A BIOLOGICAL EVALUATION OF THE *Delaware River Estuary*

Carl N. Shuster, Jr.

INFORMATION SERIES, PUBLICATION NUMBER 3

UNIVERSITY OF DELAWARE MARINE LABORATORIES

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Carl N. Shuster, Jr. -- Director

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SYNOPSIS

This report deals with the biological productivity of a unit of Nature, the Delaware River estuary. In many respects this estuary and its productivity is similar to that of the several other estuaries along the Atlantic coast of North America, but each, like a person, has its own individual characteristics. This productivity and related biological, chemical, geological, and physical characteristics of the Delaware River estuary are not known fully, yet they are being studied and the descriptions and knowledge obtained each year can be useful to those persons concerned with the best use of our coastal areas.

In dealing with the economic value of the Delaware River estuary, we are concerned with an area some 4,000 square miles in extent which directly affects the economy of the coastal portion of New Jersey, Delaware, and Maryland. This coastal water area is responsible for a large fisheries harvest, for minerals, and for recreational uses valued at many millions with an annual ultimate value to the consumer probably measurable only by hundreds of millions of dollars. The capital investment to provide this annual economic benefit from estuarine resources is obviously of great magnitude. The fact that Nature furnishes the initial portion of the capital does not give mankind the right to misuse or squander it.

INTRODUCTION

During recent years Delawareans have been increasingly concerned over the availability of freshwater for the future growth of their state. This concern has been heightened by the actual and projected increases in diversion of freshwater from the Delaware River watershed as well as by population growth estimates of three and seven times the present Delaware population in the years 2010 and 2060, respectively. In addition to the many uses to which man puts freshwater, it is important to the plants and animals of the estuary. This importance is highlighted by this report.

Prediction of the future water needs of the biota within the Delaware River watershed can be based upon a single principle: the abundant plant and animal populations now living in the watershed area would be adversely affected if the characteristics of the available usable water supply were markedly changed. Since it is also axiomatic that all living organisms are dependent upon water, any marked variations of long duration in the chemical and physical characteristics of that water, either natural or man-made, will determine to a large extent what organisms will survive the changes. These principles apply, with even more restrictions, to the biota in the lower reaches of the watershed, namely, the Delaware River estuary (Figure 1). There live and grow multitudinous populations of all kinds of organisms, acclimated through millions of generations to the dynamic present-day estuarine environment.

It can be predicted that an increase in the human population will create greater demands for food and recreational space than are now being exerted upon coastal areas. This pressure for more food and greater use of recreational areas means that the resources of estuaries will be utilized to a much greater extent than at present. Indeed, greater biological production will be needed to meet these needs, and freshwater will be one of the key environmental factors in the plans for increasing food production in our estuaries and increasing the recreational advantages of coastal areas.

It is not the intent of the writer to deal with predictions concerning the future of estuarine life. Much research will be required before tolerances of estuarine organisms can be related to guesses on the possible magnitude and duration of changes in the kind and amount of water that might occur in the estuary. More important, at the present time, is an outline of what is known about biological production in the Delaware River estuary. This outline will form a reference from which comparisons and predictions can be made with more understanding and accuracy, as research data and observations accumulate.

The concept of biological production, which is a central theme of this report, bears a close resemblance to that of industrial production. Instead of reporting upon the number of automobiles manufactured at a certain factory per day, the marine biologist may seek to record the weight of oysters harvested per acre per year or the amount of microscopic plant life produced per gallon of seawater per day. One objective in productivity studies is to measure the rate at which production occurs. The calculation of this rate serves a useful purpose: it permits the comparison of the production in different marine areas and enables the economic evaluation of either an area or a crop or both. In succeeding portions of this report the concept of biological production will be used to estimate the value of the Delaware River estuary and certain of its crops and areas.

Emphasis is placed also upon the estuary as an environment and upon some commercially harvested estuarine animals. This

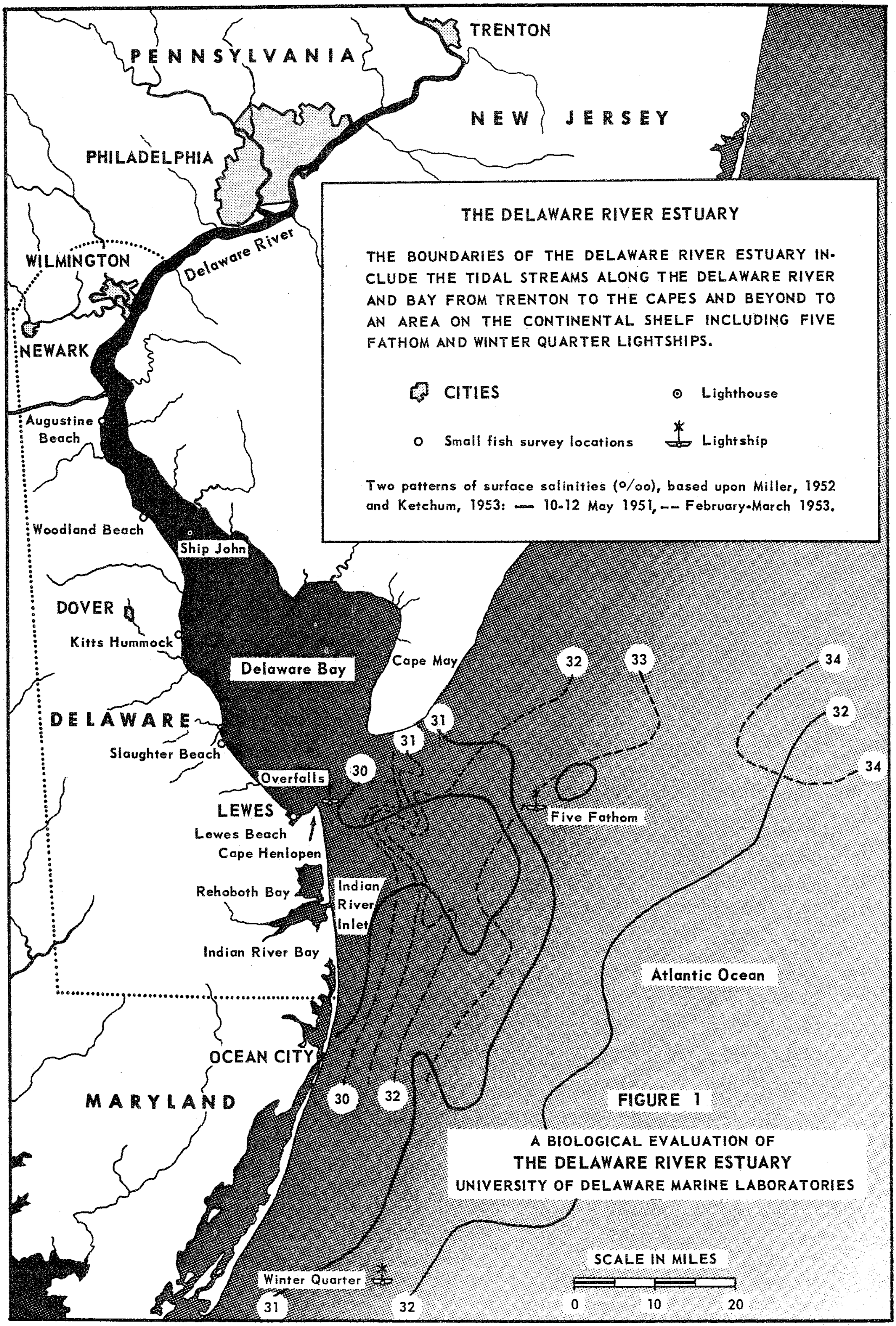

FIGURE 1

A BIOLOGICAL EVALUATION OF
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report is not intended as an exhaustive treatise, but as a document highlighting what we know about some of the salient features of our Delaware coastal areas from the marine biology viewpoint.

Acknowledgements. The information contained in this report is based largely upon the collective research experiences of the Marine Laboratories staff and upon the results of special projects undertaken by graduate students. The writer is indebted to his colleagues for the use of their research data and their valuable critiques: Dr. Franklin C. Daiber, Mr. William H. Amos, and Dr. Donald P. deSylva. Mr. Frederick A. Kalber, Jr. has contributed an intriguing hypothesis on a role of tidemarshes in estuarine productivity. The data and discussion on the mysid shrimp, *Neomysis americana*, are based upon the research of Mr. Thomas L. Hopkins. Appreciation is extended to our students for their excellent project reports, without which the writer's task could not have been so easy: Paul A. Haefner, Jr. (Morphometry), Charles M. Bearden (Shore Zone Fishes), Theodore P. Ritchie (Shellfisheries), and Paul W. Hess (Sport and Commercial Fisheries).

During the winter-spring period of 1959, Dr. Daiber and his students (Charles Bearden, Paul Haefner, Paul Hess, Robert E. Hillman, and Frederick Kalber) made a pilot study of the Canary Creek marsh near the Bayside Laboratory at Lewes. This exploratory study was undertaken as the field problem portion of the Fish Ecology course at the University of Delaware. Organized by Dr. Daiber as a cooperative research project, the number of participants enabled a wide attack upon the problem of production in a tidemarsh. Major segments of the research included: hydrography, nutrients, the rooted plant crop, organic detritus, plankton, tidemarsh invertebrates, and fishes. Although the data collected and the observations made during this study have not been fully analyzed, a few of the results have been incorporated into the section on the significance of tidemarshes in estuarine production.

Mr. E. A. Power (Chief, Branch of Statistics, Division of Industrial and Research Services, Fish and Wildlife Service, U. S. D. I.) has kindly made available to us data supplementary to the annually published statistical digests, "Fishery Statistics of the United States."

The content of this report has benefited from the work and advice of the people mentioned above: its organization, and whatever shortcomings are present, are the responsibility of the writer.

THE UNIVERSITY OF DELAWARE MARINE PROGRAM

Establishment. In 1951, during the 116th Session of the General Assembly, an appropriation was made to the University of Delaware to establish "a program of research on past, present and potential products from the salt waters of the State, of instruction of special students, teachers and public citizens on the fishery, biology and conservation of aquatic resources, of encouragement of all types of investigation on salt and estuarine waters and their inhabitants, and for provision of advisory assistance to administrative and other agencies concerned with the utilization of marine and estuarine resources." (LAWS OF THE STATE OF DELAWARE: Volume 48, Chapter 73, pages 155-156).

A legislative appropriation in 1953 made possible the construction of a permanent field station, the Bayside Laboratory at Lewes, Delaware. There the M. Haswell Pierce Building was dedicated in 1956. Physical facilities for the marine program are also provided on the University campus in Wolf Hall.

Organization. The marine program is an integral part of the Department of Biological Sciences at the University of Delaware. A program has been evolved in the department to carry through from research to education to conservation advisement on all matters pertaining to tidewater resources in adhering to the threefold purpose stated in the law enacted by the General Assembly in 1951. The threefold organization and the scope of the marine program are illustrated in Figure 2. This is the blueprint upon which the Marine Laboratories program is being developed.

Objectives. The objectives continue as originally and broadly conceived in the establishing legislation. This broad base of objectives is a valuable heritage. It permits the development of a program not hampered by restrictions upon its scope but governed largely by the abilities of its participants. Since it is not now practical to conduct the full scope of possible activities, due both to financial and practical reasons, the responsibility for the kind of program rests largely upon its administrators. In recent years the emphasis has been upon strengthening the graduate program, increasing research, and upon communicating the results of the research to the public. Accomplishments within these and other activity areas are documented in a Biennial Report series (1952, 1953-1954, 1955-1956, 1957-1958) published by the Marine Laboratories.

Income. The University budget is augmented by contracts with governmental agencies and by research grants from individuals and national organizations. A substantial portion of the

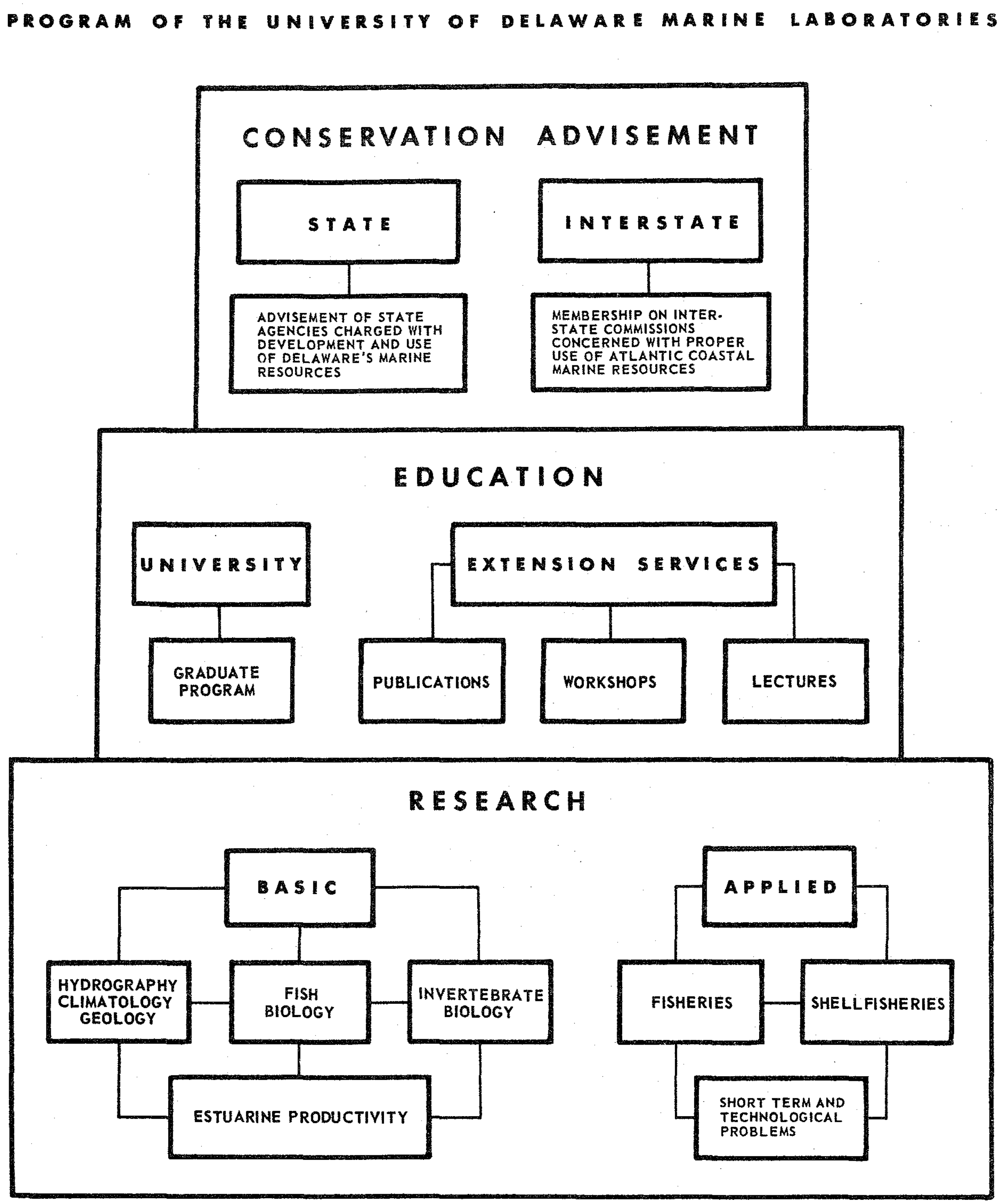

FIGURE 2

A BIOLOGICAL EVALUATION OF THE

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income is required to maintain and operate the Bayside Laboratory facilities: the isolated building plant, research equipment, research vessels, docks, bulkheads and roads. Indeed, if it were not for the financial augmentation there would not be much research. Expenditures in recent years have varied from $49,000 to $63,000 yearly. This low cost for the marine program contrasts with an estimated minimum annual $10,000,000 fisheries-dependent income in the State of Delaware.

MORPHOMETRY OF DELAWARE BAY

Morphometry (dealing with the measurement of the topographical features of a lake basin or a stream bed and their included water mass) has developed traditionally as a branch of limnology, the study of lakes and ponds. Since certain fundamental conditions of biological productivity arise directly from the structural relations of bodies of water, it is common procedure to make various measurements of the morphological features of basins to determine the role which the feature may play in biological phenomena. Morphometric studies also provide a convenient quantitative means to compare different bodies of water (Hutchinson, 1957). In this report, morphometric techniques have been used to describe topographic characteristics of Delaware Bay.

