa	*	***
Phascolosoma gouldi	*	*
Arthropoda:		
Pinnixia chaetopterana	*	*
Mollusca:		
Cumingia tellinoides	**	
Ensis directus	*	*
Mactra lateralis	*	*
Mya arenaria	***	*
Solemya velum	**	
Tellina tenera	**	**
Venus mercenaria	**	**
Chordata:		
Dolichoglossus kowalevskyi	*	*
Total number of characteristic burrowing species	**25**	**20**
Grand total of characteristic species	**55**	**36**

the Zostera loss resulted in a loss of feeding grounds, support and shelter for fish, invertebrates, and epiphytes. Stauffer (1937) pointed out that indirect effects could result in changes in patterns of the water circulation, amounts of dissolved oxygen and pH.

The loss of eelgrass resulted in the shifting of mud and sand by the tides which killed a great many other plants and animals. As a final result, the whole ecological community was altered (Clarke, 1954). Probably no one could accurately estimate the economic effect of the loss of Zostera.

After 1941, Zostera started making substantial growth gains. Dexter (1950) in his study in Goose Cove at Cape Ann, Massachusetts showed that the whole complex of animals returned when eelgrass returned. Although eelgrass has returned, the "wasting disease" could possible decimate it again. As already pointed out by Orth (personal communication) the cownose ray is causing extensive damage in the lower bay. What effect will this destruction have on fish that use the eelgrass beds as nursery grounds? If it continues, we can expect the same results observed in the 1930's.

Oyster Community

Oyster bars represent another type of community. Here, an animal rather than a plant is the dominant controller of energy flow. This type of community, found mainly in the mesohaline zone, is formed when young oysters attach themselves to a suitable substrate. Succeeding generations of oysters attach to the original settlers, increasing the length, width and height of the area suitable as a substrate. An oyster bar, as it increases in size, has a great effect on altering current patterns and velocity,and on structure. The bar also provides a substrate for species which in turn form a distinct faunal composition. The pictorial portrayal presented in Figure 24 shows several of the organisms associated with an oyster bar community. Many forms of algae, hydroids, bryozoans, barnacles, mussels and tube-building worms can be found in such a community Chestnut (1974).

Because of the commercial value of oysters, information on them is abundant. This portion of the oyster community description will be limited to the oyster Crassostrea virginica, found in the Chesapeake Bay and associated tributaries. A detailed description will not be presented here because much of the literature has already been synthesized by Korringa (1952) and Galtsoff (1964), both infinitely better prepared than I to prepare such a report.

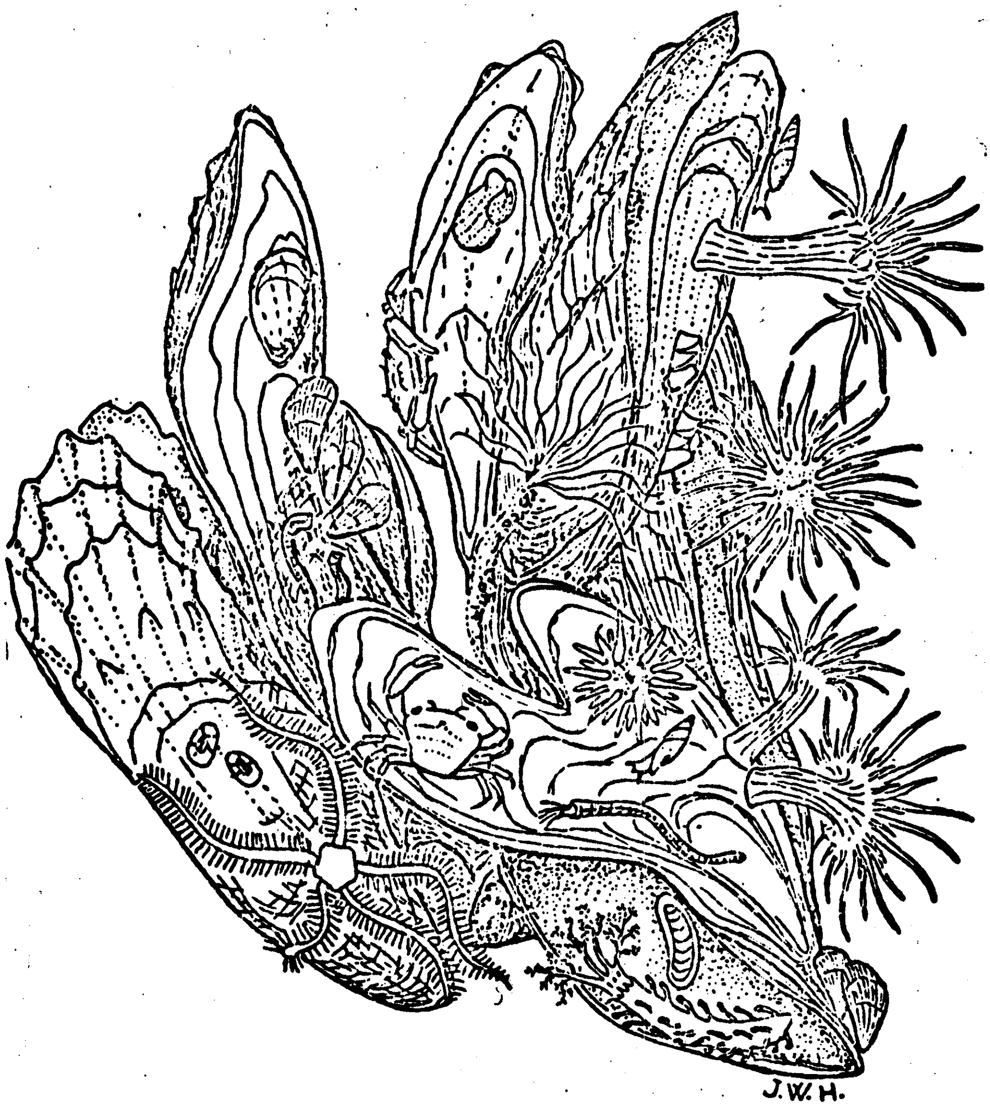


Figure 24. Sketch of an oyster clump from South Bay, near Port Isabel, Texas. Animals represented include the anemone, Aiptasia pallida; the brittlestar, Ophiothrix angulata; the cucumber, Thyonacta sabanallensis; a chiton, Ischnochiton papillosus; Brachidontes exustus, Crepidula fornicata, and Anachis avara, various worms, barnacles, and a small xanthid crab (Odum and Copeland, in press).

The material presented is an extract of the information most directly applicable to the Chesapeake Bay. Both Korringa's (1952) and Galtsoff's (1964) reports have been relied on heavily; other literature sources have been used as supplemental material.

In general, the various species of oysters occupy many square miles of littoral and intertidal zones in coastal waters between 64°N and 44°S (Galtsoff, 1964). Galtsoff's (1964) observations over the years led him to believe that certain major environmental factors are common to all oyster bottoms. He considered these factors as representing two major subdivisions: the positive factors of the environment, including type of bottom, water movements, salinity, temperature and food, and the negative factors of environment, e.g. sedimentation and disease.

These positive and negative environmental factors will be discussed in succeeding paragraphs. All information for this discussion was derived from Galtsoff (1964) unless another literature source is cited.

Positive Factors of Environment

Oysters cannot survive on bottoms of shifting sand and soft mud. As a rule of thumb, a *water manager* can assume that a bottom that will not support the weight of one shell will be entirely unsuitable for oyster bar development. Normally, oysters will be found on hard rocky bottoms on semi-hard mud. They may also be found on submerged logs, or on man-made objects, (e.g. jetties, piers, etc.). If the suitable surfaces, however, are exposed to several hours of temperature below freezing, oysters will not occupy the habitat.

There are several ways to convert bottoms in order to obtain the desired firmness for oyster bar growth. One of the most practical ways is to deposit empty oyster and clam shells along the bottom where other environmental conditions are favorable for oyster growth. This substrate will provide the desired firmness for attachment of the spat. Another method to provide a suitable substrate is to dump gravel and/or slag from blast furnaces on the bottom, but this action is more expensive than the abovementioned method. Oysters themselves have been known to convert a soft muddy area into a suitable area for settlement and development. Several larvae attach themselves to a hard object on the surface of the mud. A cluster is formed, and as the oysters die, shells fall from the cluster, providing additional hard substrate. Obviously this method, although more natural, is slower than the depositing of shells, gravel or slag.

Another positive environmental factor is water movement. Growth, fattening and reproduction all depend upon the oyster having a free circulation between its body tissues and the surrounding water. Galtsoff cited the ideal condition as a steady, nonturbulent flow of water over an oyster bed, strong enough to carry away the liquid and gaseous metabolites and feces and capable of supplying oxygen and food.

The increased distribution of oyster bars depends on water movement since the larvae are carried by currents. When it is time for the larvae to set, the currents are the determining factor of whether or not the larvae contact a hard surface. Estuaries have been noted for a long time as suitable for the expansion of oyster communities and for the rehabilitation of populations which have been reduced by harvesting. The oscillating movement of tidal waters carries the larvae back and forth so that eventually they will resettle somewhere beyond their place of origin, whether it is the same bar or further up or down the estuary.

As mentioned previously, the type of oscillation that prevails in a specific estuary depends on a variety of physical factors (i.e. size, depth, bottom configurations, river flow and the vertical salinity gradient from the head to the mouth of the estuary). The distribution of oysters and the transport of sediments, pollutants and plankton, including larvae of other sedentary invertebrates, depend upon circulation patterns and mixing of the waters. These factors determine where the larvae will set and the sedimentation rate. If the sedimentation rate is great, oysters can be smothered, but if the mixing water maintains the particles in suspension, they may not affect the oyster community at all. The circulation pattern will determine if pollutants contact the oysters, and the amount of mixing will determine the concentration of the pollutant to which the oyster is exposed. If mixing is fairly good, the pollutant will be diluted to such an extent that its effect on the community is minimal.

Since oysters are sedentary, their food source must be carried to them. Certain phytoplankters are one food source. The plankton may be brought in contact with the oyster bar or may be carried over it, depending on the circulation pattern and mixing. Water movement also influences the amount of competition to which the oysters are exposed. If the larvae of other sedentary invertebrates settle in close proximity to the oyster bed, they may compete with the oyster for living space and food.

Oyster larvae, as well as other bivalves and barnacles, have a tendency to swarm; therefore, their distribution may not be uniform, even in a homogeneous environment. Observations by Carriker (1951), Manning and Whaley (1955). and Nelson (1952) led to the conclusion that there is a tendency of the late umbo larvae of Crassostrea virginica to remain in the lower and more saline waters of an estuary. They are probably stimulated to swim by salinity changes at flood tide (Galtsoff, 1964).

Turbulent patterns of water movement with high velocities are not conducive to oyster development. A high velocity current will carry the young larvae away, making rehabilitation of the bed impossible. In addition, the small pebbles and sand carried by a high velocity turbulent current can cause abrasion of the shells and valves of the oyster.

Calculations from Galtsoff's investigations show that an average Crassostrea virginica can filter 15 liters of water per hour under optimal conditions. There are 250 oysters to a bushel and 1,000 bushels per acre. At this rate, 3.75 million liters of water would be needed per acre of water per hour. Since oysters cannot take in water more than two inches from the shell, it should be apparent to a *water manager* that a large quantity of water will have to pass over an oyster to insure adequate waste removal, replenishment of oxygen and food supply.

Crassostrea virginica, because it occupies estuaries, tidal rivers and streams, faces diurnal, seasonal and annual fluctuations. The average salinity range for oysters is between 5 and 30 ppt. Populations living above or below this range exist under marginal conditions. Beaven (1946) was able to demonstrate that each period of excessive stream flow from the Susquehanna River resulted in a period of low salinity in the upper Bay. In contrast, precipitation did not cause a corresponding decline in salinity. It is Beaven's contention that periods of heavy mortalities in the upper Bay are correlated with periods of frequent and prolonged exposure to low salinities that result from runoff of the Susquehanna River. These low salinities are also responsible for the erratic production and slow growth characteristic of the oyster areas above Kent Island. Because the bars with the greatest death rate were above Baltimore, Beaven (1946) ruled out the mortalities being caused by industrial pollutants. Freshets in the James River, Virginia also have been observed to cause oyster mortalities.

Oysters can be "conditioned" to low salinities. Andrews, Haven and Quayle (1959) found that oysters living in low salinities exhibit a low physiological state, characterized by absence of heart beat, absence of ciliary motion and loss of mantle sensitivity. This "conditioning" permits an oyster to survive both low salinities and low temperatures for a prolonged period of time. The degree of survival needs to be tested. It has long been known that oysters can survive adverse conditions if not exposed to them indefinitely. Loosanoff and Smith (1949) and Loosanoff (1952) demonstrated that oysters conditioned to live in low salinities can tolerate still lower salinities for a period of time, but those oysters conditioned to high salinity waters cannot withstand the very low salinities the oyster of lower salinities can tolerate. Loosanoff showed that C. virginica can withstand short durations of a change from low to high salinity without experiencing physiological injuries; however, tissue starvation can occur with prolonged exposure to low salinities (Korringa, 1952). Korringa (1952) believes that C. virginica is like many other estuarine species in that it has a wide tolerance of environmental changes, but thrives especially well under estuarine conditions because its normal competitors in the more saline waters cannot endure the low salinities of estuaries. Butler (1949 a) showed that reproductive capability of oysters is inhibited by the low salinities of the marginal areas of the upper Chesapeake Bay because the gonads fail to develop.

There are also areas of high salinity which are less conducive to oyster production because of the presence of predators such as drills, starfishes and boring sponges. Galtsoff reported on observations made by Parker (1955). Parker noted that central Texas bays experienced increased salinity because of the six-year drought (1948-1953). With increasing salinity, there was a gradual replacement of most of the C. virginica by Ostrea equestris. Other reasons for this change are not known. The C. virginica that survived developed different shell characteristics: the valves became crenulated, and the shell became thin, sharp and highly pigmented. Such morphological changes have not been reported for the Chesapeake Bay but a permanent salinity change could cause them.

Temperature is always an important factor for any organism; oysters are no exception. Galtsoff reported that C. virginica has been known to exist from 1°C in winter in northern states to 36°C in Texas, Florida and Louisiana. Korringa (1952) stated that C. virginica has survived freezing of body tissues under certain conditions (Needler, 1941 a; Loosanoff, 1946). When thawed carefully with a minimum of handling, they survive. Normally exposure of two to three hours is maximum for oysters in the tidal zone to withstand before death results.

The physiological aspects of oyster well-being, such as rate of water transport, respiration, feeding, gonad formation and spawning are all controlled to a large extent by temperature. Galtsoff reported that at 6° to 7°C, C. virginica ceases to feed. At 25° to 26°C, ciliary activity, which is responsible for water transport, is at its maximum rate. Above 32°C, the movement of cilia rapidly declines. At 42°C nearly all of the body functions cease or are reduced to a minimum. The temperature has to be 20°C or above for mass spawning and setting to occur.

The actions of salinity and temperature often integrate to such a degree that it is difficult to separate the single effect of either one. For example, oysters were moved from low salinities (10 to 12 ppt) of the upper Bay and were transplanted to Sinepuxent Bay, where the salinity ranged from 32 to 33ppt. All the oysters perished in three to four weeks. It has already been pointed out that oysters can survive a change from low to high salinity without physiological injury. So what caused the mortalities? Galtsoff stated that the transplant was made when the temperature was high and that the heat, coupled with high salinity, caused the mortalities. Transplanting during cooler weather caused only minimal casualities.

During this discussion on positive environmental factors, something should be said concerning oxygen and pH. Anyone who has ever bought oysters at the docks knows that oysters can withstand prolonged periods out of the water. They simply close their shell. Korringa (1952) was not sure whether the limits to length of exposure were a result of loss of moisture or respiratory difficulties. It also is not known whether or not oysters are influenced by oxygen in the air. When processing oysters for marketing, it should be remembered that the metabolic rate is greatly increased to satisfy the oxygen debt incurred by removal from water and maintenance in air. As far as pH is concerned, Korringa (1952) reported that Loosanoff and Tommers (1947) observed that a lowering of pH below 7.0 reduces the rate of water pumping in C. virginica. An acidic situation does not occur often, but with increase in pollution, it could happen. A large scale acid spill or dumping of acidic wastes into an estuary would cause this condition. It must be pointed out that oyster populations can themselves create an acidic condition by overcrowding and fouling of shells. *Water managers* should be aware that the Chesapeake Bay is one of the most productive estuaries in the world. Any contaminant that irritates the oyster's neuromuscular system causes increased shell movement, which in turn increases oxygen demand and results in the burning-up of the reserve supply in the body tissues.

A decrease in pH reduces oxygen consumption, and at a pH of 5.5 respiration slows down to 10% of its normal rate. Oxygen consumption increases if there is a sudden decrease in salinity, e.g. from 31 to 24 ppt. Oxygen demand is greater during the spawning season; therefore, when bottoms are selected as spawning grounds, there must be enough oxygen to supply the additional amount necessary during spawning.

Korringa (1952) discussed the various aspects of oyster feeding. Ciliary action is capable of driving a current of water through the ostia (gill slits). During passage through the ostia particulate matter is filtered off and wrapped in mucous. This mucous is transported to the labial palps where the oysters ingest it or reject it as pseudofeces. Environmental disturbances can stop mucous secretion, but may not necessarily stop the pumping of water; therefore, *water managers* should be aware that the water flow does not necessarily indicate feeding. The mucous feeding sheets are believed to be important in determining which small particles may be used as a food source. Korringa (1952) pointed out that MacGinitie (1945) stressed the need to obtain the small particles because most of the organic matter is dissolved. Korringa (1952) believed that the electrical properties of food particles and feeding sheets are important because positive polyvalent ions such as Al^{++}, Ca^{++}, Fe^{++}, Zn^{++}, Hg^{++} and Mg^{++} are caught and accumulated, whereas the positive monovalent ions like Na^{+} and K^{+} and the negatively charged ions are not.

Cerruti (1941) recorded the stomach contents of Ostrea edulis in Mar Piccolo, Italy. His findings revealed large quantities of organic detritus, diatoms and flagellates, annelid larvae, sand, silt, sponge spicules, mollusk larvae, eggs and gastrulae of a variety of marine invertebrates, plant fibers, pollen grains and smuts from nearby marine wharfs. Whether all this material was being utilized as food or not is a matter of conjecture. It is known that many things pass through an oyster's digestive tract completely unchanged. Because detrital particles are often covered with bacteria, Nelson (1947) assumed that bacteria could be an important food source. Galtsoff (1964) stated that although the energy requirement of certain filter feeders are known, there is no information available about the specific foods needed for growth and reproduction.

Oysters are known to feed on plankton. However, it has been difficult to determine which ones. It is known that the planktonic genera Rhizosolenia and Chaetoceras cannot be ingested by the oyster because of size and shape. Apparently, Chlorella and certain phytoplankters have antibiotic properties that are harmful to some bivalves. The "red tide" caused by Gymnodinium breve is known to kill oysters along the shores of an affected area. Galtsoff pointed out that analysis of the plankton sampled near the oyster bar is needed. Sampling of the plankton by using the vertical haul method is useless because there is no way to determine which plankton are caught at the water surface and which at the bottom near the oyster bar.

Loosanoff and Engle (1947) conducted experiments concerned with the effects of different concentrations of micro-organisms on the feeding of the oyster C. virginica. The micro-organisms used were the green algae, Chlorella sp.; the diatom, Nitzschia closterium; the dinoflagellate, Prorocentrum triangulatum; and the euglenoid Euglena viridis. (Note: Martin (1929) reported Prorocentrum triangulatum as sometimes the most abundant organism in the Chesapeake Bay). The experiments showed that there are rather definite densities at which a micro-organism begins to interfere with the oyster's ability to feed. In very heavy concentrations, pumping may cease entirely or large quantities of pseudofeces may be formed as the oysters try to clear their gills and palps. Lesser concentrations of micro-organisms often result in a greater pumping rate than when the oysters are kept in sea water. Cell size is important, as illustrated by the need for a greater number of small Chlorella to produce the same effect as caused by smaller number of Euglena. Characteristics displayed by an oyster maintained in a heavy concentration for a prolonged period of time were (1) the tonus of the abductor muscle became either totally or partially impaired and (2) the oyster became sluggish and its response to stimuli decreased. It was mentioned earlier that certain plankters produce antibiotics harmful to oysters. Loosanoff and Engle (1947) found that the filtrate of cultures containing cell metabolic products and the cells themselves both affected the oyster by reducing or entirely stopping the rate of pumping when the oyster was exposed to strong concentrations of either component. Galtsoff stated that the ideal time for oyster feeding is when the water is free of pollutants, the concentration of diatoms and dinoflagellates is low and the water flow over the bottom is nonturbulent.

So far, feeding of only the adult oyster has been discussed. Davis (1950) conducted experiments on the types of organisms that the larvae of C. virginica utilize as food. He concluded that the types of microorganisms the larvae can use as food are limited. The most satisfactory organism for laboratory feeding was Chlorella sp., but it occasionally appeared to be insufficient nutritionally, especially for the early larval stages of the oyster. If they reach 125 microns, however, all continued to grow and metamorphose to adults on the Chlorella sp. diet.

Negative Factors of Environment

Sedimentation is considered by Galtsoff to be a negative factor of the environment because, in general, sedimentation affects oyster development adversely. In the discussion on environmental conditions of the Chesapeake Bay, sedimentation was one of the factors presented and should be reviewed for the present discussion.

Several factors influence sedimentation: periodic changes in current velocities; turbulence; salinity; temperature; density and viscosity of water; size, shape, roughness and specific gravity of the particles; and the ability of the particles to flocculate. Galtsoff reported that in both the Rappahannock and the York Rivers of Virginia, layers of loose sediments, 1 to 2 mm thick, have caused the surface of shells and rocks to become unsuitable for the attachment of larvae, therefore resulting in failure of oyster setting. Sedimentation is a natural occurrence. It is not particularly harmful until it increases to the degree that it interferes with reproduction. High sedimentation rates have destroyed many formerly productive oyster beds in the United States.

Loosanoff (1961) conducted experiments on the effects of turbidity on larvae and adult C. virginica. The materials he used to create turbid conditions were fine silt from the tidal flats of Milford Harbor; kaolin (aluminum silicate), a clay-like substance; powered chalk; calcium carbonate; and Fuller's earth. All of these materials can be found in estuarine waters.

Under natural conditions, as little as 0.1 g/liter of silt can cause a reduction of pumping action in the oyster. However, Loosanoff discovered that one or two of the oysters appeared to be stimulated by the silt. As concentrations of silt increase, reduction in the rate of pumping increase proportionally. At concentrations of 3.0 to 4.0 g/liter, the average pumping reduction was 90%. Loosanoff was quick to point out that although a concentration as high as 3.0 to 4.0 g/liter seldom occurs naturally, it does occur during periods of heavy floods and in areas of extensive dredging. Whenever the oysters were returned to regular sea water, they quickly recovered; both the pumping rates and shell movement returned to normal. The experiment described so far was of short duration (3 to 6 hours). During a longer experiment (48 hours), when the oysters were returned to clean water after being subjected to turbid conditions, they did not demonstrate the return to normal rates of shell movement and pumping, indicating that possibly their ciliary mechanisms had been damaged. Another aspect of this problem is that during exposure to continuous high temperatures, the oysters are forced to function at higher metabolic rates. If the water is turbid, and they are unable to open their shells, they will die of starvation and suffocation. According to Loosanoff, this result is a logical inference because oysters keep their shells open from 97 to 99% of the time at temperatures of 20 C and above.

The other substances used by Loosanoff in his experiments produced similar effects in that the pumping rate was reduced, shell movement became abnormally vigorous and large quantities of pseudofeces were discharged. Loosanoff reported on the observations of Harry C. Davis (unpublished data) with regard to the effects of turbidity on larvae. Davis demonstrated that at concentrations of 0.25 g/liter of silt only 73% of the oyster eggs survived and at 0.5 g/liter only 31% survived. At higher ratios, the survival rate was almost nil. Contrarily, in suspension of kaolin or Fuller's earth at 1.0 g/liter, nearly all the oyster eggs developed to the straight hinge stage. Even at concentrations of 4.0 g/liter some of the oyster eggs developed. It must not be construed that these substances aided development, but merely that this result was noted. These results should be investigated more fully because the findings may improve handling of larval cultures.

So far, sedimentation has been discussed as a physical factor. Biologically, certain organisms such as mud-gathering and mud-feeding invertebrates can cause an accumulation of silt over oyster bottoms. As an example, Galtsoff reported that the mud worm, _Polydora ligni_, was observed to reproduce so rapidly in Delaware Bay that nearly every live oyster was smothered by a deposit of mud several inches thick.

Sedimentation can be created by the oysters themselves. They are known to discard large quantities of organic sediments as pseudofeces. Also, the material used during feeding can be discharged as fecal ribbons at the rate of several centimeters/hour. This fecal mass, in conjuction with sluggish water movement, can result in a contaminated bed. Ito and Imai (1955) observed a decline in productivity of oyster beds because of contamination by fecal material. Galtsoff contended that the biochemical changes associated with bacterial decomposition of organic components of sediments which results in carbon dioxide, ammonia, phosphates, sulphates and various organic acids plus hydrogen sulphide and methane formed during anaerobic oxidation, are responsible for the slower growth of oysters on the bottom of the bed than ones kept above the bottom on trays.

The second factor that Galtsoff considered as a negative environmental factor is disease. Symptoms for the most part are nonspecific. Galtsoff listed several symptoms usually indicative of disease: slow growth; failure to fatten; failure to develop gonads; recession of the mantle; valves slightly agaped, probably resulting from a weakened adductor muscle; abnormal deposition of shell material, which causes formation of short and thick shells; a watery and discolored dirty green or brown body; and/or a bloody body with accumulated blood cells on the mantle and surface.

Galtsoff listed several diseases as affecting oysters. Among them are the Malpeque Bay Disease; Dermocystidium marinum, a fungus; a disease associated with Haplosporiduem, better known by the acronym MSX; shell disease, thought to be a fungus; foot disease, another thought by Korringa to be the same causative agent as shell disease; Hexamita, a flagellate; Nematopsis ostrearum; and parasitic trematodes and copepods. The above-mentioned diseases will not be discussed to any great extent. The symptoms exhibited by oysters are reviewed in Galtsoff's work. It should be noted that several of the "diseases" are caused by organisms that belong to the community associated with oysters. For this reason, they will be discussed at greater length in the following discussion of the oyster bar community.

Oyster Community

The organisms associated with the oyster community are probably better known than the organisms that make-up other communities in the Bay. In fact, the oysters and associated animals hauled up onto a boat deck led Karl Möbius (1877) to introduce the term biocoenosis (p. 2-4). The oyster, the dominant organism, provides a habitat for a number of organisms. Wells (1961) listed the various types of habitats that exist in oyster-dominated areas. The oyster shell provides a substrate for many encrusting organisms such as protozoans, sponges, coelenterates, bryozoans, barnacles and ascidians. Other animals such as many of the annelids, decapods, amphipods, isopods, insects, pycnogonids, nemerteans, flatworms, echinoderms, fishes, gastropods and sipunculids live between the encrusting organisms or in the crevices between the shells. Some organisms actively burrow into the shell. The substrate between or under the oyster provides a conducive habitat for still more animals. Table 13 is a list of organisms found by Wells (1961) during his study. Many of the organisms are common to the Chesapeake

FAUNAL COMPOSITION

Protozoa:

Poreoponides cf. *lateralis*

Porifera:

Cliona celata
Cliona lobata
Cliona spirilla
Cliona trutti
Cliona vastifica
Dictyociona adioristica
Haliclona permollis
Halisarca
Hymeniacides heliophila
Lissodendoryx isodictyalis
Microciona prolifera
Scypha barbadensis

Coelenterata:

Aiptasia eruptaurantia
Aiptasia pallida
Astrangia astreiformis
Bunodosoma cavernata
Diadumene leucolona
Diadumene luciae
Epizoanthea americanus
Eudendrium carneum
Hydractinia echinata
Leptogorgia setacea
Leptogorgia virgulata
Obelia sp.
Oculina arbuscula
Tubularia crocea

Platyhelminthes:

Bdelloura candida
Euplana gracilis
Gnesioceros floridana
Latocestus whartoni
Oligoclado floridanus
Prosthiostomum lobatum
Stylochus ellipticus

Table 13. List of species collected on oyster beds. Newport River, North Carolina, 1955-1956. (From Wells, 1961)

Nemertea:

Amphiporus ochraceus
Micrura leidyi
Tetrastemma elegans
Tubulanus pellucidus

Mollusca: Amphineura:

Chaetopleura apiculata

Gastropoda: Prosobranchia:

Anachis avara avara
Anachis floridana
Anachis translirata
Bittium varium
Busycon canaliculatum
Busycon carica
Busycon contrarium
Caecum pulchellum
Calliostoma euglyptum
Cantharus tinctus
Cerithiopsis greeni
Cerithiopsis sublata
Cerithium floridanum
Crepidula convexa
Crepidula fornicata
Crepidula plana
Diodora cayenensis
Epitonium apiculatum
Epitonium humphreysi
Eupleura caudata
Fasciolaria hunteria
Hydrobia minuta
Littorina irrorata
Mangelia guarani
Mangelia plicosa
Melanella conoidea
Mitrella lunata
Murex fulvescens
Nassarius obsoletus
Nassarius vibex
Neosimnia uniplicata
Niso interrupta
Pleuroploca gigantea
Rissoina chesneli
Rissoina decussata
Seila adamsi
Thais floridana
Triphora nigrocincta
Urosalpinx cinerea

Opisthobranchia:

Ancula evelinae
Aplysia morio
Berghia coerulescens
Catriona tina
Chromodoris aila
Corambella baratariae
Cratena kaoruae
Dondice occidentalis
Doriopsilla leia
Doriopsilla pharpa
Hermaea dendritica
Miesea evelinae
Odostomia dianthophila
Odostomia dux
Odostomia impressa
Odostomia modesta
Odostomia seminuda
Okenia impexa
Polycera hummi
Tritonia wellsi
Turbonilla interrupta

Pelecypoda:

Abra aequalis
Aequipecten irradians concentricus
Anadara ovalis
Anomia simplex
Arca umbonata
Acropsis adamsi
Atrina rigida
Barbatia candida
Brachidontes exustus
Brachidontes recurvus
Chama macerophylla
Chione cancellata
Chione grus
Congeria leucophaeata
Corbula swiftiana
Crassostrea virginica
Cumingia tellinoides
Diplodonta punctata
Diplodonta semiaspera
Gemma gemma purpurea
Hiatella striata
Lima pellucida
Lithophaga bisulcata
Lyonsia hyalina
Martesia smithi
Mercenaria mercenaria

Table 13 (Con't.)

Modiolus americanus
Modiolus demissus
Mulinia lateralis
Musculus lateralis
Mytilus edulis
Noetia ponderosa
Ostrea equestris
Petricola pholadiformis
Pteria colymbus
Rangia cuneata
Rocellaria hians
Rupellaria typica
Tagelus plebius

Annelida: Oligochaeta:

Enchytraeus albidus

Polychaeta:

Amphitrite ornata
Armandia agilis
Autolytus varians
Axiothella mucosa
Capitella capitata
Cistenides gouldii
Dexiospira spirillum
Diopatra cuprea
Dorvillea sociabilis
Eteone heteropoda
Eumida sanguinea
Eunice rubra
Eupomatus dianthus
Glycera americana
Haplosyllis spongicola
Harmothoe aculeata
Heteromastus filiformis
Hypsicomus torquatus
Lepidametria commensalis
Lepidonotus sublevis
Lepidonotus variabilis
Loimia medusa
Marphysa sanguinea
Naineris laevigata
Neanthes succinea
Nereiphylla fragilis
Nereis occidentalis
Petaloproctus socialis
Pista palmata
Podarke nr. _guanica_
Polydora websteri
Prionospio treadwelli
Pseudopotamilla reniformis

Table 13 (Con't.)

Sabella melanostigma
Sabella microphthalma
Sabellaria vulgaris
Spiophanes bombyx
Streblospio benedicti
Terebella rubra
Tharyx setigera
Thelepus setosus

Sipunculida:

Aspidosiphon parvulus
Physcosoma capitatum

Arthropoda: Amphipoda:

Caprella acutifrons
Caprella linearis
Carinogammarus mucronatus
Corophium cylindricum
Gammarus locusta
Jassa marmorata
Melita appendiculata
Melita dentata

Isopoda:

Cassidisca lunifrons
Chiridotea caeca
Cilicaea candata
Cyathura carinata
Dynamene perforata
Erichsonella filiformis
Idothea baltica
Leptochelia rapax
Leptochelia savignyi
Ligia exotica
Limnoria lignorum
Sphaeroma quadridentata

Decapoda:

Alpheus armillatus
Alpheus heterochaelis
Alpheus packardi
Callinectes ornatus
Callinectes sapidus
Cancer irroratus
Clibanarius vittatus
Eurypanopeus depressus
Heterocrypta granulata
Hexapanopeus angustifrons

Table 13 (Con't.)

Hippolysmata wurdemanni
Hippolyte pleurocantha
Libinia dubia
Libinia emarginata
Menippe mercenaria
Metoporhapis calcarata
Neopanope texana sayi
Neopanope sp.
Neopontonides beaufortensis
Pachygrapsus transversus
Pagurus longicarpus
Pagurus pollicaris
Palaemonetes intermedius
Palaemonetes pugio
Palaemonetes vulgaris
Panopeus herbsti
Pelia mutica
Penaeus aztecus
Petrolisthes galathinus
Pilumnus dasypodus
Pilumnus lacteus
Pilumnus sayi
Pinnixa cylindrica
Pinnotheres ostreum
Plagusia depressa
Porcellana soriata
Portunus sp.
Rithropanopeus harrisi
Sesarma cinerea
Sicyonia laevigata
Synalpheus townsendi
Thor floridanus
Uca pugilator

Cirripedia:

Alcippe lampas
Balanus amphitrite niveus
Balanus eburneus
Balanus improvisus
Balanus tintinnabulum
Chthamalus fragilis

Insecta:

Anurida maritima

Pycnogonida:

Anoplodactylus lentus
Nymphon rubrum
Tanystylum orbiculare

Table 13 (Con't.)

Xiphosurida:

Limulus polyphemus

Bryozoa--Entoprocta:

Pedicellina cernua

Bryozoa--Ectoprocta:

Aeverrillia setigera
Alcyonidium hauffi
Alcyonidium polyoum
Amathia convoluta
Amathia distans
Anguinella palmata
Bowerbankia gracilis
Bugula californica
Bugula neritina
Cryptosula pallasiana
Electra crustulenta
Electra hastingsae
Membranipora tenuis
Microporella ciliata
Nolella stipata
Parasmittina trispinosa
Schizoporella cornuta
Schizoporella unicornis
Victorella pavida

Echinodermata:

Arbacia punctulata
Asterias forbesi
Lytechinus variegatus
Ophiothrix angulata
Thyone briareus

Chordata: Urochordata:

Ascidia interrupta
Didemnum lutarium
Molgula manhattensis
Perophora viridis
Styela plicata

Vertebrata:

Ancylopsetta quadrocellata
Chaetodipterus faber
Chasmodes bosquianus
Fundulus majalis
Gobiesox virgulatus

Table 13 (Con't.)

Gobionellus boleosoma
Gobiosoma bosci
Hippocampus hudsonius
Hypleurochilus geminatus
Hypsoblennius hentz
Opsanus tau
Orthopristis chrysopterus
Paralichthyes dentatus
Synodus foetens

Bay area, but others are not. Wells' study was in the Beaufort area of North Carolina, a geographic location noted as the demarcation line between northern and southern species. An extremely rich fauna is found here because of the overlap between the two regions.

Not every animal within the oyster community will be discussed, but the more important ones will be mentioned as to their affect on the community sturcture as a whole. In addition, references will be made to important papers that *water managers* should be aware of for their context of oyster bar locations within the Bay and for the organisms associated with the bars.

Frey (1946) wrote a report concerning the oyster bars of the Potomac River for the U.S. Fish and Wildlife Service of the Department of the Interior. In this report, he described the bars of the Potomac and reviewed their past history. It is an important document from a historical perspective and for information that managers could apply to their programs.

Frey (1946) reported that oysters can be found from the mouth of the Potomac to Maryland Point, a distance of 61 miles. At the time of his report, however, commercial oystering was conducted from Lower Cedar Point downstream. The river was fairly free of oyster enemies. Frey (1946) reported observations of Polydora websteri, the mud worm; Cliona truitti, the boring sponge; Pinnotheres ostreum, the oyster crab; Bucephalus, the trematode worm, and there was a high probability that the parasite Nematopsis was present, but it was not found.

Although Frey's (1946) study was primarily a survey, he also collected most of the organisms he encountered with the oysters, preserved them and then transferred them to the collections of the National Museum of Natural History. Table 14 lists the organisms Frey found associated with the oysters in the Potomac River.

Table 15 lists the organisms found in the York River by Galtsoff, Chipmon, Engle and Calderwood (1947). As in Frey's (1946) study, not all inhabiting organisms were collected and identified, but only those organisms which were intimately associated with the oyster or which constituted a definite danger to them were reported.

Table 16 is the last list used to illustrate the oyster community structure of the Chesapeake Bay. This list was taken from Merrill and Boss's (1966) work on the lower Patuxent River in Maryland. Merrill, Emery and Rubin (1965)

Sponges

Microciona prolifera
Haliclona permollis
Cliona truitti

Coelenterates

Clytia longicyatha
Thuiaria argentea
Bimeria tunicata
Anemones (unidentified but abundant)
Dactylometra quinquecirrha

Ctenophores (not collected for identification)

Mnemeopsis sp.
Beroe sp.

Flatworms

Stylochus ellipticus
Bucephalus sp.

Nemerteans

Micrura leidyi

Bryozoa

Acanthodesia tenuis
Membranipora crustulenta

Polychaete worms

Neanthes succinea
Polydora websteri
Nereis culveri
Scolelepis viridis
Nereiphylla fragilis

Leech

Homibdella sp.

Table 14. Organisms observed associated with oyster bars in the Potomac River (From Frey, 1946).

Amphipods

- Carinogammarus mucronatus
- Corophium lacustre
- Grubia compta
- Melita nitida
- Gammarus sp.
- Caprella acutifrons

Isopods

- Cassidinidea lunifrons
- Erichsonella attenuata
- Cyathura carinata

Decapods

- Palaemonetes carolinus
- Palaemonetes vulgaris
- Crangon septemspinosus
- Pinnotheres ostreum
- Eurypanopeus depressus
- Rhithropanopeus harrisii
- Callinectes sapidus
- Sesarma cinereum

Molluscs

- Odostomia trifida
- Nassarius vibex
- Littorina irrorata
- Crepidula convexa
- Melampus lineatus
- Epitonium lineatum
- Mya arenaria
- Brachidontes recurvus
- Volsella demissa
- V. papyria
- Mulinia lateralis
- Congeria leucopheata
- Arca campechiensis
- Macoma balthica
- Tellina tenera
- Gemma gemma manhattensis
- Corambella sp.

Tunicates

- Molgula manhattensis

Table 14 (Con't.)

Spermatophytes

- _Potamogeton pertinatus_
- _Potamogeton perfoliatus_
- _Ruppia maritima_
- _Zostera marinus_

Algae

- _Ulva_ sp.
- _Enteromorpha_ sp.
- _Polysiphonia_
- _Ceramium_
- _Dasya_
- _Gracilaria_

Table 14 (Con't.)

Sponges

1. *Cliona celata* - sulfur sponge (boring)
2. *Microciona prolifera* - red-bearded sponge

Coelenterates

3. *Thuiaria*
4. *Dactylometra quinquecirrha*
5. *Cyanea* sp.
6. *Aurelia* sp.
7. Sea anemones were seen on many shells and oysters brought in from all parts of the river.

Ctenophores

8. *Mnemiopsis gardeni*: several other species observed.
9. Unknown *turbellarian* worm

Nemerteans

10. *Cerebratulus lacteus*
11. Bryozoan colonies

Annelids

12. *Nereis limbata* Ehlers - clam worm
13. *Hydroides hexagonus*
14. *Polycirrus eximius*
15. *Polydora ligni* Webster
16. *Polydora calca* Webster
17. *Polydora* sp. - probably *anaculata* Moore

Arthropods

18. *Eurypanopeus dissimilis* - mud crab
19. *Panopeus herbstii* - mud crab
20. *Neopanope texana texana* - mud crab
21. *Rhithropanopeus harrisii* - mud crab
22. *Callinectes sapidus*
23. Hermit crabs
24. *Libinia dubia* and *L. emarginata* - spider crabs
25. Fiddler crabs
26. *Ocypode albicans* - sand crabs
27. Barnacles
28. *Pinnotheres ostreum* - oyster crab

Table 15. Organisms Found in Association with Oysters in the York River. (From Galtsoff, Chipman, Engle and Calderwood, 1947)

Gastropods

29. *Nassa* sp. - mud snail
30. *Littorina*
31. *Urosalpinx* or *Eupleura*
32. *Polynices* sp.
33. *Busycon carica*
34. *B. canaliculatum*
35. *Purpura*
36. *Crepidula*
37. *Modiolus demissus* - horse mussel
38. *Mytilus edulis* - mussel
39. *Ensis directus* - razor clam
40. *Diplothyra* - boring clam
41. *Asterias forbesi* - starfish
42. Tunicate - *Molgula* sp.

Organism	Station numbers and depths in feet in parenthesis					
	1 (130)	2 (65)	3 (10)	4 (130)	5 (65)	6 (10)
Porifera						
Microciona prolifera (Ellis & Solander)	-	-	-	-	abundant	-
Coelenterata						
Aiptasia eruptaurantia (Field)	400	-	-	52	308	-
Aiptasimorpha luciae (Verrill)	-	-	-	-	4	-
Diadumene leucolena (Verrill)	-	-	2	-	-	66
Thuiaria argentea (Linnaeus)	-	-	-	some	-	-
Annelida						
Nereis (Neanthes) succinea (Frey & Leuckart)	-	5	54	32	114	122
Polydora ligni Webster	-	1	1	-	-	-
Phyllodoce (Anaitides) maculata (Linnaeus)	-	-	-	6	11	-
Glycera dibranchiata Ehlers	-	-	-	2	-	-
Polyclad worms	-	-	-	-	3	3
Crustacea						
Balanus improvisus Darwin	many	many	-	-	common	common
Balanus eburneus (Gould)	common	common	-	-	rare	rare
Callinectes sapidus Rathburn	-	-	4	-	-	-
Eurypanopeus depressus (Smith)	8	101	1	23	66	52
Rithropanopeus harrisii (Gould)	36	12	-	12	2	-

Table 16. Benthic fauna, in numbers of individuals per 5-minute tow, taken at stations off Point Patience in the lower Patuxent River, Maryland (Stations 1-3, June 1964; Stations 4-6, December 1964). (From Merrill and Boss, 1966).

Organism	Station numbers and depths in feet in parenthesis					
	1 (130)	2 (65)	3 (10)	4 (130)	5 (65)	6 (10)
Crangon septemspinosus (Say)	2	-	-	7	-	-
Palaemonetes pugio Holthuis	-	6	-	-	-	-
Palaemonetes vulgaris (Say)	-	-	-	1	10	-
Palaemonetes intermedius Holthuis	-	-	-	-	6	-
Mollusca						
Nassarius vibex (Say)	6	-	1	18	-	-
Epitonium rupicola (Kurtz)	16	-	-	2	-	-
Odostomia impressa (Say)	-	-	2	-	-	-
Odostomia bisuturalis (Say)	-	-	-	-	4	-
Haminoea solitaria (Say)	-	-	34	-	-	-
Crassostrea virginica (Gmelin)	258	1677	227	49	1058	162
Branchidontes recurvus (Rafinesque)	1004	1356	47	51	546	62
Mulinia lateralis (Say)	-	-	-	-	-	5
Gemma gemma (Totten)	-	-	12	-	-	-
Mya arenaria (Linnaeus)	3	18	4	-	-	-
Tagelus plebius (Solander)	-	-	41	-	-	-
Macoma balthica (Linnaeus)	5	8	1	-	-	1
Laevicardium mortoni (Conrad)	-	1	-	-	-	-
Tunicata						
Molgula manhattenensis (DeKay)	200	120	5	30,000	648	293
Pisces						
Gobiosoma bosci (Lacepede)	-	6	4	3	2	1
Gobiesox strumosus Cope	-	-	2	1	2	-
Chasmodes bosquianus (Lacepede)	-	-	1	1	6	1
Opsanus tau (Linnaeus)	-	-	3	3	2	-
Syngnathus fuscus Storer	-	-	-	3	2	-

estimated that, in the Chesapeake Bay, six meters is the average depth at which oysters are found. In the vicinity of Point Patience in the lower Patuxent, oysters were found at a depth of 120 to 130 feet. This depth difference prompted Merrill and Boss's (1966) study. They established three stations: at 10, 65 and 130 feet. They sampled each station twice, in June and December, 1964 (Table 16).

Merrill and Boss's work can be utilized to determine some aspects of depth limitation and seasonal cycles of certain organisms, but it will take more sampling to firmly establish any conclusions.

The three tables presented can be utilized by *water managers* in determining the common occurrence of organisms within the oyster community. They also represent three distinct locations in the Bay, therefore increasing their value. An idea of the type of organisms associated with oysters should now be apparent.

Galtsoff (1964) discussed the commensals and competitors that are a part of the oyster community's make-up. To avoid confusion in terminology, the same terminology will be used as that Galtsoff used. His definition of a commensal is an "organism which stores food gathered by the host." Parasites "live at the expense of their host and sometimes inflict serious injury." "Competitors are organisms which live in close proximity to one another and struggle for food and space available in the habitat."

One of the most common animals associated with sponges is the boring sponge; there are seven species of Cliona found along the Atlantic coast. Almost all oyster bottoms are affected to a certain degree by sponges. In a heavy infestation, the oyster shell will become brittle and break under the slightest pressure. Species identification is based on type of cavity formed by the sponge and by the type of spicules present.

Although the boring sponge does not derive nourishment from the oyster body, it may from the shell. Apparently this sponge has cytoplasmic filaments which penetrate calcite by secretion of minute amounts of acid. The excurrent canal of the sponge carries out the fragments that break off the shell. The oyster generally is able to deposit shell material quickly enough to prevent the sponge from actually contacting its body. However, if the sponge does come in contact with the body of the oyster, there is a lysis of the epithelium and underlying connective tissue. Obvious features are dark pustules on the oyster tissue opposite the shell holes, flabby tissue and a mantle easily detached from the shell surface.

Diplothyra smithii, better known as the boring clam, has a distribution from Cape Cod (Provincetown, Massachusetts) to Florida, Louisania and Texas. Galtsoff has collected specimens from dead oyster shells around Tangier Sound in the Chesapeake Bay. As with the boring sponge, the boring clam rarely comes in contact with the oyster's tissues because the oyster keeps depositing layers of conchiolin over the areas that are nearly perforated. The presence of the clam is indicated by a small hole. The main effect of this organism on the oyster is the weakening of shell structure.

Mud worms were mentioned earlier in the discussion of Frey's survey in the Potomac River. The two that affect the oyster are *Polydora websteri* and *P. ligni*. *P. websteri*, found inside the shells or on the inner surface near the valve, builds a U-shaped tube from accumulated mud. The oyster secretes a semi-transparent shell material over the tube, forming a blister. *P. websteri* is not considered to cause visible injuries although Loosanoff believes that heavily infested oysters are generally in poor condition; therefore, it is not beneficial nor neutral in its effects on the oyster (Loosanoff and Engle, 1943).

P. ligni makes U-shaped or straight tubes by holding together mud particles with a mucous secreted by the antennae and body surface. These mud worms become destructive when they become so numerous that they smother the oyster population with their shells.

The oyster crab, *Pinnotheres ostreum*, is abundant, especially in the Virginian part of the Bay. This crab enters the mantle cavity of the oyster when its carapace is 0.59 to 0.73 mm long. Although male crabs do not permanently attach to the host, the females remain attached, especially in various parts of the water-conducting system. The crabs can cause a form of "lesion" on the oyster gills which impairs their function. Severe lesion cause leakage from the water tubes and a reduction in the efficiency of the food-collecting apparatus and gills. Oysters, for the most part, are able to rapidly regenerate damaged gills; however, infestation interferes with gill function and causes the oyster to be in poor physical condition.

Spirochaetes are bacteria, often found in the crystalline style sac of the oyster and in the gonads after spawning. Dimitioff (1926) identified ten spirochaetes found in oysters. They are *Saprospira grandis*, *S. lepta*, *S. puncta*, *Cristispira balbiani*, *C. anodontae*, *C. spiculifera*, *C. modiola*, *C. mina*, *C. tena* and *Spirillum ostrae*. Of the oysters in the Baltimore area, 91% were affected. Apparently these organisms are harmless to man and oysters.

Occasionally in shallow bays and estuaries oysters are infested by a perforating alga. In most cases, this alga is *Gomontia polyrrhiza*, which is distributed from North Carolina to Connecticut and on up to New Brunswick, Canada. It does not appear to be harmful to the oyster except possibly for causing the greenish color found on the inner surface of the valve. Continuous growth of the algae in empty shells is thought to accelerate the shell's disintegration and return calcium salts to the sea.

So far the organisms that have been discussed live within the oyster shell. There are also numerous organisms that utilize the shell as a convenient place for attachment. The effect these organisms have on the oyster is that they compete for food and space and have been known to accumulate to such an extent that they actually smother the oysters.

One of these fouling organisms is the slipper shell, *Crepidula fornicata*, which attaches to hard objects near or below low water. *Crepidula* and the gastropod *Anomia* have both been observed in the Chesapeake Bay (Beaven, 1947). However, they are not serious fouling organisms as far as the Chesapeake Bay is concerned (Beaven, 1947). Generally they are limited to salinities above 15 ppt.

Molgula manhattensis, the sea squirt, has been observed so populous in the Chester River, Maryland, that they hide the oysters. Beaven (1947) reported that, although they interfere with harvesting, they do not interfere with setting. If heavy aggregations die en masse in the late winter or early spring, the decaying animal matter may form a smothering deposit, killing the oysters underneath.

Barnacles are more abundant at salinities under 20 ppt, but can be found throughout the Bay (Beaven, 1947). The setting of the barnacle *Balanus improvisus* was reported in Broad Creek, in Talbot County, Maryland by Shaw (1967). In higher salinities, the barnacles are either killed by drills or have to compete with sponges and other organisms. Beaven (1947) reported two periods of intense setting of barnacle larvae. The first set occurs in April or May and the second in November or December. In either case, the setting peaks when the water temperature is about 15°C. The setting of the barnacles can interfere with the setting of the oyster spat. Oyster spat may attach to barnacles if there is not a natural surface available, but the setting efficiency is greatly decreased.

Galtsoff observed that the appearance of bryozoans usually precede the time of oyster setting, making the oyster shell surface unsuitable for the setting of spat.

The bryozoans Acanthodesia tenuis and Membranipora crustulenta occur throughout the oyster-producing waters, but are especially abundant at 10-18 ppt salinity (Beaven, 1947). Setting of the bryozoans occurs when the water temperatures are 20°C or higher. Because the setting occurs primarily in late summer, the oyster sets are not interfered with until then. Beaven (1947) also stated that it was fortunate that the bryozoans do not thrive in the oyster seed areas. In the Solomons area, Beaven (1947) observed a decrease in the late summer setting . spring-planted oyster shells; therefore, he suggested a delay in shell planting until sure of an imminent oyster set. Shaw (1967) suggested the placing of shells or asbestos plates in July to avoid fouling that occurs in the spring by several organisms, including the bryozoans Electra crustulenta and Membranipora tenuis.

In Broad Creek, Maryland, Shaw (1967) reported that the mussel Branchidontes recurvus is a fouling organism of oyster shells. Beaven (1947) stated that mussels are common in the upper Bay and tributaries where the salinities are low. He observed one bar comprised of one-half oysters and one-half mussels. Such a condition decreases oyster production. The bivalve Mytilopsis is commonly found on the oysters and cultch in the lowermost salinities where oysters occur (Beaven, 1947). Galtsoff (1964) observed that with the exception of the mussel Mytilus edulis, most fouling organisms die off in the winter. Mytilus edulis has been known to cover an oyster bed with a thick layer of mud and excreta.

Annelid worms live between oyster clusters and/or in the shells. Galtsoff reported that Hartman (1945) listed seven species of worms found between clusters of living oysters. Korringa (1951) observed 30 species in Dutch water. Beaven (1947) noted that in salinity ranges above 15 ppt serpulids could be found; they can easily be recognized by their calcareous tubes. The sabellids or membranous tube worms have a more general distribution. Beaven stated that generally the worms are not harmful, but occasionally Sabellaria has been observed encrusting shells with deposits an inch or more in thickness. These deposits prevent the attachment of the spat and smother the oysters. The locations where such deposition has occurred are where the bottom is comprised of fine sand or silt and the wave action keeps it in suspension over the bed. The worms use the material from the heavily laden water for building their tubes.

Beaven (1947) found that encrusting sponges are abundant among the deeper rocks of Tangier Sound during the fall when the salinities are above 20 ppt. These sponges make harvesting difficult and also smother some spat and small oysters. The boring sponges are common at higher salinities. After an area has been prepared by shell deposition to attract spat, the sponges do not seem to have much effect the first season, but cause decline in productivity in succeeding seasons. Galtsoff (1964) observed that the red sponge Microciona prolifera is often found in highly productive oyster areas.

Folliculid protozoans are often found on clean shells. They are present year round. Beaven (1947) reported that they do not appear to affect oyster setting or survival. Andrews (1915) recorded a mass occurrence in the Chesapeake Bay.

Galtsoff (1964) reported on the different types of algae that have been known to attach themselves to oyster shells. Among those mentioned as affecting oysters are Enteromorpha, Ulva, Griffitsia, Ceramium, Chondria, Champia and Scytosiphon. Gracillaria confervoides has been known to sometimes completely cover an oyster bottom.

Seaweeds also often cover oyster bottoms. One such seaweed is Zostera marina which was previously discussed in detail. One seaweed, known as the "oyster robber" (Codium fragile), was introduced to Cape Cod waters with oysters from Peconi Bay, Long Island, New York. On sunny days, the branches of the seaweed fill-up with gas produced by photosynthesis. The gas-filled branches float up and out with the tide, carrying off the oysters to which they were attached. Another seaweed of particular importance to the Chesapeake Bay is the Eurasian watermilfoil, Myriophyllum spicatum, which became established on the Maryland and Virginia sides of the Potomac River in 1933. Since then its distribution has increased to more of the Bay. This plant became a problem when it died after a period of spectacular growth. The decomposing leaves and stems smothered the oyster by using up available oxygen necessary for the decomposition process.

Beaven (1947) noted an organic film often found on oyster shells. This film consists of diatoms, algae, bacteria, other small organisms and silt. It usually develops over most of the shell surface. It can cause a decrease in the number of fouling organisms and spat that may attach, and in fact, has been observed to accumulate so heavily it can be peeled off in sheets.

So far in considering the oyster community, only the commensals and competitors have been discussed. Now attention must be turned to the predators, those organisms which utilize the oysters as food. Oyster predators include flatworms, mollusks, echinoderms, crustaceans, fishes, birds, and mammals.

Among the carnivorous gastropods that feed on oysters are Urosalpinx cinerea, Eupleura caudata, Busycon carica and B. canaliculatum. Urosalpinx cinerea has a distribution range from Canada to Florida. Its migration rate is limited in that it can average, under its own power, 15 to 24 feet a day in the direction of food. This distance can be increased if it attachs to floating debris or to organisms, such as the hermit and horseshoe crabs. This drill, Urosalpinx, is particularily detrimental to young oysters. Galtsoff stated that between Chincoteague and Cape Charles oyster drills have killed 60 to 70% of the seed oysters and in certain locations have killed the entire crop. Urosalpinx cinerea is limited to some extent by the combined influence of the salinity and temperature factors. At summer temperatures, the minimum survival salinity varies from 12 to 17 ppt. Given a choice between barnacles and oysters, the drill seems to prefer barnacles.

The drill Eupleura caudata is less abundant than Urosalpinx cinerea but is found in the same waters. MacKenzie (1961) reported that E. caudata becomes active in the York River when the temperature goes above 10°C. It starts spawning in May when the water temperature reaches 18° to 20°C and peaks in June or early July as the water temperature reaches 21° to 26° C.

The whelks Busycon carica and B. canaliculatum are common in the shallow Atlantic coast waters. Occasionally they attack oysters. They get inside the oyster by a combination of chipping the oyster shell with the edge of their shell and by the rasping action of the radula.

Odostomia are small parasitizing snails which congregate at the edge of the oyster shell. When the valves are open, the snail extends its proboscis to the edge of the oyster mantle where it feeds on mucous and tissue. It is not considered a particularily important nuisance. Two species that have been reported as associated with C. virginica are Odostomia bisuturalis which ranges from New England to Delaware Bay and O. impressa which ranges from Massachusetts to the Gulf of Mexico.

The starfish Asterias forbesi is a highly destructive predator of the oyster. This predator is usually found in waters of high salinity and is not found in brackish water. Galtsoff reported that salinities of 16-18 ppt represent the limits of distribution of Asterias. This predator can be controlled by mopping, dredging or by dispersing chemicals such as calcium oxide to kill it.

"Oyster leeches" are flatworms that are oyster and barnacle predators. The flatworm that *managers* of the Chesapeake Bay are primarily concerned with is Stylochus ellipticus. The predatory activity of S. ellipticus is retarded at temperatures below 10°C. Salinities as low as 5 ppt cause only a temporary pause in activity (Landers and Rhodes, 1970). Webster and Medford (1961) observed a high predation correlation between the worms and oyster spat. Landers and Rhodes (1970) came to the same conclusion although they reported a worm 20 mm long killed an oyster 61 mm long in the Tred Avon River. The collections made by Webster and Medford (1961) occurred in the Maryland sector of the Bay. The greatest numbers were reported off the oyster beds in the lower Potomac.

Landers and Rhodes (1970) reported that S. ellipticus is a predator of either oysters or barnacles, but not both. Scientists of the Virginia Institute of Marine Science were unable to induce the worm to oyster predation, but they did prey on barnacles and several species of bivalves. At Cape Charles where salinity averages 27 ppt, the worms prey on barnacles, but in the Tred Avon River where salinity averages 9-12 ppt, it preys on oysters. Landers and Rhodes were not able to determine the discrepancy in food sources. This difference needs to be researched in greater detail.

Other predators of oysters that deserve mention are the blue crab (Callinectes sapidus), the common rock crab (Cancer irroratus) and the green crab (Carcinides moenas). Galtsoff (1964) stated that although there was not any evidence that the crabs were attracted to oysters, they have been observed destroying many small oysters by cracking the oyster's shell. Mud prawns or burrowing shrimp and fish also represent predators. Mud prawns belonging to the genera Upogebia and Callianassa evacuate deep burrows under oyster bars. It is known that oysters of the genus Ostrea lurida have been destroyed by material thrown-up by the mud prawns during burrowing. The black drum fish, Pogonias cromis, has been observed feeding on both mollusks and oysters by crushing the shells between their powerful pharyngeal teeth.

Galtsoff did not give specific examples of birds on the Atlantic coast that utilize oysters as a food source, but he did report on birds of the Pacific coast. Among the examples he gave were the bluebills and white-winged scoters.

Galtsoff discussed disease in connection with negative environmental factors. It was stated earlier that those organisms that cause disease would be discussed when the oyster community was described. One of the organisms mentioned as a causative agent of disease was the fungus Dermocystidium marinum. The distribution of this organism has been reported from Delaware Bay to the Gulf of Mexico. Andrews (1965) experimented with this fungus in the Chesapeake Bay. He determined that in the 1950's D. marinum was prevalent in all the areas of the Bay where the salinity was above 15 ppt. It requires a temperature above 25°C to proliferate readily. It causes mortalities in Virginia from July thorugh October. Infections can persist into December, but its effects become subclinical until the following June or July. Some facts about the disease and some suggestions to *water managers* concerned with oysters were:

1. This organism is density dependent; therefore, it requires several years to become epidemic on isolated, disease free or fallowed beds. Short rotation of crops (as in agriculture) with regular harvesting and intensive clean-ups of beds will greatly limit damage by the fungus.

2. Less than 10% mortality occurred in oysters from disease-free low salinity locations in the first summer.

3. Private beds of oysters demonstrated more D. marinum than sparsely populated public beds.

4. Those areas where oysters do not normally reside, such as isolated private grounds which are harvested regularly, do not have losses as great as plantings near natural oyster reefs.

5. If a bed were allowed to become fallow, (until nearly all the oysters were dead) and then replanted, the epizootics would be slow to develop.

It was interesting to note that dying, infected oysters in proximity to healthy oysters hasten the development of the disease. Andrews (1965) observed that since the appearance of the disease MSX, D. marinum has most been eliminated as a cause of oyster mortality. It has a slightly greater tolerance of low salinities that allows it to persist along the fringe of the MSX range. However, if MSX research leads to the development of a means of eradication, D. marinum could become a problem again.

The disease MSX is associated with a Haplosporidium. (Haplosporidia is one of 4 subclasses of Sporozoa, a class of the phylum of Protozoa). This organism invades the connective tissue surrounding the intestine and digestive diverticulum. Andrews (1966) characterized the disease in the Chesapeake Bay by its occurrence in waters above 15 ppt and its continuation of activity in the absence of appreciable oyster populations. Andrews and Wood (1967) reported that the disease kills during all seasons. Infections occur during the five warm months of the year and have variable inoculation periods. Infections have not been obtained in the laboratory. A classification has been developed for the type of infections in various localities in the Bay by Andrews and Wood (1967). The authors attempted to determine the origin of the disease, but for the most part the origin still remains obscure. It is speculated that a large scale importation of oysters from Virginia's seaside into Delaware Bay in the 1950's may have provided the circumstances needed to produce a virulent race of MSX. Because Virginia's seaside does not appear to be a favorable location for the disease, it is postulated that salinities close to oceanic salinities may be an inhibiting factor. Puzzlement about the disease arises because some populations in the infested areas do not appear to be affected. There may possibly be some sort of resistance.

Galtsoff (1964) listed a shell and a foot disease. The shell disease, thought to be caused by a branching fungus which causes green or orange brown warts on the inner surface of the shell, is not very important in C. virginica. The foot disease is thought by Korringa to be the same as the shell disease (Galtsoff, 1964). Whether or not they are one and the same, the foot disease caused by fungus affects the attachment of the adductor muscle. In advanced cases the muscle may become detached from the shell. This organism has been found in C. virginica, particularily in the muddy waters of the southern states. It is not considered a serious problem.