As far as is known, little or no work had been done on a morphometric analysis of Delaware Bay prior to the present study. The only record in the Marine Laboratories files is an estimate of the depth and volume of the river, bay, and ocean along the coast of Delaware prepared in 1953 by Dr. Eugene L. Cronin, former director of the marine program. This estimate, however, did not include the eastern portion of the bay.

The following material provides morphometric information on Delaware Bay which should prove useful in environmental studies and in evaluating the productivity of the bay.

Methods and results. Measurements made on the U. S. Coast and Geodetic Survey Chart #1218, corrected as of September 13, 1958, were the source of the data reported in this morphometric study of Delaware Bay. The chart is a Mercator projection with a scale of 1:80,000 at Latitude 39°06'.

Various methods, measurements, and calculations described by Welch (1948) and Hutchinson (1957) were used in this analysis. Linear measurements were made with the use of a rotometer calibrated in inches. Areas were determined with the use of a Keuffel and Esser Compensating Polar Planimeter, model # 4236, calibrated to read in square inches. All measurements obtained were converted to larger units of area by the use of conversion factors.

Upper and lower boundaries of Delaware Bay were established arbitrarily for the purpose of analysis as follows (see Figure 3):

Upper Boundary. Indicated by a line across the bay from the Smyrna River Light (Delaware) to a point on the New Jersey shore midway between the tower on Arnold Point and the tower at Mad Horse Creek. This point is in the region of Lower Deep Creek.
Lower Boundary. Inland waterway boundary line from Cape Henlopen (Delaware) to Overfalls Lightship to Cape May Inlet (New Jersey).

The data compiled included the following measurements and calculations:

(1) Maximum Length (MxL): 46.7 Statute Miles;
40.7 Nautical Miles.

Length of line connecting the two most remote extremities of the bay. In this case, a straight line from the Ship Channel at the Smyrna River to Overfalls Lightship.

(2) Maximum Effective Length (MxEL): 46.7 Statute Miles;
40.7 Nautical Miles.

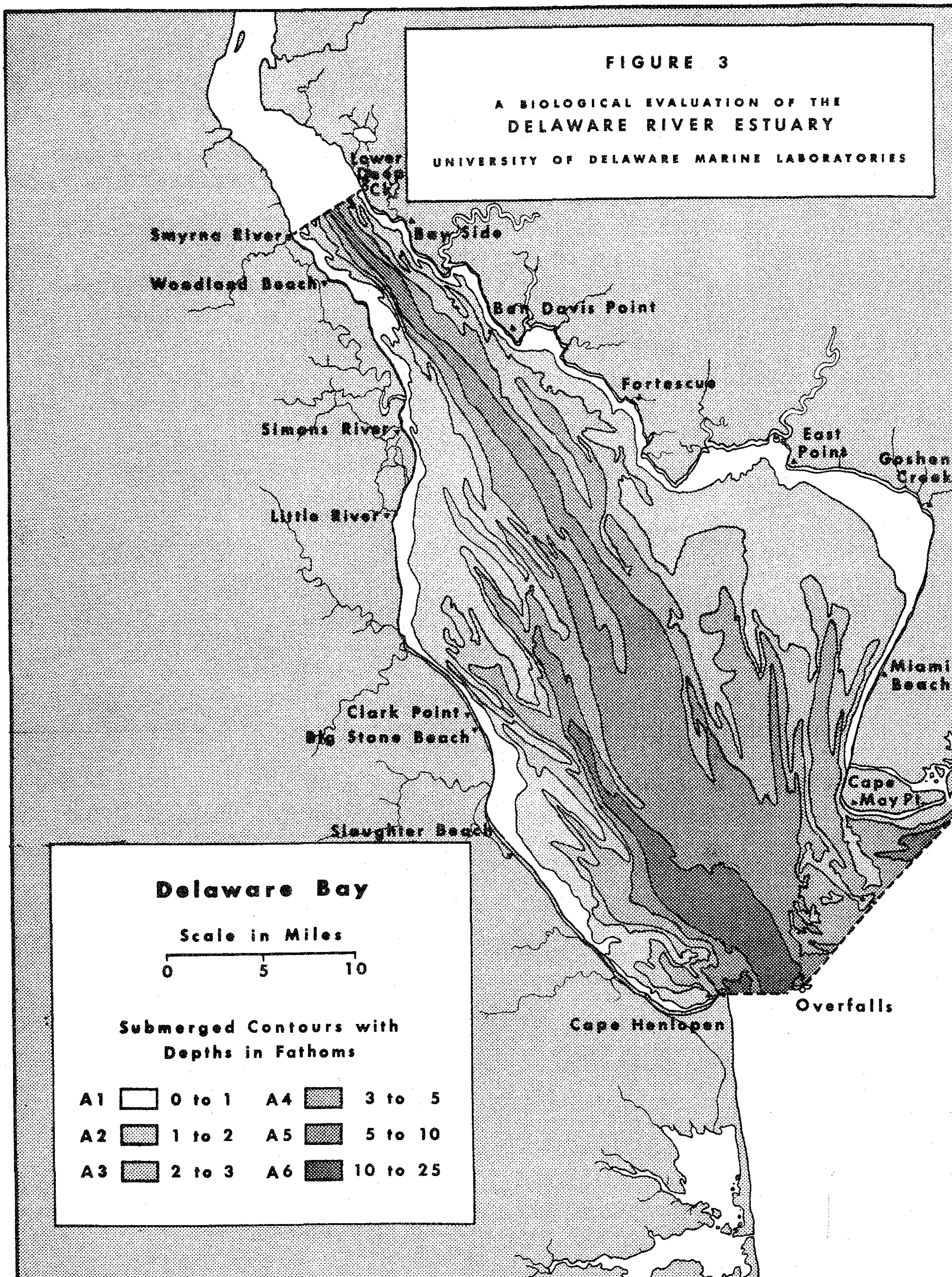
Length of straight line connecting the most remote extremities of the bay along which wind and wave action occur without any kind of land interruption. Same as Maximum Length in this case.

(3) Maximum Width (MxW): 27.1 Statute Miles;
23.7 Nautical Miles.

Length of a straight line connecting most remote extremities of the bay and crossing no land other than islands. It is a line approximately at right angles to the maximum length axis. It is a line from Goshen Creek, New Jersey to Cedar Beach, Delaware.

(4) Maximum Effective Width (MxEW): 27.1 Statute Miles;
23.7 Nautical Miles.

Length of straight line connecting the most remote extremities of the width of the bay along which wind and wave action occur without any kind of land interruption.



SUBMERGED CONTOURS OF DELAWARE BAY. TONGUES OF DEEPER WATER RADIATE FROM THE BAY ENTRANCE INTO THE BAY. THE TERMINAL POINTS OF THE PROFILES GIVEN IN FIGURE 5 ARE SHOWN HERE FOR EASY COMPARISON.

(5) Mean Width (MeW): 15.3 Statute Miles;
13.2 Nautical Miles.

The area of the bay divided by its maximum length.

(6) Maximum Depth (MxD): 151 Feet; 46.0 Meters;
25.2 Fathoms

The maximum depth known.

(7) Mean Depth (MeD): 31.7 Feet; 5.3 Fathoms.

The volume of the bay divided by its surface area.

(8) Mean Depth - Maximum Depth Relation (MeD/MxD): 0.21

The mean depth divided by the maximum depth. This is expressed as a decimal value and serves as an index figure which indicates in general the character of the approach of basin shape to conical forms.

(9) Maximum Depth - Surface Area Relation (MxD/As): 0.004

The maximum depth divided by the square root of the surface area. It is expressed as a decimal value and is an indication of the relation of depth to horizontal extent.

(10) Total Surface Area (As): 720 Square Miles (Statute);
460,000 Acres.

Total surface area of the bay. Chart #1218 was divided into fifteen sectors to enable easier and more accurate handling of the planimeter. The results for each sector were combined to give the total area.

(11) Length of Shoreline (Lsh):

Delaware:	55.1 Statute Miles
New Jersey:	73.2 Statute Miles
Total:	128.3 Statute Miles

The length of the shoreline enclosing the bay measured in statute miles.

(12) Shore Development (s): 1.26.

The ratio of the actual length of shoreline of the bay to the length of the circumference of a circle the area of which is equal to that of the bay. Methods and formulae used in calculating this data were obtained from Olson (1952).

TABLE 1

AREA OF SUBMERGED CONTOURS (see Figure 3)

A1 = surface to 1 fathom contour depth; A2 = 1 to 2 fathoms; A3 = 2 to 3 fathoms; A4 = 3 to 5 fathom contour depth; A5 = 5 to 10 fathom contour depth, and A6 = 10 to 25 fathoms.

(A) AREA OF SUBMERGED CONTOURS IN DELAWARE BAY

Depths	Square Miles (Statute)	Acres (x1000)	% of Total
A1	98	63	13.6
A2	167	107	23.2
A3	147	94	20.4
A4	177	113	24.6
A5	83	53	11.5
A6	48	30	6.7
	720	460	100.0

(B) AREA OF SUBMERGED CONTOURS IN THE DELAWARE OR WESTERN PORTION OF DELAWARE BAY

Depths	Square Miles (Statute)	Acres (x1000)	% of Delaware Portion	% of Total
A1	47	30	15.2	6.5
A2	69	44	22.3	9.6
A3	53	34	17.1	7.4
A4	42	27	13.6	5.8
A5	52	33	16.8	7.2
A6	46	29	14.9	6.4
	309	197	99.9	42.9

(C) AREA OF SUBMERGED CONTOURS IN THE NEW JERSEY OR EASTERN PORTION OF DELAWARE BAY

Depths	Square Miles (Statute)	Acres (x1000)	% of New Jersey Portion	% of Total
A1	51	33	12.4	7.1
A2	98	63	23.8	13.6
A3	94	60	22.9	13.1
A4	135	86	32.9	18.8
A5	31	20	7.5	4.3
A6	2	1	0.5	0.3
	411	263	100.0	57.2

(13) Volume (V): Delaware: 371,700,000,000 cubic feet.
New Jersey: 262,100,000,000 " "

Total: 633,800,000,000 " "
4,734,400,000,000 gallons

Determined by computing the volume of each horizontal stratum as limited by the several submerged contours on the hydrographic map and taking the sum of the volumes of all such strata. The depths used were those indicating the mean low water level on the geodetic chart.

(14) Hypsographic Curve: A curve constructed by plotting depth along the ordinate and area along the abscissa. Such a curve provides not only certain elements in the form of a basin but it also provides a means whereby areas at any depth level may be determined. (See Figure 4).

(15) Profiles: These provide a pictorial representation of the basin configuration along a selected line. The profiles were constructed with a vertical scale of 1 mm equal to 1 foot and a horizontal scale of 1 inch equal to 1.1 nautical mile. The profiles selected were perpendicular to the ship channel with the exception of Number 7. The profiles illustrated in Figure 5 are:

	Delaware Shore	to	New Jersey Shore
1.	Woodland Beach		Bay Side
2.	Simons River		Ben Davis Point
3.	Little River		Fortescue
4.	Clark Point		East Point
5.	Big Stone Beach		Goshen Creek
6.	Slaughter Beach		Miami Beach
7.	Cape Henlopen		Cape May Point

Discussion. Although the morphometric data presented on the preceding pages is a beginning toward an understanding of the Delaware River estuary basin, much more work remains to be done. One fruitful research approach would be along the lines developed by geographers and agriculturists in relating crop production with climatic and topographic conditions. The need to better define the habitats of bottom-dwelling organisms can be largely satisfied by more fully utilizing geological and morphometrical research in conjunction with studies on the physical and chemical characteristics of the water environment. The reader is invited to read the excellent articles by Thorson (1957) and Hedgpeth (1957) on the interrelationships between organisms and the bay bottom and beaches.

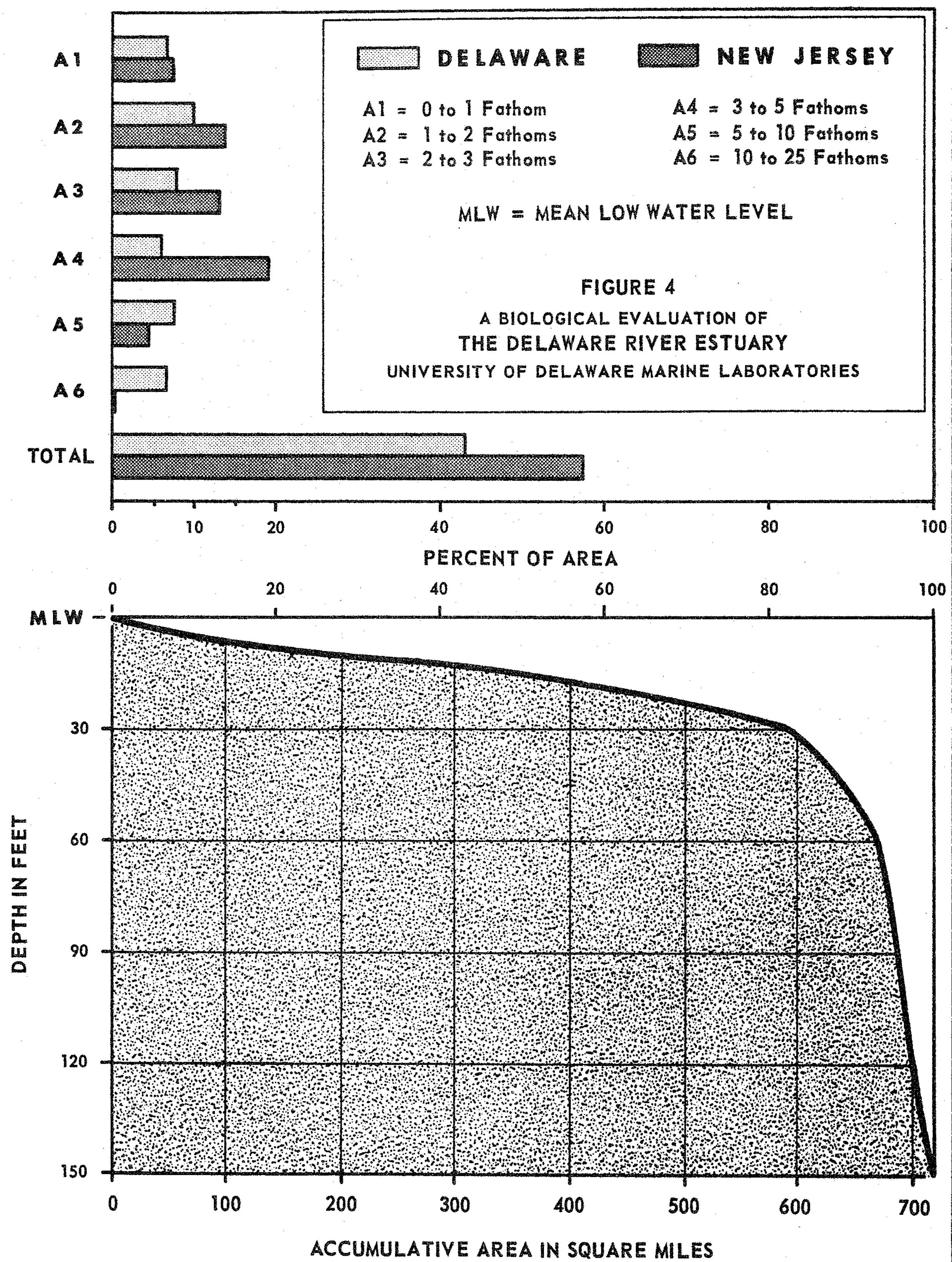
Some of the biological productivity implications suggested by the morphometric data on the Delaware Bay basin are discussed below.

(1) Maximum depth-surface area relation (MxD/ As). By definition, a body of water having a maximum depth equal to the square root of its surface area has a depth-area relation value of 1.0. A body of water with a relationship greater than 1.0 indicates a maximum depth greater than the square root of its surface area. The larger the relation value, the greater is the overall depth of the body of water. In the case of the Delaware Bay, MxD/ As is less than 1.0. It is 0.004, a value indicating a relatively shallow body of water in regard to its area.

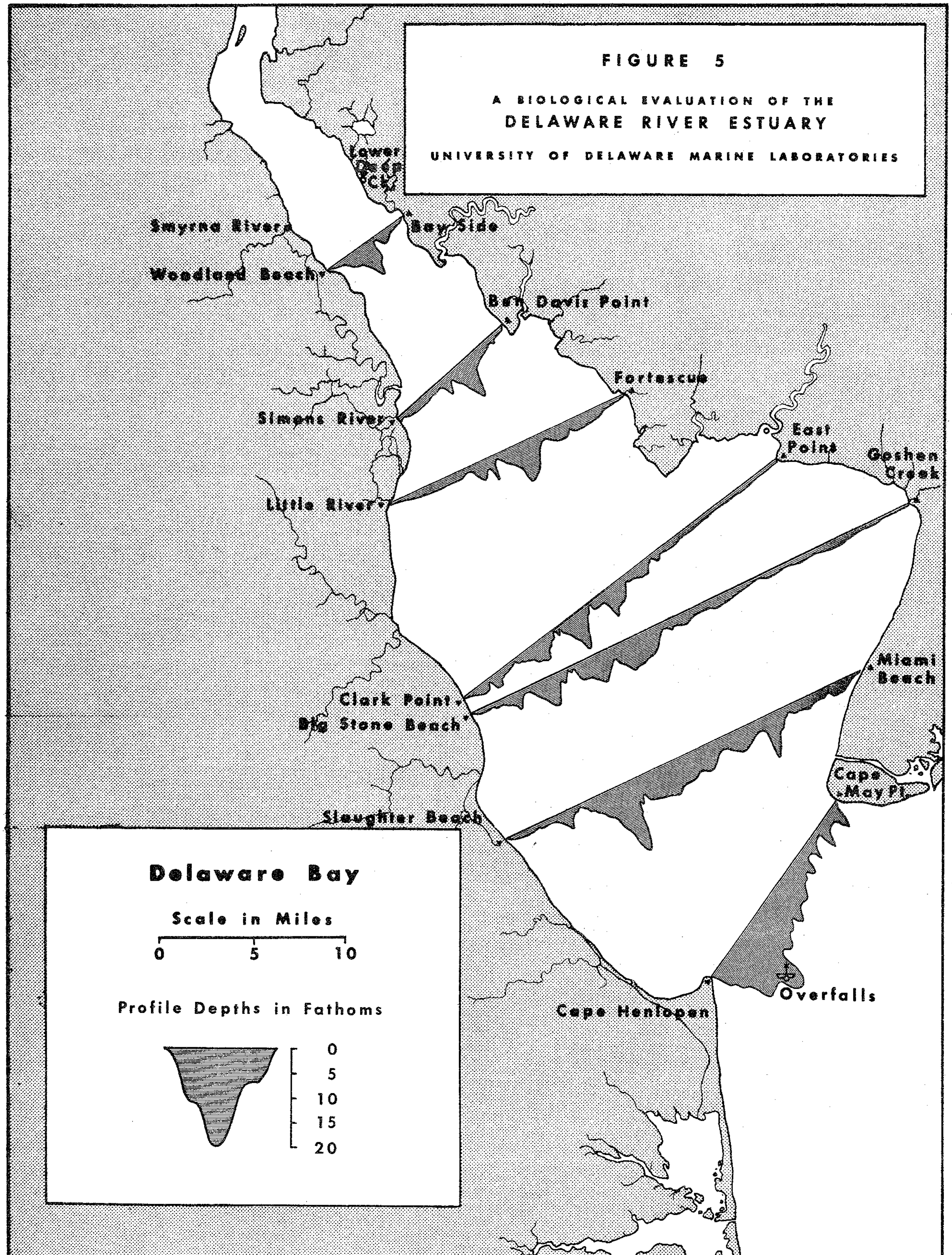
(2) Shore development. When comparing the length of the shoreline of a bay with the circumference of a circle having the same area as that of the bay, a ratio of 1.0 would indicate that the shoreline is entirely undeveloped, lacking any inlets, coves or other irregular formations. The greater the development of the shoreline, the larger the value of the ratio. The ratio from USC&GS chart #1218 for Delaware Bay is 1.26, a value indicating very little development. In brief, the shoreline shows only 1.26 times more development than that of the circumference of a circle of equal area. A shore development ratio for Chesapeake Bay is not readily available, yet it is evident that the 1,591 miles of shoreline reported for seven Maryland counties on the bay (Nicholson and Van Deusen, 1954) denote a much greater shore development than found in Delaware Bay. Much useful information would result from research upon the comparative productivity of these two bays.

(3) Morphometry and productivity. The morphometry of a body of water, as its shore development, depth, and surface area, indicates the extent of areas suitable for early development and growth of organisms of importance to food chains. Areas rich in nutrients generally provide a suitable habitat for many important organisms. The extent and geological characteristics of these areas are believed to have an influence upon overall biological productivity.

Our research experiences and the commercial fisheries statistics substantiate the general belief that the biological productivity of Delaware Bay is high. Certain of the morphometric values given in this report, however, as the low shore development ratio, suggest that productivity should be lower than it actually is. Generally, a shallow water area is more productive than a deep body of water, due to the greater volume of water, in relation to the total volume, that is exposed to sunlight. Since plants are dependent upon sunlight for photosynthesis (the manufacture of sugar), the depth of light penetration into deep or murky water is a limiting factor for plant



THIS HYPSOGRAPHIC CURVE SHOWS THE AREA WITHIN DELAWARE BAY THAT IS ABOVE OR BELOW ANY GIVEN DEPTH (SEE TABLE 1). FOR EXAMPLE, SLIGHTLY OVER 80% OF THE BAY IS LESS THAN 30 FEET DEEP. BAR GRAPHS SHOW THE PERCENT OF EACH DEPTH IN DELAWARE AND IN NEW JERSEY.



THIS SERIES OF PROFILES SHOWS THE VARIATIONS IN DEPTH ACROSS DELAWARE BAY AT SELECTED LOCATIONS (SEE FIGURE 3) FROM THE HEAD OF THE BAY TO THE BAY ENTRANCE. THE SCALE OF THE LARGER DRAWING FROM WHICH THIS FIGURE WAS PRINTED IS GIVEN ON PAGE 11 IN (15) PROFILES.

growth. The shallowness of Delaware Bay, which should be ideal for phytoplankton (floating microscopic plants) production, is offset by the opaqueness of the sediment and organic detritus-laden water. Exposure to sunlight of the microscopic algae in the surface muds of intertidal areas may compensate for the general opacity of the bay water. A critical evaluation of these and other factors, in addition to the morphometry of the bay, which contribute to the high productivity, or hinder it, awaits further research data.

The tidal marshes fringing Delaware Bay were not considered in our morphometric study, due to the difficulty of obtaining meaningful data even from the large scale chart (1:80,000) used. Useful data could be obtained from an intensive study of aerial photographs. Yet it is obvious, without performing the required tedious computation, that the banks of tidal streams greatly increase the length of the shoreline available to estuarine organisms and the substratum for the biological and chemical phenomena that occur at the "mud"-air interface in intertidal areas. A measure of the tidal stream shoreline, when added to the bay shoreline calculated from Chart #1218, would probably significantly increase the shore development ratio. Increased shoreline is only one of the important contributions that tidal marshes make to the overall biological productivity of the Delaware River estuary. Other factors in the probable role of these tidemarshes in productivity are discussed in a succeeding section.

The shape of the Delaware Bay basin is essentially that of a flattened funnel, with a more extensive shallow water area in its eastern side. Indeed, the only extensive intertidal flats are along the Cape May shore. The deepest areas are in the western portion of the bay. These facts are well known, but the calculations given on page 10 present data useful in quantitative comparisons of the various portions of the bay.

Extent of the bottom contours, the geology of the bay at the various depths, and the characteristics of the water mass moving over each area play an important role in the ecology of the organisms, particularly the bottom-dwelling species, living in each area. From our observations upon these environmental factors it is evident that the relationships between the basin contour, the geology of the bay bottom, and the water masses must be understood before intelligent recommendations and decisions affecting fisheries can be made. These recommendations and decisions would be in such fields as: new and enlarged navigation channels; dredge spoil areas; and fisheries management areas, such as spawning sanctuaries, nursery grounds, and artificial habitats.

EXTENT OF THE DELAWARE RIVER ESTUARY

The generally accepted definition of an estuary is as an arm of an ocean: a coastal tidal body of water where measurable dilution of seawater by freshwater occurs. An estuary is defined, therefore, by several types of boundaries, among which the more prominent are due to variations in the transition between land and water masses caused by changes in the water level, as by tides and runoff. Further, an estuary is an integral and natural part of a watershed and the hydrologic phenomena associated with it. Estuaries are affected, therefore, by any man-caused changes in the water cycle and in the land-water relationships.

There are three geographical boundaries, as illustrated in Figure 1: (1) lower river, (2) Delaware Bay, and (3) an offshore area. Along the Atlantic Coast the "Fall Line" or boundary between the Piedmont and Coastal Plain generally marks the upstream limits of estuaries within watersheds (see Ward, 1958). There the low tidal amplitude is effectively blocked by the height of the Fall Line Zone of falls and rapids.

Another boundary, the transition zone between the land and water masses, is critical for several reasons. From the ecological viewpoint, both the bay bottom and the air-land-water boundary are important transition zones: the geology of the bay bottom determines in part the kind of inhabiting bottom-dwelling species; the intertidal zone is an important region of photosynthetic activity and the habitat of many species which play a prominent role in estuarine productivity. The boundary between land and water surface is a function of the usual tidal fluctuation and phenomena which cause variations in that amplitude. A clearly marked horizontal boundary, the intertidal zone, exists between the low and high water level. It is a zone critical to estuarine productivity, particularly in the tidemarsh area (Kalber, 1959b).

Another important ecological portion of the Delaware River estuary is the segment within which the Ship John Lighthouse is located. Here extreme conditions exist for estuarine organisms, especially in the range of salinity changes. This segment of the estuary should be intensively studied, hydrographically, geologically, and biologically.

An unseen boundary, but of prime importance to groundwater resource problems, is saltwater intrusion into groundwater supplies through freshwater-bearing strata -- aquifers. This is a perennial problem in coastal areas where heavy demands upon groundwater supplies or the exposure of aquifers by channel dredging bring about the danger of saltwater intrusion into the coastal freshwater supplies.

The extent of the freshwater influence upon coastal waters, particularly the amount of nutrients and pollutants transported downstream into the estuary, must be considered in any estimation of estuarine and coastal biological productivity. This is obvious, since the influence of freshwater runoff can be measured in the continental shelf water, where the salinity varies seasonally (see Figure 1). At Five Fathom Lightship about 28 miles due east of Cape Henlopen, the salinity of the surface water varied during the year of 1956 from 29.7 to 33.1 $^{o}/oo$ (salinity is recorded in parts of sea salt per thousand parts of seawater, on a weight basis, and is represented by the symbol $^{o}/oo$); from 30.5 to 33.2 $^{o}/oo$ at Winter Quarter Lightship (Bumpus, 1957). If 35.0 $^{o}/oo$ is taken as the salinity of undiluted seawater, then the above data represents the amount of dilution resulting mainly from the Delaware River watershed runoff. The salinity cycle at each lightship was from the higher salinity in the winter to lower salinity during the summer, with a return to the higher salinity in the fall of the year.

In the summary of a study on the offshore area of the Delaware River estuary, Ketchum (1952) traced the freshwater contribution of the Delaware River and its tributaries over a wide area (2,000 to 3,500 square miles in two surveys analyzed), outside and to the south of the entrance to Delaware Bay. The volume of freshwater influencing the salinity of this large area was computed to correspond to slightly more than two weeks flow from the Delaware River watershed.

The Southwest Drift, a southwesterly flowing coastal current described by Miller (1952) and Ayers (1955) transports freshwater runoff from the Hudson River and from New Jersey coastal streams. Yet the major influx of freshwater into the region off Delaware Bay and southward, to the coastal region more affected by the Chesapeake Bay drainage, is from the Delaware River watershed. This freshwater-diluted seawater affects other areas. It is an important environmental factor in Rehoboth and Indian River Bays (Shuster, 1957a).

It is clear from the foregoing discussion that the coastal fisheries in the Delaware Bay offshore area come under the direct influence of the Delaware River watershed runoff and, indeed, are located within easily recognizable salinity boundaries of the Delaware River estuary.

ROLE OF TIDEMARSHES IN ESTUARINE PRODUCTION

Estuaries are spawning and nursery areas for several species of commercially valuable aquatic animals and the home of others. Evidence on the importance of estuaries to coastal fisheries is accumulating from the research of many marine laboratories, but the precise role of tidemarshes in estuarine production is less well known.

Nelson (1947) was the first to focus attention on the contributions of the land to production in the Delaware Bay. Among the several points emphasized on physical, biological, and chemical contributions, he illustrated the interrelationships of these contributions upon the production of microscopic plants on the intertidal flats along the Cape May shore. These flats are doubly important to the shellfish industry, through the production of bacteria and algae upon which oysters and other mollusks feed, and as setting and growing areas (Nelson, 1959).

Vitamin B_{12} is produced in coastal waters by microorganisms and is used by them and by higher forms of life for growth and development. Starr (1956) called attention to the role of tidemarshes as important production sites of this growth factor. He found that the waters draining from a tidal marsh in Georgia contained detritus richer in vitamin B_{12} immediately after high slack water than at any other stage of the tide or in the nearby ocean water. Starr further pointed out that the flushing process, of periodic flooding and draining of salt marshes, causes a continual exchange of nutrients between the coastal waters and the marsh lands. A similar exchange occurs between the tidemarshes and the Delaware River estuary.

The pilot study of Canary Creek Marsh near the Bayside Laboratory at Lewes indicated that all three forms of inorganic nitrogen (ammonia, nitrite, and nitrate) were, on the average, more abundant in the water immediately after the high slack period than at any other stage of the tide. The results for phosphorus (inorganic and organic) were less decisive, but the contribution of nutrients from the marsh to the tidal waters was obvious.

The production on Georgia salt marshes of 4.8 tons of dry matter per acre per year of the cordgrass, *Spartina alterniflora* (Smalley, 1959) is comparable to that on the Canary Creek Marsh, which is a high-level tidal marsh, completely flooded only by the high spring tides. Upon its 123 acres grows each year a 323 ton (dry weight) plant crop, principally cordgrasses. Part of this crop, through decomposition, probably forms the major portion of an estimated 84 tons (dry weight) of organic matter that is flushed from the marsh each year. The relationship between bacteria and detritus has been cited above in the vitamin B_{12} study by Starr (1956) and its importance in estuarine production has been summarized by Daiber (1959).

A further indication of the nutrient value of Spartina alterniflora is the 3.3% ± 0.9 protein content of air-dry hay from South Carolina marshes (Taschdjian, 1953). Since this air-dry cordgrass hay had a water content of about 10%, the 3.3% protein content compares favorably with the 2.9% digestible protein in timothy hay. In one cordgrass hay infusion experiment using bacteria and protozoa, Taschdjian (1953) increased within a month an initial vegetal protein yield of 4.2% to 10.2% of mixed plant and animal protein. A similar build-up of protein undoubtedly occurs naturally in tidal streams.

The energy flow diagram for the Sapelo Island, Georgia, salt marsh (Teal, 1959), shows only insects and bacteria as consumers of the marsh grasses. Our studies in the Canary Creek marsh area on the salt marsh crab Sesarma reticulatum, principally by Mr. Oliver W. Crichton during the summer of 1959, show that this crab feeds heavily on Spartina. Other species may also be involved.

Pomeroy (1959) found that the productivity of algae on the surface layers of sediment on Georgia salt marshes is a significant contribution to the total primary production. He estimated that the mean annual net production was 100 grams of carbon per square meter per year (1,000 pounds/acre/year). In a general account, Shuster (1958a) utilized data from these studies on Georgia marshes and calculated that a minimum crop of 547 pounds of sugar per acre per year are produced by microscopic plants on the flooded mud surfaces of Delaware marshes. If only one-half of Delaware's 130,000 acres of tidemarshes have this level of production, this is still an annual crop of 35,555,000 pounds which is food for estuarine animals. At ten cents a pound this tidemarsh sugar crop produced by the microscopic plants is worth $3,555,500. To this must be added the value of the food produced by the rooted plants, as the marsh grasses and sedges.

Dramatic evidence of the high productivity of estuaries and coastal lands is contained in a summary by Odum and Odum (1959) of what is known about the world distribution of primary production. Primary production (the rate at which energy is stored, chiefly by green plants, in the form of food) is generally recorded in grams per square meter per day (gms/M^2/day). Corresponding values in pounds per acre per day are included below.