The flagellate Hexamita and the vegetative stage of the gregarine Nematopsis probably should be mentioned. Neither organism is considered to be a major problem to the oyster.

The trematode Bucephalus haimeanus has been found in C. virginica. Cheng and Burton (1965) conducted a study on the relationship between this trematode and C. virginica. However, they did not identify Bucephalus to species. Areas reported by Cheng and Burton as sites of infection in the Chesapeake Bay were Lambstone Bar, upper Tangiers Sound, and Hooper Strait Bar in Maryland. In the Virginia part of the Bay, Egg Island Bar near the York River was reported to be infected by the trematode. Trematode sporocysts were found in the area occupied by the gonad, but there were few or none in the digestive gland. Oysters collected in Niniget Pond, Washington County, Rhode Island, demonstrated infections primarily in the spaces between the digestive diverticula. As sporocysts increase in size they may infiltrate the connective tissue enveloping the digestive tract and then later spread to gonads and other tissue. Cheng and Burton (1965) made no statements regarding mortalities of C. virginica caused by Bucephalus, but the extensive tissue damage the trematode causes cannot help but impair the oyster's health.

A group of organisms often not considered when one considers a community is the bacteria. Lovelace, Tubiash and Colwell (1968) studied Marumsco Bar where oyster mortalities occur annually and Eastern Bay, a productive, commercial oyster area. Qualitative differences were observed between the two areas. In Marumsco Bar, there was greater abundance of Vibrio and Pseudomonas than of Cytophage/Flavobacterium. The bacteria Achromobocter, Corynebacterium, Micrococcus, Bacillus and enterics were approximately equal in both areas. Vibrio and Pseudomonas appear to be more dominant in late spring and early autumn, and as far as the Marumsco Bar samples were concerned, they were dominant especially in the water and in the animals. Vaughn and Jones (1964) in their bacteriological survey of an oyster bed in Tangier Sound, showed the bottom samples consistently contained higher coliforms than the overlying water.

The final predator to be discussed is the one that represents the top of the food chain, namely man. Although man is not part of the oyster community, the oyster is part of his because he can control the energy flow of the oyster to a large extent. Oysters represent both a commodity and a food source to the human species. Our actions probably affect this population more than those of any other organism. Bars have been destroyed and/or condemned because of mankind's pollution, e.g. bars in the upper Bay near Baltimore, on the other hand, bars have been "built up" by those interested in farming oysters. Galtsoff (1964) made a statement that I feel should be emphasized: "A balance between the needs associated with industrial progress and population pressure on one side and effective conservation of natural aquatic resources on the other can and must be found."

Pollution

The oyster is a sedentary animal, meaning that it stays in one location. It does not have a means of locomotion to assist it in escaping predators or contaminants dissolved in the water. Because of this lack of mobility, there is a great concern both by commercial watermen and the Public Health Services about the quality of the water flowing over the bar. Galtsoff (1964) recognized two types of pollution common to oyster beds: domestic sewage and industrial wastes. Pesticides represent a third type of contaminant, presently of increasing interest.

Untreated domestic sewerage affects oysters in one or all of three ways: 1) the sludge can be of such quantity that it covers the oysters; 2) the sewage utilizes dissolved oxygen as it decomposes, thereby causing the oyster physiological stress, and 3) the sewage greatly increases the bacterial content of the water. This increase does not necessarily affect the development of an oyster bar, but it does affect the utilization of the bar by commercial fisheries. The numbers of Escherichia coli (an intestinal bacteria of humans that passes out with the feces) found in water flowing over a bar is an index of pollution utilized by State and Federal Health officials. The bacterial counts indicate whether or not the bar should be closed.

Domestic sewage, per se, does not necessarily have to be deleterious. Tenore and Dunston (1973) ran growth comparisons on the American oyster, C. virginica, the blue mussel, Mytilus edulis, and the bay scallop, Aequipecten irradians. Some of the animals were fed algae in a 20% dilution of "f medium" (Guillard and Ryther, 1962), and the others in a 10% dilution of secondary treated sewage effluent. Both the organisms grown on the nutrient medium and on the sewage effluent showed statistical growth and no apparent harmful effects. Both media were dominated by diatoms especially Stephanopryxis costata. Tenore and Dunston (1973) were quick to point out that more research is necessary before the use of sewage effluent as an inexpensive source of nutrients for aquaculture is wholeheartedly recommended. The reasons they gave are: 1) the experiment was too short (3 months) to determine what the long-term effect of any pollutant, e.g., a harmful trace metal or organic compound, might be on the organisms and 2) juveniles were not used in the experiment, although many juveniles are more sensitive to pollutants than adults. This sewage effluent utilized in the experiment was from an efficient secondary treatment plant, and trace metal concentrations were low. Tenore and Dunston (1973) suggested the use of chemical analyses and bioassay tests to determine the suitability of a particular effluent before it is used in aquaculture.

Another waste source is industrial waste. Galtsoff, Chipman, Engle and Calderwood (1947) researched the effects of pulp mill waste on oysters in the York River, Virginia. These investigators were able to demonstrate that the morphological and physiological characteristics of the oysters of the upper York River are closely correlated to the effluent of the pulp mill. These oysters, in a fairly emaciated condition, do not accumulate glycogen and have an abnormal shell condition as a result of a disturbance of calcium metabolism. They were able to recover when removed to cleaner waters. The poor productivity of the area could not be blamed on the oysters' condition because the available food sources of the area were equivalent to or surpassed the availability of similar areas. Galtsoff et al. (1947) conducted laboratory experiments with the pulp mill effluent. He observed that it had a general depressive effect on the physiology of the oyster. It reduced the time the shell was open, thereby decreasing feeding time; affected the efficiency of the ciliated epithelium of the gills; and reduced the rate of pumping by the gills. The actual toxic substances in the pulp mill liquor could not be determined at the time of the experiment because there was not a chemical test available for the detection and determination of these substances.

The type of study conducted by Galtsoff et al. (1947) needs to be conducted on several "problem" areas of the Bay. It was detailed and included the experiences and observations of several scientists working in collaboration to solve a specific problem.

On 30 June 1965, there was an industry-wide conversion by detergent manufacturers to a biodegradable linear alkylate sulfonate type of detergent known under the acronym LAS. Calabrese and Davis (1967) conducted experiments on the effect of this soft detergent on oyster eggs and larvae. Their observations revealed that oyster eggs have a low tolerance of active LAS. Only 51 to 64% of the eggs developed in concentrations of 0.05 and 0.10 mg/l and even then, many of the eggs were of abnormal size and/or shape. At concentrations of 0.25 mg/l none of the eggs developed. Calabrese and Davis compared their study to Hidu's (1965) results which revealed that the old detergent base of alkyl benzene sulfonate (ABS), in concentration as high as 0.50 mg/l affected only 53% of the oyster eggs, allowing the rest to develop normally. From the evidence it appeared that active LAS is more toxic than active ABS.

Larvae have a higher tolerance of LAS, but this tolerance decreases significantly between concentrations of 0.50 mg/l and 1.00 mg/l. Between concentrations of 0.25 mg/l and 0.50 mg/l of active LAS, development of the larvae was interrupted. At 1.00 mg/l, all the larvae died. Concentrations of treated LAS that reached 200 mg/l apparently did not hinder normal growth of the oyster. It is therefore assumed by Calabrese and Davis that LAS loses its toxicity when passed through a sewage treatment plant and that if there is any residual toxicity, it is masked by the toxicity of the effluent itself.

A source of contamination that is rapidly becoming increasingly important is pesticide pollution. Scientists are still not able to fully define the problem or to evaluate the long-range effect on man and the coastal environment (Butler, 1964). They do know that they have caused fish kills and other wildlife mortalities. However, this grim picture does not present the benefits of pesticides. The destructive and beneficial aspects of pesticides can be illustrated in the following examples. Cottam and Higgins (1946) reported that DDT is harmful to fish, amphibians, crustaceans, birds and insects. Loosanoff (1947) reported that if a cultch of oysters is sprayed with a DDT suspension, the cultch's value is enhanced for catching spat because fouling organisms are inhibited by DDT. Several experiments with pesticides and herbicides have been conducted on the Chesapeake Bay; both the beneficial and detrimental observations will be presented.

Castagna, Chanley, Wass and Whitcomb (1966) reported the effects of Polystream and Sevin upon an oyster bed near Hog Island Bay, Wachapreague, Virginia. The purpose was to see if Polystream and Sevin could be used as a drill control. Results demonstrated only limited mortality, but there were adverse effects noted on several macroinvertebrates. There was a heavy mortality of polychaetes, amphipods, mantis shrimp (Squilla empusa), sand shrimp (Crangon septemspinosa) mud shrimp (Upogebia affinis) and short razor clams (Tagelus divisus) within three days of treatment. Many blue crabs and mud crabs showed abnormal coordination of muscles, and a few died. Of the drills, no moralities were noted, although about 50% did not firmly attach to the substrate. Another 2% had swollen foot tissue and 10-15% were unable to retract their foot quickly when stimulated.

The effects of Polystream and another pesticide called Drillex were studied by Shaw and Griffith (1967). Their observations were similar to those of Haven et al. In the Tred Avon River, it was observed that at the 5% significance level, more spat settled on the Polystream-treated shells than on the controls. Treatment with Drillex did not result in significant differences. However, in both the Tred Avon River and Broad Creek, the barnacle *Balanus improvisus* set two and one-half to three times more heavily on chemically treated shells than on untreated shells. The conclusions drawn from their report are: 1) neither pesticide repelled the principal fouling organisms of Chincoteague or Chesapeake Bay, 2) shell growth of oysters was neither improved nor hindered by the pesticides and 3) the treatments did not protect spat from drill predation.

A set of experiments by Shaw and Griffith (1967) involved dipping shells in Polystream and then adding sand mixed with Drillex. The sediment containing treated sand resulted in death of the shrimps *Crangon* and *Palaemonetes*, the mud crabs and polychaetes. Boxes (empty oyster shells) were observed immediately after application of the treated sand, but fatalities ceased after two weeks. After all the negative statements made above, it must be noted that on rocks in Chincoteague Bay treated with Drillex - treated sand and Polystream shells, over seven times more spat settled than on plots with only Polystream-treated shells. Because of significant differences between chemically treated and untreated plots, further investigations need to be conducted.

Earlier, effects of DDT were glossed over. Brodtmann (1970) attempted to isolate the entry site and uptake mechanism of DDT. His data showed that uptake is apparently caused by diffusion and that the primary entry site is the gills. The gut may also be an entry site, but it is of secondary importance. As with many of the heavy metals, the oyster is able to accumulate DDT, but Brodtmann found that there is a rapid rate of elimination of pesticides when placed in uncontaminated water. Butler (1964) reported essentially the same results as far as accumulation and elimination is concerned. Butler (1964) observed that under experimental conditions, if DDT concentration increased from 1.0 ppb to 1.0 ppm, oyster growth decreased 20 to 90%. Butler (1964) also reported that DDT is stored in the eggs of oysters. He was unable to continue experiments at that time on the development of contaminated eggs and sperm, but he did report that Davis (1961) observed 100% mortality in the oyster larval culture within six days.

Rawls (1965) conducted experiments on the toxicity of some estuarine animals to herbicides. The herbicides were to be utilized to control the Eurasian milfoil *Myriophyllum spicatum* L. The usual practice is to apply herbicides during its most vulnerable period, just before flowering. This period is from mid May to mid June, after the water warms to about 18 C. Rawls (1965) recommendation was that 2,4 - DBE (2, 4 D butoxyethanol ester) or IOE (Iso octyl ester) be utilized at rates of 20 to 30 lb acid equivalent/acre in areas subject to tidal flushing. The reason for advocating use in an area of total flushing is that in one test, Rawls noted that the dead milfoil sank to the bottom and smothered the oysters while it decomposed. If a tidal current had carried it off, however, this would not have happened. Rawls (1965) pointed out that he does not advocate control of aquatic vegetation by chemical application. He feels that a bio-control developed through research would be more advantageous. Rawls (1965) paper should be read closely by all *water manager*, not only to understand the results of his own experiments, but to glean the results he summarizes for other experiments on studies of juvenile and/or eggs and the effects of herbicides on them.

Lowe, Wilson, Rick and Wilson (1971) conducted experiments on the insecticides DDT, toxaphene and parathion. Two experiments were conducted. In the first experiment, the oysters were exposed to all three pesticides simultaneously. Each pesticide was in a concentration of about 1.0 ppb, making a total pesticide quantity of 3.0 ppb. The results revealed that there was a statistical difference in body weight between the experimental oysters and the controls. The controls outweighed the experimental by an average of 2.8 g. The organophosphate parathion did not accumulate in the tissue, but DDT and toxaphene did. Histopathological studies revealed that there was a pathological response in the kidney visceral ganglion, tissues beneath the gut, possibly the gills and frequently the digestive tubes. After 36 weeks, the experimental oysters were infected by a mycebial fungus which caused lysis of the mantle, gut, gonads, gills, visceral ganglion and kidney tubules. Intense inflammation and leucocytic infiltration also was observed. The control oysters remained normal.

The second experiment conducted by Lowe, Wilson, Rick, and Wilson (1971) consisted of raising the oysters in separate containers, each containing 1.0 ppb of either DDT or parathion or toxaphene. After twelve weeks, the mean weight of the control oysters was consistently higher, but there were no statistical differences. Again DDT and toxaphene were accumulated in the body tissues. Histopathological studies after 12 weeks did not show significant observable effects, but after 36 weeks, there was a suggestion of harm by parathion and toxaphene. Long-term experiments need to be run to obtain more conclusive evidence. The authors were not sure whether the difference in effects was a result of total pesticidal exposure or a synergistic effect of the three or both.

It is well known that oysters and many other marine invertebrates are capable of accumulating various heavy metals, such as zinc, copper, iron, manganese, lead and arsenic, even when the concentrations in the water are low. This accumulation can become a health problem. Galtsoff (1964) reported that Hunter and Harrison (1928) demonstrated that oysters from coastal areas of Connecticut, New York, and New Jersey contained traces of lead and arsenic. In the Chesapeake Bay, Roosenberg (1969) observed an apparent relationship between copper uptake in oysters and power plant operation. The copper probably came from the condensor tube in the plant, but Roosenberg (1969) stated that the rate of accumulation is probably affected by multiple factors such as temperature, time of exposure and physiological activity. It must be pointed out that oysters had been observed to take copper before the plant began to operate, but the addition of copper plus the changes associated with the plant and the environment caused an increase in accumulation. Additional work will have to be conducted to determine the mechanisms that stimulated copper accumulation. Copper affects the oyster economic value because of the greening effect and the bitter taste. In extreme cases, the toxic effect will leave the oysters totally unmarketable.

So far, man-made types of pollutants have been discussed. Nature can cause considerable damage herself. The tropical storm AGNES was responsible for damage still felt by the oystermen in the summer and fall of 1974. The fresh water associated with the storm disrupted the set for the year 1972 even though the more mature oysters survived. Since it takes two to three years for a young oyster to reach the three-inch limit necessary for marketing, it is understandable why oyster production is down. On the positive side, officials of Maryland and Virginia have reported a healthy set which can be taken as a good sign for future harvests (Richards, 1974).

Miscellaneous Communities

The benthic organisms Mya, Macoma and Gemma occupy the mesohaline region. They are dominant organisms controlling energy flow to some extent and represent benthic organisms of different substrates in the Bay. Mya arenaria is of economic importance. Around 1951, Maryland began to supply the market with softshell clams when New England production declined primarily because of green crab predation

(Pfitzenmeyer, 1962). Also, Ward, Rosen, and Tatro (1966) showed that *Mya* might be used as a source of glycogen. Oysters presently are used for this purpose, but due to declining numbers and rising costs, *Mya* could be utilized as a replacement.

Mya, *Macoma* and *Gemma* live in sand or mud. To a casual observer a sand or mud flat appears barren, but when covered by overlying water the bivalves extend their siphons; horseshoe crabs, rays and flounders dig in substrate for food; and large polychaete worms such as *Arenicola* excrete castings forming fecal mounds. A flat also contains a tremendous number of smaller organisms. "Each gram of substrate may contain 500,000 bacteria, thousands of diatoms and other algae, nematodes, copepods, ostracods, amphipods, etc." (Pearse, Humm, and Wharton, 1942). Intertidal flats are not composed of a uniform distribution of organisms, but rather exhibit discontinuities. "The reasons for the irregularities are not apparent, but usually are associated with such factors as type and stability of substrate, strength of current, wave action and salinity" (Gray, 1974).

So far salinity zones in relationship to the organism involved have been discussed. Every zone reflects the plankton community, made up of both zooplankton and phytoplankton. Plankton forms the basic step in the estuarine food web (review Figure 14). Phytoplankton fixes energy of the sun for utilization as an energy source in the upper levels of an estuary. Zooplankton are the primary and secondary consumers on which still larger organisms can feed. A great deal of information on Chesapeake Bay plankton communities is lacking, but a few generalities are known. Smayda (1973) reported the results of Cowles' (1930) investigations:

1. "A winter-spring diatom bloom and a fall maximum are interspersed by a summer minimum."

2. "Dinoflagellates predominant in the summer, and diatoms at other seasons."

3. "Phytoplankton pulses tend to be associated with lower surface salinities" (Note: it is impossible to state to what extent this reflects higher nutrient levels through runoff, or is due to reduced mixing of the water column caused by the halocline or neither)."

4. "There is inconclusive evidence whether diatom growth is stimulated in the vicinity of river mouths."

Cowles (1930) found that Skeletonema costatum, Cerataulina pelagica, Rhizosolenia fragilissima and R. stolterfothii are the dominant winter diatoms in Chesapeake Bay. Ceratium furca and Prorocentrum micans are the dominant dinoflagellates. Whaley and Taylor (1968) agreed with Cowles findings in almost every respect except they found Asterionella japonica instead of Rhizosolenia stolterfothii in their collections and were unable to demonstrate phytoplankton stimulation through river discharge.

Generalities about zooplankton communities in Chesapeake Bay are scarce. It generally appears that copepods are the dominant organisms in the water column. Two species, in particular, are important. They are Acartia clausii, dominant in the winter, and A. tonsa, dominant in the spring (Smayda, 1973). The substitution that occurs between the two appears to be caused by salinity and temperature changes. Plankton in general are difficult to study because little is known about their life cycles, and because they are subject to water currents as a mode of transportation.

Fish are also difficult to study because of their movement throughout an estuary, both by swimming and by being transported by water currents. The Chesapeake Bay is well known as a nursery ground for many sport and commercial fish. Dovel (1970) considered fish as belonging to three major groups depending on the salinity zone in which they spawn: freshwater spawners, estuarine spawners and marine spawners. Table 17 illustrates the fish involved in each zone. Although he applied this division only to the upper Bay, it also applies to many Chesapeake tributaries.

White and yellow perch, several species of herring and the striped bass are freshwater spawners. (Note: Dovel (1970) found these fish in salinity concentrations up to 13 ppt.) Striped bass spawn in the Nanticoke, Choptank, Potomac, Patuxent, Rappahannock, York and James Rivers (Saila and Pratt, 1973). Dovel (1970) concluded that juveniles move into the higher salinities, utilizing the plankton available there as a food source. In freshwater they do not appear to require nutrients in the immediate environment because they posses yolk sacs.

Table 17. List of common and scientific names of larval juvenile fishes collected (Dovel, 1970).

Common Name	Scientific Name
FRESHWATER SPAWNERS	
Blueback herring	*Alosa aestivalis*
Alewife	*Alosa pseudoharengus*
American shad	*Alosa sapidissima*
Silvery minnow	*Hybognathus nuchalis*
White catfish	*Ictalurus catus*
Channel catfish	*Ictalurus punctatus*
White perch	*Morone americana*
Striped bass	*Morone saxatilis*
Warmouth	*Chaenobryttus gulosus*
Pumpkinseed	*Lepomis gibbosus*
Bluegill	*Lepomis macrochirus*
Johnny darter	*Etheostoma nigrum*
Yellow perch	*Perca flavescens*
ESTUARINE SPAWNERS	
Bay anchovy	*Anchoa mitchilli*
Atlantic needlefish	*Strongylura marina*
Halfbeak	*Hyporhamphus unifasciatus*
Northern pipefish	*Syngnathus fuscus*
Naked goby	*Gobiosoma bosci*
Striped blenny	*Chasmodes bosquianus*
Rough silverside	*Membras martinica*
Tidewater silverside	*Menidia beryllina*
Atlantic silverside	*Menidia menidia*
Winter flounder	*Pseudopleuronectes americanus*
Hogchoker	*Trinectes maculatus*
Skilletfish (clingfish)	*Gobiesox strumosus*
Oyster toadfish	*Opsanus tau*

Table 17 (Continued).

Common Name	Scientific Name
MARINE SPAWNERS	
Atlantic menhaden	*Brevoortia tyrannus*
American eel	*Anguilla rostrata*
Ballyhoo	*Hemiramphus brasiliensis*
Threespine stickleback	*Gasterosteus aculeatus*
Silver perch	*Bairdiella chrysura*
Weakfish	*Cynoscion regalis*
Spot	*Leiostomus xanthurus*
Southern kingfish	*Menticirrhus americanus*
Atlantic croaker	*Micropogon undulatus*
Seaboard goby	*Gobiosoma ginsburgi*
Southern harvestfish	*Peprilus alepidotus*

Estuarine spawners reproduce and mature in brackish water areas. Some may stay in the same relative area where they hatched whereas others, such as the bay anchovey and hogchoker, move to the low salinity areas in the summer and fall (Dovel, Mihursky and McEarlean, 1969).

Marine spawners, i.e., menhaden, American eel, spot, weakfish and Atlantic croaker use the Bay as a nursery ground. The larvae or juveniles of these species, expect for menhaden, appear in the Atlantic coast estuaries from late summer to early winter. Juvenile menhaden appear in early spring.

Dovel (1970) listed several generalities of particular application to the upper Bay. They are:

1. In the early spring the channel area displays the greatest biological activity as a result of fish moving downstream.

2. When the water temperature rises in the early summer, the developing fish move to shallow areas and feed among the vegetation.

3. As summer progresses, the estuarine and marine fish move upstream or inshore toward the fresh-saltwater interface.

4. The deeper, warmer channels contain numerous fish in the winger.

Figure 25 illustrates the movement of estuarine-dependent fish larvae and juveniles to a low salinity nursery. Interesting to note is that many juveniles appear to prefer the low salinity nursery during the cold period (December through March). It is felt by Clark (1967) and Dovel, et al. (1969) that this exposure to cold might be necessary for the biological success of the species.

The last community that is under consideration really comprises several communities, all of which fall under the calssification "wetlands". Marcellus (1972) defined wetlands as "all that land lying between and contiguous to mean low water and an elevation above mean low water equal to the factor 1.5 times the tide range...". At the present time many governmental agencies, both state and Federal, are concerned about wetlands protection. They are beginning to appreciate the practical value of maintaining

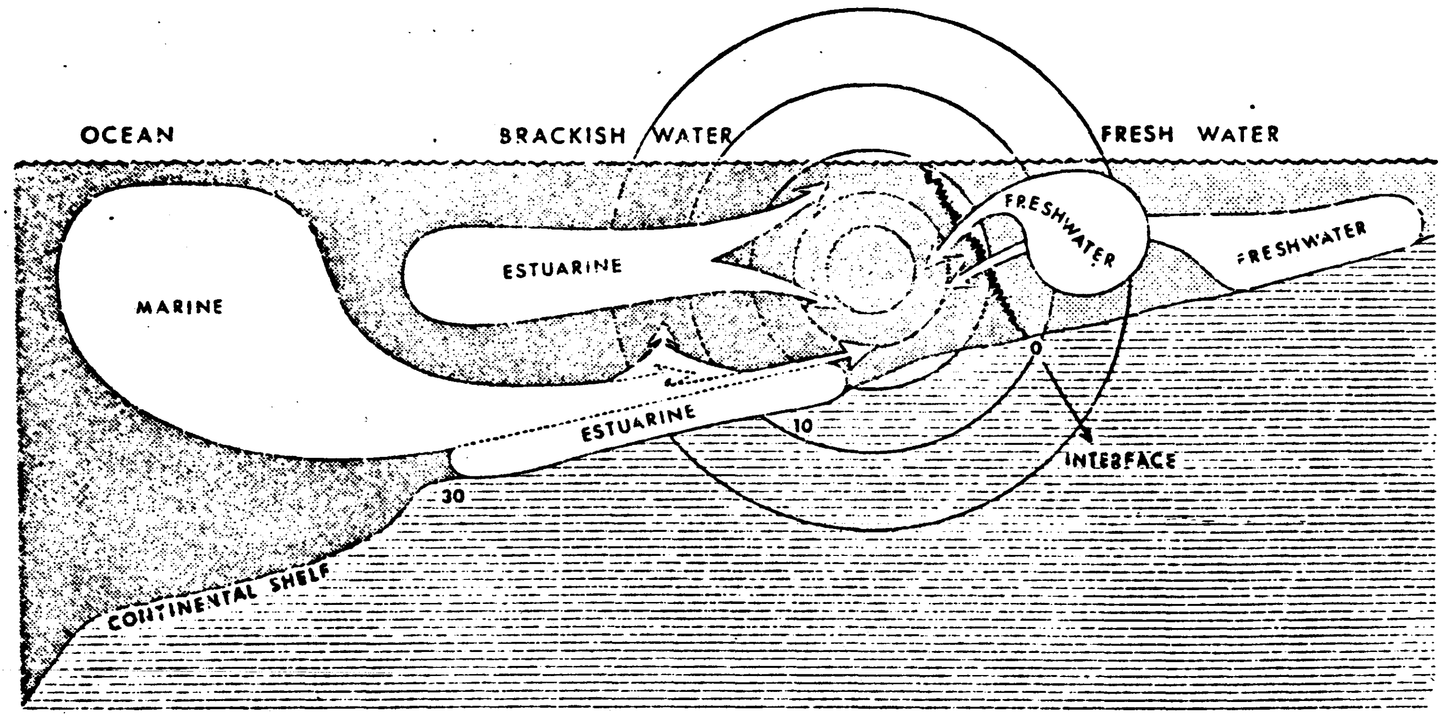


Figure 25. Schematic diagram of the movements of estuarine-dependent fish larvae and juveniles toward a common low salinity nursery area. Numbers represent approximate salinity in parts per thousand (Dovel, 1970).

the status quo.

Wetlands are important for numerous reasons. Some of these, as listed by Wass and Wright (1969) are:

1. "By converting inorganic compounds (nutrients) and sunlight into plant tissue, they are of prime importance as energy transfer mechanisms to consumer organisms in the marsh and estuary."

2. "At the same time that nutrients are being converted into vegetation, sediment and suspended materials are being mechanically and chemically removed from the water and deposited in the marsh."

   a. "Were the nutrient not removed in the marsh, they might stimulate blooms of undesirable algae."

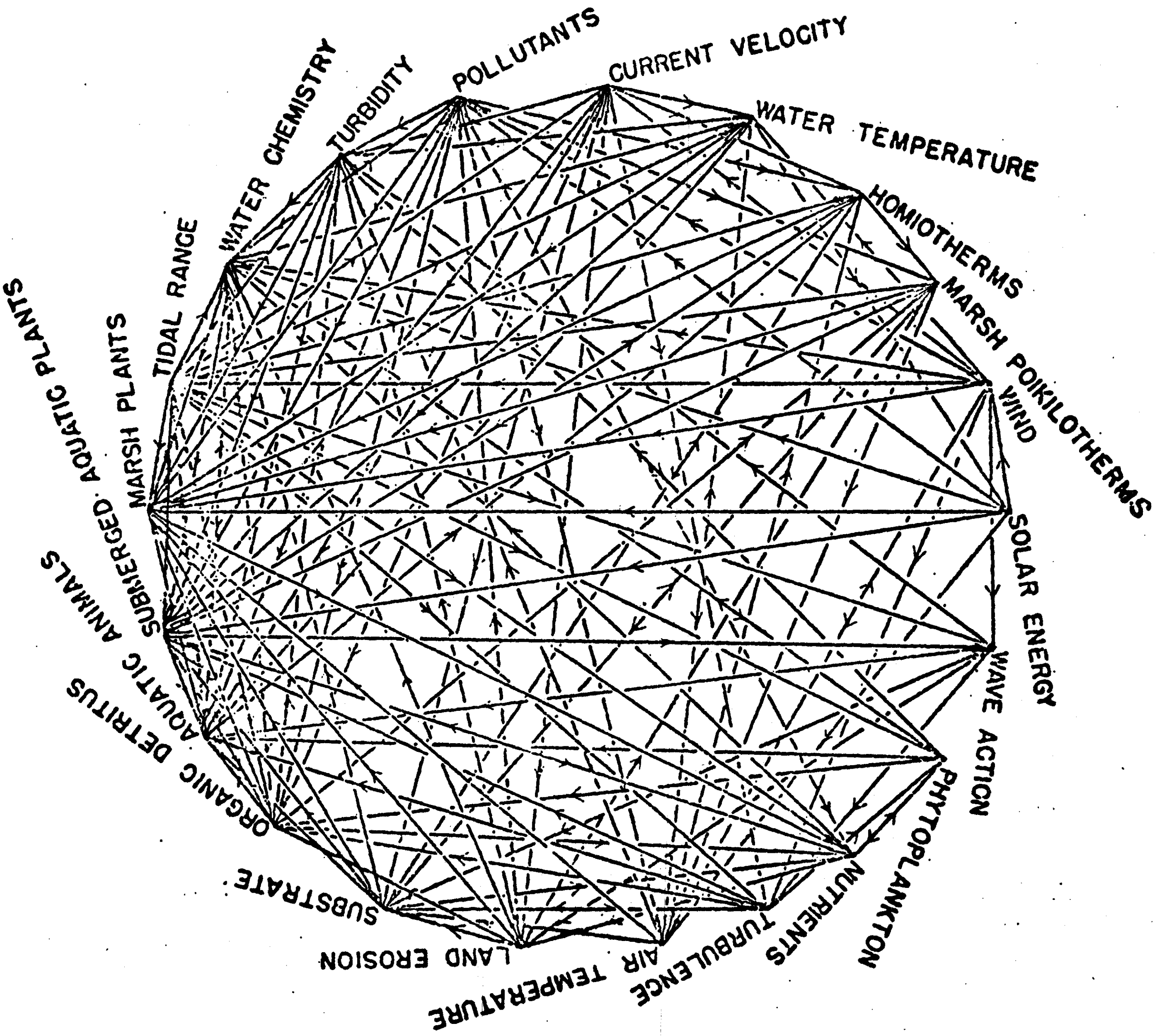
   b. "Were the sediments not removed, some of it would come to rest in navigation channels and shellfish beds."

3. "Marsh vegetation slows flood waters and helps stabilize channels, banks and water levels."

4. Yeast and bacteria transform the complex molecules of cellulose "into other carbon compounds digestable by animals and the changing of nitrogenous wastes of animals into compounds available to plants or lower animals".

5. "... seeds of several brackish and freshwater marsh plants and the leaves and rest of some submerged aquatic plants are prime duck food."