Three major production levels are recognized by the Odum's: 1) the greatest surface area of the earth, the open ocean and desert areas, is the least productive, around 0.1 gms/M^2/day

(1.2 lbs/acre/day): 2) coastal seas, shallow lakes, grasslands, and ordinary agriculture crops range upward from 0.5 t0 5.0 gms/M^2/day (6.1 to 60.5 lbs/M^2/day), and 3) the greatest primary productivity, 5.0 to 20.0 gms/M^2/day (60.5 to 242 lbs/acre/day), occurs in some estuaries, coral reefs, some mineral springs, semi-aquatic and terrestrial plant communities on alluvial plains, evergreen forests and intensive agriculture (as year-round sugar cane production). The Odum's (1959) believe that a production rate higher than 25 gms/M^2/day (303 lbs/acre/day) cannot be maintained over a period of years, although short-period productivity may be as high as 60.0 gms/M^2/day (786 lbs/acre/day. An essential point emphasized by the Odum's is that although "man has not increased maximum primary productivity beyond that which occurs in the absence of man," he is capable of improving conditions where less than maximum production does occur.

The foregoing discussion prompts at least one question -- What is the primary production rate of the Delaware River estuary, or in other words, how near is the actual production rate to the expected maximum yield? This we do not know, but data, from sources such as fisheries statistics, indicate high production is possible.

It is also of interest to note that the agricultural and forest lands, in addition to the estuaries of Delaware, probably rank in the top category of primary production described by Odum and Odum (1959). There is good cause, therefore, to emphasize the fact that these natural land and water areas are top priority food and renewable resources production sites. Their value to future generations cannot be overestimated.

An overabundance of nitrogen and phosphorus due to pollution in the lower Delaware River may accidentally contribute to the productivity of the bay. To guide us in an exploration of this paradox -- of pollution contributing to production -- as well as other factors in the overall biological production of the estuary, Kalber (1959a) has outlined a working hypothesis (Appendix).

SHORE ZONE FISHES OF DELAWARE BAY

This section is based largely upon a one-year survey by Dr. Franklin C. Daiber of the shore zone fishes of the Delaware Bay during the period October 1952 through November 1953. Five areas were selected as sites for the survey (Daiber, 1954): Augustine Beach, Woodland Beach, Kitts Hummock, Slaughter Beach, and Lewes Beach (see Figure 1). These collecting stations are approximately equidistant along the bay shore and are characterized by steep sand beaches formed by a barrier dune with tidal marshes behind the dune. The intertidal zone at these five stations is, in general, narrow and steep, leveling off to form extensive mud or sand flats. At low tide the water over these stations is only a foot or two in depth.

Methods. A 25-foot beach seine with a bag was employed on twenty-two collecting trips made every two to three weeks to each of the five stations on the western shore of Delaware Bay. The fishes seined at each station were preserved in formalin and later were identified and measured. A record of the tidal stage, water temperature and salinity, weather condition, and other data was obtained at the time of each collection.

Results and conclusions. The results of the survey showed that the most abundant shore zone fishes of the Delaware Bay are euryhaline (capable of withstanding wide salinity ranges) species. This survey also indicates that the shore zone is a highly productive area for small forage (food for other animals) fishes and for the young of certain commercially important species.

The most important forage fishes of the shore zone in terms of numbers collected were:

Menidia menidia - common silversides
Anchoa mitchilli - common anchovy
Fundulus heteroclitus - common killifish
Fundulus majalis - striped killifish
Membras vagrans - rough killifish
Menidia beryllina - tidewater silversides

The most common immature or young commercial species collected were:

Brevoortia tyrannus - menhaden
Cynoscion regalis - weakfish
Pomatomus saltatrix - bluefish
Roccus saxatilus - striped bass
Paralichthys dentatus - northern flounder

Menidia menidia, the common silversides, is probably the most important forage fish of the Delaware Bay shore zone. This species was very abundant throughout the year at all of the five collection stations. It was the most abundant species at all stations, except at Augustine Beach, where it ranked second in numbers to the common anchovy, *A. mitchilli*. *Menidia menidia* is a very important food item in the diet of such commercial species as the flounder and striped bass, as well as large weakfish. The rough silversides, *Membras vagrans*, and the tidewater silversides, *Menidia beryllina*, are also quite common along the shore zone and have similar roles as forage fishes.

The common anchovy, Anchoa mitchilli, is also a very abundant and important forage fish of the Delaware Bay shore zone. This species ranked second in total numbers to the common silversides during Dr. Daiber's collection period. The anchovy is an important food item in the diet of the weakfish, Cynoscion regalis. The majority of anchovies found along the shore zone are immature; they move out to deeper water later in life (Stevenson, 1958).

The various species of killifish are quite common along the shore zone of the Delaware Bay and in the tidal creeks that flow into the Bay. The most abundant species is the common killifish, Fundulus heteroclitus. The striped killifish, Fundulus majalis, is also quite common. Killifish are important forage fishes for flounders and striped bass which move in close to shore with the tide and up into the tidal creeks.

Of the commercial species, the most abundant found along the shore zone of the Bay are the young of the menhaden, Brevoortia tyrannus. This species ranked high in Dr. Daiber's collections at Augustine Beach and Woodland Beach. In recent years, large schools of young menhaden have been very common in the shallow water near shore throughout the summer and early fall. The importance of the shore zone and tidal creeks along the Delaware Bay as nurseries for young menhaden cannot be overestimated.

Dr. Daiber's records show that the young of the bluefish, Pomatomus saltatrix, were fairly common all along the shore zone of Delaware Bay during the summer of 1953. The beach seining records of Dr. Donald P. deSylva and Frederick A. Kälber, Jr. for the summer of 1958, also indicate, on the basis of the large number collected, that the shore zone of the lower Delaware Bay is important as a nursery for young bluefish.

Immature striped bass, Roccus saxatilus, also seem to utilize the shore of Delaware Bay. Although few striped bass were taken during Dr. Daiber's survey period, collections during the summer of 1958 show that immature striped bass were quite common along the shore zone.

Young and immature individuals of several other important commercial species are also found along the shore zone of the Delaware Bay. Young weakfish, Cynoscion regalis, although not abundant during the 1952-1953 survey, were common within the shore zone during the summer of 1958. Young flounder, Paralichthys dentatus, are fairly common in the shore zone. This zone, rich in terms of small forage fishes, is a feeding area for the older flounder.

The following tables, compiled from Dr. Daiber's collection data for 1952-53, summarize the nature of the shore zone fish population and the environmental conditions encountered by these species. The common name of each of these species is included in Table 3. A total of 14,261 individual fish, comprising 44 species classed among 20 families found in 8 orders, were collected from the five stations along Delaware Bay.

TABLE 2

WATER TEMPERATURE AND SALINITY RANGES AT THE FIVE SURVEY STATIONS AT THE TIME OF SEINING

	TEMPERATURE (°C)		SALINITY ($^{o}/oo$)		
STATIONS	Min.	Max.	Avg.	Min.	Max.
1 - Augustine Beach	2	28	4.61	0.80	9.90
2 - Woodland Beach	2.5	29	8.80	3.80	14.90
3 - Kitts Hummock	3	36	18.81	13.50	25.37
4 - Slaughter Beach	3	32	24.26	20.80	28.16
5 - Lewes Beach	4.5	28	27.02	23.01	29.05

TABLE 3

A SUMMARY OF THE DISTRIBUTION OF SHORE ZONE FISHES AT FIVE COLLECTING STATIONS ON DELAWARE BAY (See Figure 1)

STATIONS	NUMBER OF FISHES COLLECTED	NUMBER OF SPECIES COLLECTED	RELATIVE ABUNDANCE
1 - Augustine Beach	2,054	20	+++ = very common
2 - Woodland Beach	1,699	19	++ = common
3 - Kitts Hummock	1,089	24	+ = few or occasional
4 - Slaughter Beach	7,144	20	0 = absent
5 - Lewes Beach	2,275	21	

FRESHWATER SPECIES	STATIONS 1	2	3	4	5	COMMON NAMES
Carassius auratus	+	0	0	0	0	Goldfish
Cyprinus carpio	+	0	0	0	0	Carp
Notemigonus c. crysoleucas	+	0	0	0	0	Golden Shiner
Notropic amoenus	+	0	0	0	0	Attractive Minnow
Notropis bifrenatus	+	0	0	0	0	Bridled Minnow
Notropis rubellus	+	0	0	0	0	Rosy-faced Minnow
Pomoxis annularis	0	+	0	0	0	White Crappie
Pomoxis nigro-maculatus	0	+	0	0	0	Black Crappie
EURYHALINE SPECIES						
Alosa sapidissima	+	+	0	0	0	Shad
Anchoa m. mitchilli	+++	+++	+++	+++	+++	Common Anchovy
Anguilla rostrata	+	0	+++	+	+	Common Eel
Apeltes quadracus	0	0	+	0	0	4-Spined Stickleback
Bairdiella chrysura	0	0	+	+	0	Silver Perch
Brevoortia tyrannus	++	+	+	++	+	Menhaden

TABLE 3 continued

EURYHALINE SPECIES	STATIONS 1	2	3	4	5	COMMON NAMES
Cyprinodon variegatus	0	+	0	+	+	Broad Killifish
Fundulus heteroclitus	++	++	+	+	+	Common Killifish
Fundulus majalis	+	+	+++	+	+	Striped Killifish
Fundulus ocellaris	+	+	+	+	+	Ocellated Killifish
Gasterosteus aculeatus	0	+	0	0	0	3-Spined Stickleback
Lucania parva	0	0	+	0	0	Rainwater Killifish
Membras vagrans	+	+	0	+++	+	Rough Silversides
Menidia beryllina	+	+	+	+	+	Tidewater Silversides
Menidia menidia	+++	+++	+++	+++	+++	Common Silversides
Mugil curema	0	0	+	+	0	White Mullet
Roccus americana	+	0	+	0	0	White Perch
Roccus saxatilus	0	0	+	0	0	Striped Bass
Syngnathus fuscus	0	+	+	+	0	Pipefish
MARINE SPECIES						
Alosa aestivalis	+	++	+	+	++	Glut Herring
Alosa pseudoharengus	0	0	+	0	0	Alewife
Anchoviella eurystole	0	0	0	0	+	Broad-striped Anchovy
Cynoscion regalis	0	0	++	+	0	Weakfish (Trout)
Hyporhamphus unifasciatus	0	0	0	0	+	Halfbeak
Menticirrhus saxatilus	0	0	+	0	+	Kingfish
Micropogon undulatus	+	+	+	+++	+	Croaker
Mugil cephalus	0	+	+	+	+	Striped Mullet

TABLE 3 continued

MARINE SPECIES	STATIONS 1	2	3	4	5	COMMON NAMES
Orthopristis chrysopterus	0	0	0	+	0	Pigfish
Otophidium marginatum	0	0	+	0	0	Cusk Eel
Pogonias cromis	0	0	++	0	0	Black Drum
Pomatomus saltatrix	+	+	0	0	+	Bluefish
Sciaenops ocellatus	0	0	0	0	+	Red Drum
Sphoeroides maculatus	0	0	0	+	+	Northern Swellfish
Strongylura marina	0	+	0	+	+	Needlefish
Trachinotus carolinus	0	0	0	0	+	Common Pompano
Trinectes maculatus fasciatus	0	0	+	0	0	Hog Choker

TABLE 4

ANALYSIS OF THE SHORE ZONE FISH POPULATION BY SPECIES

I. Order OSTARIOPHYSI

Family CYPRINIDAE

Cyprinus carpio (Linnaeus)
Carassius auratus (Linnaeus)
Notemigonus c. chrysoleucas (Mitchill)
Notropis amoenus (Abbott)
Notropis bifrenatus (Cope)
Notropis rubellus (Agassiz)

II. Order APODES

Family ANGUILLIDAE

Anguilla rostrata (Lesueur)

TABLE 4 continued

III. Order ISOSPONDYLI

Family CLUPEIDAE

Alosa sapidissima (Wilson)
Alosa aestivalis (Mitchill)
Alosa pseudoharengus (Wilson)
Brevoortia tyrannus (Latrobe)

Family ENGRAULIDAE

Anchoa mitchilli (Cuvier)
Anchoviella eurystole (Swain & Meek)

IV. Order HAPLOMI

Family CYPRINODONTIDAE

Fundulus heteroclitus (Linnaeus)
Fundulus majalis (Walbaum)
Fundulus ocellaris (Jordan and Gilbert)
Cyprinodon variegatus (Lacépède)
Lucania parva (Baird and Girard)

V. Order SYNENTOGNATHI

Family BELONIDAE

Strongylura marina (Walbaum)

Family HEMIRHAMPHIDAE

Hyporhamphus unifasciatus (Ranzani)

VI. Order THORACOSTEI

Family GASTEROSTEIDAE

Apeltes quadracus (Mitchill)
Gasterosteus aculeatus (Linnaeus)

VII. Order LOPHOBRANCHII

Family SYNGNATHIDAE

Syngnathus fuscus (Storer)

VIII. Order ACANTHOPTERYGII

Family ATHERINIDAE

TABLE 4 continued

Menidia menidia notata (Mitchill)
Menidia beryllina (Cope)
Membras vagrans (Goode & Bean)

Family MUGILIDAE

Mugil cephalus Linnaeus
Mugil curema (Cuvier)

Family CARANGIDAE

Trachinotus carolinus (Linnaeus)

Family POMATOMIDAE

Pomatomus saltatrix (Linnaeus)

Family CENTRARCHIDAE

Pomoxis nigromaculatus (Rafinesque)
Pomoxis annularis (Lesueur)

Family SERRANIDAE

Roccus saxatilis (Walbaum)
Roccus americana (Gmelin)

Family HAEMULIDAE

Orthopristis chrysopterus (Linnaeus)

Family SCIAENIDAE

Cynoscion regalis (Bloch & Schneider)
Bairdiella chrysura (Lacépède)
Sciaenops ocellatus (Linnaeus)
Micropogon undulatus (Linnaeus)
Menticirrhus saxatilus (Bloch & Schneider)
Pogonias cromis (Linnaeus)

Family TETRAODONTIDAE

Spheroides maculatus (Bloch & Schneider)

Family OPHIDIIDAE

Otophidium marginatum (De Kay)

Family SOLEIDAE

Trinectes maculatus fasciatus (Lacépède)

TABLES 5 and 6

MAXIMUM AND MINIMUM WATER TEMPERATURES AND SALINITIES ENCOUNTERED BY THE MORE ABUNDANT SPECIES OF FISHES

	TEMPERATURES IN DEGREES CENTIGRADE			SALINITIES EXPRESSED IN PARTS PER THOUSAND (ppt)		
SPECIES	Date (1953)	Temp.	Station	Date (1953)	Sal.	Station
Menidia menidia	23 June	36.0	Kitts H.	14 Sept.	29.1	Lewes
	27 Jan.	3.0	Kitts H.	20 May	0.8	Augustine
Anchoa mitchilli	23 June	36.0	Kitts H.	14 Sept.	29.1	Lewes
	17 Feb.	5.0	Lewes	20 May	0.8	Augustine
Fundulus majalis	23 June	36.0	Kitts H.	14 Sept.	29.1	Lewes
	27 Jan.	3.5	Slaughter	9 July	4.7	Augustine
Brevoortia tyrannus	23 June	36.0	Kitts H.	9 July	25.5	Slaughter
	29 Apr.	12.5	Woodland	20 May	0.8	Augustine
Alosa aestivalis	20 May	23.5	Kitts H.	29 Apr.	26.7	Lewes
	3 Apr.	12.0	Woodland	3 May	4.6	Kitts H.