Figures 26 & 27 vividly demonstrate the complexity of reactions that occur between the biotic and abiotic factors of the wetland. Wass and Wright (1969) explained the use of the plant material (detritus) to the rest of the estuary. As plant material sinks, it is utilized by many juvenile species because it is not yet fine enough for suspension feeders. That material not used by the juvenile forms is mechanically worn down until it is small enough to be used as a food source by small amphipods (e.g., Ampelisca abdita) and opposum shrimp. As the detritus moves out into the channels and downstream, bivalves utilize this material.



MARSH-ESTUARY INTERACTIONS

Figure 26. Diagrammatic flow of biotic and physical effects, both unidirectional and reciprocal, in a marsh-bordered estuary (Wass and Wright, 1969).

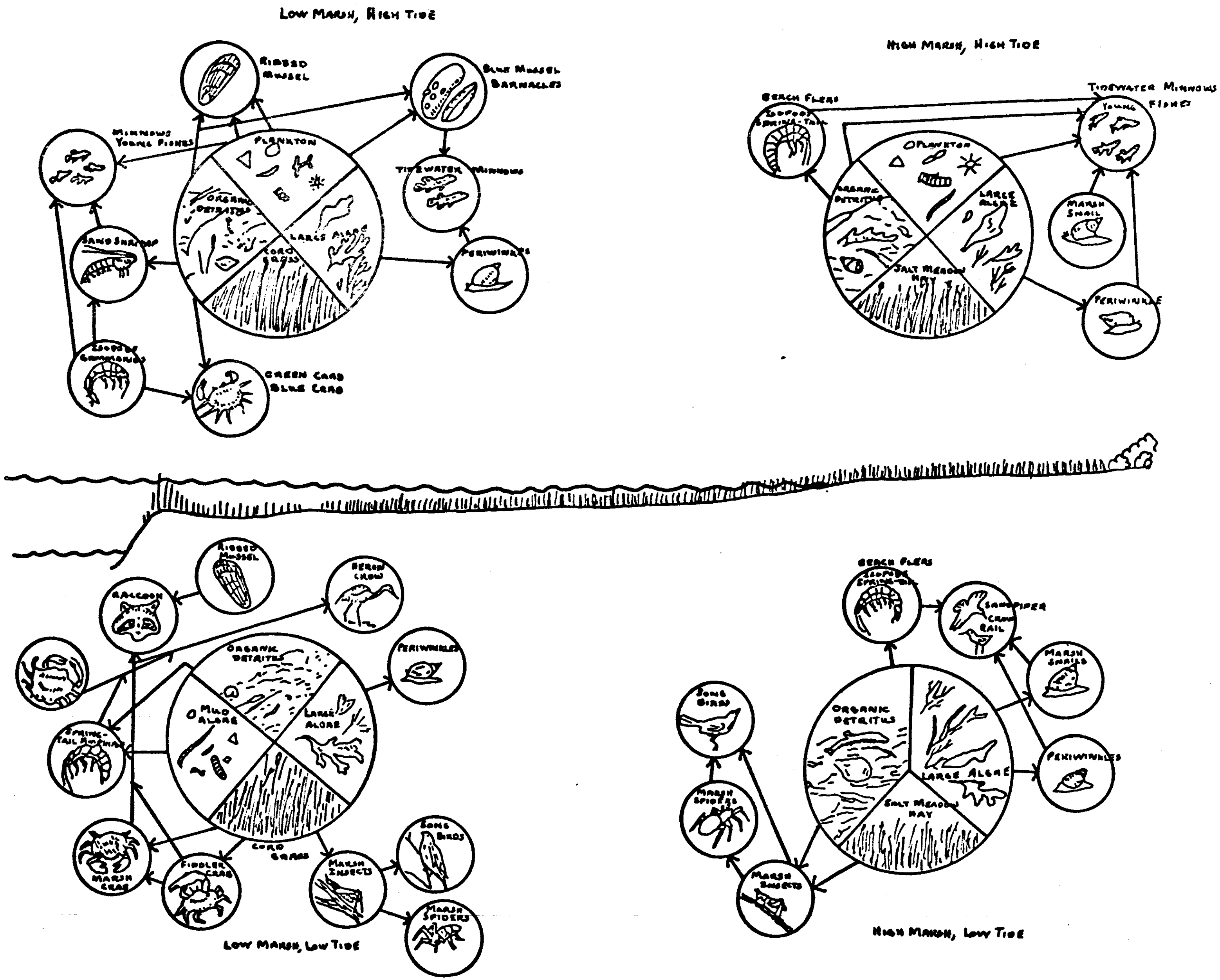


Figure 27. Characteristic animals present in salt marsh at low and high tides and feeding inter-relationships (Shuster, 1966)

Dr. Marvin Wass prepared a detailed classification scheme for the wetlands of Chesapeake Bay in Appendix I. In Appendix II, Dr. Donald Boesch has listed the dominant organisms of the polyhaline, mesohaline, tidal fresh-water, and oligohaline zones.

EPILOGUE

The purpose of this review was to help *estuarine managers* grasp the basic concepts of estuarine ecology and to illustrate the complexity of the ecosystem for which they are responsible. *Managers* and mankind in general have always been preoccupied with production to the exclusion of all else. It was not necessary to be concerned about waste products as long as "progress" benefited. It has only been in the past few years that a concerned population has started complaining about the polluted environment. Up till now gas exchange, water purification, nutrient cycling and other protective functions of self-maintaining ecosystems have been taken for granted. Other population numbers and environmental manipulations were not of the magnitude that affected regional and global balances. It was not obvious, as it is now, that mankind's actions were detrimental to natural processes. As Odum (1969) stated: "the one problem, one solution approach" is no longer adequate and must be replaced by some form of ecosystem analysis that considers man as a part, not apart from the environment".

Estuaries are productive units that must be managed with a new insight (e.g., an ecological insight). A complex system is being manipulated to provide a food source, and an area of recreation for mankind, but it is not separated into distinct boundaries as is an agricultural system. It is a fluctuating system of water with all the complexities of an aquatic environment. The concept of *estuarine managers* is a real challenge.

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APPENDIX I

Wetland Communities

Prepared by

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Wetland Communities

I. Low saltmarsh community

Dominant plants
- Saltmarsh cordgrass (*Spartina alterniflora*)

Dominant animals
- Periwinkle (*Littorina irrorata*)
- Ribbed mussel (*Modiolus demissus*)
- Marsh fiddler (*Uca pugnax*)
- Diamond-back terrapin (*Malaclemys terrapin*)
- Mummichog (*Fundulus heteroclitus*)
- Clapper rail (*Rallus longirostris*)

II. High saltmarsh community

Dominant plants
- Saltmarsh cordgrass (Short-form) (*Spartina alterniflora*)
- Saltmeadow hay (*Spartina patens*)
- Saltgrass (*Distichlis spicata*)
- Black needlerush (*Juncus roemerianus*)

Subdominant plants
- Saltmarsh pluchea (*Pluchea purpurascens*)
- Saltmarsh fimbristylis (*Fimbristylis spadicea*)
- Saltwort (*Salicornia* - 3 sp.)

Dominant animals
- Saltmarsh mosquito (*Aedes sollicitans*)
- Greenhead Fly (*Tabanus nigrovittatus*)
- Saltmarsh snail (*Melampus*)
- Long-horned grasshopper (*Orchelimus*)
- Sharp-tailed sparrow (*Ammospiza caudacuta*)

Subdominant animals
- Willet (*Catoptrophorus semipalmatus*)
- Seaside sparrow (*Ammospiza maritima*)

III. High salinity creek community

Dominant animals
- Mummichog (*Fundulus heteroclitus*)
- Striped killifish (*Fundulus majalis*)
- Blue crab (*Callinectes sapidus*)
- Great blue heron (*Ardea cinerea*)

Subdominant animals
- Atlantic silverside (*Menidia menidia*)
- Sheepshead minnow (*Cyprinodon variegatus*)

White mullet (*Mugil curema*)
Striped mullet (*Mugil cephalus*)
Naked goby (*Gobiosoma bosci*)
Menhaden (*Brevoortia tyrannus*)
Oyster toadfish (*Opsanus tau*)
Laughing Gull (*Larus atricilla*)
Forster's Tern (*Sterna forsteri*)

IV. Oligohaline marsh community

Dominant plants
Big cordgrass (*Spartina cynosuroides*)
Punctate smartweed (*Polygonum punctatum*)
Narrow-leaved cattail (*Typha angustifolia*)
Saltmarsh bulrush (*Scirpus robustus*)
Saltmarsh cordgrass (*Spartina alterniflora*)
Pickerelweed (*Pontederia cordata*)
Marsh hibiscus (*Hibiscus moscheutos*)

Subdominant plants
Swamp dock (*Rumex verticillatus*)
Olney threesquare (*Scirpus olneyi*)
Common threesquare (*Scirpus americanus*)
Great bulrush (*Scirpus validus*)
Saltmarsh mallow (*Kosteletskya virginica*)

Dominant animals
Muskrat (*Ondatra zibethicus*)
Raccoon (*Procyon lotor*)
Red-jointed fiddler (*Uca minax*)
Great blue heron (*Ardea cinerea*)

Subdominant animals
Long-horned grasshopper (*Orchelima* sp.)
Long-billed Marsh Wren (*Telmatodytes palustris*)
Red-winged blackbird (*Agelaius phoeniceus*)

V. Oligohaline creek community

Dominant animals
Mummichog (*Fundulus heteroclitus*)
American eel (*Anguilla rostrata*)
White perch (*Morone americana*)
Bluegill (*Lepomis gibbosus*)
Garfish (*Lepisosteus osseus*)
Snapping turtle (*Chelydra serpentina*)
Great blue heron (*Ardea cinerea*)

Subdominant animals

- Otter (Lutra canadensis)
- Black duck (Anas platyrhynchos rubripes)
- Belted kingfisher (Ceryle alcyon)
- Menhaden (Brevoortia tyrannus)
- White catfish (Ictalurus catus)
- Sheepshead minnow (Cyprinodon variegatus)
- Banded killifish (Fundulus diaphanus)
- Tidewater silverside (Menidia beryllina)
- Pumpkinseed (Lepomis gibbosus)
- Naked goby (Gobiosoma bosci)
- Hogchoker (Trinectes maculatus)

VI. Freshwater tidal marsh community

Dominant plants

- Arrow arum (Peltandra virginica)
- Pickerelweed (Pontederia cordata)
- Wild rice (Zizania aquatica)
- Rice cutgrass (Leersia oryzoides)
- Swamp dock (Rumex verticillatus)
- Punctate smartweed (Polygonum punctatum)
- Narrow-leaved cat-tail (Typha angustifolia)
- Beggars-tick (Helenium autumnale)

Subdominant plants

- Common cat-tail (Typha latifolia)
- Southern wild rice (Zizaniopsis miliacea)
- Walter's millet (Echinochloa walteri)
- Arrow-leaved tearthumb (Polygonum sagittatum)
- Halberd-leaved tearthumb (Polygonum arifolium)

Dominant animals

- Raccoon (Procyon lotor)
- Muskrat (Ondatra zibethica)
- Red-winged blackbird (Agelaius phoeniceus)
- Bullfrog (Rana catesbeiana)
- Great blue heron (Ardea cinerea)
- King rail (Rallus longirostris elegans)

Subdominant animals

- Northern water snake (Natrix s. sipedon)
- Green frog (Rana clamitans melanota)
- Southern leopard frog (Rana sphenocephala)
- Otter (Lutra canadensis)
- Mink (Mustela vison mink)
- Long-billed marsh wren (Telmatodytes palustris)
- Green heron (Butorides virescens)
- Yellowthroat (Geothlypis trichas)

VII. Freshwater tidal creek community

Dominant plants (great variation with locality)
- Eurasian water milfoil (Myriophyllum spicatum)
- Horned pondweed (Zannichellia palustris)
- Yellow pond lily (Nuphar luteum)

Subdominant plants
- Readhead grass (Potamogeton perfoliatus)
- Wildcelery (Valisneria americana)
- Sago pondweed (Potamogeton pectinatus)

Dominant animals
- Snapping turtle (Chelydra serpentina)
- Red-bellied turtle (Chrysemys rubriventris)
- Eastern painted turtle (Chrysemys p. picta)
- American Coot (Fulica americana)
- Belted kingfisher (Ceryle alcyon)
- American eel (Arguilla rostrata)
- Carp (Cyprinus carpio)
- White catfish (Ictalurus catus)
- Bluegill (Lepomis macrochirus)
- Pumpkinseed (Lepomis gibbosus)
- Largemouth bass (Micropterus salmoides)
- Chain pickerel (Esox niger)
- Black crappie (Pomoxis nigromaculatus)

Subdominant animals
- Dragonflies (Odonata)
- Midges (Tendepedidae)
- Mosquitoes (Culicidae)
- Spattail shiner (Notropis hudsonius amarus)
- Pirate perch (Aphredoderus sayanus)
- Golden shiner (Notemigonus c. crysoleucas)
- Creek chubsucker (Erimyzon o. oblongus)
- Banded killifish (Fundulus diaphanus)
- Mosquito fish (Gambusia affinus)
- Yellow perch (Perca flavescens)
- Eastern mudminnow (Umbra pygmaea)
- Northern water snake (Natrix s. sipedon)
- Pied-billed grebe (Podiceps auritus)
- Canada goose (Branta canadensis)
- Wood duck (Aix sporsa)
- Mallard (Anas p. platyrhynchos)
- Black duck (Anas platyrhynchos rubripes)
- Pintail (Anas acuta)
- American widgeon (Anas penelope)
- Green-winged teal (Anas carolinensis)
- Ring-necked duck (Aythya collaris)
- Bufflehead (Bucephala albeola)
- Common merganser (Mergus merganser)
- Ring-billed gull (Larus delawarensis)

APPENDIX II

Benthic Communities

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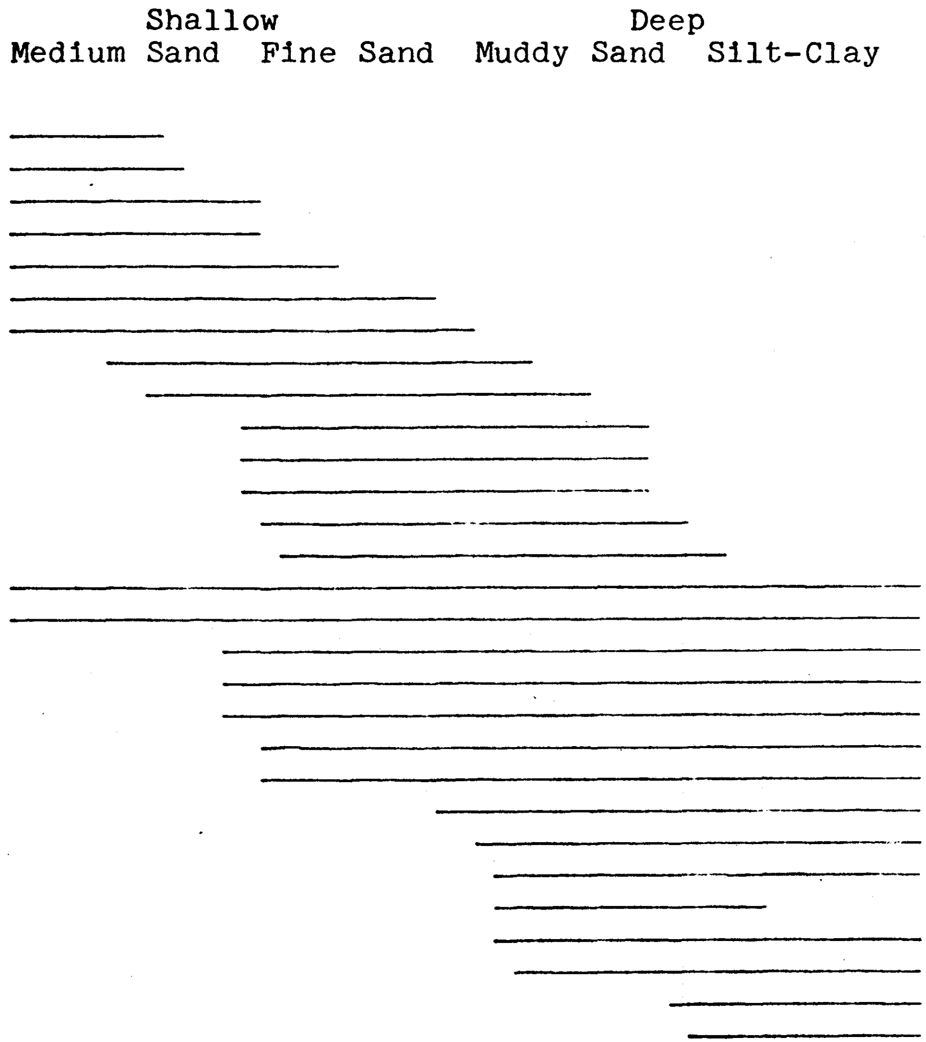
ZONATION OF DOMINANT MACROBENTHOS IN THE POLYHALINE ZONE



Leptosynapta tenuis (E)
Gemma gemma (B)
Ampelisca verrilli (A)
Nephtys picta (P)
Spiophanes bombyx (P)
Tellina agilis (B)
Phoronis psammophila (Ph)
Ampelisca vadorum (A)
Nephtys magellanica (P)
Clymenella torquata (P)
Turbonilla interrupta (G)
Macoma tenta (B)
Peloscolex gabriellae (O)
Ceriantheopsis americana (An)
Acteocina canaliculata (G)
Mulinia lateralis (B)
Heteromastus filiformis (P)
Spiochaetopterus oculatus (P)
Pseudeurythoe sp. (P)
Edwardsia elegans (An)
Paraprionospio pinnata (P)
Phoronis muelleri (Ph)
Sigambra tentaculata (P)
Nephtys incisa (P)
Ampelisca abdita (A)
Micropholis atra (E)
Ogyrides limicola (D)
Cirriformia grandis (P)
Asychis elongata (P)

A - Amphipoda
An - Anthozoa
B - Bivalvia
D - Decapoda (Crustacea)
E - Echinodermata
G - Gastropoda
O - Oligochaeta
P - Polychaeta
Ph - Phoronida

DOMINANT MACROBENTHOS OF THE MESOHALINE ZONE

Species Largely Restricted to Sand Bottoms

Gemma gemma (B)
Mya arenaria (B)
Cyathura polita (I)
Leptocheirus plumulosus (A)

Eurytopic Species More Common or More Abundant on Sand Bottoms

Glycera dibranchiata (P)
Edotea triloba (I)
Heteromastus filiformis (P)
Macoma mitchelli (B)
Pseudeurythoe paucibranchiata (P)
Eteone lactea (P)

Species Largely Restricted to Mud Bottoms

Leucon americana (C)

Eurytopic Species More Common or More Abundant on Mud Bottoms

Nereis succinea (P)
Macoma balthica (B)
Scoloplos fragilis (P)

Very Ubiquitous Species

Glycinde solitaria (P)
Paraprionospio pinnata (P)
Pectinaria gouldii (P)
Peloscolex gabriellae (O)
Peloscolex heterochaetus (O)
Acteocina canaliculata (G)

A - Amphipod
B - Bivalvia
C - Cumacea
G - Gastropoda
I - Isopoda
O - Oligochaeta
P - Polychaeta

DOMINANT MACROBENTHOS IN TIDAL FRESH WATERS

Oligochaeta
- *Dero digitata*
- *Ilyodrilus templetoni*
- *Limnodrilus cervix*
- *Limnodrilus udekemanus*
- *Peloscolex multisetosus*

Bivalvia
- *Corbicula manilensis* (James River)
- *Pisidium casertanum*

Amphipoda
- *Gammarus fasciatus*

Insecta
- *Chaoborus punctipennis*
- *Coeloptanypus* sp.
- *Procladius* sp.
- *Hexagenia mingo*

DOMINANT MACROBENTHOS OF THE OLIGOHALINE ZONE

Rhynchocoela
- Unidentified white nemertean

Polychaeta
- *Scolecolepides viridis*
- *Laeonereis culveri*
- *Heteromastus filiformis*

Oligochaeta
- *Peloscolex heterochaetus*

Bivalvia
- *Congeria leucophaeta*
- *Macoma balthica*
- *Macoma mitchelli* (=*phenax*)
- *Rangia cuneata*

Isopoda
- *Chiridotea almyra*
- *Cyathura polita*
- *Edotea triloba*

Amphipoda
- *Gammarus daiberi*
- *Leptocheirus plumulosus*

Insecta
- *Cryptochironomus fulvus*

SECTION 4

WATER QUALITY STANDARDS AND CRITERIA PERTINENT TO THE CHESAPEAKE BAY

by

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INTRODUCTION

As concern about water pollution has grown, water quality standards have understandably developed as a consequence of the desire to simplify and objectivize pollution control procedures. From the start standards and water use classifications have been controversial, often thought to be too restrictive by those discharging wastes, or oversimplified by those seeking to preserve or enhance water quality. However, current trends are toward both proliferation and formalization of standards affecting water quality.

As one facet of the continuing studies on the existing conditions of the Biota of the Chesapeake Bay we undertook to: 1) identify all federal and state standards, criteria and guidelines concerning or affecting water quality; 2) indicate which of these are most pertinent to water quality in the Chesapeake Bay; 3) evaluate the biological bases of these regulations and objectives with particular emphasis on the biota occurring in the Bay; 4) indicate those areas where water quality may not conform to the standards or guidelines; and 5) assess the impact of compliance with these standards on Chesapeake Bay ecosystems.

In our Interim Report we presented summaries of the water quality criteria existent or being proposed at that time and identified those pertinent to the Chesapeake Bay. In this report we update this compendium. For the indepth evaluation of these criteria and standards (goals 3, 4 and 5 above), we planned to address eight specific water quality problems identified as being of importance in Chesapeake Bay. These together with a brief description of the reasons for selection, are (order of listing of no particular significance):

1) Nutrients (specifically nitrogen and phosphorus compounds): even with the broad application of secondary treatment of sewage, nutrient loading will continue to be a problem as the area population grows; nutrient loading is implicated in algal blooms in tidal-freshwater Potomac and James rivers and may be a factor in red water blooms in higher salinities.

2) Dissolved oxygen: low DO phenomena occur annually in deeper waters of the Bay (e.g., upper Bay and Rappahannock River) and the feeling exists that they are increasing in frequency, duration and distribution; extensive oxygen depletion of waters below 17 ft in the lower Potomac this summer; even though direct organic loading via sewage

and industrial wastes should diminish, the secondary effects of nutrient loading may cause oxygen depletion.

3) Temperature: effects of power plants have generated much controversy; power plant siting has thus become a serious problem.

4) Chlorine: residual chlorine has been responsible for mortalities of plankton entrained in power plant cooling waters and for fish kills near sewage treatment plants (e.g. James River, summer 1973); and may become an increasing problem because of new limitations for coliform bacteria in sewage effluents.

5) Fecal pathogens: high fecal coliform counts have recently caused closure of extenisve shellfish grounds, particularly in Maryland and there is widespread feeling that coliform determinations are indadequate and/or inappropriate.

6) Dredge spoil: local agencies increasingly disfavor overboard disposal of "polluted" spoil; availability of "land" disposal sites is decreasing, although the material from maintenance dredging requiring disposal is probably increasing.

7) Heavy metals (particularly mercury, copper, lead, zinc, chromium and cadmium): concentration occurs in sediments and organisms; association with sewage and industrial effluents and dredge spoil.

8) Oil: increasing transport occurs in the Bay; several refineries are planned; there is a potential onshore impact of outer continental shelf oil development.

Because of the mid-contract reduction of funding, however, we were able to complete analyses for only two -- chlorine and oil. It is unfortunate that the other topics could not be covered similarily, but fortunate that these two represent pollutants whose potential importance in the Chesapeake Bay is just becoming realized and thus has not been reviewed before.

Nonetheless, we have endeavored to point out, where possible, the implications of new water quality criteria and effluent standards for Chesapeake Bay environmental quality problems in addition to those thoroughly reviewed.

Standards, Criteria, Objectives, Classifications and Limitations

Considerable misunderstanding exists concerning the semantics of the various regulations and recommendations related to water quality. The terms "standard" and "criterion" have distinctly different and now rather formal meanings (Fig. 3-1).

Standard applies to a definition, established by governmental authority, of acceptable quality for an intended use. As such it has official regulatory or quasi-legal status. Standards reflect political, economic and social, as well as scientific, factors and may include plans for implementation and questions of water use and management.

Criterion applies to a scientifically based recommendation of the limits of alteration which do not affect the suitability of water quality for an intended use. Criteria are taken into consideration and often form the bases of standards. Neither "standard" nor "criterion" are synonyms for such commonly used terms as "objectives" and "goals". Objectives represent aims or goals toward which to strive to achieve certain desirable conditions. As such they are not rigid regulations, but may in fact include certain standards and schedules which may be enforced. An example is the National Pollution Discharge Elimination System (NPDES) which is discussed below. Despite the rather precise definitions of the terms "standard" and "criterion" to be found in such sources as McKee and Wolf (1), Federal Water Pollution Control Administration (2), Warren (3), and National Academy of Sciences/National Academy of Engineering (4), confusion is often propagated by alternate uses of these terms or by the introduction of new terms.

Standards and criteria are generally developed to apply to particular water use classes. Thus, water use classifications are made with the intention that all waters within a certain class be maintained suitable for a particular designated use. The proposed Environmental Protection Agency water quality criteria apply to five classes of usage: Recreation, Public Water Supply, Freshwater Life and Wildlife, Marine Life and Wildlife, and Agriculture. State water use classifications are generally based on suitability for public water supplies, contact recreation, shellfish harvesting, and propagation of trout.

Other terms are often used concerning regulations and recommendations related to water quality, e.g. "guidelines", "requirements" and "limitations". Of these the meaning of "limitations" deserves elaboration because its usage is becoming widespread in the context of effluent limitations. These are in reality effluent "standards" in that they set

Fig. 3-1. Relationship of water quality criteria and standards (NAS/NAE, 1973).

CRITERIA
Qualities and quantities, based on scientific determinations, which must be identified and may have to be controlled.

for specific uses in

Recreational and Aesthetic Waters
Public Water Supplies
Fresh Waters
Marine Waters
Agricultural Waters
Industrial Water Supplies

Identification pathway

IDENTIFICATION
Analytical methods (chemist, biologist, engineer, recreational specialists & others).

(The operation needed for detecting and measuring characteristics of water.)

FEEDBACK

MONITORING
Deployment of measuring instruments to provide criteria and information for assessment and control

(The chronological and spatial sampling operations needed.)

STANDARDS
Definition of acceptable quality related to unique local situation involving political, economic and social factors and including plans for implementation and questions of water use and management.

specific limits on the permissible characteristics of effluents which must be met in obtaining discharge permits. Thus, although effluent limitations may not relate specifically to the quality of natural water bodies, their effect on water quality may be profound.

Background

Early water quality criteria concerned the suitability of water for human consumption and evolved from simple physical tests of taste, odor or appearance to microbiological criteria, once the germ theory of disease was recognized. But it was not until this century that scientific advances were broadly applied to the measurement of water quality and that criteria were developed for uses other than public water supplies.

Water quality criteria and standards have been extensively promulgated by federal, state and interstate agencies since the 1940's (see 1 and 3 for a full discussion of these developments). Of particular significance was the impact of the Federal Water Pollution Control Acts of 1948 and 1956 as amended by the Water Quality Act of 1965, which required that the states adopt water quality standards applicable to interstate waters and a plan of implementation and enforcement of these standards. As a means of assisting the states in determining standards, the Federal Water Pollution Control Administration published in 1968 the Report of the National Technical Advisory Committee entitled "Water Quality Criteria", often referred to as the "Green Book", containing recommendations on criteria for various water uses.

By far the most sweeping legislation on water pollution control ever passed is the Federal Pollution Control Act of 1972 (P.L. 92-500). It extends ultimate jurisdiction of all navigable waters to the Federal government and sets a national goal of elimination of all discharges by 1985. P.L. 92-500 requires the development by the states of water quality standards which must be approved by the Administrator of the Environmental Protection Agency, and requires that effluent limitations for point source discharged be promulgated. The Act also requires that the Administrator develop and publish water quality criteria accurately reflecting the latest scientific knowledge on health and welfare, aquatic organisms and communities and on the concentration and dispersal of pollutants. EPA has released proposed water quality criteria (5), to replace the "Green Book", which are largely based on recommendations from the National Academies of Science and Engineering (4). When the full implications of the Act are realized, it is apparent that these water quality criteria will have impacts, unprecedented by their predecessors, on the water quality standards developed by the states.

The Scientific Bases of Standards and Criteria

The bases of scientific knowledge upon which water quality criteria for public, agricultural, and industrial water supplies are based are far more adequate than those for aquatic life. Also, in these cases our technology allows some pretreatment of substandard quality. Determination of acceptable water quality for the survival, reproduction and growth of marine and freshwater organisms is far more difficult than determining the water quality needs of other uses.

Water quality criteria for marine and freshwater life are typically based on short-term laboratory bioassays in which there is a determination of the concentration of pollutant which is lethal to half of the population of a test species in a fixed period of time, often 96 hours (96 hour LC_{50}). The criterion is usually set lower (perhaps by one or two orders of magnitude) than this lethal level by multiplication by a more or less arbitrary "application factor". The application factors are set with a consideration of the sublethal effects which are known or predicted for the particular pollutant and the propensity for accumulation and concentration of the pollutant in the environment and in organisms.

Acute toxicity bioassays have been widely criticized on a number of grounds. The most basic criticism is that tests run on one or a few species cannot be expected to reflect the response of the many species which constitute aquatic communities. Often, exceptionally hardy species, such as goldfish, flathead minnows or killifish, are used as the test organisms because they are generally easily obtainable and can be maintained in the laboratory with relative ease. "Fragile" species which are difficult to keep in the laboratory, yet are more sensitive to toxicity, are not generally used for practical reasons. Furthermore adult organisms are most often used, whereas the juveniles and larvae are generally the more sensitive life stages. The existence within species of physiological races with varying susceptibility to toxicants further complicates the extrapolation of bioassay results.

Most bioassays are of short duration and the assessment of chronic effects, perhaps as measured by the ability to complete a life cycle, although highly desirable, remains often prohibitively expensive. Acute and chronic bioassays of lethal toxicity do not, of course, reveal the potential of sublethal effects, such as those influencing migration and other behavior patterns, susceptibility to disease and predators, reproduction, genetics, nutrition, or physiology. Such sublethal effects are of increasing concern and their assessment offers the biggest challenge to water pollution biology.

Despite these serious shortcomings, practical considerations often leave little choice but to develop criteria based on acute lethal bioassays and conservative application factors. Further research on chronic and sublethal effects and on the effects on communities of organisms will undoubtedly enhance our understanding and should be strongly supported, but within the time frame of the implementation of water quality standards as dictated by the Federal Water Pollution Control Act of 1972, it will be acute toxicity data which will provide the bases of water quality criteria.

IDENTIFICATION OF RELEVANT STANDARDS AND CRITERIA

This compilation is limited to criteria and standards for marine and freshwater life, wildlife, recreation and aesthetics. Standards and criteria pertaining to water supplies and agricultural and industrial uses are not included. In addition to water quality standards and criteria, federal legislation and effluent limitations are discussed because they bear importantly on water quality.

Federal Water Pollution Control Act of 1972

In addition to setting the goal of the elimination of the discharge of pollutants by 1985, providing legislative approval of a massive program of water pollution control technology, and establishing a discharge permit system, the Act (especially Title III) includes sections which have far-reaching consequences for water quality standards and criteria.