MAXIMUM AND MINIMUM WATER TEMPERATURES AND SALINITIES ENCOUNTERED BY SOME OF THE LESS ABUNDANT SPECIES

	TEMPERATURES IN DEGREES CENTIGRADE			SALINITIES EXPRESSED IN PARTS PER THOUSAND (ppt)		
SPECIES	Date (1953)	Temp.	Station	Date (1953)	Sal.	Station
Anguilla rostrata	3 Aug.	25.5	Slaughter	11 Mar.	26.5	Lewes
	17 Feb.	2.0	Augustine	17 Feb.	2.0	Augustine
Cynoscion regalis	1 Sept.	27.8	Slaughter	14 Sept.	29.1	Lewes
	1 Oct.	19.4	Lewes	23 May	18.0	Kitts H.
Fundulus heterocl.	23 June	32.0	Slaughter	23 June	24.4	Slaughter
	19 Dec.*	3.5	Augustine	20 Apr.	0.8	Augustine
Membras vagrans	1 Sept.	29.1	Slaughter	14 Sept.	29.1	Lewes
	1 Oct.*	19.6	Slaughter	1 Sept.	8.9	Augustine
Menidia beryllina	1 Sept.	28.0	Lewes	19 Dec.*	29.0	Lewes
	17 Feb.	2.0	Augustine	20 Apr.	0.8	Augustine
Micropogon undulatus	4 June	25.0	Kitts H.	27 Jan.	28.5	Lewes
	27 Jan.	3.5	Slaughter	4 May	1.2	Augustine

* (1952)

TABLE 7

FISHES FOUND IN THE SHORE ZONE OF DELAWARE BAY, LISTED ACCORDING TO THE NATURE OF THEIR RESIDENCE

I. RESIDENT AT ALL STAGES.

Menidia menidia
Menidia beryllina
Membras vagrans
Fundulus heteroclitus
Fundulus majalis

II. RESIDENT ONLY DURING IMMATURE STATES.

Anchoa m. mitchilli

III. IMMATURE OFFSPRING OF BREEDING MIGRANTS.

Brevoortia tyrannus
Cynoscion regalis
Micropogon undulatus
Pogonias cromis
Bairdiella chrysura

IV. IMMATURE MIGRANTS.

Pomolobus aestivalis
Roccus saxatilus
Trachinotus carolinus
Pomatomus saltatrix

V. ACCIDENTALS

Apeltes quadracus
Carassius auratus
Cyprinus carpio
Gasterosteus aculeatus
Lucania parva
Menticirrhus saxatilis
Notemigonus crysoleucas
Notropis amoenus
Notropis rubellus
Notropis bifrenatus
Pomoxis annularis
Pomoxis nigromaculatus
Otophidium marginatum
Alosa pseudoharengus
Spheroides maculatus
Orthopristis chrysopterus
Sciaenops ocellatus
Hyporhamphus unifasciatus
Trinectes maculatus fasciatus
Alosa sapidissima
Anchoviella eurystole
Mugil curema
Roccus americana
Mugil cephalus
Cyprinodon variegatus
Fundulus ocellaris
Strongylura marina

TABLE 8

THE SIX MOST ABUNDANT FISH SPECIES AT EACH OF THE SURVEY STATIONS, RANKED ACCORDING TO THEIR ABUNDANCE

AUGUSTINE BEACH

1. *Anchoa mitchilli*
2. *Menidia menidia*
3. *Brevoortia tyrannus*
4. *Menidia beryllina*
5. *Notemigonus crysoleucas*
6. *Fundulus heteroclitus*

WOODLAND BEACH

1. *Menidia menidia*
2. *Anchoa mitchilli*
3. *Menidia beryllina*
4. *Brevoortia tyrannus*
5. *Alosa aestivalis*
6. *Fundulus heteroclitus*

KITTS HUMMOCK

1. *Menidia menidia*
2. *Fundulus majalis*
3. *Anchoa mitchilli*
4. *Anguilla rostrata*
5. *Cynoscion regalis*
6. *Pogonias cromis*

SLAUGHTER BEACH

1. *Menidia menidia*
2. *Anchoa mitchilli*
3. *Micropogon undulatus*
4. *Membras vagrans*
5. *Brevoortia tyrannus*
6. *Bairdiella chrysura*

LEWES BEACH

1. *Menidia menidia*
2. *Anchoa mitchilli*
3. *Alosa aestivalis*
4. *Menidia beryllina*
5. *Trachinotus carolinus*
6. *Anchoviella eurystole*

COMMENTS ON THE ECOLOGY OF ESTUARINE INVERTEBRATES

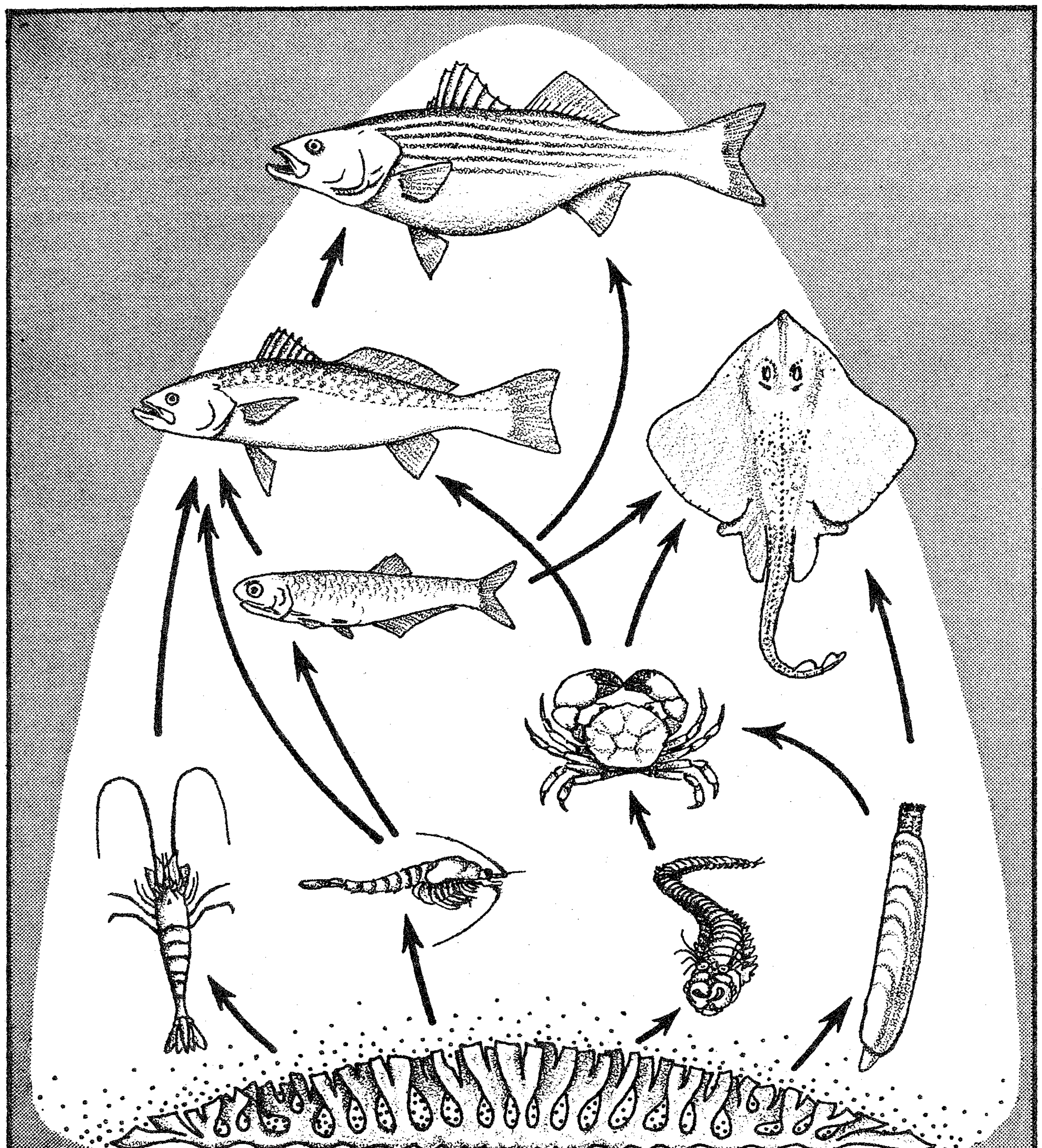
Estuarine ecology, or interrelationships among estuarine organisms and their environment, is too large a topic to be adequately discussed here. There are, however, certain aspects of estuarine ecology pertinent to biological production that will be outlined and examples given. Our attention will be mainly upon a few selected species, on estuarine invertebrates as food for other animals, and how the environment, particularly salinity, forms a barrier to the distribution of estuarine organisms.

Invertebrates as food. Invertebrate animals play an important role in the overall productivity of the Delaware River estuary. A portion of this total production, such as oysters, clams, squid, and blue crabs, is harvested directly as food for man. Many other species of invertebrates, chiefly marine worms, mollusks, and crustacea, are food for fishes, some of which are commercially harvested. Although it has not been emphasized previously in this account that the total productivity of our coastal waters is an important part of our economy, those invertebrates we use as food and those species eaten by the fishes we harvest have an obvious direct or indirect economic value.

The second group of invertebrates, those that are food for fishes, are not so conspicuous as those harvested for human food, but their value cannot be overlooked. Accumulating research evidence indicates that the disappearance of these food organisms could markedly affect our coastal fisheries.

When a group of organisms are interdependent due to their diets, these interrelationships are shown by a food web diagram. One use of a food web diagram is to illustrate the direction of food energy transfer from a plant source through a series of herbivores and carnivores. One such web is described below and is illustrated with a few selected species in Figure 6. Many other species, that also are involved, are not mentioned because the simplified version of a food web serves best to highlight major food pathways.

(1) An estuarine food web. Several years ago Dr. Franklin C. Daiber, Mr. William H. Amos, and the writer showed the animals concerned and explained to a television audience the significance of the food web in which the weakfish occurred (WDEL-TV, University of Delaware Search Program, May 1, 1955: "There is More in the Water Than Fish"). Since then certain organisms within this web have been studied in the Delaware River estuary. A diet study of the striped bass in Chesapeake Bay had been reported previously by Hollis (1952). The data summarized in Tables 9 through 12, clearly indicate the extent



A SIMPLIFIED FOOD WEB ILLUSTRATING SOME OF THE PATHWAYS OF FOOD IN THE FOOD PYRAMID INVOLVING THE WEAKFISH. THE ARROWS POINT TO THE CONSUMERS. THE INSERT (RIGHT) IDENTIFIES EACH ORGANISM. (MODIFIED FROM DAIBER, 1959)

FIGURE 6

A BIOLOGICAL EVALUATION OF

THE DELAWARE RIVER ESTUARY

UNIVERSITY OF DELAWARE MARINE LABORATORIES

	STRIPED BASS		
WEAKFISH		SKATE	
	ANCHOVY		
		MUD CRAB	
GLASS SHRIMP	MYSID SHRIMP	CLAM WORM	RAZOR CLAM
	ORGANIC DETRITUS AND PLANT LIFE		

of the diet of the predators, but more research is required to determine the nutritional value of the food species.

Hollis (1952) found seasonal as well as regional variations in the food eaten by striped bass since these fish range throughout waters of all salinities, from ocean water to freshwater, and are found in Chesapeake Bay throughout the year. The observations summarized in Table 9 do not reveal these variations which the reader will find upon consulting Hollis (1952). The striped bass feeds more abundantly during the colder period of the year as shown by the percentage of fishes which had food in their stomachs during the summer (49%), autumn (52%), winter (70%), and spring (80%). Hollis (1952) found that 95% of the weight of all food items were fish; crustaceans were of secondary importance, furnishing less than 2% of the diet by weight.

A preliminary observation on the diet of weakfish by Dr. Daiber is given in Table 10. The data show that crustaceans occur most frequently in the diet of the weakfish, while mollusks and fishes also supply a sizeable portion of the diet.

The "frequency of occurrence" method of summarizing the data reported in Tables 9 through 11 is used by fishery biologists to obtain an index to the relative importance of the food organisms. Data so reported give the number of stomachs in which the same food occurred. Since some stomachs contained more than one food organism, the total number of occurrences was higher than the number of food-filled stomachs studied.

Comparable data are not available for the common anchovy (Table 12), where the total number and rank of the food organisms found in 476 stomachs is reported. This method, giving a rank of relative abundance based upon a calculation of the abundance of each food item, serves to show the species which were consistently present in the stomachs of the anchovies.

A comparison of the diets of striped bass, weakfish, clearnose skate, and the common anchovy reveal that certain food organisms are eaten by all four, as the mysid shrimps, but that the major food organisms are different for each fish (see also Table 13). The anchovy feeds upon smaller animals than do the adults of the other three species. Skates feed heavily upon organisms that burrow in or feed upon the bay bottom. The weakfish also feeds upon these bottom-dwelling species as well as swimming ones, while the striped bass is chiefly a predator of fishes. More important, however, are the chains of food energy transfer that cut across and connect the diets of the four fishes. When several of these food chains, like the one including organic detritus and phytoplankton-mysids-anchovies-weakfish-skate, are placed together a food web diagram results (Figure 6).

TABLE 9

FREQUENCY OF OCCURRENCE OF FOOD ORGANISMS IN THE STOMACHS OF STRIPED BASS, *Roccus saxatilis*.

(Summarized from examination of 968 stomachs from striped bass collected during a one-year period in Chesapeake Bay -- Hollis, 1952)

FOOD ORGANISMS	FREQUENCY OF OCCURRENCE Number of stomachs		FREQUENCY OF OCCURRENCE Percent of stomachs	
ALGAE		5		0.6
WORMS		12		1.3
MOLLUSKS		4		0.5
CRUSTACEANS				
Cladocerans		61		6.4
Shrimps		47		4.9
Isopods		45		4.7
Blue crab		17		1.8
Mysids		16		1.7
Other species		16		1.7
FISHES	818		84.6	
Anchovy, common		218		22.6
Spot		135		14.0
Croaker		124		12.9
Menhaden		108		11.2
Herring sp.		75		7.8
Weakfish		17		1.8
Other species		111		11.5
Unidentified species		185		19.2
BAIT		97		10.1
UNIDENTIFIED SPECIES		9		0.9

TABLE 10

FREQUENCY OF OCCURRENCE OF FOOD ORGANISMS IN THE STOMACHS OF WEAKFISH, *Cynoscion regalis*.

(Unpublished observations upon 205 stomachs of weakfish, size range 12-30 cm, with a mean standard length of 19cm, during July-October, 1952, Delaware Bay -- Dr. Franklin C. Daiber)

FOOD ORGANISMS	FREQUENCY OF OCCURRENCE			
		Number of stomachs		Percent of stomachs
WORMS				
Nemerteans		1		0.5
Gephyreans		1		0.5
Nereids		1		0.5
MOLLUSKS	71		34.6	
Solen viridis		65		31.7
Loligo sp.		4		2.0
Mytilus edulis		2		0.9
CRUSTACEANS	193		94.1	
Neomysis sp.		130		63.4
Crago sp.		33		16.1
Ampelisca sp.		11		5.4
Erichthonius brasiliensis		10		4.9
Other Corophiids		1		0.5
Labidocera sp.		8		3.9
Decapod remains		5		2.4
Ovalipes ocellatus		1		0.5
Gammarids		1		0.5
Isopods		1		0.5
Limulus polyphemus		1		0.5
FISHES	74		37.1	
Anchoa sp.		71		3.4
Poronotus tricanthus		2		0.9
Menidia sp.		1		0.5
Unidentified fish remains		66		32.2

TABLE 11

FREQUENCY OF OCCURRENCE OF FOOD ORGANISMS IN THE STOMACHS OF CLEARNOSE SKATES, *Raja eglanteria*

(Data obtained from observations on 363 skate stomachs containing food -- Fitz, 1956)

FOOD ORGANISMS	FREQUENCY OF OCCURRENCE Number of stomachs	Percent of stomachs
WORMS		
Nereis limbata	9	2.4
MOLLUSKS		
Ensis directus	131	36.0
Solen viridis	41	11.2
Loligo pealii	8	2.2
Crepidula fornicata	2	0.6
Modiolus demissus	1	0.3
CRUSTACEANS		
Crago septemspinosus	218	60.0
Neopanope texana	74	20.0
Pagurus pollicaris	50	13.7
Pagurus longicarpus	50	13.7
Libinia dubia	48	13.2
Ovalipes ocellatus	36	9.9
Neomysis americana	28	7.7
Panopeus herbstii	26	7.1
Eurypanopeus depressus	24	6.6
Ampelisca macrocephala	18	4.9
Chloridella empusa	9	2.4
Euceramus praelongus	9	2.4
FISHES		
Cynoscion regalis	26	7.1
Lophopsetta aquosa	15	4.1
Anchoa mitchilli	4	1.1
Peprilus alepidotus	3	0.8
Bairdiella chrysura	2	0.6
Rissola marginata	2	0.6
Merluccius bilinearis	2	0.6
Syngnathus fuscus	1	0.3
Micropogon undulatus	1	0.3
Raja eglanteria	1	0.3
Unidentified fish remains	49	13.4

TABLE 12

FOOD ORGANISMS FOUND IN THE STOMACHS OF THE COMMON ANCHOVY, *Anchoa mitchilli*.

(Data obtained from observations on 476 anchovy stomachs containing food; anchovies measured 15-84mm in standard length -- Stevenson, 1958)

FOOD ORGANISMS	TOTAL NUMBER OF FOOD ORGANISMS Number	Percent	RELATIVE ABUNDANCE Rank
DIATOMS	391	3.3	8
CHAETOGNATHS	7	0.1	12
MOLLUSKS			
Snails	618	5.2	5
Bivalves	24	0.2	7
CRUSTACEANS			
Copepods	6,376	53.6	1
Crab zooea and megalops	2,724	22.9	3
Mysids	581	4.9	2
Amphipods	88	0.7	4
Ostracods	16	0.1	9
Shrimps	14	0.1	10
FISHES			
Fishes	19	0.2	6
Fish eggs	1,042	8.8	11

TABLE 13

ESTIMATE OF THE RELATIVE OCCURRENCE OF SELECTED FOOD ORGANISMS IN THE DIETS OF FOUR SPECIES OF FISHES (Tables 9 through 12)

Symbols indicate the relative abundance of food items:

0 = absent or negligible
+ = present
++ = common
+++ = abundant
++++ = major food item

SELECTED FOOD ORGANISMS	STRIPED BASS	WEAKFISH (TROUT)	CLEARNOSE SKATE	COMMON ANCHOVY
ALGAE	0	0	0	+
WORMS	+	+	+	0
MOLLUSKS	0	++	+++	+
CRUSTACEANS	+	++++	++++	++++
Mysids	+	++++	+	+++
Shrimps	+	++	++++	+
Copepods	0	0	0	++++
Mud crabs	0	0	+++	0
FISHES	++++	++	++	+
Anchovy	++++	+++	+	0
Weakfish	+	0	++	0

These interrelationships between the various species as represented by their diets and by their predators, although probably in balance over a long period of time, show seasonal and yearly fluctuations. If only one species is considered, like the weakfish, then any environmental change that drastically reduces or favors the populations of its food or its predators can have a marked effect upon the weakfish population. Fisheries biologists believe that fluctuations in the abundance of one species are offset generally by an abundance of other species, so that over a period of time the gross productivity of the estuary remains relatively stable.

An economic headache can arise from this probable pattern of overall estuarine production stability. Suppose, to illustrate with an over-simplified case, that the decline of a commercial food fish such as the weakfish was balanced by an increase of a trash fish, the skate. Although the total tons of fish flesh produced per year might be the same as for the reverse situation (abundant weakfish, few skates) and the overall estuarine productivity unchanged, there would be fewer fishes for food. This is an important point for an economist to keep in mind when evaluating the production of a species in contrast to overall estuarine production.

(2) Zooplankton productivity. In the foregoing section, especially in Tables 10 and 12, several small animals were reported as abundant in the diets of weakfish and anchovies. These and other small current-drifted animals, the zooplankton, form a large source of food for larger animals. Since changes in their abundance can have a direct effect upon animal populations dependent upon them for food, the quantity and quality of the zooplankton is one index to the productivity of the estuary. Cronin (1954b), reporting upon a two-year study of the zooplankton, calculated that, if the entire Delaware River estuary had an average zooplankton content of one-half gallon in each one million gallons of water, there would be over 12,000,000 pound of these small food organisms present.

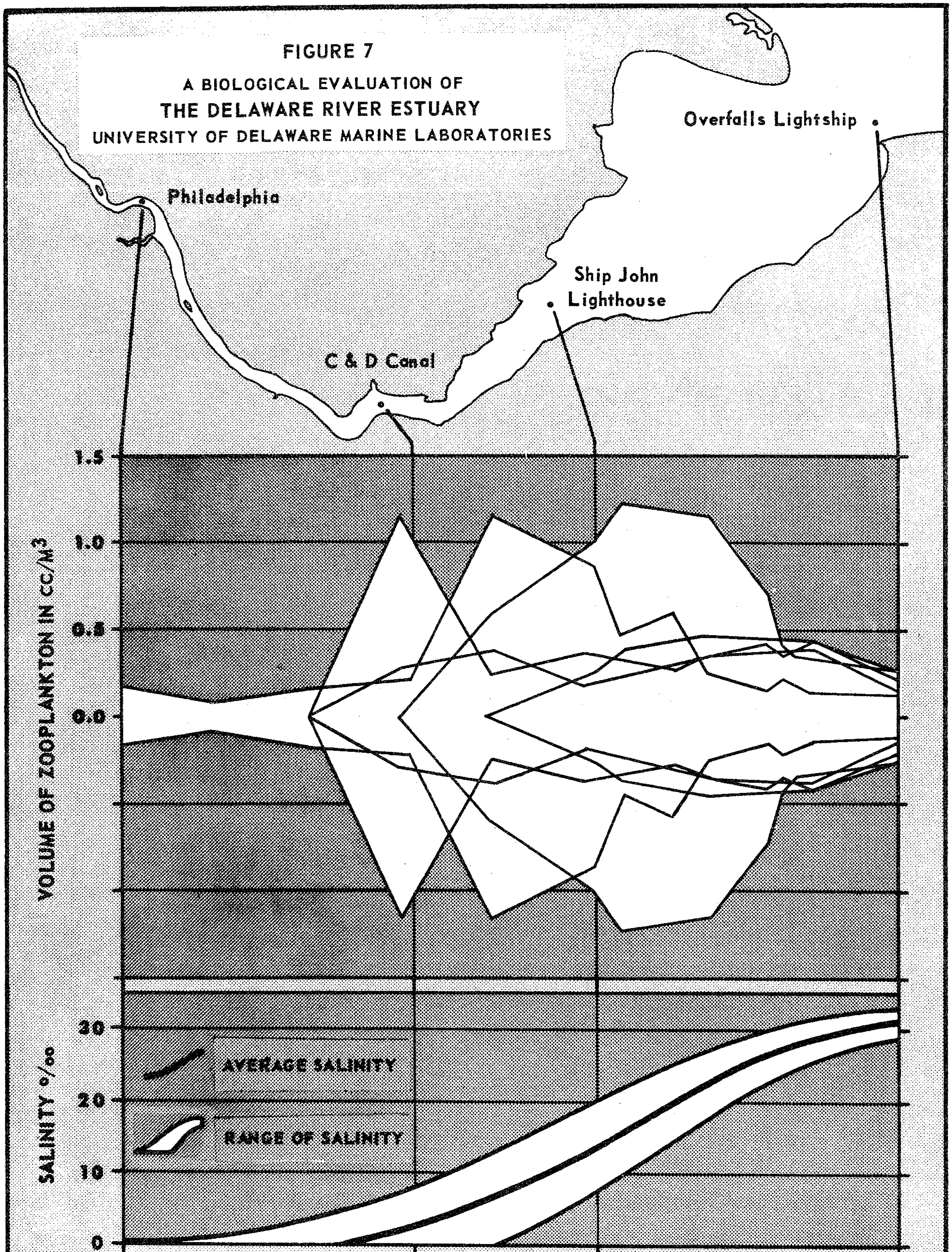
The bulk of this small animal-food crop is comprised of five crustaceans: Acartia tonsa, Eurytemora hirundoides and affinis, Gammarus fasciatus, and Neomysis americana. Each of these and the many other species involved shows its own relationship to salinity, temperature, and other environmental factors. According to Cronin (1954b), Acartia tonsa and the two species of Eurytemora are found in greatest numbers in the lower river-upper bay portion of the estuary where the salinity range is generally from 5 to 25 °/oo. Gammarus fasciatus is found in greatest numbers upstream from these three, in waters less than 5 °/oo. Another species, Cyclops viridis is most abundant in freshwater but is found in decreasing abundance down to but not below Ship John Lighthouse. At Ship John two species of Centropages, typicus and hamatus, first appear in downbay samples, being most numerous in the region of Overfalls Lightship.

Evidence of the extent of zooplankton productivity in the Delaware River estuary is given by the studies of Cronin (1954b), Hulburt (1957), and Hopkins (1958a). A summary of the total volume of zooplankton collected on five cruises from the Overfalls Lightship to Philadelphia (Cronin, 1954b) is given in Figure 7. This figure graphically shows the portion of the estuary, where the extremes in salinity ranged from nearly freshwater to over 30 °/oo and averaged 2-30 °/oo, in which the largest zooplankton crop was repeatedly harvested by Cronin (1954b). Hulburt (1957) believed that the large numbers of Neomysis within the bay, and presumably other marine zooplankton species, was due largely to two factors: the accumulation of animals which came from the coastal waters outside the bay and, during spring and summer, addition to this stock by reproduction.

The zooplankton richness of the nearshore and coastal waters was revealed by the studies of Hopkins. Exploratory nighttime offshore surface plankton tows made during the summer of 1958, showed that the quantity of zooplankton, particularly the mysids, fell off sharply beyond one-half mile from the shoreline. Further evidence of the relative abundance of zooplankton species in the along-shore waters was reported by Hopkins (1958a) and is summarized here in Tables 14 and 15. Comparable information on comb jellies and copepods was not reported by Hopkins because of the difficulty and extra time required to deal with these animals and yet accomplish the primary task of separating the mysids from the plankton samples. During the first portion of his study Hopkins recorded that the mysids were never more than 15%, with an average of 5%, of the combined volume of copepods and detritus in 17 plankton tows from November 1956, to April 1957. This finding corroborates the observations of Cronin (1954b).

Data on the range in numbers and volume of the various zooplankton animals, as recorded in Tables 14 and 15, furnish information on the variability of these animals in the plankton. The narrower the range between the minimum and maximum values, the more consistent the contribution of the population to overall productivity. Some of these ranges are recorded in Table 16 along with a seasonal index. This index reveals the percentage of the year average, taken as 100%, at which each plankton group stands during each season. These range and index values serve to highlight the evenness or the sporadic nature of the rise and fall of each plankton group during the year. The high index for decapod larvae during the summer, resulting from spawnings in the spring, serves to further indicate that the success of crab populations, such as the blue crab for example, may be largely dependent upon the environmental and predator conditions during the summer months when the greatest number of larvae are exposed to these conditions.

A comparison of the zooplankton groups listed in Table 14 with the food organisms listed in Tables 10 and 12, shows the relative importance of these zooplankton species to weakfish and anchovies. Roughly estimated, two-thirds of the weight of the weakfish harvested yearly by sport and commercial fishermen is due, directly or indirectly, to the zooplankton and plankton-feeding animals upon which weakfish feed. One species, *Neomysis americana*, is an important portion of that diet. Hopkins (1958b) concluded that the abundance of mysids and the frequency of their occurrence in fish stomachs indicates that mysids are an important link in the food chain of the estuarine and inshore coastal waters of the northeastern coast of America.



VOLUME OF ZOOPLANKTON PRESENT IN THE CHANNEL OF THE DELAWARE RIVER ESTUARY DURING FIVE CRUISES. COMPARE THESE VOLUMES WITH THE AVERAGE SALINITY CURVE AND RANGE OF SALINITY. (ADAPTED FROM CRONIN, 1954a, 1954b)

TABLE 14

NUMERICAL COMPOSITION, IN PERCENT, OF LARGER ZOOPLANKTON COLLECTED BIWEEKLY ON 24 FLOODING TIDES, APRIL 1957, THROUGH APRIL 1958 (based upon data obtained by Hopkins, 1958a)

T = trace (less than 1%); * Worms includes Platyhelminthes, Nemertea, and Annelida; ** Miscellaneous includes Cephalopods, Pteropods, Salps, and *Limulus* larvae; *** Stomatopod larvae are included.

	SPRING			SUMMER			AUTUMN			WINTER			ONE
ZOOPLANKTON	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	YEAR AVERAGE
Mysids	60	79	90	9	49	78	30	56	85	75	92	99	69
Amphipods	T	3	7	T	T	1	T	6	13	T	2	11	3
Isopods	T	2	8	T	T	T	T	2	10	T	T	T	1
Shrimps	0	1	5	T	T	T	T	2	6	T	T	1	1
Cumaceans	T	5	8	T	1	4	T	7	32	T	3	9	4
Crabs	0	T	T	0	T	T	0	T	1	0	0	0	T
Chaetognaths	0	5	18	0	T	1	4	21	44	T	1	4	7
Worms *	T	T	1	T	T	T	T	T	1	T	T	T	T
Coelenterates	T	1	6	0	T	1	T	2	4	0	2	11	1
Miscellaneous **	0	0	0	T	T	T	0	T	T	0	0	0	T
Decapod larvae ***	0	5	22	21	50	89	0	3	13	0	0	0	15

TABLE 15

VOLUMETRIC COMPOSITION, IN PERCENT, OF LARGER ZOOPLANKTON COLLECTED BIWEEKLY ON 24 FLOODING TIDES, APRIL 1957, THROUGH APRIL 1958 (based upon data obtained by Hopkins, 1958a)

T = trace (less than 1%); * Worms include Platyhelminthes, Nemertea, and Annelida;
** Miscellaneous includes Cephalopods, Pteropods, Salps, and <u>Limulus</u> larvae;
*** Stomatopod larvae are included.

	SPRING			SUMMER			AUTUMN			WINTER			ONE YEAR
ZOOPLANKTON	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	AVERAGE
Mysids	40	69	90	11	55	86	12	58	89	66	84	98	66
Amphipods	1	6	16	T	1	3	T	8	14	T	5	16	5
Isopods	T	4	17	T	1	4	T	5	23	T	1	4	3
Shrimps	0	5	14	T	2	4	T	13	36	T	9	22	7
Cumaceans	T	4	6	T	1	5	T	2	7	T	1	2	2
Crabs	0	T	T	0	1	3	0	T	T	0	0	0	T
Chaetognaths	0	5	14	0	T	T	1	10	20	T	1	4	4
Worms *	T	4	16	T	1	2	T	2	12	T	T	T	2
Miscellaneous **	0	0	0	T	1	6	0	T	T	0	0	0	T
Decapod larvae ***	1	4	17	10	38	83	0	3	6	0	0	0	11

TABLE 16

THE RANGE BETWEEN THE MINIMUM AND MAXIMUM AND THE SEASONAL INDEX, IN PERCENT, OF THE NUMBERS AND VOLUMES OF CERTAIN ZOOPLANKTON GROUPS SELECTED FROM TABLES 14 AND 15 (based upon the data obtained by Hopkins, 1958a)

DATA ON NUMBERS:

	SPRING		SUMMER		AUTUMN		WINTER	
ZOOPLANKTON	Range	Index	Range	Index	Range	Index	Range	Index
Mysids	30	114	69	71	55	81	24	133
Amphipods	7	100	1	13	13	200	11	67
Decapod larvae	22	33	68	330	13	20	0	0

DATA ON VOLUMES:

	SPRING		SUMMER		AUTUMN		WINTER	
ZOOPLANKTON	Range	Index	Range	Index	Range	Index	Range	Index
Mysids	50	105	75	83	77	88	32	127
Amphipods	15	120	3	20	14	160	16	100
Decapod larvae	16	36	73	345	6	27	0	0

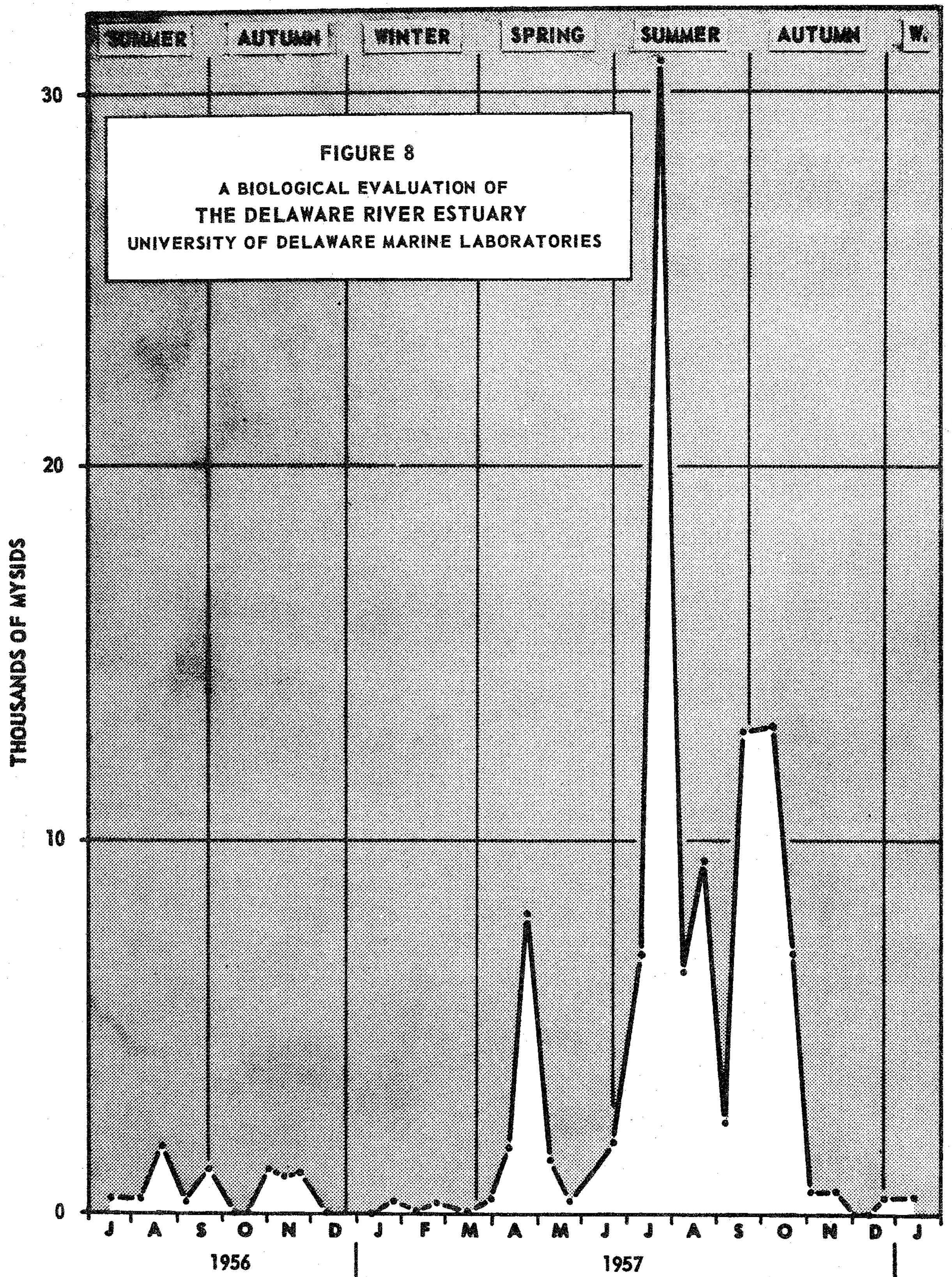
(3) Neomysis americana. This small shrimp-like crustacean is not only an abundant item in the diet of the weakfish, it is also eaten by spot, croakers, some flounders, and other commercially important fishes (personal communication -- Dr. Franklin C. Daiber). It is also the most-studied zooplankton species in the Delaware River estuary.