The Act requires achievement of effluent limitations for point sources, other than publicly owned treatment works, through the "best practicable control technology currently available", (BPCTCA) by July 1, 1977; appropriate pretreatment for discharges into public treatment facilities; and "secondary treatment" of wastes from publicly owned treatment works by the same date. Effluent limitations for point sources requiring application of the "best available technology economically achievable" (BATEA) must be achieved by July 1, 1983 and they must reflect significant progress toward the goal of elimination of discharge of pollutants. Publicly owned treatment works must achieve "best practicable control" by the 1983 date. The Environmental Protection Agency is currently developing effluent limitations reflecting BPCTA and BATEA levels for a number of classes of point sources and for "secondary treatment". These are discussed below under Effluent Limitations.

The Act requires EPA to review all state water quality standards, water use classifications and the criteria on which these are based (for all waters within state), and to promulgate appropriate standards if a state does not adopt them. It also requires EPA to develop and publish criteria for water quality accurately reflecting the latest scientific knowledge on health and welfare, aquatic organisms and communities, and concentration and dispersal of pollutants.

Other stipulations of the Act which bear on water quality relate to enforcement, water quality inventories which must be conducted by the states and EPA, oil and hazardous substances, marine sanitation devices, and thermal discharges.

EPA Water Quality Criteria

As directed by the Federal Water Pollution Control Act of 1972, the EPA released in October, 1973, "Proposed Water Quality Criteria" to be used in the development of standards by the states. These criteria were to reflect the latest scientific knowledge on: (1) all identifiable effects of pollutants on human health, fish and aquatic life, plant life, wildlife, shorelines and recreation; (2) concentration and dispersal of pollutants; and (3) effects of pollutants on biological community diversity, productivity and stability, including factors affecting rates of eutrophication and sedimentation.

These criteria are largely based on those developed at the request of EPA by the Committee on Water Quality Criteria of the Environmental Studies Board of the National Academies of Science and Engineering (4) which were summarized in our Interim Report. The EPA criteria vary little from those proposed by NAS/NAE, and a full comparison of the two has been published by the EPA (6).

Included for reference in this report are summaries of the criteria for marine and freshwater aquatic life (Table 3-1), wildlife (Table 3-2), and recreation (Table 3-3).

Although some of the criteria are specific numerical limits, most of those pertaining to aquatic life are put in terms of acute toxicity to species in the locality under consideration. They are of the typical form of an application factor (usually 0.1 - 0.01) applied to the concentration of the constituent in the water in question which causes death within 96 hours to 50 percent (LC_{50}) of a test group of the most sensitive important species in the locality under consideration. This is often supplemented by a specific more liberal numerical limit which should not be exceeded. It should be noted that for the purposes of the criteria, an "important species" is defined as an organism that is: (1) commercially or recreationally valuable; (2) is rare or endangered; (3) affects the well-being of valuable, rare or endangered species; or (4) is critical to the structure and function of the ecological system.

Table 3-1. Summary of EPA Proposed Water Quality Criteria for freshwater and marine and estuarine aquatic life.

Parameter	Freshwater	Marine & estuarine
1. Acidity, Alkalinity and pH		
a. pH	6-9 no change of 0.5 above seasonal extremes	6.5-8.5
b. Alkalinity	75% of natural	-------
c. Acidity	no addition	-------
2. Dissolved Gases		
a. Ammonia	0.05 LC_{50} never >0.02 mg/l	0.1 LC_{50} never >0.4 mg/l
b. Chlorine	0.003 mg/l 0.005 mg/l for 30 min.	0.1 LC_{50} never >0.01 mg/l
c. Dissolved Oxygen	Based on seasonal temperature; minimum 4 mg/l at 31°C	6.0 mg/l except by natural phenomena
d. Hydrogen Sulfide	0.002 mg/l	0.1 LC_{50} never >0.01 mg/l
e. Gas Pressure	110% atmospheric	--------

Table 3-1 (Continued)

Parameter	Freshwater	Marine & estuarine
3. Inorganics (Ions and Free Elements/Compounds)		
a. Aluminum	----------	0.01 LC_{50}, never >1.5 mg/1
b. Antimony	----------	0.02 LC_{50}, never >0.2 mg/1
c. Arsenic	----------	0.01 LC_{50}, never >0.05 mg/1
d. Barium	----------	0.05 LC_{50}, never >1 mg/1
e. Beryllium	----------	0.01 LC_{50}, never 1.5 mg/1
f. Bismuth	----------	none prescribed
g. Boron	----------	0.1 LC_{50}
h. Bromide (molecular)	----------	0.1 mg/1
(ionic)	----------	100 mg/1
i. Cadmium	0.03 mg/1 in hard water 0.004 mg/1 in soft water one tenth of these where salmonids or crustaceans develop.	0.01 LC_{50} (0.001 96 hr LC_{50} in presence of other metals). never >0.01 mg/1)
j. Chromium	0.05 mg/1	0.01 LC_{50}, never >0.1 mg/1
k. Copper	0.1 LC_{50}	0.01 LC_{50}, never >0.05 mg/1

Table 3-1 (Continued)

Parameter	Freshwater	Marine & estuarine
3. Inorganics (Ions and Free Elements/Compounds (continued)		
l. Fluorides	----------	0.1 LC_{50}, never >1.5 mg/1
m. Iron	----------	0.3 mg/1
n. Lead	0.03 mg/1	0.02 LC_{50} 24 hr average, 0.01 LC_{50}, never 0.05 mg/1
o. Manganese	----------	0.02 LC_{50}, never >0.1 mg/1
p. Mercury	0.2 ug/1	0.01 LC_{50}, never <1.0 ug/1
q. Molybdenum	----------	0.05 LC_{50}
r. Nickel	0.02 LC_{50}	0.02 LC_{50}, never >0.1 mg/1
s. Phosphorus	----------	0.01 LC_{50}, never >0.1 ug/1
t. Selenium	----------	0.01 LC_{50}, never >0.01 mg/1
u. Silver	----------	0.05 LC_{50}, never >0.5 ug/1
v. Thallium	----------	0.05 20 day LC_{50}, never >0.1 mg/1
w. Uranium	----------	0.01 LC_{50}, never >0.5 mg/1
x. Vanadium	----------	0.05 LC_{50}
y. Zinc	0.005 LC_{50}	0.01 LC_{50}, never >0.1 mg/1

Table 3-1 (Continued)

Parameter	Freshwater	Marine & estuarine
4. <u>Organic Compounds</u>		
a. Cyanides	0.05 LC_{50}, never >0.005 mg/l	0.1 LC_{50}, never >0.01 mg/l
b. Linear alkylate sulfonates	0.05 LC_{50}, never >0.2 mg/l	--------------------
c. Oils	1. not visible on surface 2. emulsified concentrations 0.05 96 hr LC_{50} 3. hexane extractable substances in sediments not >1000 mg/kg	1. no visible film 2. no odor or tainting 3. no deposits on shores or bottoms
d. Phthalate esters	never >0.3 ug/l	--------------------
e. Organic Mercury	never >0.2 ug/l (average total never >0.05 ug/l)	--------------------
f. Polychlorinated biphenyls	not >0.002 ug/l not >0.5 ug/g in tissue	--------------------
g. Phenolic compounds	0.05 LC_{59}, never >0.1 mg/l	--------------------
5. <u>Pesticides</u>		
a. General	0.01 LC_{50}	0.01 LC_{50}

Table 3-1 (Continued)

Parameter	Freshwater	Marine & estuarine
5. Pesticides (continued)		
b. Organochlorines	Recommended permissible maximum concentration (ug/l)	
Aldrin	0.01	
DDT	0.002	
TDE	0.006	
Dieldrin	0.005	
Chlordane	0.04	
Endosulfan	0.003	
Endrin	0.002	
Heptachlor	0.01	
Lindane	0.02	
Methoxychlor	0.005	
Toxaphene	0.01	
c. Organophosphates		
Azinphosmethyl	0.001	-------------
Ciodrin	0.1	
Coumaphos	0.001	
Diazinon	0.009	
Dichlorvos	0.001	
Dioxathion	0.09	
Disulfate	0.05	
Dursban	0.001	
Ethion	0.02	
EPN	0.06	
Fenthion	0.006	
Malathion	0.008	
Mevinphos	0.002	
Naled	0.004	

Table 3-1 (Continued)

Parameter	Freshwater	Marine & estuarine
5. Pesticides (continued)		
c. Organophosphates (continued)		
Oxygenmeton methyl	0.7	
Parathion	0.03	
Phosphamidon	0.03	
TEPP	0.3	
Trichlorophon	0.002	
d. Carbamates		-------------
Carbaryl	0.02	
Zectran	0.1	
e. Herbicides, Fungicides and Defoliants		-----------
Aminotriazole	300	
Dalapon	110	
Dicamba	0.2	
Dichlobenil	37	
Dichlone	0.7	
Diquat	0.5	
Diuron	1.6	
2-4, D (BEE)	4	
Fenac (sodium salt)	45	
Silver (BEE)	2.5	
Silver (PGBE)	2	
Simazine	10	
f. Botanicals		------------
Allethrin	0.002	
Pyrethrum	0.01	
Rotenone	10.0	

Table 3-1 (Continued)

Parameter	Freshwater	Marine & estuarine
6. Physical (Except Temperature)		
a. Color	<10% change in compensation point, no more than 10% of biomass of photosynthetic organisms below compensation point	--------------
b. Turbidity	" "	--------------
7. Radioactivity	organisms harvested must not exceed radiation protection guidelines	organisms harvested must not exceed radiation protection guidelines
8. Solids		
a. Total dissolved solids and hardness	no significant changes in biological communities	--------------
b. Suspended and settleable solids	not >80 mg/l	--------------
9. Tainting Substances	bioassays and organoleptic tests	--------------
10. Temperature	complex criteria depending on thermal tolerances and requirements of sensitive species	increase not $>2.2^{o}C$ ($4.0^{o}F$) during Sept.-May or $0.8^{o}C$ ($1.5^{o}F$) during June-August

Table 3-2. Summary of EPA Proposed Water Quality Criteria for freshwater and marine wildlife.

Parameter	Freshwater	Marine[1]
1. Acidity, Alkalinity and pH		
a. pH	same as for aquatic life	------
b. Alkalinity and Acidity	alkalinity 30-130 mg/l departure from natural conditions not >50 mg/l	------
2. Light Penetration		
	<10% change in compensation point, no more than 10 o/oo of biomass below compensation point	------
3. Solids		
a. Salinity	close to natural conditions, no rapid fluctuations	------
b. Settleable solids	should be minimized	------
4. Specific Harmful Substances		
a. Toxins (botulism poisoning)	factors should be managed as to minimize risk of disease outbreak	------
b. Oils	no visible floating oils	------
c. DDT and derivatives	1 mg/kg (wet weight) in aquatic plants & animals	50 mg/kg/wt weight in fish consumed by birds

Table 3-2 (Continued)

Parameter	Freshwater	Marine[1]
4. <u>Specific Harmful Substances</u> (continued)		
d. Aldrin, dieldrin, endrin, and heptachlor	----------	sum of 5 mg/kg (wet weight) in fish eaten by birds
e. Other chlorinated hydrocarbons	----------	50 mg/kg (wet weight) in fish eaten by birds
f. Polychlorinated biphenyls (PCB's)	no increase	0.5 mg/kg (wet weight) in fish eaten by birds
g. Mercury	0.5 ug/g in fish	------
5. <u>Temperature</u>	no changes in natural freezing patterns and dates	------

[1] Except for specific substances listed, the marine aquatic life criteria are acceptable for application to coastal and marine waters inhabited by wildlife. The freshwater wildlife criteria are in general acceptable for application to estuarine wildlife.

Table 3-3. EPA Proposed Water Quality Criteria for recreational waters.

A. <u>Aesthetic Considerations</u>

1. Aesthetics - General
   a. All surface waters should be capable of supporting life forms of aesthetic value

   b. Surface waters should be "free" of
      (1) materials that form objectionable deposits
      (2) floating debris, oil, scum, etc.
      (3) substances producing objectional color, odor, taste or turbidity
      (4) materials which produce undesirable physiological responses in humans, fish and other animal or plant life
      (5) substances or conditions which produce undesirable aquatic life

2. Nutrient (Phosphorus)
   -- no limit is prescribed

B. <u>Recreational Waters</u>

1. Clarity
   -- secchi disc visible at 4 ft. for bathing and swimming waters
   -- bottom visible in "learn to swim" areas
   -- equal to minimum required safety standards in diving areas

2. Microorganisms
   a. Bacteriological indicators (fecal coliform bacteria)
      -- as a minimum be suitable for recreation where there is little risk of ingestion (not to exceed average of 2000/100 ml or maximum of 4000/100 ml)
      -- for intimate contact recreation average of 200/100 ml and <10% of samples during 30 day period >400/100 ml

Table 3-3 (Continued)

B. <u>Recreational Waters</u> (continued)

b. Viruses	-- no limit prescribed
3. pH	-- bathing waters 6.5 to 8.3 -- never <5 or >9
4. Shellfish	-- fit for human consumption as per "Sanitation of Shellfish Growing Areas"
5. Temperature	-- <30°C (86°F) in bathing or swimming waters except where caused by natural conditions

The practice of establishing criteria based on toxicity data for the locality under consideration has the desirable attribute of allowing the criteria (and thus standards) to reflect local variability, however it also may cause confusion in the setting and enforcement of standards and may result in uneven application of the law. However, given the lack of data on the effects of many pollutants and the widely variable natural conditions, there seems no reasonable alternative to this practice, at least for some time to come.

It remains to be seen just how the proposed EPA criteria are to be used in setting water quality standards. EPA plans that they will be incorporated into revised state water quality standards under the direction of EPA Regions by means of policy guidelines developed by the EPA Office of Water Planning and Standards. These guidelines have not yet been fully developed but they will have provisions for waters to be exempted from specific criteria on a case-by-case basis for specified periods when naturally occurring conditions exceed limits of EPA criteria or other extenuating conditions prevail to warrant such exemptions.

Effluent Limitations

EPA has now promulgated or proposed effluent guidelines, limitations and new source standards of performance for industrial categories. These categories are listed in Table 3-4, together with reference to the publication of the final or proposed limitations. Limitations are being formulated for several other industrial categories to be finalized within a year and these are also listed in Table 3-4.

The effluent guidelines, limitations and standards of performance are generally complex, varying with industrial subcategory and usually stated in terms of mass emission per unit product. Thus, they are difficult to interpret in terms of water quality since it is often impossible even to deduce from them the concentrations of pollutants in effluents, muchless those that would result in the environment. Furthermore, they are typically based on standard waste treatment parameters such as biological and chemical oxygen demand, suspended and dissolved solids and pH, rather than considerations of the potentially harmful chemical constituents of these wastes.

We have not here attempted to summarize all of the proposed effluent limitations. Some are discussed under the detailed evaluations of criteria and standards related to oil and chlorine. However, we should point out that the impact of these regulations on water quality may be substantial for two reasons: (1) they are relatively more specific and enforceable than water quality standards and (2) they mostly

Table 3-4. Industrial categories for which effluent limitations guidelines and standards have been or are being developed.

Industrial Categories for Which Limitations Have Been Promulgated or Proposed	Code of Federal Regulations Reference
Group I, Phase I	
Glass Manufacturing	40 CFR 426
Cement Manufacturing	40 CFR 411
Feedlots	40 CFR 412
Phosphate Manufacturing	40 CFR 422
Rubber Processing	40 CFR 428
Ferroalloy Manufacturing	40 CFR 424
Inorganic Chemical Manufacturing	40 CFR 415
Electroplating	40 CFR 413
Asbestos Manufacturing	40 CFR 427
Meat Product and Rendering Processing	40 CFR 432
Plastic and Synthetic Materials Manufacturing	40 CFR 416
Nonferrous Metals Manufacturing	40 CFR 421
Sugar Processing	40 CFR 409
Canned and Preserved Fruits and Vegetables Processing	40 CFR 407
Grain Mills	40 CFR 406
Soap and Detergent Manufacturing	40 CFR 417
Fertilizer Manufacturing	40 CFR 418
Petroleum Refining	40 CFR 419
Dairy Product Processing	40 CFR 405
Leather Tanning and Finishing	40 CFR 425
Pulp, Paper and Paperboard Mills	40 CFR 430
Organic Chemicals Manufacturing	40 CFR 414
Builders Paper and Board Mills	40 CFR 431
Canned and Preserved Seafood Processing	40 CFR 408
Timber Products Processing	40 CFR 429
Iron and Steel Manufacturing	40 CFR 420

Table 3-4 (Continued)

Industrial Categories for Which Limitations Have Been Promulgated or Proposed (continued)	Code of Federal Regulations Reference
Textile Mills	Proposed 39 FR 4628 39 FR 24750
Steam Electric Power Plants	Proposed 39 FR 8294 39 FR 17449

Industrial Categories for Which Limitations Are Being Formulated

Group I, Phase II

Rubber Processing
Electroplating
Timber Products Processing
Inorganic Chemicals Manufacturing
Plastic and Synthetic Materials Manufacturing
Ferroalloy Manufacturing
Organic Chemicals Manufacturing
Nonferrous Metals Manufacturing
Phosphate Manufacturing
Fertilizer Manufacturing
Asbestos Manufacturing
Meat Products and Rendering Processing
Grain Mills
Canned and Preserved Seafood Processing
Glass Manufacturing
Sugar Processing
Iron and Steel Manufacturing
Pulp, Paper and Paperboard Mills
Builders Paper and Board Mills

Table 3-4 (Continued)

Industrial Categories for Which Limitations Are Being Formulated (continued)
Group II
Auto and Other Laundries
Paving and Roofing Materials
Transportation Industries
Paint and Ink Formulation and Printing
Fish Hatcheries and Farms
Canned and Preserved Fruits and Vegetables Industry
Miscellaneous Chemicals
Miscellaneous Food and Beverages
Machinery and Mechanical Products Manufacturing
Coal Mining
Petroleum and Gas Extraction, Handling Storage and Residues Disposal
Mineral Mining and Processing Water Supply
Ore Mining and Dressing Stream Supply
Structural Clay Products
Pottery and Related Products
Concrete, Gypsum and Plaster Products
Furniture and Fixtures Manufacturing
Point Source Discharge Categories Not Otherwise Covered

require substantial improvements in waste treatment by 1977 and virtual elimination of discharge by 1983. For example, the effluent limitations for the steam electric power industry stipulate no thermal discharge into natural waters, and thus the virtually complete reliance on recirculating cooling systems (cooling towers, etc.), by 1983. It is hard to imagine the proffering of a water quality criterion which would have an equivalently drastic effect.

With so much at stake, the development of the effluent limitations has been surrounded by substantial controversy. First, there is the matter of the degree to which economic, social and non-water quality environmental impacts should be taken into account. These were taken into account by EPA in the formulation of the effluent limitations as required under the Act (PL 92-500). However it has been further suggested that a procedure be established whereby, when applying the limitations in the issuance of discharge permits, other factors, such as plant age, size and location and economic impacts are taken into account. This so-called "matrix approach" would mean that the limitations would be no more than guidelines on which wide discretional variances could be applied. Although the matter is still far from resolved, EPA has issued a policy statement on variances from the effluent limitations (7).

The second controversy involves the relationship of the effluent limitations to water quality. It is important to note that compliance with the effluent limitations does not provide exemption from water quality standards. The Act specifically states that whenever discharges of pollutants, with the application of required effluent limitations, would interfere with the attainment or maintenance of water quality, effluent limitations shall be established which can reasonably be expected to contribute to the attainment or maintenance of water quality /Section 302 (a)/ and further requires the states to identify those waters for which the effluent limitations are not stringent enough to implement applicable water quality standards /Section 303 (d)/. But the question has been raised that, in light of the substantial costs of meeting the effluent limitations, is it justifiable to meet limitations when it would result in little or no improvement in water quality. With no industrial category is this controversy so intense as with the power generating industry. The cost of meeting the 1983 limitations has been estimated by the industry to be $48 billion and industrial representatives argue that this would result in little environmental improvement for the receiving waters of many plants. To further complicate matters, another section of the Act /Section 316 (a)/ which pertains specifically to thermal discharge allows the exemption of plants from the effluent limitations if the operators can demonstrate a lack of environmental damage due to their operation.

The Act also requires that EPA define the effluent limitations for "secondary treatment" from publicly owned sewage treatment works. These limitations must be achieved by federally financed facilities by July 1, 1977. These limitations are given in Table 3-5.

Toxic Pollutant Standards

Section 307 (a) of the Federal Water Pollution Control Act requires that the Administrator of EPA publish a list of "toxic pollutants", with effluent standards for such pollutants, which take into account their toxicity, persistence, degradability and importance of organisms which might be affected by these pollutants.

Proposed regulations on toxic pollutant effluent standards have been published (8) and are summarized in Table 3-6. These standards govern the concentrations of nine pollutants in effluents and set limits on mass emission rates. The limits depend on the size or flow rate of the water body.

Ocean Dumping Criteria

The Marine Protection, Research and Sanctuaries Act (P.L. 92-532), as well as the Federal Water Pollution Control Act (P.L. 92-500), requires the formulation of criteria on which decisions as to issuance of permits for ocean dumping may be based. The EPA has therefore published interim ocean dumping criteria (9) which shall apply to the granting of permits for dumping materials at approved dumping sites. Two of the approved sites lie off the mouth of Chesapeake Bay. Furthermore it seems probable that these criteria will be applied to the disposal of solid wastes, principally dredge spoil, within the Bay system. Thus they are of great importance to water quality in the Bay and of obvious importance to the interests and responsibilities of the Corps of Engineers.

The interim ocean dumping criteria are summarized in Table 3-7.

State Water Quality Standards

Maryland

New water quality standards have recently been promulgated by the Maryland Department of Water Resources (10) and are reproduced in Table 3-8. The Department of Water Resources has also issued ground water standards, general effluent limitations, regulations pertaining to the prevention of oil pollution, and requirements for discharge permits implementing the National Pollutant Discharge Elimination System. These recent new regulations and policy statements reflect the requirements of the Federal Water Pollution Control Act.

Table 3-5. Effluent reductions to be achieved by secondary treatment. To be met by all federally financed treatment plants by July 1, 1977.

<u>Biological Oxygen Demand</u> (BOD_5)

-- maximum monthly average, 30 mg/l

<u>Suspended Solids</u>

-- maximum monthly average, 45 mg/l

<u>Fecal Coliform Bacteria</u>

-- maximum monthly average, 200/100 ml
-- maximum weekly average, 400/100 ml

Table 3-6. Proposed Environmental Protection Agency regulations on toxic pollutant effluent standards (8). Limits are also set on mass emission rates. For particulars the EPA regulations should be consulted.

Toxic Pollutant	Low flow ≤10 cfs Lakes ≤500 acres	Low flow >10 cfs Lakes >500 acres Coastal waters
1. Aldrin & Dieldrin	No discharge	0.5 ug/l fresh water 5.5 ug/l salt water
2. Benzidine	No discharge	1.8 ug/l
3. Cadmium	No discharge	40 ug/l fresh water 320 ug/l salt water
4. Cyanide	No discharge	100 ug/l
5. DDT (including DDD and DDE)	No discharge	0.2 ug/l fresh water 0.6 ug/l salt water
6. Endrin	No discharge	0.2 ug/l fresh water 0.6 ug/l salt water
7. Mercury	No discharge	20 ug/l fresh water 100 ug/l salt water
8. Polychlorinated Biphenyls (PCB's)	No discharge	280 ug/l fresh water 10 ug/l salt water
9. Toxaphene	No discharge	1.0 ug/l

Table 3-7. Summary of Environmental Protection Agency criteria for the evaluation of permit applications for ocean dumping (40 CFR 227).

Prohibited materials

Completely prohibited:

- -- high-level radioactive wastes
- -- radiological chemical or biological warfare agents
- -- materials insufficiently described to permit evaluation of impact
- -- persistent inert materials which may float or remain in suspension

Prohibited in all but trace concentrations:

- -- organohalogen compounds (total concentration not >0.01 toxic concentration)
- -- mercury and mercury compounds (not >0.75 mg/kg in solid phase or 1.5 mg/kg in liquid phase)
- -- cadmium and cadmium compounds (not >3.0 mg/kg in solid phase or 6.0 mg/kg in liquid phase)
- -- oil taken on board for dumping (should not produce visible sheen in undisturbed water sample)

Materials requiring special care /permit based on demonstration by bioassay (0.01 of 96-hr LC_{50}) that adverse effects will be minimal/

- -- elements, ions or compounds of arsenic, lead, copper, zinc, selenium, vanadium, beryllium, chromium and nickel
- -- organosilicon compounds
- -- inorganic processing wastes including cyanides, fluorides, titanium dioxide, and chlorine
- -- petrochemicals and organic chemicals
- -- biocides
- -- oxygen consuming and/or biodegradable organic matter
- -- low-level radioactive wastes
- -- toxic pollutants and hazardous substances
- -- materials immiscible with seawater

Hazards to fishing and navigation

- -- wastes must not interfere with fishing or navigation

Table 3-7 (Continued)

Large quantities of materials

-- dumping must be controlled to prevent damage to the environment or to amenities

Acids and alkalis

-- no adverse affects on pH
-- no adverse synergistic effects

Containerized wastes

-- materials disposed of must decay, decompose or radio-decay to environmentally innocuous material within the life expectancy of container
-- only short-term localized effects would result from rupture
-- must not pose hazard to fishing or navigation

Materials containing living organisms

-- must not extend range of biological pests, viruses, pathogenic micro-organisms, etc.
-- must not degrade uninfected areas
-- must not introduce viable species not indigenous to an area

Dredged material

Unpolluted material

-- considered unpolluted if (1) essentially sand and gravel, (2) water quality at dredging site is adequate according to State water quality standards for propagation of fish, shellfish, and wildlife and associated biota typical of a healthy ecosystem, or (3) it produces a standard elutriate in which the concentration of no major constituent is 1.5 times the concentration in water at the disposal site

Table 3-7 (Continued)

<u>Dredged material</u> (continued)

Polluted material

- -- so classified if it does not meet above criteria
- -- can be disposed of if it can be shown that the place, time, and conditions of dumping are such as to produce a minimum impact on environment

Virginia

The Virginia State Water Control Board's water quality standards are, like those in Maryland, based on water use classification. There are six major classes based on waterbody type and two subclasses based on suitability for primary or secondary contact recreation (Table 3-9). Furthermore the Water Control Board has promulgated special standards for particular bodies of water. Because of the obvious importance to Chesapeake Bay, the special bacteriological standards for shellfish growing areas are included in Table 3-9.

In general, the state water quality standards are far more limited in scope than the new EPA water quality criteria. They concern at most only dissolved oxygen, temperature, pH, turbidity, and coliform bacteria. State bacteriological standards comply with the EPA criteria and pH standards are slightly more restrictive. However, state dissolved oxygen standards are lower than those recommended by EPA. Temperature standards are difficult to compare to those complex criteria proposed by EPA. It remains to be seen the degree to which EPA will require states to alter their standards to comply with the criteria and to adopt new standards for the myriad of other parameters for which there are criteria.

Table 3-8. Water quality standards for the State of Maryland.

REGULATION 08.05.04.03 - RECEIVING WATER QUALITY STANDARDS

This regulation is effective May 1, 1973

The following receiving water quality standards are established to protect the uses indicated. Where the waters of the State* are, or may be, affected by discharges* from point sources*, these standards shall apply outside of a mixing zone* designated by the Administration*.

CLASS I WATERS

Water Contact Recreation and Aquatic Life

Bacteriological Standards

There shall be no sources of pollution* as determined by a sanitary survey, and the fecal coliform* content of these waters shall not exceed a log mean of 200/100 ml.

Dissolved Oxygen Standard

The dissolved oxygen concentration must be not less than 4.0 mg/liter at any time, with a minimum daily average of not less than 5.0 mg/liter, except where, and to the extent that, lower values occur naturally*.

Temperature Standard

1. Thermal effects shall be limited and controlled so as to prevent:

   a. Temperature changes that adversely affect aquatic life;

   b. Temperature changes that adversely affect spawning success and recruitment; and

   c. Thermal barriers* to the passage of fish.

2. Temperature elevations above natural must be limited to $5^{o}F$, and the temperature must not exceed $90^{o}F$, outside of designated mixing zone.

Table 3-8 (Continued)

3. This limitation of temperature changes in Class I waters does not preclude the discharge of warmed water. Warming of a portion of a body of water is permissible if it will not produce substantial detriment and if the volume of the new temperature is of such size and duration that the exposure of organisms or life stages thereof, is less than the time associated with deleterious biological effects at that particular temperature.

pH Standard

Normal pH values must not be less than 6.5 nor greater than 8.5, except where--and to the extent that--pH values outside this range occur naturally.

Turbidity Standard

1. Turbidity shall not exceed levels detrimental to aquatic life; and

2. Within limits of Best Practicable Control Technology Currently Available*, turbidity shall not exceed for extended periods of time those levels normally prevailing during periods of base flow* in the surface waters; and

3. Turbidity in the receiving water* resulting from any discharge shall not exceed 50 JTU (Jackson Turbidity Units) as a monthly average, nor exceed 150 JTU at any time.

CLASS II WATERS

Shellfish Harvesting

Bacteriological Standards

1. The Most Probable Number (MPN) of coliform organism* must not exceed 70/100 ml, as a median value and not more than 10 percent of the samples shall exceed an MPN of 230/100 ml for a five-tube decimal dilution test (or 330/100 ml, where the three-tube decimal dilution test is used), and

Table 3-8 (Continued)

2. Must also comply with the sanitary and bacteriological requirements as set forth in the latest edition of "National Shellfish Sanitation Program Manual of Operations".

Dissolved Oxygen Standard

Same as for Class I waters.

Temperature Standard

Temperature elevations above natural must be limited to 4°F in September through May, and to 1.5°F in June through August, outside of designated mixing zones.

pH Standard

Same as for Class I waters.

Turbidity Standard

Same as for Class I waters.

CLASS III WATERS

Natural Trout Waters

Bacteriological Standards

Same as for Class I waters.

Dissolved Oxygen Standard

The dissolved oxygen concentration must be not less than 5.0 mg/liter at any time, with a minimum daily average of not less than 6.0 mg/liter, except where, and to the extent that, lower dissolved oxygen values occur naturally.

Temperature Standard

1. No significant thermal changes; and

Table 3-8 (Continued)

2. Temperature must not exceed 68°F beyond such distance from any point of discharge as specified by the Administration, except where, and to the extent that, higher temperature values occur naturally.

pH Standard

Same as for Class I waters.

Turbidity Standard

Same as for Class I waters.

CLASS IV WATERS

Recreational Trout Waters

Bacteriological Standards

Same as for Class I waters.

Dissolved Oxygen Standard

Same as for Class I waters.

Temperature Standard

1. Thermal effects shall be limited and controlled so as prevent:

   a. Temperature changes that adversely affect aquatic life;

   b. Temperature changes that adversely affect spawning success; and

   c. Thermal barriers to the passage of fish.

2. Temperature must not exceed 75°F beyond such distance from any point of discharge as specified by the Administration, except where, and to the extent that, higher temperature values occur naturally.

Table 3-8 (Continued)

pH Standard

Same as for Class I waters.

Turbidity Standard

Same as for Class I waters.

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* The meaning of this term is described in Regulation 08.05.04.01 - DEFINITIONS

Table 3-9. Water quality standards for the Commonwealth of Virginia.

PRIMARY CLASSIFICATION OF WATERS

Major Class	Geographical Area or other Description of Waters	Dis. Oxygen mg/l Minimum	Dis. Oxygen mg/l Daily Average	pH	Temperature °F Rise above Natural	Temperature °F Maximum
I	Open Ocean (Seaside of the Land Mass)	5.0	---	6.0-8.5	4.0(Sept.-May) 1.5(June-Aug.)	--
II	Estuarine (Tidal Water - Coastal Zone to Fall Line)	4.0	5.0	6.0-8.5	4.0(Sept.-May) 1.5(June-Aug.)	--
III	Free Flowing Streams (Coastal Zone and Piedmont Zone to the Crest of the Mountains)	4.0	5.0	6.0-8.5	5	9
IV	Mountainous Zone	4.0	5.0	6.0-8.5	5	87
V	Put and Take Trout Waters	5.0	6.0	6.0-8.5	--	70
VI	Natural Trout Waters	6.0	7.0	6.0-8.5	--	70

Table 3-9 (Continued)

SUBCLASSES TO COMPLEMENT MAJOR WATER CLASS DESIGNATIONS

Subclass A

Waters generally satisfactory for use as public or municipal water supply, secondary contact recreation, propagation of fish and aquatic life, and other beneficial uses.

Coliform Organisms. Fecal coliforms (multiple-tube fermentation or MF count) not to exceed a log mean of 1000/100 ml. Not to equal or exceed 2000/1000 ml in more than 10% of samples.

Monthly average value not more than 5000/100 ml (MPN or MF count). Not more than 5000 MPN/100 ml in more than 20% of samples in any month. Not more than 20,000/100 ml in more than 5% of such samples.

Subclass B

Waters generally satisfactory for use as public or municipal water supply, primary contact recreation (prolonged intimate contact; considerable risk of ingestion), propagation of fish and other aquatic life, and other beneficial uses.

Coliform Organisms - Fecal coliforms (multiple-tube fermentation or MF count) within a 30 day period not to exceed a log mean of 200/100 ml. Not more than 10% of samples within a 30-day period will exceed 400/100 ml.

Monthly average not more than 2400/100 ml (MPN or MF count). Not more than 2400/100 ml in more than 20% of samples in any month. Not applicable during, nor immediately following periods of rainfall.*

*With the exception of the coliform standard for shellfish waters, the enforceable standards will be those pertaining to fecal coliform organisms. The MPN concentrations are retained as administrative guides for use by water treatment plant operators.

Table 3-9 (Continued)

Special Standards for Shellfish Growing Areas

In those sections of Class IA, IB, IIA and IIB waters within this State where leased private, or public shellfish beds are present, the following bacterial standards shall be established in addition to other bacterial standards adopted for the protection of primary or secondary recreation:

> Coliform organisms - The median MPN shall not exceed 70/100 ml, and not more than 10% of the samples ordinarily shall exceed an MPN of 230/100 ml for a 5-tube decimal dilution test (or 330/100 ml, where a 3-tube decimal dilution is used) in those portions of the area most probably exposed to fecal contamination during the most unfavorable conditions.
>
> In addition, the shellfish area is not to be so contaminated by radionuclides, pesticides, herbicides or fecal material so that consumption of the shellfish might be hazardous.

REVIEW OF STANDARDS AND CRITERIA RELATED TO OIL

STANDARDS AND CRITERIA

A large number of federal and state laws and regulations, as well as water quality standards and criteria, relate to the discharge of oil into surface waters. In addition, several international agreements regulate the discharge of oil from ships at sea, however these apply to international waters outside of the concern of this report.

Congress has declared it a policy of the United States that there should be no discharges of oil into or upon the navigable waters, contiguous zones and adjoining shorelines of the United States (11). The difficulty of implementing this policy is manifest in the plethora of overlapping laws and regulations concerning the discharge of oil. A summarization of the various federal legal authorities relative to oil pollution control is given in Reference 12. The two most important legal authorities are the Federal Water Pollution Control Act, as amended and the Oil Pollution Act of 1961 as amended. The former Act largely supercedes the latter with regard to internal navigable waters such as the Chesapeake Bay. The Federal Water Pollution Control Act Amendments of 1972 (PL 52-900) prohibit the discharge, in harmful quantities, of oil to the waters of the U. S. The Act establishes fines and penalties for prohibited discharges, failure to report such discharges and other violations of regulations and makes the discharger liable for removal costs (11). Based on the authority of this Act, various pollution prevention regulations (12) and contingency plans (13) have been promulgated.

A key question in terms of both minimizing environmental impact and implementation of these regulations concerns the definition of "harmful quantities" of oil. PL 92-500 requires that the President determine "those quantities of oil and any hazardous substance, the discharge of which ..... will be harmful to the public health or welfare of the United States, including but not limited to, fish, shellfish, wildlife, and public and private property, shorelines and beaches." The resultant regulations issued by EPA (12, 14) define harmful discharges as those which: 1) violate applicable water quality standards or 2) cause a film or sheen upon or discoloration of the surface of the waters or adjoining shorelines or cause a sludge or emulsion to be deposited beneath the surface of the water or upon the adjoining shorelines. Exempt from this definition are discharges of oil from a properly functioning vessel engine.

This general standard of no visible sheen or sludge is similar to the relevant state water quality standards, and EPA criteria. For example, the Maryland general standards state that waters shall be free from "floating debris, oil, grease, scum, and other floating materials ... in amounts sufficient to be unsightly to such a degree as to create a nuisance, or interfere directly or indirectly with water uses (10)." The EPA water quality criteria (5) include a criterion of no visible sheen or deposits on the shore or bottoms. The criteria for marine and estuarine waters further stipulate that no odor or tainting of fish and shellfish occur and those for fresh waters include bioassay-determined concentrations (0.05 96 hr LC_{50} emulsified concentration) and a maximum level of 1000 mg/kg dry weight of hexane extractable substances ("oil and grease") in sediments. Criteria set by EPA for determining the acceptability of dredged spoil overboard disposal stipulate a maximum of 1500 mg/kg dry weight (9).

Thus the applicable standards and criteria rely, for the most part, on visual detection of oil in the environment or, at best, gross chemical analysis and, except for the bioassay criterion for freshwaters, are not based on biological effects. As will be discussed below, this is attributable to the complex and variable nature of oils and a general lack of understanding of the fate and effects of oil in aquatic environments, as well as the necessity for a quick and practical method of detection.

The laws and regulations discussed to this point are geared, for the most part, to the control of accidental or irregular discharges of oil from ships and offshore and onshore oil handling facilities. Oil may also be introduced into the aquatic environment as chronic or continuous discharges from industrial processes, domestic sewage plants and land runoff. Relatively few water quality or discharge standards are aimed at controlling these chronic discharges which often are not detectable as slicks or surface films. Effluent standards for discharge of oil have been proposed for only a few of the industrial categories considered by EPA -- this despite the fact that oil is a wastewater constituent of many industrial processes.

The most obvious industrial category for discharge of oil is petroleum refining. Only one refinery currently discharges into tidal waters of Chesapeake Bay, however several others have been proposed. Effluent limitations guidelines have been promulgated covering total discharge, storm runoff and treated ballast for several industrial subcategories (Table 3-10). The refining discharges are given in terms of allowable emission per volume of product processed (i.e. in kilograms of oil and grease in the wastewater compared to the volume of oil entering the refinery), and are difficult to relate to more familiar effluent concentrations. Using

Table 3-10. Effluent limitation guidelines for oil and grease discharges for the petroleum refining industry (15).

Industrial Subcategory	BPCTCA[1] (in kg/1000 cu m of feed product)	BATEA[2]	New Sources
A. Topping			
Max. daily	2.8	0.34	1.6
Max. ave.	2.2	0.28	1.3
B. Low Cracking			
Max. daily	4.0	0.51	2.6
Max. ave.	3.2	0.40	2.1
C. High Cracking			
Max. daily	5.0	0.68	3.3
Max. ave.	4.0	0.54	2.6
D. Petrochemical			
Max. daily	6.2	0.74	3.6
Max. ave.	5.0	0.59	2.8
E. Lube			
Max. daily	8.6	1.4	7.1
Max. ave.	6.9	1.1	5.7
F. Integrated			
Max. daily	10.8	1.5	7.4
Max. ave.	8.6	1.2	5.9

Special Allocations	BPCTA (in kg/cu m of flow)	BATEA	New Sources
Stormwater runoff			
Max. daily	0.010	0.002	0.010
Max. ave.	0.008	0.0016	0.008
Ballast water			
Max. daily	0.40	0.002	0.010
Max. ave.	0.008	0.0016	0.008

[1] BPCTCA: Best practicable control technology currently available; standards to be achieved by 1976.

[2] BATEA: Best available technology economically achievable; standards to be achieved by 1983.

the ratios for product: wastewater volumes used in the preparation of the guidelines (16) the following are approximations of oil and grease effluent concentrations for all industrial subcategories:

	BPCTCA	BATEA	New Source
Maximum daily	10 ppm	1.5 ppm	6 ppm
Maximum average	8 ppm	1.0 ppm	5 ppm

However, as will be later discussed, mass emission rates based on plant capacity may be more valuable in assessing impact. Thus the oil refinery located on the York River which produces 50,000 barrels/day would be required to discharge on the average no more than 32 kg (70 lbs. or roughly 10 gallons) of oil and grease per day. However the Virginia Water Control Board (17) estimates a mass emission rate of 707 lb/day (320 kg/day) from this facility,* despite the low effluent concentrations reported (1.8 ppm).

A new "high cracking" refinery, say of 100,000 barrels/day capacity, locating on the Chesapeake Bay would be required to discharge no more than an average of 41.31 kg/day oil and grease and be required to cut that to 8.58 kg/day by 1983. Thus, its yearly discharge would be 15 metric tons (ca. 4,500 gallons) initially and 3.1 metric tons (ca. 940 gallons) subsequent to 1983.

Effluent limitations are also given for oily storm water runoff and ballast water treated at a refinery. They would allow an average discharge of not more than 8 ppm oil and grease in the effluent and 1.6 ppm after 1983.

Effluent limitations guidelines for several other industrial categories also set standards for "oil and grease" discharges, e.g. those for the fertilizer, ferrous and nonferrous metals, ferroalloy, meat, seafood and rubber industries. These are also based on emission rates per unit of production and the units of production vary widely, making the standards difficult to translate into environmentally meaningful terms. Also the chemical nature of the "oil and grease" (i.e. hexane extractable materials) emitted varies tremendously, depending on the industry. By way of comparison though, new source standard mass emission rates of oil and grease

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* Discharge includes process wastewater, cooling water, stormwater runoff and ballast water.

would only be 3.1 kg/day from an average (100,000 tons/year) ammonia plant. These should be compared with the 41.3 kg/day from the hypothetical 100,000 barrel/day oil refinery considered above.

OIL IN CHESAPEAKE BAY

The Chesapeake Bay has thus far been spared from large catastrophic oil spills of the type that has gained notoriety in recent years. However, several small, biologically damaging spills have occurred. The United States Coast Guard maintains oil spill statistics for the Bay area based on field observations and investigations. These records show that the amount of oil spilled annually in the Bay has been typically 60,000 to 100,000 gallons, or on the average 300 metric tons/year. Oil spills are most frequent in Hampton Roads and Norfolk port areas, in the lower York River, and in the Baltimore Harbor area.

More difficult to estimate are the chronic discharges of oil into the Chesapeake Bay. The potential sources of discharge are many, including municipal sewage industrial wastes, ship generated wastes, commercial and pleasure boats, urban runoff and river input.

Municipal Sewage

No data exist on the oil and grease content of sewage discharged into the Bay. Oil and grease content of Hyperion Outfall effluents (one-third of which receive secondary treatment) discharged into the Pacific Ocean off Los Angeles averaged 19 mg/l oil and grease (18). Effluents from other outfalls in Southern California generally had higher oil and grease concentrations -- up to 70 mg/l. Oil and grease from municipal sewage has been estimated to be one-half composed of petroleum oils (19). Thus, a realistic estimate for the typical concentration of petroleum oil in sewage is 10 mg/l. The discharge of municipal sewage into the tidal waters of the Chesapeake Bay system is estimated to be roughly 900 million gallons per day (mgd) (20), thus the discharge of oil from this source would be 36 metric tons/day or just over 13,000 metric tons/year or approximately 3 million gallons/year.

Industrial Wastes

Available data on effluent emissions and concentrations for industrial discharges are generally confined to those reported on permit applications filed with the Corps of Engineers. They are usually based on the analysis by the industry of a very few samples and thus are notoriously unreliable. Nonetheless it is possible to use these data to loosely approximate emission rates.

Table 3-11. Mass emission of "oil and grease" into tidal waters of southeastern Virginia (17).

	Mass Emission Rate lbs/day
James River Basin	
James River	
Fall Line to Appomattox Riv.	57
Appomattox Riv. to Chickahominy Riv.	19,736
Chickahominy Riv. to Pagan Riv.	18
Pagan Riv. to Nansemond Riv.	61
Nansemond Riv. to Elizabeth Riv.	(0.02)
Elizabeth River to Mouth	(0.26)
Appomattox River	
Chickahominy River	24
Pagan River	(0.24)
Nansemond River	74
Elizabeth River	298
Total James River Basin (below Fall Line)	20,294
York River Basin (below Fall Line)	707
Chesapeake Bay Basin (south of York River Mouth)	8
Total	21,013

Mass emission rates from industrial sources have been compiled for the southeastern Virginia area (17) (Table 3-11). Based on these data the mass emission rate for this area is 3,500 metric tons/year of oil and grease. Assuming that southeastern Virginia accounts for no more than half of all the industrial emissions to the Bay and again making the admittedly unsubstantiated assumption that one-half of this is petroleum oil, the annual mass emission rate of oil into the Chesapeake Bay from industrial sources would be at least 3,500 metric tons (roughly 0.8 million gallons) or about one-fourth of the amount from municipal sewage.

Shipping

Waste oil generated by commercial ships may be contained in bilge or ballast water, the release of which is prohibited in navigable waters if a visible sheen would be formed. Thus, technically, very little oil should be willfully discharged into the Bay by the more than 9,000 commercial vessels which annually call on Chesapeake Bay ports (21). Illegal or accidental discharges do occur, but it is impossible to accurately estimate the magnitude of these emissions. But it seems improbable that this addition would amount to more than 100,000 gallons or roughly 400 metric tons would be discharged from commercial ships.

Federal regulations regarding the discharge of oil in contiguous zones, new international agreements on the discharge of oil from ships on the high seas, and the possibility of the extention of territorial seas, all combine to make the shore based treatment of ship borne oily wastes more desirable or necessary. The volume of oily wastes which must be discharged at Hampton Roads if ships are prohibited from discharging at sea is estimated to be 102 million gallons by 1975 (22). This waste contains approximately 2% oil (i.e. over 2 million gallons), however if this waste is treated onshore and the resulting discharge is <10 ppm oil, a mass emission of only about 3 metric tons/year (ca. 1000 gallons) results. Thus, although the release of treated or untreated ship-generated oily wastes may yet have adverse local environmental effects, in terms of mass emission to the Bay this source would be minor.

Boats

The input of petroleum into the Bay from small vessels is similarly difficult to account. In fact, the great variations in vessel size, engine type, fuel consumption and operation time makes impossible anything but a crude, educated guess.

The total number of registered vessels in the portions of Maryland, Virginia and the District of Columbia adjacent to the Chesapeake Bay and its tidal tributaries is over 160,000 (21). Outboard engines discharge 8-10% of their fuel consumption through the cooling water-exhaust system (23). Boats with inboard engines lose a considerably smaller portion of their fuel to the water body. Nonetheless, a per boat average of 5 gallons of petroleum lost per year is probably of the right order. Thus the annual emission of petroleum from boats is estimated at 800,000 gallons or 3000 metric tons.

Urban Runoff

The National Academy of Sciences (19) estimated an annual contribution of 0.1 million metric tons (ca. 27 million gallons) of oil to the world's oceans from urban runoff. Runoff from suburban Long Island contained from 10 to as much as 60 ppm of oil and grease, a substantial proportion of which would be petroleum oil. Comparable data are not available for Chesapeake Bay urban areas, and extrapolation is difficult because of lack of information on the volume of urban runoff. However, if contaminated runoff were 10% of the total annual rainfall within the 470 square miles encompassed by Washington, Baltimore, Richmond, Norfolk and Newport News/Hampton, and if the concentration of petroleum oil in this runoff were 10 ppm, then over 300,000 gallons or approximately 1000 metric tons annually enters from runoff. This hypothetical figure appears a realistic proportion (i.e. one percent) of the NAS global estimate.

River Inputs

Estimating the input of petroleum hydrocarbons from the rivers draining into the Bay is again made difficult by the lack of data. NAS (19) estimated the global input from rivers to be 1.6 million metric tons per year. Based on their estimate of a concentration of 0.3 mg/l of petroleum hydrocarbons for the Mississippi River and a freshwater discharge of 6×10^{10} m^3/year to the Chesapeake Basin, the annual addition of petroleum from river runoff is estimated to be 18,000 metric tons. The NAS report suggested much of this would be adsorbed to sediment particles.

Summary of Inputs

A balance sheet of these crude approximations of inputs of petroleum to the Chesapeake Bay is given in Table 3-12.

The overwhelming percentage of total input attributable to chronic, low-level inputs of petroleum from sewage, industry and upstream sources is striking. In most minds, oil pollution in the coastal environment is thought of mainly, if

Table 3-12. Summary of estimated annual inputs of petroleum into the Chesapeake Bay.

Source	Estimated Annual Input (metric tons = 1.1 short tons)	Percentage of Total
Oil Spills	300	0.8%
Municipal Sewage	13,000	34.9%
Industrial Sources	3,500	9.4
Ship Generated Wastes	400	1.1%
Boats	3,000	8.1%
Urban Runoff	1,000	2.7%
River Inputs	16,000	43.0%
Total	37,200	

not exclusively, in terms of marine transportation related sources. The subject usually brings to mind tanker or terminal spills. This exercise in estimating a mass emission budget does not suggest that these accidental losses are unimportant, because they have resulted in documented biological damage in the Bay, but emphasizes the magnitude and, thus, potential seriousness of non-accidental chronic inputs.

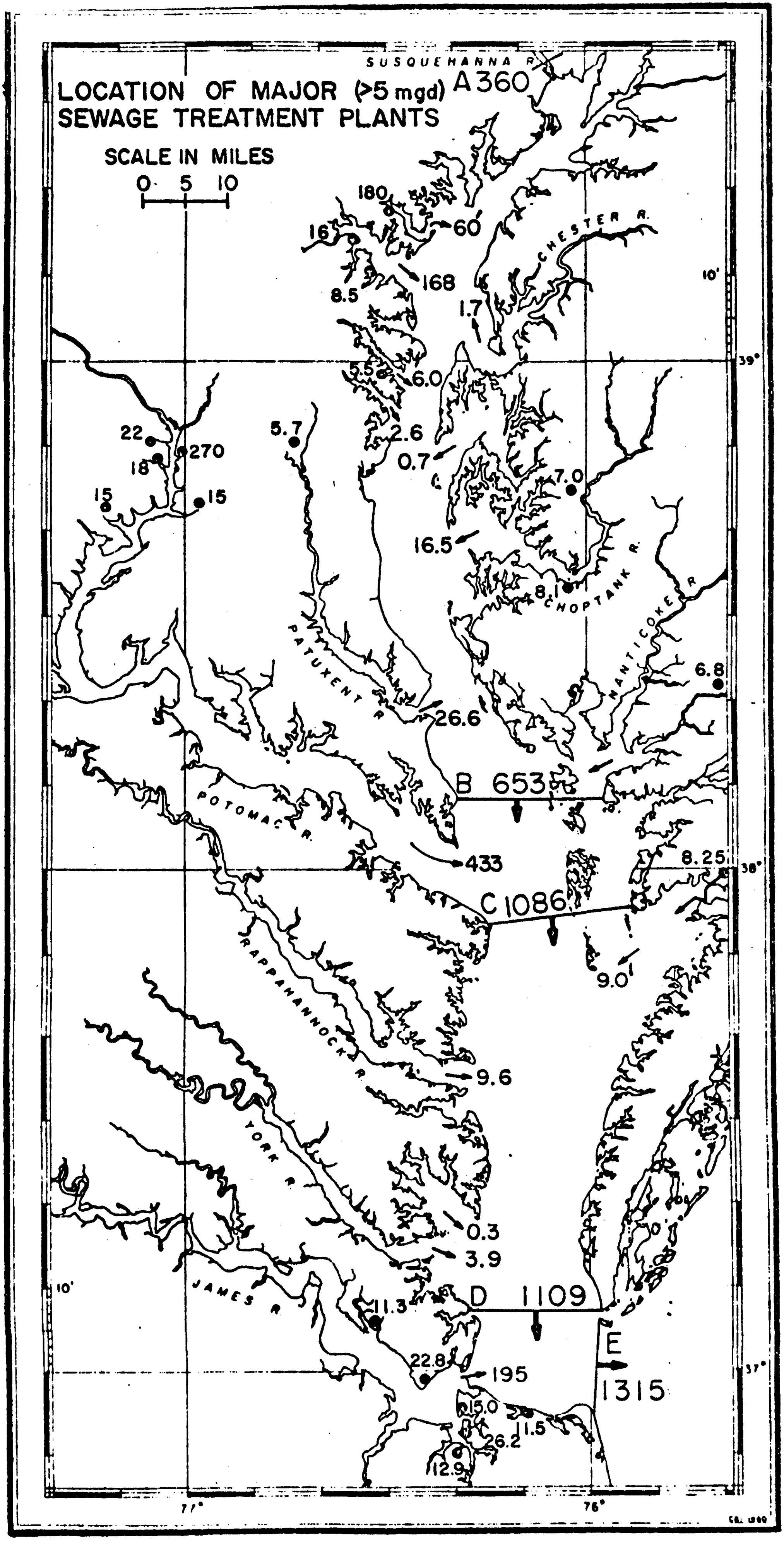
To be sure, the petroleum inputs from sewage, industry and runoff come in very small, albeit continuous, doses. The effective concentrations in the environment would therefore be expected to be less than in the case of an oil spill. Disperson of these low concentrations and biodegradation of the petroleum may be expected to further lessen the chance of toxic buildup of petroleum. However, petroleum hydrocarbons may persist in the environment for very long periods of time (some compounds longer than others) and may have a tendancy to be taken up and concentrated in bottom sediments and in organisms (24). Thus the low levels emitted from the source may allow buildup of toxic concentrations of petroleum hydrocarbons.

The sources of oil pollution are not spread round the Bay but are concentrated primarily on the James River estuary (Hampton Roads and the Richmond-Hopewell area) and in the Baltimore area. Of course these are sites of input of many other pollutants as well and the synergistic effects of the petroleum with other pollutants must be considered. Oil spills are most frequent in the lower York River, the Hampton Roads area, and the Baltimore Harbor area. Largest inputs of municipal sewage (Fig. 3-2) and greatest urban runoff are at Baltimore, Washington, Hampton Roads and Richmond. Industrial sources of petroleum hydrocarbon center at Hopewell, Yorktown, the Elizabeth River and Baltimore Harbor. Some ship generated wastes are released in Hampton Roads and Baltimore harbors and along shipping lanes. Oil pollution from motor boats may be especially intense in the vicinity of the many marinas in the Bay area, which are often located in poorly flushed creeks. The input of petroleum from the Susquehanna and James rivers must be greater than that from other rivers entering the Bay, since they have high flow rates and drain more urbanized or industrialized areas. Much of this petroleum must be degraded or deposited in the uppermost Bay and the upper tidal James where much of the suspended sediment load is deposited.

Oil in the Bay Environment

One may ask, in light of these seemingly substantial chronic inputs of oil to the Chesapeake Bay, what level of contamination exists in Bay environments? Here again, assessment of the problem is hampered by lack of data. No data exist for concentrations of petroleum hydrocarbons in water or in

Figure 3-2. Location of major sewage treatment plants in the Chesapeake Bay. Numbers are discharge rates in million gallons per day. Larger numbers are cumulative sums of inputs into the Bay. (After 20).



LOCATION OF MAJOR (>5 mgd) SEWAGE TREATMENT PLANTS
SCALE IN MILES
0 5 10
SUSQUEHANNA R.
A 360
CHESTER R.
180
16
60
168
8.5
1.7
5.5
6.0
5.7
2.6
22
270
18
0.7
7.0
15
15
16.5
CHOPTANK R.
8.1
PATUXENT R.
NANTICOKE R.
6.8
26.6
B 653
POTOMAC R.
433
8.25
C 1086
9.0
RAPPAHANNOCK R.
9.6
YORK R.
0.3
3.9
JAMES R.
D 1109
11.3
E
22.8
195
1315
15.0
11.5
26.2
12.9
10'
39°
38°
37°
77°
76°

fish, shellfish or other organisms. Some data do exist for "oil and grease" concentrations in sediments. Sediment samples taken in Baltimore Harbor by EPA's Annapolis Field Office (25) ranged from 420 to as much as 81,220 mg/kg oil and grease. Many samples from the inner harbor had concentrations in excess of 10,000 mg/kg (i.e. 1% by weight). In contrast sediments in the vicinity of Tangier Island contained only from 140 to 460 ppm oil and grease. Sediments collected from the York River Entrance Channel ranged from 30 to 1210 mg/kg, with most with less than 700 mg/kg (26).

"Oil and grease" content represents naturally occurring lipids and hydrocarbons as well as petroleum hydrocarbons, thus it is impossible to determine what portion of the "oil and grease" concentration is petroleum. Also the natural hydrocarbon-lipid content of bottom sediments and their ability to concentrate petroleum depend on the grain size of the sediments and the sedimentation rate. All things considered, it appears that any "oil and grease" concentration above 1000 to 1500 mg/kg almost certainly represents contamination with petroleum. The EPA criterion for overboard disposal of dredged material of 1500 mg/kg (9) and the EPA water quality criterion (5) of 1000 mg/kg in freshwater sediments thus do not appear unreasonably strict.

ENVIRONMENTAL EFFECTS

In the only study of the effects of oil on Chesapeake Bay organisms, Bender, Hyland and Duncan (27) described the effects of a small oil spill on intertidal communities in the lower York River. The species richness of the intertidal benthos was substantially reduced where the oil reached shore, compared to adjacent control sites. Furthermore, recovery in terms of both species richness and similarity of the fauna to control sites was not shown until two years after the spill. Aqueous extracts of Bunker C fuel oil, similar to that spilled, proved most toxic to two of the crustaceans (*Gammarus mucronatus* and *Pagurus longicarpus*) and one polychaete worm (*Spiochaetopterus oculatus*) tested.

Oil Spills

The extensive literature on the environmental effects of oil spills has been summarized in several reviews (24, 28, 29), thus a detailed review will not be attempted here. In summary though, oil can kill marine life directly through: (1) coating and asphyxiation, (2) poisoning through direct contact or ingestion, (3) exposure to water-soluble toxic petroleum components, (4) destruction of juvenile forms, and (5) disruption of body insulation of warm blooded animals. Furthermore, oil may have harmful indirect effects, including: (1) destruction of food sources, (2) synergistic effects that reduce resistance to other stresses, (3) incorporation of carcinogenic and potentially mutagenic chemicals, (4) reduction of reproductive success, and (5) disruption of chemical clues essential to survival, reproduction or feeding.

The actual observed effects of oil spills have varied tremendously, though, and many spills have been reported to do little damage. The severity of an oil spill is dependent on: (1) the dosage of oil an environment receives, (2) the physical and chemical nature of the oil spilled, including the effects of weathering, (3) the location of the spill, (4) the time of year of the spill, (5) the prevailing weather conditions, and (6) the techniques used to clean up the spill (30). Biological recovery from the effects of oil spills may be quite rapid or may extend to more than a decade after the initial accident (19) depending on the community in question and whether oil persists in the environment, particularly in sediments.

Chronic Pollution

Surprisingly, very little research has been conducted on the effects of chronic inputs of petroleum on coastal and estuarine communities. Much of the information available has been reviewed by the National Academy of Sciences (19), Copeland and Steed (31) and Baker (32).

Refinery effluents may have considerable impact on benthic life in confined bodies of water where dispersion of the effluent is not rapid (32). For example, animals inhabiting sediments in Los Angeles Harbor that received large quantities of oil industry wastes were eliminated or limited to a single tolerant polychaete (33). The greatest effects were apparently due to the depletion of oxygen on the bottom by oxygen-demanding wastes that concentrated in the sediments. Also, saltmarsh plants were killed by a refinery effluent released in sheltered tidal creeks at Southampton, England (34). On the other hand, effluents released in more exposed waters with rapid dispersion seem to have considerably fewer biological effects (32).

Studies on phytoplankton (35) and zooplankton (36) of Galveston Bay, Texas, indicate decreased species diversity in the area near the Houston Ship Channel, which is heavily burdened with petrochemical as well as other toxic wastes. The effects of lowered salinity and other toxicants compound the picture, however, and the field evidence that chronic oil pollution affects planktonic communities is not complete. However, the more refined experiments of Gordon and Prouse (37) indicate photosynthesis in chronically polluted coastal waters may be affected.

Swimming animals may vacate an unfavorable area and thus avoid harm. Hence, fish may be absent or less diverse around refinery outfalls or bleedwater discharges (38). This may effectively reduce fishery productivity in certain local areas (39).

Among the shallow water ecosystems of the Texas coast, those receiving oily wastes are characterized by lowered species diversity, large diurnal fluctuations in dissolved oxygen concentration, and sometimes near-anaerobic reducing conditions at the bottom (31). Community metabolism -- the combined amount and relationship of photosynthesis and respiration of the whole community -- fluctuates wildly. Under some conditions, both photosynthesis and respiration are depressed by highly toxic materials; under others, metabolism is stimulated due to the decomposition of waste products and release of nutrients.

The effects of oil inputs from such land-based sources as domestic and industrial wastes and urban runoff have received even less attention. Farrington and Quinn (40) traced the cause of high concentrations of petroleum hydrocarbons in sediments and clams in Narragansett Bay, Rhode Island to domestic sewage effluents. Hard clams from contaminated sediments there showed signs of physiological stress and abnormal growth (41). Pfitzenmeyer (42) found the benthic communities in Baltimore Harbor especially depauperate in black, petroleum-smelling muds, but of course the addition of a wide range of pollutants there complicates the delimiting of causitive factors.

EVALUATION

Adequacy of Standards and Criteria

The legislation and regulations pertaining to oil spills are certainly adequate for the protection of life in the Bay, in that they virtually prohibit any spilling of oil. The improvements of safety regulations, surveillance and tracing of spilled oil, control and enforcement would probably reduce the frequency, magnitude and impact of oil spills in the Bay. However, it is impossible to completely eliminate the risk of oil spills. If tanker traffic substantially increases in the Bay, maritime traffic control schemes and other safety precautions should be established to prevent the chance of collision.

On the other hand, the regulations, standards and criteria pertaining to chronic discharges of petroleum do not seem adequate. The inputs of petroleum from three major sources, domestic sewage, boats and urban runoff are largely unregulated. For those sources for which discharge standards apply, the standards are put only in terms of total hexane extractable "oil and grease", while it may be trace pollutants not easily treatable by conventional means which may be environmentally harmful. For example, although the biological treatment of oils in waste water set forth in the refinery industry effluent limitations guidelines may be effective in reducing total "oil and grease" concentration, petroleum hydrocarbons less susceptible to biodegradation, such as the more toxic aromatics and naphthalenes, may escape treatment. Unfortunately, very little is known of the hydrocarbon constituents of treated wastes from refineries and other industrial sources, and they probably vary widely.