Hopkins (1958a) conducted a biweekly zooplankton survey at the Indian River Inlet over a two-year period. During this time four species of mysids were found in the plankton but only two, Neomysis americana and Mysidopsis bigelowi, consistently contributed large numbers and bulk to the plankton. Mysidopsis generally reached its peak in abundance during the late fall and winter when it occasionally ranks first in the mysid population. On a yearly basis, however, Neomysis is the predominant species, contributing 90 percent of the mysids more than half of the time.

Though Hopkins (1958a) found that the mysid population varied from month to month (see Figure 8), day to day, and even from hour to hour, he collected voluminous evidence that this group of animals, at least locally, constantly ranked second in numbers and bulk in the total zooplankton, being exceeded only by the tiny copepod crustaceans. Data for a twelve-month period at Indian River Inlet, summarized in Tables 14 and 15, show that, exclusive of the copepods and occasionally comb jellies, mysids ranked first in number and volume of all the species that exceeded one millimeter (about one-sixteenth of an inch) in length, 85% of the time. The mysids were over one-half of the total number of zooplankton species in three-fourths of the plankton collections and over half of the bulk in two-thirds of the collections.

Hulburt (1957) reported that Neomysis was much more abundant in the deep-water of Delaware Bay during daylight hours than in the near-surface or shallow water, or in the coastal waters at the mouth of the bay. This difference from the observations of Hopkins can be explained on the basis of when the plankton collections were made, nighttime or daytime, since Hulburt (1957) attributed the fewer numbers of Neomysis in surface waters during daylight hours to their avoidance of excessive light. A change in the turbidity of the bay water could, therefore, affect the distribution of mysids. Beside the light intensity factor, Neomysis is further limited in its distribution by salinity. Hulburt (1957) found that its up-estuary extent was restricted by waters less than 4 $^{o}/oo$. Thus, light intensity limits the vertical distribution of Neomysis, salinity its horizontal distribution in the estuary.

The estuarine environment. Among the everchanging variables within an estuary, salinity is generally singled out as the key factor in the distribution of organisms. That it is



FLUCTUATION IN THE ABUNDANCE OF MYSIDS IN AN ESTIMATED 10,000-GALLON SAMPLE OF WATER, FROM 17 JULY 1956 TO 7 JANUARY 1958. DESPITE THE MARKED FLUCTUATIONS IN ABUNDANCE, MYSID SHRIMP CONSISTENTY RANKED SECOND AMONG ALL ZOOPLANKTON SPECIES. (MODIFIED FROM HOPKINS, 1958a) a key factor cannot be disputed, but there are also many other important ecological factors such as currents, tides, silt, pollution, shoreline development, and geology. It may be more correct to use salinity as an index of the environment since salinity, indirectly probably can be related to, as an example, the silt load of the river discharge. Also, it would be difficult to consider the effect of the density of the baywater and of density currents upon the distribution of planktonic organisms if salinity and temperature of the water were not both considered. Since temperature influences the metabolism of cold-blooded animals it would be impractical to consider only salinity as a factor in survival. Not only is it necessary to correlate many environmental factors and biological processes when considering the possibilities of survival for any species, but the duration of each factor is just as important to consider. When considering each factor and how it affects other phenomena and biological processes -- in time and space, in quantity and quality -- the average mind soon loses comprehension of the multidimensional aspects of the problems involved. These problems are best relegated to a team of researchers and a biomathematician.

In spite of our realization of the complexity of the interreactions of the several ecological factors and the several dimensions in which they may act, for brevity our emphasis will be placed upon salinity and pollution as two factors affecting the livelihood and distribution of estuarine organisms.

(1) Biological conservation of water. Their ability, or lack of it, to conserve the water and salt content of their cells, tissues, or body fluids under varying environmental salinity conditions determines to a large extent where aquatic organisms can survive. Only those organisms capable of maintaining some level of water and salts within their bodies can survive the changes of salinity which occur in an estuary. The manner in which the body fluids and salts are conserved varies in type and efficiency among the different species. Indeed, it is this species difference of tolerance or adjustment to various degrees of salinity that determines where a particular species may exist.

Species that are restricted by salinity in their downstream movements or habitation area are said to be held in check by a "salinity barrier." The reverse situation is due to a "freshwater barrier." The important biological factor in either case, is that the barrier is due to the inability of the organism to conserve or maintain its own water and salt supply. The real barrier, therefore, is an osmotic one.

(2) The osmotic barrier. Within a container partitioned into two wells, one containing freshwater and the other an equal volume of seawater, separated by a membrane through which water

molecules will pass, the level of seawater will rise. This is due to osmosis, whereby water molecules tend to distribute equally within the volume available to them. Since there are proportionately fewer water molecules in seawater, due to the dissolved salts, than in the same volume of freshwater, the flow of water molecules is greatest into the seawater well until an equilibrium of flow is established. In an organism this flow of water into the body and tissues is much more complicated, but in our discussion our chief concern is the osmotic flow of water.

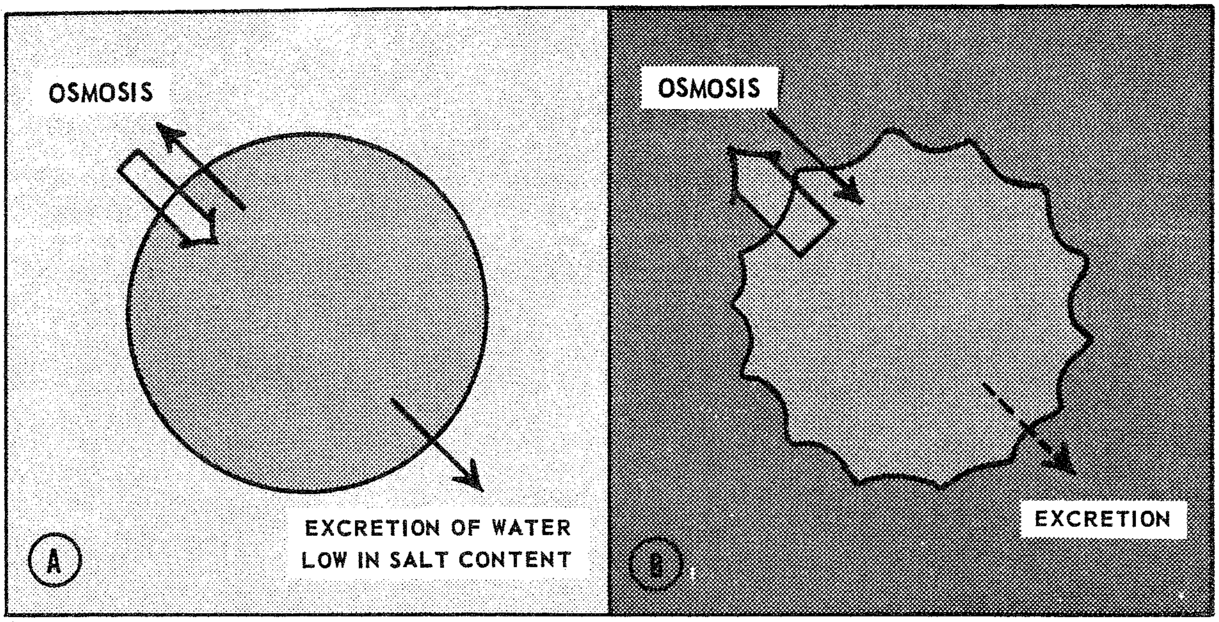
Figure 9 illustrates the importance of osmotic flow of water as a barrier to the distribution of species unable to adapt or to adjust to the varying salinity conditions within an estuary. What happens to a freshwater organism, shown as a single cell for simplicity, that cannot maintain its water supply in a seawater environment is illustrated in A and B of Figure 9. A species living in freshwater maintains its fresh-water balance by excreting the excess water due to osmotic flow (a). When placed in seawater, if the able-to-live-in-freshwater species cannot control the now outward osmotic flow of water, it soon collapses.

The reverse situation, of a marine organism in freshwater, is shown in C and D. One way in which a marine species can maintain its water balance against the outward osmotic flow, is to drink the seawater and excrete salts (C). If unable to prevent the inward flow of water, when placed in freshwater, the marine organism bloats and dies.

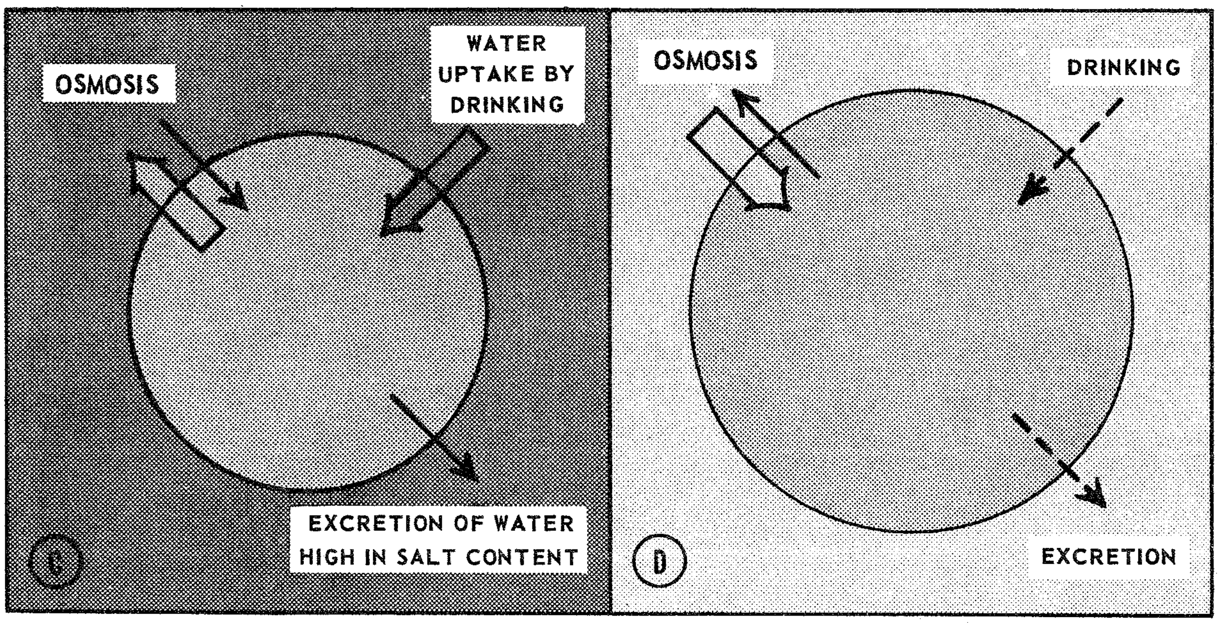
The above explanation and accompanying diagrams show the problem of water conservation faced by aquatic species; it does not give the reader an adequate impression of the many kinds of excretory and osmoregulatory (water-regulating) systems found among these species. Prosser (1950) gives an interesting well-documented account of the importance of water conservation to organisms.

Each species living within the estuary has its own range of tolerance or adjustment to salinity change. This of course determines where they can survive. Some species can withstand gradual changes, as the shad and eels that migrate to and from freshwater and marine habitats. The ranges of salinity within which some estuarine invertebrates are reported to be able to survive are given in Table 17. Differences between these species ranges may have economic importance.

A notable example is seen in the prevention of the invasion by the oyster drill _Urosalpinx cinerea_ onto the natural oyster beds in the upper bay region by a freshwater barrier. The drill is considered to be the most destructive predator on oysters in the upper portion of the Delaware River estuary.



A FRESHWATER SPECIES TAKEN FROM NATURAL CONDITIONS (A) AND PLACED IN SEAWATER (B) LOSES WATER AND SHRINKS.



A MARINE SPECIES TAKEN FROM NATURAL CONDITIONS (C) AND PLACED IN FRESH-WATER (D) GAINS WATER AND SWELLS.

DIAGRAMMATIC REPRESENTATION OF THE EFFECT OF OSMOTIC FLOW OF WATER UPON A FRESHWATER SPECIES (A AND B) AND A MARINE SPECIES (C AND D) UNDER USUAL AND EXTREME CONDITIONS.

FRESHWATER — NORMAL FLUID CONTENT OF ORGANISM

SEAWATER — SIZE OF ARROWS INDICATES EXTENT OF WATER FLOW

FIGURE 9

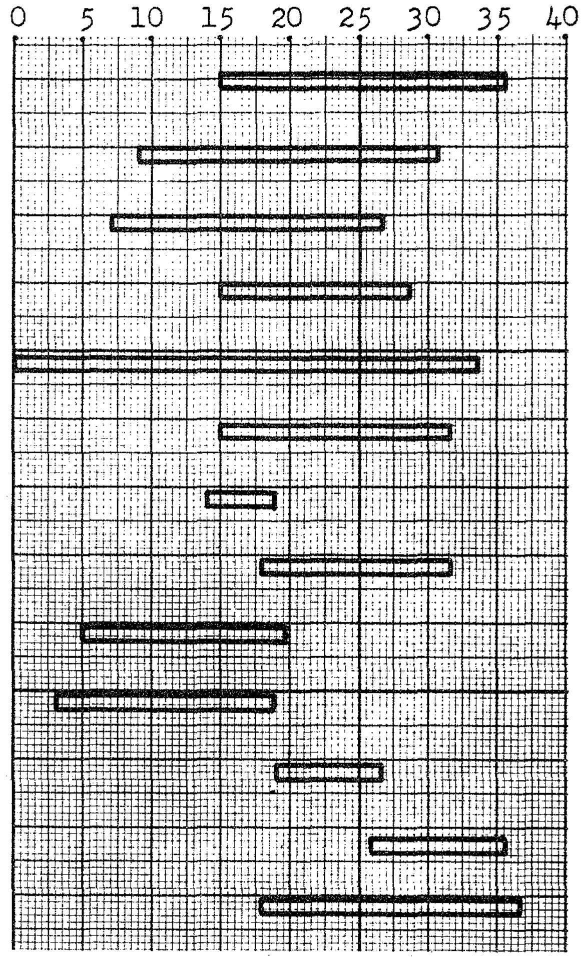
A BIOLOGICAL EVALUATION OF
THE DELAWARE RIVER ESTUARY
UNIVERSITY OF DELAWARE MARINE LABORATORIES

TABLE 17

SALINITY TOLERANCES OF SOME INVERTEBRATES OCCURRING WITHIN THE DELAWARE RIVER ESTUARY (compiled from several sources)

*	ORGANISMS
(1)	Cliona celata (boring sponge)
(2)	Nereis succinea *** (a clamworm)
(1)	Crassostrea virginica **** (Atlantic oyster)
(3)	Urosalpinx cinerea ***** (oyster drill)
(1)	Callinectes sapidus (blue crab)
(4)	Neopanope texana sayi (Say's mud crab)
(5)	Panopeus herbsti (a mud crab)
(4)	Hexapanopeus angustifrons (a mud crab)
(5)	Eurypanopeus depressus (flat mud crab)
(5)	Rhithropanopeus harrisi (brackish water mud crab)
(2)	Aeginella longicornis (long-horned caprellid)
(1,6)	Loligo pealii (common squid)
(1)	Lolliguncula brevis (short squid)

RANGE OF SALINITY TOLERANCE **



* Sources: (1) Spector, 1956; (2) Amos, 1954 and unpublished data; (3) Carriker, 1955; (4) Cowles, 1930; (5) Ryan, 1956, and (6) Haefner, 1959.