Our uncomfortable ignorance about the effects of chronic petroleum pollution does not allow a realistic appraisal of the effects of inputs from chronic sources on Bay ecosystems. The high levels of oil in sediments in Baltimore Harbor and probably in the Hampton Roads area nonetheless provide cause for concern. Furthemore, the real probability of greatly expanded development of an onshore petroleum industry in the Chesapeake Bay area, which may attend recovery of oil under the outer continental shelf off Delmarva or deep water port development, poses a threat of unknown proportions for the Bay. Clearly, more information on petroleum pollutants and their effects is required in order to set standards and guidelines adequate for the protection of the environment.

Research Recommendations

1.) Characterization of the chronic petroleum inputs into the Bay is required.

2.) The fate, including processes of degradation and concentration of oil in the Bay environment needs investigation.

3.) Research on the effects of acute and, particularly, chronic inputs of petroleum on Chesapeake Bay communities is needed.

4.) Sublethal effects of low concentrations of petroleum hydrocarbons on aquatic organisms should be studied. Particularly worrisome are the possible effects of petroleum hydrocarbons on the detection of chemical clues by migrating estuarine organisms.

5.) Finally, research on the character, fate and effects of chronic additions of petroleum should be coupled with research on effective treatment technologies.

REVIEW OF STANDARDS AND CRITERIA RELATED TO CHLORINE

INTRODUCTION

Chlorine is used in many industrial processes but its main uses which are of greatest importance to water pollution are (1) as a disinfectant of waste waters for the protection of public health and (2) for antifouling in water intakes and cooling water systems, particularly by power plants.

Chlorine is a powerful oxidizing agent and its high toxicity is the reason for its use as a biocide. It is highly soluble in water, where it may be present as free available chlorine in the form of hypochlorous acid or hypochlorite ion. However free chlorine degrades rather rapidly, especially in the presence of light, to chlorides, major and harmless constituents of marine and brackish waters. Chlorine may react with other compounds in solution, however, and the end product may be much more stable than free chlorine. Especially in waste waters, chlorine may react with ammonia to form chloramines which are slightly less toxic than free chlorine but decompose much more slowly. The sum of free chlorine, inorganic chloramines and some organochloramines is referred to as available chlorine.

STANDARDS AND CRITERIA

Neither Maryland nor Virginia have water quality standards for maximum levels of chlorine permissible in natural waters. On the other hand, states often have regulations concerning the minimum levels of residual available chlorine in waste waters. For example, Virginia requires a residual chlorine level of 1.0 mg/l for sewage effluent leaving contact tanks and 2.0 mg/l for facilities discharging into shellfish waters.

The Environmental Protection Agency's Water Quality Criteria (5) suggest that 0.003 mg/l of residual chlorine be the maximum for chronic exposure and 0.05 mg/l for short term exposure for freshwater aquatic life and that an application factor of 0.1 applied to the 96 hour LC_{50} should be the criterion for marine and estuarine waters but that concentrations in excess of 0.01 mg/l are unacceptable. The document hastens to add, however, that as more knowledge of toxicity of chlorine to marine organisms becomes available the criterion should probably be equivalent to that set for fresh water.

The proposed Effluent Limitations Guidelines for the steam electric power generating industrial category includes standards for the discharge of chlorine (43). Under these proposed regulations, free available chlorine concentration must not exceed an average of 0.2 mg/l nor a maximum of 0.5

mg/l during one two hour period per day under the Best Practicable Control Technology Currently Available by 1977. Furthermore, no discharge of available chlorine would be allowed under the Best Available Treatment Economically Achievable, the 1983 limitations. Currently, it is common practice in the operation of power plants to chlorinate to a 0.5 to 1.0 mg/l residual chlorine level for 30 minutes to an hour several times a day or to continuously maintain a residual level of 0.5 mg/l.

There are stipulations both in the proposed effluent limitations and in the Federal Water Pollution Control Act (PL 92-500) for variances from these rigid standards. The proposed limitations allow, at the discretion of EPA, for higher levels of chlorination and/or longer dosing periods if required to maintain necessary cleanliness in the cooling water system. Section 316 (a) of the Act further allows exemption of electric power generating plants from the effluent limitations if it can be shown that no environmental harm is resulting from its operation.

It is significant to note that no effluent standards for chlorine have yet been proposed for sewage treatment plants. In fact the standards for secondary treatment set by EPA for maximum concentration of fecal coliform bacteria of 200/100 ml require substantial disinfection. In this country chlorine is almost exclusively used as the disinfectant. It is not known at this time whether future sewage effluent standards required by the Federal Water Pollution Control Act will stipulate effluent standards for chlorine.

CHLORINE AND THE CHESAPEAKE BAY

Although known as a water pollution problem in fresh waters for some time (45), chlorine was not suspected of being harmful to Chesapeake Bay organisms until recently. The researchers at the Natural Resources Institute of the University of Maryland showed that chlorination of cooling water at the Chalk Point power station reduced primary productivity of the phytoplankton passing through by as much as 91%, resulting in as much as a 6.6% maximum loss in primary production in the adjacent tidal segment of the Patuxent River (46). Heavy mortalities in zooplanktonic copepods passing through the plants cooling water system were likewise attributed to chlorination (47). Experiments done with populations of the important zooplanktonic copepod <u>Acartia tonsa</u> from the York River showed that residual chlorine concentrations of 0.75 mg/l similar to those employed at the Yorktown power station were likewise lethal (48).

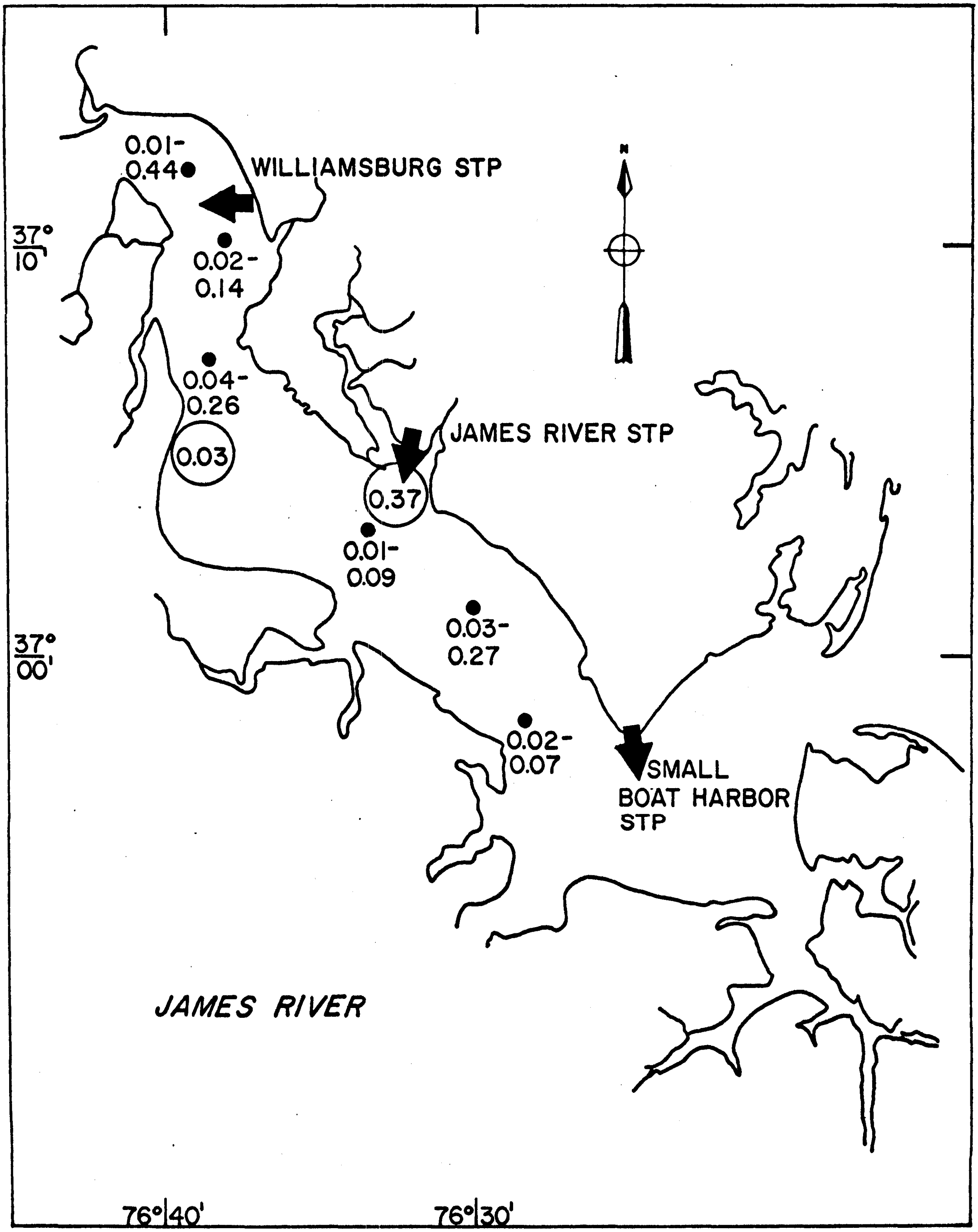
Although previously shown by Tsai (49) to be the cause of serious effects on fish communities in freshwater streams in the Chesapeake Bay drainage basin, chlorination of sewage had not been known to have deleterious environmental effects in the tidal waters of Chesapeake Bay until it was implicated as the cause of large fish kills in the James River during the spring and summer of 1973 (50). An investigation led by the Virginia State Water Control Board concluded, after extensive field surveys and bioassays in the field and laboratory, that the cause of the mortality of over one half million fish was residual chlorine from the James River and Small Boat Harbor sewage treatment plants of the Hampton Roads Sanitation District. It was shown that the processed waste water was routinely overchlorinated largely because of inadequate application of analytical techniques. In fact, probably one of the most common causes of environmental problems with chlorinated discharges is gross overchlorination (45). Reduction in the level of chlorination resulted in immediate alleviation of the fish mortality, but necessitated temporary closure of shellfish grounds.

Measurements of residual chlorine in the vicinity of the sewage outfalls during the period of the fish kill yielded concentrations of 0.2 to 0.7 mg/l at the James River treatment plant (at the mouth of the Warwick River) and 1.0 - 2.2 mg/l at the Small Boat Harbor plant (at Newport News Point). Subsequent monitoring (51, 52) of available chlorine concentrations in the James River has found concentrations often greater than 0.5 mg/l in the vicinity of sewage outfalls and concentrations of up to 0.4 mg/l, but usually less than 0.1 mg/l at locations quite far removed from outfalls (Fig. 3-3).

Currently, the Virginia State Water Control Board at the request of the Virginia Marine Resources Commission has ordered a reduction in the level of chlorination during the season of larval recruitment to the important James River seed oyster grounds. However, because of plans to greatly enlarge the capacity of the James River plant, necessitated by a burgeoning population and extension of service, periodic reductions of chlorination can be, at best, only a temporary solution.

The James River fish kill suggests that deleterious effects--though not necessarily of equivalent magnitude--may be realized in other segments of the Bay receiving chlorinated sewage effluents. Nearly one billion gallons of sewage is discharged into the tidal waters of the Chesapeake Bay system every day (20). Most of this is chlorinated to varying degrees. The distribution of these inputs (Fig. 3-2) suggests that the areas where the potential of deleterious effects of waste water chlorine is most serious are the Baltimore Harbor-Back River area, the upper tidal Potomac River, the lower James River-Hampton Roads-Elizabeth River

Figure 3-3. Residual chlorine concentrations in the lower James River estuary. Values are ranges of monthly measurements taken in spring, 1974 by Adams (51). Circled values were measured by Huggett (52).


0.01-
0.44
WILLIAMSBURG STP
37°
10'
0.02-
0.14
0.04-
0.26
0.03
JAMES RIVER STP
0.37
0.01-
0.09
0.03-
0.27
37°
00'
0.02-
0.07
SMALL
BOAT HARBOR
STP
JAMES RIVER
76° 40'
76° 30'

area and the upper tidal James River. However, this does not preclude the possibility of deleterious effects resulting from small sewage treatment plants, particularly if they discharge into small or confined bodies of water.

ENVIRONMENTAL EFFECTS OF CHLORINE

Several timely reviews of the effects of chlorine on aquatic life have recently been published (45, 53, 54) so no attempt will be made to provide a complete review. Most of the available information pertains to freshwater organisms and it indicates that aquatic organisms vary widely in their tolerance of chlorine. Generally short term exposure (several minutes to several hours) to concentrations of residual chlorine of 0.2 mg/l is lethal or otherwise harmful to many freshwater fishes and brown trout are killed after only 2 minutes exposure to 0.04 mg/l. Longer exposure to concentrations of 0.1 to 0.2 mg/l is lethal to most species tested and some crustaceans may be killed by concentrations of less than 0.01 mg/l.

Few data exist on the chlorine toxicity levels for marine and estuarine species. However, it appears that LC_{50}'s for several fishes and invertebrates common to Chesapeake Bay are in the neighborhood of 0.2 to 0.1 mg/l, i.e. similar to those for all but the most sensitive freshwater species. On this basis and considering the application factor of 0.1 recommended in the Water Quality Criteria, residual chlorine concentrations greater than 0.01 mg/l are potential harmful. Concentrations exceeding this level are routinely encountered in the lower James River.

Free chlorine degrades rapidly in the environment but the combined forms, chloramines and chlorinated organic compounds, are much longer lived. Given the high concentration of ammonia and reactive organic compounds in treated sewage, it is unlikely that much of the residual chlorine discharged would be in the form of free chlorine. Little is known of the residence time of chloramines and organochlorides in the estuarine environment.

EVALUATION

The seriousness of the problem suggests that states should adopt water quality standards for residual chlorine. For these the EPA proposed criteria appear reasonable. However, analytical problems (45) would make monitoring and enforcement difficult.

Because the major source of residual chlorine is public treatment facilities, they cannot simply be turned off if water quality standards are exceeded. The societal conflicts between the need for economical waste disposal, public health requirements and environmental considerations do not meet with easy solutions. From the environmental perspective, however, it seems imperative to test and implement alternate disinfection technology in order to eliminate or reduce the input of toxic chlorine into aquatic ecosystems. Alternatives include disinfection with ozone and ultraviolet light (51). Both of these have drawbacks. Ozone is expensive and ultraviolet light is ineffective with turbid effluent. More practical seems to be dechlorination of chlorinated wastes by reaction with sulfur dioxide, sodium bisulfite, sodium thiosulfate or activated carbon (53). Investigations conducted on dechlorinated effluents in the San Francisco Bay area (55) indicate that dechlorination by the addition of sodium bisulfite consistently removed all chlorine-induced toxicity in both primary and secondary sewage effluents. Furthermore, Dean (53) estimated that disinfection with chlorine followed by dechlorination should cost not more than 1.3 times the cost of disinfection alone.

Finally, it is obvious that research is urgently needed on the effects of residual chlorine on estuarine species and communities, the fate and persistence of combined chlorine in the Chesapeake Bay, and analytical methods for the routine analysis of chlorine in estuarine waters.

CONCLUSIONS

Recently promulgated regulations and others in the process of development -- most of which were provided for by the Federal Water Pollution Control Act of 1972 -- will result in substantial changes in water quality standards and in the patterns of input of pollutants into the Nation's waters. In the immediate future, industrial discharges will be most directly affected as effluent limitations are applied and the National Pollution Discharge Elimination System is more fully developed. More difficult to predict is the success of reducing or eliminating pollutant discharges from publically owned sewage treatment plants and from non-point sources.

To accurately assess the impact of compliance with these standards and regulations on Chesapeake Bay ecosystems is a virtually impossible task. In part this is due to a lack of knowledge about the fate of pollutants introduced into the Bay. Thus, our ability to predict environmental concentrations which would result after elimination of point sources is limited. More basically, though, there is an embarrassing ignorance of the present effects of pollutants on Bay ecosystems. This lack of knowledge of the state of health of the Bay makes difficult any prognosis for improvement or recovery. Perhaps the forthcoming National Commission on Water Quality studies on the environmental impact of the Federal Water Pollution Control Act will shed some light, but it seems, for the time being at least, that discharge elimination goals will be pursued with little or no quantitative knowledge of the environmental effects of these actions.

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SECTION 5

APPLICABILITY OF THE CHESAPEAKE BAY HYDRAULIC MODEL FOR BIOLOGICAL PROBLEMS

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INTRODUCTION

Although hydraulic models have been used for many years in dredging studies relative to navigation, their aid in attempting to understand biological processes has been largely neglected. Probably the reasons for this slow development can be attributed to the relatively few models constructed of the estuary or river where biological research is conducted and the comparative inaccessibility of the actual model to the scientists wishing to use them. Another factor may be that the scientific community was not familiar with the capabilities of the physical models and instruction on its potential uses was not made available.

With the construction of the Chesapeake Bay Hydraulic Model on Kent Island, Maryland, many of these limitations are removed. This model of the largest and probably most important estuary in the world will soon be available for investigators who might have use for such an instrument. Also, this model is probably accessible to more scientists than any other similar model yet constructed.

An objective of this phase of the contract was to determine the various uses the Chesapeake Bay Hydraulic Model will have for biological problems. This information was to have been obtained by means of questionnaires sent to various workers in the field.

An earlier study of this contract identified and inventoried scientists, especially biologists, who are active in Chesapeake Bay research (Kerby and McErlean, 1972). Approximately 1200 workers were contacted of which 644 responded. This list of respondent investigators formed the basis of the participants in the questionnaire survey for data on biological uses of the hydraulic model.

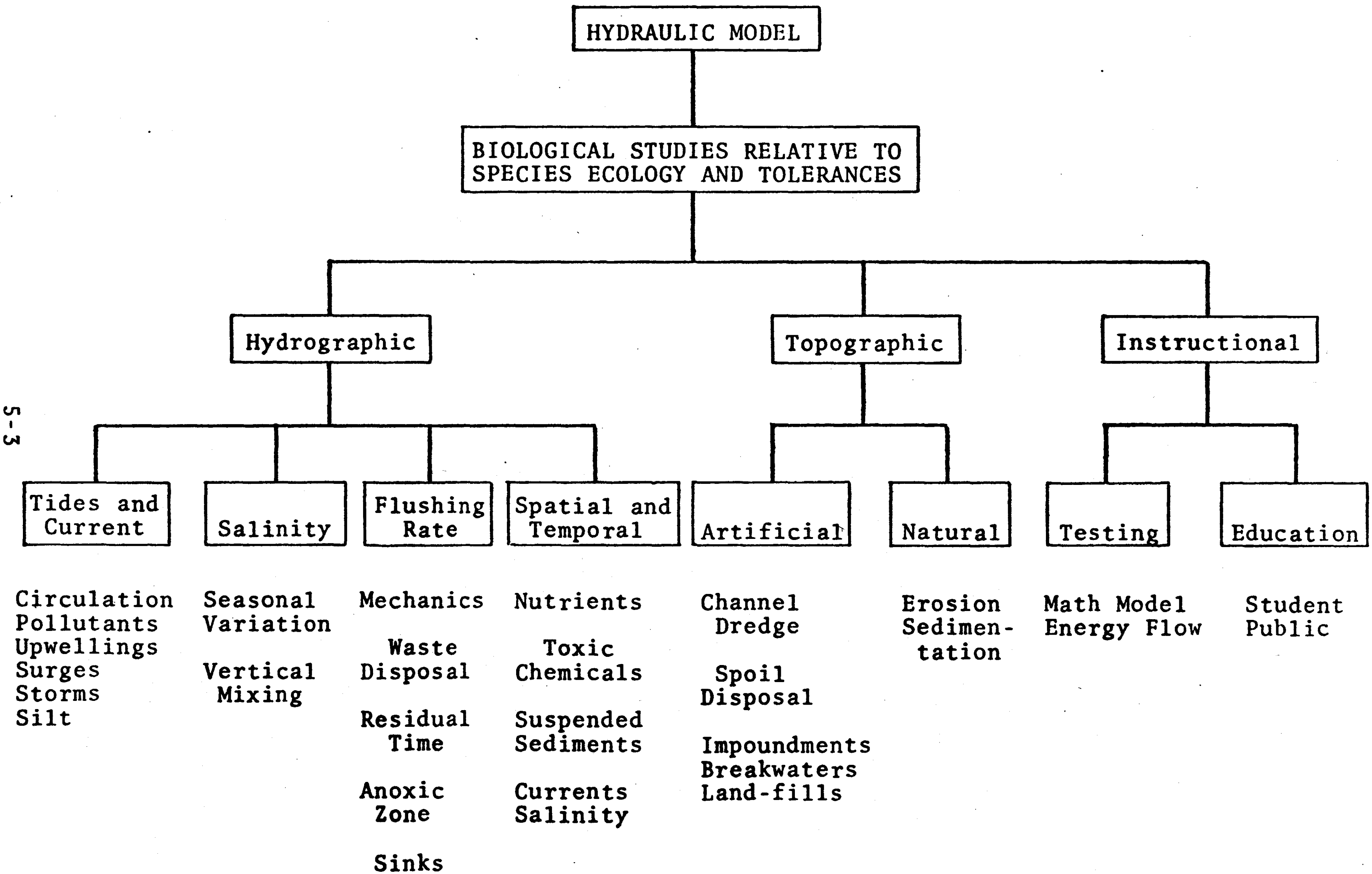
A total of 559 questionnaires were sent to scientists from this above list and a list of other more recent personnel involved in Bay research, of which approximately 15% were returned (85). This rate of response must be considered good if one examines the type of information solicited on the questionnaire. It was decided that a "question and answer" type of survey would provide more information than merely a "choice" type questionnaire even though the percent response would be less. The respondents were not requested to identify themselves, which, hopefully, was to give more freedom on imaginative answers.

Replies to each of the five questions listed on the questionnaire are listed in Appendix I of this report. It was felt important to retain as much original wording and individual thought as possible, therefore, the answers are essentially the same as received. Only word-for-word duplication of ideas, as well as personal references, have been eliminated. Some of the biological studies expressed on the questionnaires, in the writer's opinion, cannot possibly be conducted with the model as designed, however, these ideas were also included in the replies. These fall into the categories of direct observation of particular biological phenomena.

Possible uses of the hydraulic model as an aid in understanding particular biologically related problems have been summarized and presented in the diagram (Fig. 1). These are the physical and chemical parameters upon which biological systems in the Bay are so dependent. For an orderly placement, the possible uses as listed on the returned questionnaires, have been arranged under three major headings: hydrographic, or those studies concerned with water quality or movement; topographic, those involving physical change; and instructional, which is concerned with education, demonstration, and tests to prove some particular theory or mathematical model. Under each of these major headings of concern are the general physical and chemical investigations capable of being tested with the hydraulic model in order to explain some biological phenomena. More specific studies are listed below each of these as one or two word summaries. These are the areas of investigation, as suggested by the canvassed scientific personnel, to which the hydraulic model may be employed.

Studies dealing with specific organisms or biological activities which may be investigated with the hydraulic model are listed in the order of the number of times they appeared on the questionnaires (Table 1). Replies to the first question, pertaining to the research in which they are presently engaged, are separated from the answers to the second question which dealt with their opinion of possible uses of the model. These two lists are very similar, which may be expected since both questions were completed by the same person with specific interests in a particular field of research. It is of interest to learn that the hydraulic model has uses in practically all phases of biological research, including algae, rooted aquatic plants, bacteria, invertebrates, and vertebrates. Several investigators pointed out that direct biological simulation with a hydraulic model is an impossibility and would probably lead to erroneous results. The research would have to be of the physical and chemical nature as diagrammed in Fig. 1, and then applied to data from the prototype before it would be of any biological value.

Figure 1.



HYDRAULIC MODEL
BIOLOGICAL STUDIES RELATIVE TO SPECIES ECOLOGY AND TOLERANCES
Hydrographic
Topographic
Instructional
Tides and Current
Salinity
Flushing Rate
Spatial and Temporal
Artificial
Natural
Testing
Education
Circulation
Pollutants
Upwellings
Surges
Storms
Silt
Seasonal Variation
Vertical Mixing
Mechanics
Waste Disposal
Residual Time
Anoxic Zone
Sinks
Nutrients
Toxic Chemicals
Suspended Sediments
Currents
Salinity
Channel Dredge
Spoil Disposal
Impoundments
Breakwaters
Land-fills
Erosion
Sedimen-tation
Math Model
Energy Flow
Student
Public

An inquiry as to the amount of knowledge various investigators have had with other hydraulic models indicated a general lack of experience in this field. The James River Hydraulic Model used by the Virginia Institute of Marine Science with reference to oyster larvae distribution was the most well-known. Other models referred to were the Waterways Experiment Station model of the Chesapeake and Delaware Canal, the model of the Hudson estuary and New York Bight, and the Narragansett Bay Model. Private ownership, availability, and physical limitations of the model have apparently restricted usage of the models in the past. These will be eliminated with the completion of the Chesapeake Bay Hydraulic Model.

Prototype data which may be made available to various investigators for use in conjunction with model studies appear to cover a wide range of activities. Many of these data have appeared in previous publications and are already available to the scientific community. Some investigative institutions have been collecting data for many years and these will never appear for public distribution but are available from their files for general usage. Specific knowledge of data required and familiarity of the many research institutions of the Chesapeake area is necessary. As the Chesapeake Bay Hydraulic Model matures, a reference library of such available data and where it may be located can be incorporated in its facilities for scientific investigators.

Mathematical modeling of entire biological systems is becoming more common as research data on specific processes and interactions are made available. These conceptual models remain more or less in the realm of theory unless they can be proven to be correct. One method of testing would be through the use of the hydraulic model. Also, the hydraulic model can be used in many instances to obtain input data for the numerical model. The summary of responses to this question on mathematical biological techniques is interesting and indicates the importance of computer science in biological research. More and more research personnel are being trained in this area and the hydraulic model will become an essential instrument of their progress.

Table 1. Summary of replies where specific organisms or biological fields of research were mentioned to questions: 1 (Can the model be of use to your present research program?), and 2 (What possible uses do you foresee?).

Present research	Possible uses
1. Planktonic organisms	1. Plankton distribution
2. Fish movements	2. Shellfish larvae dispersal
3. Menhaden larval transport	3. Menhaden transport
4. Sea nettle distribution	4. Invertebrate larvae
5. Nursery area production	5. Oyster spawning
6. Fish distribution	6. Fish larvae
7. Juvenile blue crab dispersal	7. Eelgrass distribution
8. Shellfish setting	8. Bacteria and virus patterns
9. Flora and fauna changes	9. Algae growth
10. Oyster hatchery work	10. Crustacean recruitment
11. Bacterial associations	11. Fish eggs movements
12. Benthic invertebrate ecology	12. Microbial pollutants
	13. Clam spawning/setting
	14. Oyster drills
	15. Disease organisms
	16. Benthic invertebrate ecology

May 1974

Dear Colleague:

The Chesapeake Bay Hydraulic Model being constructed by the U. S. Army Corps of Engineers on Kent Island, Maryland, near the eastern end of the Chesapeake Bay Bridge, promises to be very valuable to the engineer, water resource planner, and scientist. It will provide a means of reproducing on a manageable and measurable scale some of the physical phenomena that occur in the Bay system, and will promote effective liaison among the agencies working in the Bay, help to reduce duplication of research, and assist public understanding of the Bay and its best uses.

It should be emphasized that the hydraulic model, with inherent capacities and limitations, is only another instrument of the scientist; there are questions it cannot answer and it cannot interpret results. It can help define certain physical effects such as thermal discharges and changes in salinity patterns resulting from the diversion of fresh or salt water inflows, but the model will not be able to define the effects of these environmental changes on the organisms and biological conditions of the Bay. Biologists and others will have to interpret the effects of these physical changes on the biota of the Bay and give the planners and decision-makers an assessment of the full environmental impact.

The Baltimore District of the Corps, who is responsible for construction of the model, has requested that members of the scientific community identify desired testing programs in order to promote greater and more effective uses of the model. These uses do not necessarily have to be within your particular area of expertise, but may encompass any phase involving model testing. After reading the enclosed pamphlet, would you please complete the questionnaire and return it in the prepaid envelope. Your help will be invaluable and appreciated.

Sincerely,

Hayes T. Pfitzenmeyer

Hayes T. Pfitzenmeyer
Chesapeake Bay Biota Project

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The Johns Hopkins University
University of Maryland
Smithsonian Institution
Virginia Institute of Marine Science

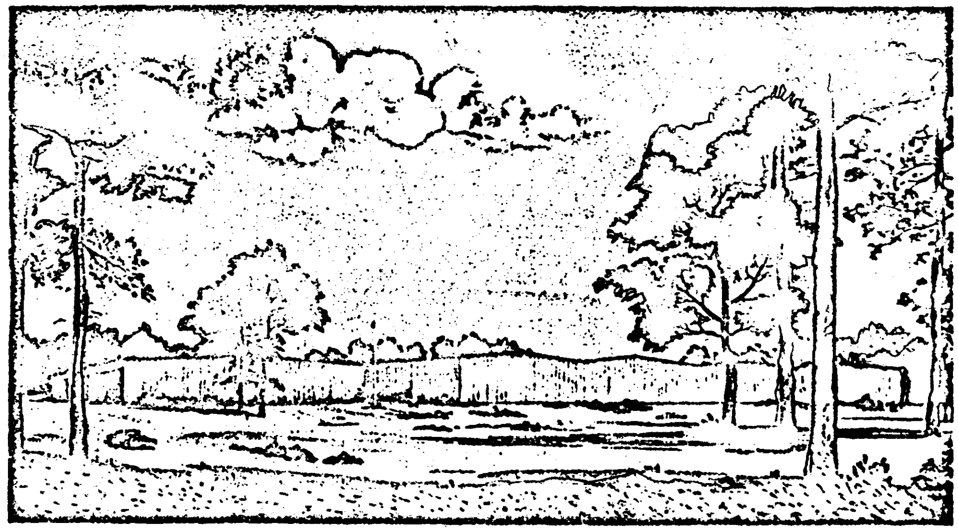
Uses of the Hydraulic Model

The hydraulic model is one of the most versatile instruments available to the hydraulic engineer and water resource planner, scientist, and engineer. In the Chesapeake Bay Study the hydraulic model will provide a means of reproducing to a manageable scale phenomena that occur throughout this large and complex estuarine body. Undoubtedly, studies planned in conjunction with the model will uncover problems of which serious students of the Bay regime are as yet unaware. As an instrument and physical display, the hydraulic model will be unexcelled in its potential for the education of an interested public in the scope and magnitude of the problems and conflicts of use that can beset this water resource in the future. As an operational focal point, it will promote more effective liaison among the agencies working in the Bay waters, helping to reduce duplication of research and leading also to accelerated spreading of knowledge among the interested parties of the public.

Research problems that will use the hydraulic model for their study include:

1. Determine the salinity distribution within the Bay system and study the effects of various factors on salt water intrusion.
2. Study the mechanics of estuary flushing.
3. Determine the effects of upstream impoundments and basin diversions on salinity distribution.
4. Study seasonal variations of salinity distribution.
5. Determine the effects of navigation projects and channel geometry changes on currents and salinities.
6. Develop better information on the circulation and upwelling current patterns of the Bay waters.
7. Determine preferred site locations of sewage treatment plants, under water outfalls, nuclear and fossil fuel power plants, and port facilities.
8. Investigate existing waste disposal facilities, outfall locations, etc., for improvement of discharge conditions relative to the Bay system.
9. Investigate waste assimilation capacity of the Bay and its tributaries. (Time of passage and waste dispersion tests, re-aeration coefficients.)
10. Study shoaling characteristics of the Bay and its tributaries.
11. Locate ship handling problems, current actions peculiar to Bay's waters that may be dangerous to both recreational and commercial boating, and the effects of storm conditions on the movement of water masses.
12. Make a qualitative appraisal and location of shore erosion problem areas.
13. Study the dispersion of oyster larvae by tides and currents to areas suitable for culture.
14. Study the possible biological effects in conjunction with the disposal of silt particles in certain methods of dredging disposal.
15. Study the possible influences of environmental conditions in the estuarine environment on the control of noxious weeds, jellyfish, and certain parasites.

CHESAPEAKE BAY STUDY & HYDRAULIC MODEL COMPLEX



Department of the Army • Baltimore District, Corps of Engineers

General Information

AUTHORITY: Section 312 of the River and Harbor Act of 1965

SCOPE: Complete investigation and study of water utilization and control of the Chesapeake Bay Basin including, but not limited to, navigation, fisheries, flood control, control of noxious weeds, water pollution, water quality control, beach erosion, and recreation.

Construction, operation, and maintenance of a hydraulic model of the Chesapeake Bay Basin.

DESCRIPTION: Chesapeake Bay is the largest estuary in the United States.

Length of Bay – 195 miles

Width of Bay – 4 to 30 miles

Average depth of Bay – 28 feet

Water surface area (Maryland & Virginia) – 4,300 square miles

Chesapeake Bay Drainage Basin – 64,170 square miles

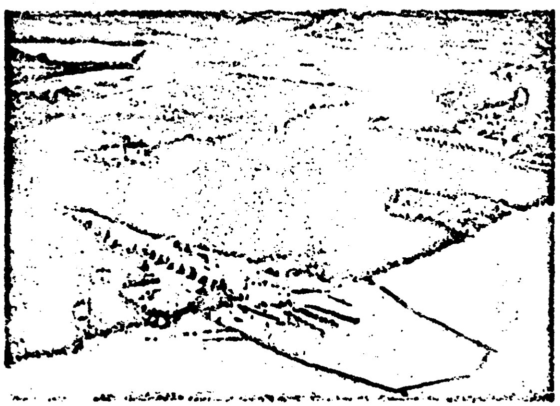
Tidal Shoreline – 7,300 miles

Deepest point in Bay – 174 feet near Bloody Point

Fed by nine major river streams:

Choptank	Patuxent	Rappahannock
James	Pocomoke	Susquehanna
Nanticoke	Potomac	York

Approximately 50% of the total fresh water entering the Bay comes from the Susquehanna River.



This site, the former eastern terminus of the Sandy Point – Matapeake Ferry, will be developed as the Chesapeake Bay Model Complex, which will include one of the world's largest working scale models of an estuary.

Model Information

Type – Fixed Bed, Distorted

Shelter – Approximately 635,000 sq. ft.

Length	1080 ft
Width	680 ft.

Area of Model:

Mean Low Water	166,000 sq. ft.
Mean High Water	184,000 sq. ft.
+20 Contour	273,000 sq. ft.
Total paved	9 acres

Volume of Water:

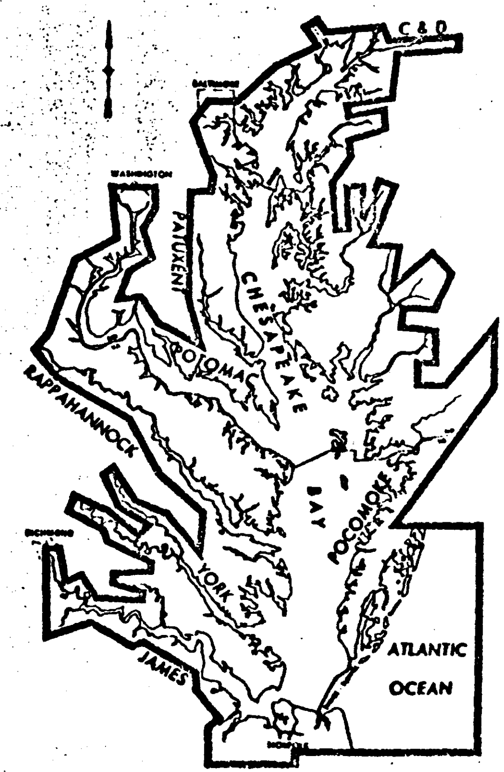
Mean Low Water	60,000 cu. ft.
Ordinary Tide	4,000 cu. ft.
Spring Tide	5,000 cu. ft.

Length of templets 130,000 ft. (26 miles) used in model construction.

Water Supply Sump 85,000 cu. ft.

Pipe Diameters for supply-return 24 to 36 in.

Metal strips embedded in model permit adjustment of frictional resistance to accurately reproduce the bay's tides, currents, and salinities.



APPROXIMATE MODEL LIMITS

CONVERSION OF MODEL DATA TO PROTOTYPE REQUIREMENTS

Model	Factor	Prototype
1 ft.	Depth	100 ft.
1 ft.	Length or width	1,000 ft.
10	Slope	1
1 cu. ft.	Volume	100,000,000 cu. ft.
1 cu. ft. per sec.	Discharge	1,000,000 cu. ft. per sec.
1 ft. per sec.	Velocity	10 ft. per sec.
7.45 minutes	Time	12 hours and 25 minutes
1	Salinity	1

QUESTIONNAIRE

1. Can the Chesapeake Bay Hydraulic Model be used in any research in which you are presently involved? If yes, please explain.

2. What biological applications or tests can you foresee for the Chesapeake Bay Model?

3. Have you had previous experience with another hydraulic model, testing some biological parameter? If so, briefly describe.

4. Do you have any data of unique environmental or biological conditions which have occurred in the Chesapeake Bay or tributaries which you think might be used in future research involving the model?

5. Do you work with, or are you aware of, any mathematical biological techniques that can be utilized with hydraulic model studies? If so, please specify.

MODEL CAPABILITIES AND LIMITATIONS

1. To a degree, the limitations of tests will vary according to the area and the depth of water being tested.

2. Tidal elevations in the model will be measured to 0.001 foot, which represents 0.10 foot in the prototype.

3. Current velocities will be measured to 0.02 foot per second (fps) in the model, corresponding to 0.2 fps in the prototype. Verification procedures will probably indicate that representative model velocities may vary up to a maximum of 20 percent from that in the prototype.

4. Salinity in the model will be measured to the same accuracy as prototype measurements; horizontally, vertically, and with respect to time.

5. Regarding temperature measurements, the model cannot be used to predict prototype temperature; however, changes in model temperatures can be measured to ± 0.1 degrees.

6. Sedimentation and shoaling tests will normally be conducted with a shoaling material simulant called gilsonite. Test results are generally qualitative.

7. Dye concentrations in dispersion tests will be measured to one part per billion. Previous model studies indicate that the model can be used to predict the distribution of concentration of conservative water quality constituents to an accuracy of about 20 percent.

8. Wind effects and prototype evaporation will not be reproduced since the model scale is distorted.

9. A semi-diurnal tidal cycle of 12.41 hours can be reproduced in the model to 7.45 minutes, and a year of record in nature can be simulated in less than 4 days of continuous operation.

APPENDIX I.

SUMMATION OF REPLIES TO QUESTIONNAIRE

A. CAN THE CHESAPEAKE BAY HYDRAULIC MODEL BE USED IN ANY RESEARCH IN WHICH YOU ARE PRESENTLY INVOLVED? IF YES, PLEASE EXPLAIN.

1. Distribution of planktonic organisms with respect to salinity gradients and tidal cycles.
2. Modeling and predicting the advection of pollutants, especially nutrients.
3. Qualitative indications of sediment dispersion at mouths of rivers.
4. Higher density, nutrient and trace element enriched water accumulates in anoxic zone of central Bay during summer. In what way does this water mix into upper Bay water and into lateral tributaries? Does this water act as a nutrient source for late summer plankton blooms (mahogany water) in upper Bay?
5. Transport mechanics of menhaden larvae from the Atlantic Ocean to the low-salinity tributaries of Chesapeake Bay.
6. To assist in understanding how certain locations are hydrodynamically prone to infestation of sea nettles. Also the production and contribution of nursery areas of many organisms may be enlightened through this facility.
7. Salinity ranges throughout Bay and under various flushing conditions. Could help explain fish and zooplankton distribution.
8. Estuarine flushing: Possibly residual times of toxic organic and inorganic compounds.
9. Studies of tidal flushing and salinity gradients will reveal that physical parameters of a system are as important as any biological ones.
10. Effects of sewage discharge and power plant discharge on aquatic organisms.
11. Teaching students about hydraulic modeling.

12. Study of current direction and velocity relative to geometric changes, i.e., jetties - manmade structures. Study of tidal surges - flooding. Study of nearshore sediment transport.

13. For studies on dispersal of juvenile blue crabs, it would be helpful to know the current patterns moving up the Bay, at depth, between June and October. Halocline patterns would also be useful.

14. The Chesapeake Bay Hydraulic Model could be of use to us in helping to determine which areas are most likely to need frequent biological surveys because of changing environmental conditions. An example of this would be oyster settings, clam settings, and fish migration patterns which can be greatly affected by both environmental and manmade changes in the topography of the Chesapeake Bay and its tributaries.

15. We feel the model may bear on our interest in the persistence of plankton patches in river systems and the main Bay-stem.

16. Many possible uses by the State of Virginia as a regulatory agency involving permits for discharges.

17. Remote possibility to study the survival and dispersion of phytoplankton species that are natural to or introduced into the model.

18. The model, with some modifications, will be very useful in shoaling studies.

19. Physical relationships to magnitudes of specific populations.

20. Sediment movement; stratified flows; shore erosion.

21. In a saline marsh-ecology project conducted in St. Mark's Wildlife Preserve, Florida. One of the areas of investigation is loss of nutrients and detritus to the estuary and quantification of energy movement. Such a model as you describe would be very useful in determining nutrient and detrital movement per tidal cycles. The rate of washing out dyes or tagged detritus could be followed.

22. The Model can be used to site sewage-treatment plant outfalls (i.e., the present siting activity).

23. If model is sufficiently sophisticated, it may be used to predict the dispersion and advection of pollutants from a specified source.

24. I am working with the distribution and abundance of canvasbacks and other waterfowl in the Bay in relation to the flora and fauna of the Bay. If the model can be used to predict the changes and abundance of the flora and fauna, I should be able to make a correlation with the waterfowl.

25. We are presently involved with shellfish sanitation work on the estuaries leading into the larger rivers. We are interested in how these larger rivers (Potomac, Rappahannock, e.g.) affect flushing characteristics of the sub-estuarine (e.g., Yeocomico R., Nomini R., etc.).

26. The Hydraulic Model should be useful in connection with the oyster hatchery being built in the Bay area. The determination of the effect of multiple-layer oyster-growing trays in the rivers and bays could be ascertained.

27. Studies of Water Supply Problems.

    a. Effects of embayments, impoundments, and other flow alterations on supply patterns.

    b. Consequences of increasing consumptive-use patterns such as possible fresh-water shortages.

    Studies of Water Quality Problems.

    a. Determination of area and degree of impact of certain urban and/or industrial wastes and runoff.

    b. Patterns of suburban and/or agricultural runoff and dispersion.

    c. Waste-water control and reclamation.

    d. Effects of wetlands on water quality.

    e. Areas affected by sewage treatment plant effluents.

    f. Dredging and overboard spoil disposal problems.

    Conservation of Fish and Wildlife Resources

    a. Mechanics of input, transport, and dispersal of materials toxic to Chesapeake Bay organisms.

b. Dispersal patterns of regulated food contaminants throughout the habitats of commercially utilized species.

c. Boundaries and potential effects of basic habitat alterations such as salinity displacements.

d. Definition of environmental alterations induced by natural phenomena such as hurricanes and tropical storms.

e. Tides, currents, and dispersal patterns associated with fish mortalities.

Studies of Erosion and Sedimentation.

a. Patterns of natural erosion and sedimentation in estuarine waters.

b. Effects of specific human activities on sedimentation rates and patterns.

c. Evaluation of methods of stabilizing shorelines and protecting tributaries from excessive sedimentation.

Recreation.

a. Site capacity studies for marinas, fishing piers, and other recreational facilities.

b. Effects on established recreational areas such as beaches by other activities such as dredging and spoil disposal.

c. Studies of the effects of municipal, industrial, and agricultural activities on the habitats of sports-harvested species.

Feasibility and Impact Studies for Proposed Projects.

a. Power plant siting studies.

b. Sewage treatment plant siting studies.

c. Waste and spoil disposal siting studies.

d. Any other proposed project involving potential physiochemical alteration of the environment.

28. We are interested in bacteria associated with suspended particulate matter and with sediment. Therefore, the effects of current, salinity, and

temperature in affecting distribution of particulate matter, hence, bacteria would be of interest to us.

29. To study changes in benthic invertebrate population and community structure under altered environmental conditions.

30. Fish movements, effects of alterations upon fish avoidance or attractions. General zones of salinity in which fish might be encountered.

31. Studies of water motion and mixing in Bay using radioactive cesium fallout as a tracer. Model will be valuable to test tracer method.

32. Scaled-down nutrient enrichment studies. Sedimentation studies. Dispersion studies.

33. Entrainment of biota at power plant sites.

B. WHAT BIOLOGICAL APPLICATIONS OR TESTS CAN YOU FORESEE FOR THE CHESAPEAKE BAY MODEL:

1. Plankton distributions

2. Biological applications must be inferred from relatively few physicochemical parameters. These can, however, be used to identify geographically the various hydrographic regimes, which may require different management procedures. More biological information would be indicated.

3. This model could be useful in determining expected salinities and temperatures along Chesapeake Bay, which in turn could be used to assess the impact of power plants and other industrial development along the Bay.

4. Gross indications of dispersion of larval stages of shellfish.

5. Physical models may be very important in the testing and managerial implementation of biological models. This importance stems from the use of hydraulic models to predict the spatial and temporal distributions of nutrient materials, toxic chemical species, suspended sediment, currents, and other factors which may be inputs to biological response models. Hence, even though biological phenomena cannot be directly considered using physical models, these models may be required for the real worlds of application of mathematical models to biological processes.

6. With proper light-energy and source-water, would it be possible to reconstruct the late summer hydrographic conditions and attempt to see effects on algae growth?

7. Effects of long-term re equivalent to 10-20 years of perhaps Melon Kovetch cycle studies.

8. Current transport mechanics for menhaden, other fishes and invertebrate larvae.
Distribution of detritus, plankton and other nutrients.
Sedimentation and cycling of metallic ions.

9. Oyster spawning success - seed areas - characterize from known and look for similarities. Use statistical reliability criteria.

10. Prediction of extreme salinity conditions under periods of maximum and minimum discharge.

11. Analysis of the fate of waste plumes under varying conditions so that a real extent of discharges and concentrations can be estimated. Biologists can then use this information on the planning of laboratory experiments to determine the effects of living systems.

12. I would like to know the relative importance or lack of importance of the tributaries such as the Anacostia River to the water-flow down this section of the Potomac. I would also like to know the proportional roles played by man-made effluents - sewage plants and heated power plants.

13. Evaluate impact of STP outfalls on shellfish growing areas.

14. Life cycle studies.

15. Effect of power plants, pesticide programs, and industrial development. Transport of fish larvae within Bay. Effect of residential development and resulting pollution. Recruitment studies involving commercially important crustaceans.

16. Changes in distribution of fish and invertebrates related to the impact of power plants and sewage discharge.

17. Movement of fish eggs due to circulation of water in the Bay.

18. Distribution and dilution effects on microbial pollutants as related to shellfish resources; public health aspects of waterborne toxicants and viable disease agents.

19. Movement of pollutant chemicals in water and sediment, into, within, and out of the estuarine model.

20. If changes in salinity, temperature, turbidity, and silt deposition occur to an extent whereby marsh, swamp and other wetland vegetation is affected, or if pollution deposition occurs to such an extent, then certainly any research involving marsh and/or aquatic vegetation would benefit from knowledge of indicated changes as predicted by the model. How much change would be required and whether or not such a degree of change would be within the model's capability would have to be determined. Effects of erosion on wetlands. Transport of detritus from marshes throughout the Bay - greatest and/or most valuable source of productivity and sinks and transport. Effects of ice formation and scouring.

21. The Chesapeake Bay Model could provide mass transfers of materials, species, etc., among sections of the Bay as inputs to "seasonal", or quasi-steady state, ecosystem models.

22. Helping to determine what effects weather changes, etc., can have on oyster settings, clam settings, clam/oyster spawnings, etc. An example of this would be the effects of the changing of a shoreline pattern by building a bulkhead, etc.

23. Using dye innocula or, with suitable illumination, an actual phytoplankton introduction which is subsequently sampled over time.

24. Thermal (Nuclear Power Plant Discharges).

25. Erosion and shoaling in beds of oysters, clams, eelgrass, and marshland at water's edge. Effects of unusual storms or seasons on salinity and silt load. Rate of transport for pollutants.

26. Hydrodynamic distribution of pollutants from point-sources through dye and chemical studies.

27. Effects of dispersed wastes as related to aquatic life.

28. The dispersion and rate of degradation of various pollutants.

29. The model can be used to determine some circulation change (mostly local) due to natural abnormal stages (flood or storm surges) or pollutant movements. Then the results can be applied to ecosystems as input functions. Direct biological simulation (for instance dispersion of larvae, etc.) is impossible and the results may be misleading.

30. Flushing rates and relations between net flows, in and out, surface and bottom, and precipitation rates as they affect change in biological recruitment of certain species.

31. Investigations of pollution and alteration of estuarine systems.

32. Influence of organisms on sedimentation (by deduction).

33. Environmental pollution.
Plankton studies.
Chemical and physical, ocean or estuarine studies.
Sedimentation.

Vegetative experimentation.
Controlled radiation.

34. Mixing at river junctions and in vicinity of wetlands. Movement through defined channels in wetland areas.

35. I think the model should increase its biological capability especially in regard to determining the cause of the decline of vegetation.

36. We need to know dilution, flushing and time of travel in order to understand coliform and fecal coliform patterns throughout the Bay.

37. Sewage effluent tracing.
Bacterial die-off.

38. Comparison of distribution of hypothetically totally passive plankton organisms with actual distribution, in a study of intrinsic controls over dispersion.

39. Distribution and setting of oyster larvae.
Intrusion of oyster drills with dredging and increased salinities.
Intrusion of MSX and other disease organisms.
Modifications of spawning grounds of fishes - and larval distributions.

40. By determining current patterns in the Bay, it may be possible to predict and lessen the impact of toxic pollutant discharges on fisheries.

41. Planktonic larval distribution and dispersal.
Population control by salinity, temperature, etc.
Population dispersal.

42. The ability to define and project certain significant physical parameters of the physico-chemical environment allows a more refined focusing of bioassay enterprises, endowing the model with application in the biological realm. It is appropriate to state that this type of relationship exists as a significant factor in most areas of biological investigation and given man's tendencies to constantly alter the existing environment, the model should be of considerable value to future investigations.

43. Biological applications would be to determine the distribution of bacteria and viruses in the Chesapeake Bay as affected by current, turbidity, suspended matter, etc.

44. Document herbicide and pesticide run-off to the Bay and correlate the oyster reproduction with its flow pattern. Do same for heavily chlorinated sewage effluents.

45. Study changes in benthic invertebrate populations and community structure under altered environmental conditions and studies of production (yield) under different conditions.

46. Identification of probable sinks for heavy metals and other toxins introduced in particulate form. Coupled with data on temperature, turbulence, salinity, and water depth, predictions should be feasible of the probability of remobilization of trace toxins by resuspension.

47. Thermal model studies. Electric facilities.

48. Test to check the distribution by currents of reproductive propagules of plants.

49. Widely varied uses - in problems involving circulation.

50. Predict the movement of noxious effluents with respect to the location of commercial shellfisheries.

51. Distribution of sediment, pollutants, heat and nutrients from point sources with continuous, instantaneous, or periodic releases.

52. Possibly bioassay application for certain chemicals such as chlorine, chloramines, cyanides, etc.
Phytoplankton distribution studies with respect to wind and tides.
Schooling behavior of fish (young menhaden) and their effects on the water quality with respect to uptake of algae and waste excretion along with respiratory utilization of oxygen.

53. Estimates of entrainments for multi-site power plant installation in the northern end of the Bay.

C. HAVE YOU HAD PREVIOUS EXPERIENCE WITH ANOTHER HYDRAULIC MODEL, TESTING SOME BIOLOGICAL PARAMETER? IF SO, BRIEFLY DESCRIBE.

1. Mathematical as opposed to physical modeling has been successfully used for pollution abatement on the Potomac Estuary, especially with regard to dissolved oxygen deficiencies and eutrophication parameters.

2. The use of the James River Model owned by the Virginia Institute of Marine Science and the U. S. Army Corps of Engineers was recently considered for projection of the movement of oil spills and refinery waste products in the Hampton Roads area of the James River. This information was to be utilized to assess potential impacts on the estuarine biotic community. However, due to alterations in plant design, these experiments will no longer be required.

3. Water Experimental Station Model of C & D Canal.

4. I have heard about the hydraulic model being used on the James River which has been for the most part very useful to the biologists in Virginia.

5. Models of Hudson Estuary and New York Bight.

6. A physical model developed by the Alden Laboratories was used to predict the temperature regime in the vicinity of a power plant using once-through cooling. Our company was involved in analyzing the biological effects of the discharge.

7. James River Hydraulic Model - oyster larvae distribution study.

8. We are familiar with the Narragansett Bay Model used a few years ago to predict coliform, D. O. patterns.

9. Salem Church Dam proposal. Distribution zone (nursery) for young-of-the-year alosids and striped bass. Other marine fish.

D. DO YOU HAVE ANY DATA OF UNIQUE ENVIRONMENTAL OR BIOLOGICAL CONDITIONS WHICH HAVE OCCURRED IN THE CHESAPEAKE BAY OR TRIBUTARIES WHICH YOU THINK MIGHT BE USED IN FUTURE RESEARCH INVOLVING THE MODEL?

1. Plankton data as a result of hurricane AGNES on the lower Bay. York River distributions.

2. We have extensive data holdings on upper Chesapeake Bay and some tributaries including the Potomac estuary. Monthly observations of water quality parameters, especially nutrients, are available.

3. Rice Division (Nus Corporation) is currently undertaking a study of chemical and biological water quality in the Hampton Roads vicinity of the James River estuary. These data may be utilized at some future date in conjunction with model research and/or model development.

4. Open-water metabolic estimates from Rhode and West Rivers, 1970 through 1974.

5. Over 10 years of oyster setting records for Tred Avon River, Broad Creek, and Harris Creek. Also salinity and temperature (weekly and some daily) for Tred Avon River.

6. I have biological data on Potomac River from Chain Bridge to Piscataway Creek from 1970 to 1971 and 1973 to 1974. Also I have plankton data at 10-mile sites to Pt. Lookout. Presently, I have an O. W. R. P. grant with the Dept. of Interior to study the aufwuchs microcosms collected on mid-river buoy/floats and Blue Plains sewage final sedimentation tanks.

7. Limited bacteriological data in Virginia tributaries collected in our efforts to open shellfish areas closed as a result of hurricane AGNES.

8. Tide recording in Spa Creek and noted frequencies higher than for a normal tide cycle. We think they represent seiches.

9. I have some data on the effects of declining salinity and of sedimentation upon the inshore macroinvertebrate fauna.

10. Salinity fluctuations over past years that may relate to spread of disease organisms such as MSX, Paramoeba, etc.

11. Elizabeth, Back River, etc., from present RANN Contract.

12. Much published data concerning waterfowl populations: abundance, distribution, sex ratios, etc. Also much unpublished data concerning invertebrate sampling in the Bay and extensive weights and measurements of Rangia in Potomac and Baltimore Harbor.

13. Limited data on coliform, fecal coliform, and fecal streptococcus.

14. Hydrographic nutrient and zooplankton data before, during, and after flooding from tropical storm AGNES - lower Chesapeake Bay.

15. Worked on "Operation York River" and "Over-Ride" after hurricane CAMILE hit Virginia. Measured physical parameters with other people from VIMS.

16. The broad scope and constant nature of the investigative programs of the Department of Natural Resources has contributed to compilation of a large and comprehensive data band which includes data on most environmental or biological conditions in recent years.

17. We have data concerning bacteria associated with particulate matter, and the influence of salinity and current on the distribution of these bacteria. (U. of Md. Dept. of Microbiology).

18. Have information on the distribution and abundance of aquatic grass beds.

19. Tracer work since 1968 using Cesium, including AGNES data.

20. We find the upper ends of most tidal embayments or creeks to be conducive to eutrophication as a result of the various undefined physical phenomena of flow, sedimentation rates, etc. It would be nice to be able to quantify some of these effects.

E. DO YOU WORK WITH, OR ARE YOU AWARE OF, ANY MATHEMATICAL BIOLOGICAL TECHNIQUES THAT CAN BE UTILIZED WITH HYDRAULIC MODEL STUDIES? IF SO, PLEASE SPECIFY.

1. I believe that selected studies can be described and tested.

2. Possibly bacterial densities in tidewater can be related to runoff and flow conditions, but we have no hard data pertinent.

3. My doctoral research project is concerned with the mathematical modeling of biological response. At present, a model of primary productivity has been calibrated and tested. A conceptual model of aquatic food web interactions has been formulated and calibration efforts have been initiated. The dissertation paper is entitled "A mathematical model of eutrophication in Lake Mead."

4. Only general loading, productivity models with phytoplankton and, to much lesser extent, bacterioplankton and bacteriobenthos.

5. The Annapolis Field Station of E.P.A. has done much modeling work.

6. Lehigh University has computer program for the Behrens Natural Resource Utilization Model.

7. Write College of Fisheries, University of Washington, concerning Cedar River - Lake Washington study which looked at this habitat in a systems analysis manner.

8. The Delaware Estuary Water Quality Model of the O'Connor - Thomann (Manhattan College) variety and the hydrodynamic model of D. Harleman and his colleagues at M.I.T. See Tracor, Inc., Estuarine Modeling: "An Assessment", E. P. A. (U. S. Government Printing Office, Washington, D. C., Cpts. 2, 3, and 5).

9. Analysis of variance for production data which permits assessing overtime, characteristic differences in phytoplankton performance with position in the Bay.

10. See study of Jamaica Bay.

11. Best way may be to develop numerical models based on physical data obtained from model experiments.

12. Hybrid computation involving logic gates and track and store units.

13. Systems analysis using differential equations. Use the model for scaling.

14. There are a number of computer models (e.g., Univ. of Oregon, Water Resources Engineers, E.P.A.) that simulate estuary conditions (temperature, salinity, sediment flow, etc.) which influence biological conditions: These models could be (and should be) tested under laboratory control in the Bay Model.

15. I am aware of some math techniques that might perhaps be applied to hydraulic model studies, i.e., statistics, fluid mechanics, similarity conditions, etc.

16. Attached is a list of references we have considered in some of our work. (References for Outfall Studies, see Appendix I.)

17. The Department of Natural Resources is presently contracting for two modeling studies of the Chesapeake Bay. Both studies are transport models, one involving the transport of sediments, and the other dealing with dissolved solids. While neither study is focused on the biological, both can be applied to problems involving transport of biologically significant materials, such as toxicants.

18. Larval fish dispersal may follow some dispersion tendency such as salinity. Test homing and voluntary migration versus random involuntary dispersals.

19. Use of bottom dwellers, such as clams, as indicators of tracer and salt concentrations and thus water movement and mixing.

20. Striped bass spawn-entrainment computer models.

APPENDIX I.

REFERENCES FOR OUTFALL STUDIES (Annotated)

April 21, 1971
Santo A. Furfari
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Bailey, Thomas E. 1966. Flourescent-Tracer Studies of an Estuary. J. Water Poll. Contr. Fed. 38, No. 12, 1989-2001. (Dec.) California Studies; dyes; instruments; tracing methods, evaluate results.

Beckman, Wallace J. 1970. Engineering Considerations in the Design of an Ocean Outfall. Water Poll. Contr. Fed. 42, No. 10, 1805-1831, (Oct.). Comprehensive listings of considerations for ocean outfalls. Useful list for site selection on page 1808 (19 factors). Used for Wantagh, N. Y.

Belt, Robert M. 1964. An Oceanographic Study of Sewage Discharge into Kailua (Hawaii) Bay. Water and Sewage Works. 368-373, (Aug.). Practical field studies with dye, floats, described.

Diachishin, Alex N. 1957. Report on Changes in Pollution Distribution in Narragansett Bay occasioned by Lower Bay Hurricane Protection Devices. Dept. HEW., (mimeo). Practical descriptions, examples; Pritchard's method; eddy diffusivity.

Falk, L. L. 1966. Factors Affecting Outfall Design. Water and Sewage Works, Ref. No. R-233 to R-237 (Nov.). Shows dye studies; density differences in rivers; explains Rawn's work with Froude Number.

Foxworthy, J. E. et al. 1966. Dispersion of a Surface Waste Field in the Sea. J. Water Poll. Contr. Fed. 38, No. 7, 1170-1193. (July). California studies on currents, etc., dispersion, plumes; formulae given.

Gunnerson, C. G. 1958. Sewage Disposal in Santa Monica Bay, California. Proc. ASCE, J. San. Eng. Div. SA 1, paper 1534, 1-28. (Feb.). Practical study of eddy diffusivity, bacteriological factors, combining t-90 values (dilution, die-off) and requirements of sewage treatment.

Hamemoes, Poul. 1966. Prediction of pollution from Planned Wastewater Outfalls. J. Water Poll. Contr. Fed. 38, No. 8, 1323-1333. (Aug.).

Hetling, Leo J., and O'Connel, Richard L. Estimating Diffusion Characteristics of Tidal Waters. Water and Sewage Works. How to derive scale factors, diffusion characteristics; Potomac River; turbulent pipe-flow analogy.

Ichiye, Takashi. 1968. Hydrography, Tides and Tidal Flushing of Great South Bay - South Oyster Bay, Long Island. Trans. of the National Symp. on Ocean Sciences of Engineering on the Atlantic Shelf, Marine Tech. Soc., 15-62. (Mar.). Extensive mathematical studies with tidal prism considerations. Flushing rates of pollution.

Ketchum, Bostwick H. 1951. The Flushing of Tidal Estuaries. Sew. and Ind. Wastes. 23, No. 2, 198-208. (Feb.). Tidal prism concept; useful for outfalls into tidal rivers; well-mixed, and good salinity gradients.

Pearson, Erman A. 1965. Some Developments in Marine Waste Disposal. Presented at Conf. of Inst. of Sew. Purification, Durham, South Africa, May 3-7 (mimeo.). Useful formulae for mixing, diffusion calculations; field study procedures; bacteriological decay.

Waldichuk, Michael. 1965. Estimation of Flushing Rates from Tide Height and Current Data in an Inshore Marine Channel of the Canadian Pacific Coast. Proc. of the 2nd Inter. Water Poll. Res. Conf., Tokyo, 1964. Pergamon Press Reprint. Flushing studies, rates of mixing (used by Ketchum), examples.