** Stauber (1943) pointed out, in discussing a graphic method of representing salinity condition in Delaware Bay, that species are limited to certain regions of the estuary by the effects of the extremes in the salinity range and of their duration rather than by the average conditions. For a further discussion of tolerances see Fry (1947).

*** At summer temperatures (20-27°C).

**** Can withstand short-time salinity changes of 0-42 $^{o}/oo$ in the laboratory (1).

***** Can survive salinities as low as 8 $^{o}/oo$ during the winter (2).

This predation is heaviest upon spat and seed oysters.

There is another kind of evidence on the effectiveness of the osmotic barrier in estuaries. It has long been recognized that there are fewer species living in estuaries than in either freshwater or marine habitats. This small number of species seems to be directly related to the rigorous climate of the everchanging estuarine environment. Few species can withstand, for example, the twice-daily salinity change that accompanies the tidal fluctuation. Those species that can survive, however, produce large populations. This abundance of a few species capable of living over a large area of the estuary has economic importance, as seen in the commercial shellfisheries harvest.

(3) Dangers of pollution. The harmful effect of pollution upon aquatic resources has long been recognized. Two major damages caused by pollution result from: 1) a change from the natural environment to one that is detrimental or lethal to aquatic organisms and/or 2) a commercial loss because the seafood is unfit for human consumption.

Shellfish, due to their sedentary nature, are especially susceptible to pollution. Many research reports document this fact. Baughman (1948) lists over 100 such reports and many more have been published since then. During the last half century the oyster harvest of the United States has steadily declined to about one-half of its former volume. Galtsoff (1956) attributes this decline to pollution resulting from the increase in population and accompanying industrialization.

Among the earliest dangers of pollution in the Delaware Bay were oil from mosquito ditches, waste oil from steamships, industrial chemical wastes, and excessive sewage. To these can be added the modern array of household and agricultural chemicals: detergents, insecticides, and herbicides. Artificial radioactivity due to atomic explosions of radioactive wastes poses an even more serious problem because aquatic organisms, particularly shellfish, accumulate metallic ions and radioactive substances within their tissues.

Three reports sponsored by the National Academy of Sciences - National Research Council (see Committee, Page 71) dealing with atomic radiation, radioactive waste disposal, oceanography, and fisheries can be cited. In the first of these Revelle and Schaefer (1957) state that,

> "Waste products from nuclear reactions require special care: they constitute hazards in extremely low concentrations and their deleterious properties cannot be eliminated by any chemical transformations; they can be dispersed or isolated, but they cannot be destroyed. Once they are created, we must live with them until they

become inactive by natural decay, which for some isotopes requires a very long time."

EVALUATION OF THE DELAWARE RIVER ESTUARY FISHERIES

This section is intended as a summary of the fisheries of Delaware, commercial and sport, and as a report upon the dollar value of the fisheries crops harvested from the Delaware River estuary and of the fisheries based upon these crops.

Shellfisheries in Delaware Bay. There are three large shellfisheries located in Delaware Bay: two for mollusks, the eastern American oyster (*Crassostrea virginica*) and the northern quahog (*Mercenaria mercenaria*), and one for a crustacean, the blue crab (*Callinectes sapidus*).

The information contained in this subsection is an approximation of both the economic value of the shellfisheries and the dollar value of the shellfish harvest areas in the western side of Delaware Bay. Another aspect of this section will be to point out the regions of Delaware Bay that seem to be more productive, in terms of shellfish harvested, than other areas of the bay. By establishing the extent of the more productive shellfish areas, researchers can direct their efforts toward determining the cause of high productivity in these particular areas and toward giving more positive conservation advisement.

(1) Method of study. Catch statistics data were related to actual fishery areas. The harvest data were taken from the most recent issues of "Fishery Statistics of the United States," published by the Fish and Wildlife Service, United States Department of the Interior. The total harvest for the seven-year period from 1950 to 1956, was averaged to obtain the value of the mean annual landings. These shellfish landings are given in pounds and dollar values at the dock.

The recorded price per pound is the average amount paid to the fisherman for his harvest; alive, at the dock. This price, obviously, is subject to wholesale and retail increases before it reaches the ultimate consumer.

Harvest data were compared with the shellfisheries areas plotted on U. S. Coast and Geodetic Survey Chart #1218. The extent of fishery areas, determined by our general knowledge of the bay and by personally interviewing the local commercial fishermen, is depicted in Figure 10. Measurement of the size of these areas was made by the method described previously on page 8.

(2) Oyster fishery. The major portion of the oyster fishery in Delaware Bay is a privately managed industry using the dredge method of harvest. A few oysters are tonged in the tidal creeks, but these landings are insignificant. The oyster harvesting season starts on September 1 and lasts through April; it is discontinued during the summer months when oysters spawn.

The industry is comprised mainly of individual oystermen who lease Delaware Bay bottom from the State. Rental is paid by the acre and is from $.75 to $2.00 per acre. Young oysters are planted upon these leased grounds to grow and fatten them for market. These young oysters are called seed oysters and, prior to 1951, were obtained largely from the natural seed beds of Delaware Bay. Since then many oystermen have bought "seed" from the seaside waters of Virginia. These seed oysters are planted (dumped overboard) on the rented acres and left to grow for one to four years. On some oyster bottoms (grounds), market size oysters can be harvested 1.5 years after the "seed" has been planted; in other areas, three or four years.

In the western portion of Delaware Bay, there are 45,000 acres of oyster grounds available for private planting but only about 20,000 acres are usually leased. The 6,000 acres in the natural seed beds area, although presently non-productive, are potentially the best source of seed oysters for replanting the leased grounds.

Decline of the natural seed beds of Delaware was analyzed by Shuster (1957b). During the 12-year period recorded in Table 18, the total number of bushels of shells and oysters planted were 686,000; whereas, 2,961,000 bushels were removed. The high level of seed production on the natural beds during the years from 1945 through 1949, was suddenly curtailed by a heavy mortality of the young oysters during the summer of 1950. Even without the mortality, it is doubtful that the annual production of 150,000 bushels of seed oysters could continue if there were not: sufficient shells on the bottom to catch the young oysters, a large spawning population, and environmental factors favorable to setting of young oysters. Today the natural beds are virtually barren. This is not the first time that production was low on these beds; it also occurred during the early 1900's and in 1942. Recovery was slow in the first instance, rapid in the 1940's. Rehabilitation of these beds is possible but it will be an unusually difficult task today because the oysters of Delaware Bay have suffered another widespread mortality (Shuster, 1958b).

This newest wave of mortality, starting with the planted grounds of New Jersey in 1957, has not yet run its course. The pattern of the spread of this mortality over an everwidening area suggests that it is due to a contagious cause, although

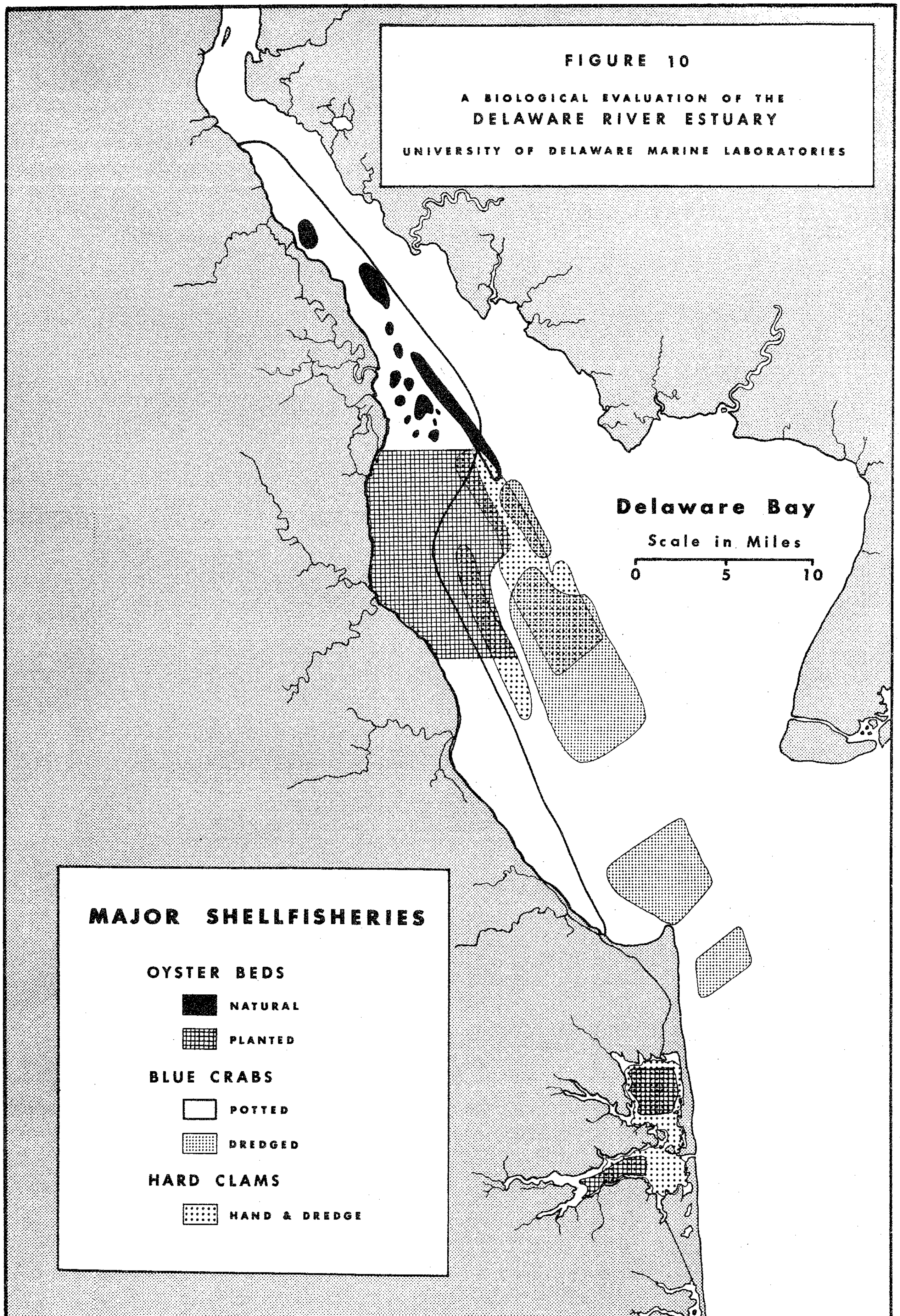


FIGURE 10
A BIOLOGICAL EVALUATION OF THE
DELAWARE RIVER ESTUARY
UNIVERSITY OF DELAWARE MARINE LABORATORIES
Delaware Bay
Scale in Miles
0
5
10
MAJOR SHELLFISHERIES
OYSTER BEDS
NATURAL
PLANTED
BLUE CRABS
POTTED
DREDGED
HARD CLAMS
HAND & DREDGE

TABLE 18

QUANTITY (IN THOUSANDS OF BUSHELS) OF SHELLS AND SEED OYSTERS PLANTED UPON OR REMOVED FROM THE NATURAL SEED BEDS OF DELAWARE

Year	Oysters Planted	Shell Planted	Oysters Removed	Shell Removed
1946	-	-	125	375
1947	-	25	144	431
1948	-	50	150	450
1949	-	100	163	487
1950	-	200	106	319
1951	-	78	75	25
1952	-	90	38	13
1953	-	55	15	5
1954	7	41	15	5
1955	-	40	14	5
1956	-	-	1	-
1957	-	-	-	-
	7	679	846	2,115

the cause is still unknown. Present evidence indicates that a microscopic enemy has invaded the tissues of the oysters. Questions concerning the origin of the mortality, what causes it, and how it is spread are unanswered. There is the possibility that the enemy was favored by a change in the environment. This change might have been caused by something like the rapid buildup of detergents in the river water during the past ten years, but the fact is, little is known about the subtle changes that man has caused in the estuarine environment and what their effect might have been upon estuarine life. Much research needs to be done to remove this blindfold of ignorance.

During the seven-year period analyzed, the Delaware oyster industry harvested an average of 2,639,581 pounds of oyster meats each year with an average value of $1,360,207. This is an average harvest value of 51¢ per pound of meats, which is equivalent to $3.06 a bushel for oysters in the shell, since about 6.0 pounds of oyster meats are shucked from a bushel of live oysters. These values of the oyster crop are augmented by the wholesale and retail values. One scale of wholesale prices of fresh shucked oysters is given in the following table, which reflects the cost of labor to shuck and package the harvest for market. By comparison, the current (1959) retail price in one chain store in Delaware, based upon $1.19 per pint, is $9.52 per gallon for standards. A gallon of retail packed standards weighs 9 pounds.

TABLE 19

THE WHOLESALE PRICE OF FRESH OYSTERS

Designation	Number/ Gallon	Wholesale Price/Gallon 1956	1957	1958	1959
Standard (Stewing)	350	$5.75	$6.25	$6.25	$6.25
Select	240	6.50	7.00	7.00	7.00
Extra-select	180	7.00	7.50	7.50	7.75
Counts	135-145	7.50	8.00	8.25	8.50

TABLE 20

AVERAGE ANNUAL OYSTER LANDINGS IN DELAWARE DURING 1950-1956

County	Average oyster harvest Pounds	Value
Kent	19,953,290	$1,006,415
Sussex	686,291	353,792
	20,639,581	$1,360,207

These values give an indication of the magnitude of the harvest for each county. Nearly all the rented oyster grounds are in Kent County; there are none in the waters of New Castle County, and only a few thousand acres in Sussex County.

(3) Hard clam fishery. The northern quahog is known locally as the hard clam. In Delaware Bay these clams are dredged during the winter. In Rehoboth Bay and Indian River Bay hard clams are tonged throughout the year.

During 1950-1956, an average of 629,143 pound of meats was obtained from the hard clams harvested each year. The clammers received an average of $207,616 a year for their harvest. Since there are about nine pounds of clam meats in a bushel of live clams, and the average price paid for clam meats was 33¢ per pound, the harvest value of a bushel of clams is nearly $3.00. The wholesale and retail value of these clams, obviously, would be greater.

Most of the 23,000 acres of clam harvest grounds in Delaware Bay are in Kent County where landings averaged 331,243 pounds a year of clams valued at $111,672. The average harvest from these Kent County clam grounds was 1.66 bushels per acre; a $5.00 harvest of clams per acre.

The Sussex County hard clam fishery in Rehoboth and Indian River Bays is included in this survey because these bays are influenced by the offshore estuarine waters. A large volume of Delaware River-diluted oceanic water moves into these bays on every flooding tide, markedly changing the hydrographic and chemical conditions there (Shuster, 1957a). The fishery extends over some 17,000 acres in these bays and continues throughout the year by tong and rake methods of harvest.

The Sussex County average yield has been 297,900 pounds of meats a year with an average value of $423,800. These clams were valued at $1.42 per pound, four times that of the Kent County product. This difference is due to the size and use of the clams: small ("cherrystone") clams are steamed or used as half-shell stock, and the larger ("chowder") clams are used in soups and chowders. The average of 17.3 pounds of clam meats produced by each acre of clam beds was also higher than the 15 pounds per acre in Delaware Bay and the average yield of clams per acre in Sussex County waters was worth $25.

(4) The blue crab fishery. The blue crab fishery is conducted throughout the year and moves about, following a regular sequence of areas in Delaware Bay. This shifting scene of the fishery is due to the seasonal migration and maturation of the crabs (Porter, 1956). Crabs are potted near shore in the lower portions of the bay during the early spring, and toward summer, as the water warms up, the fishery moves up the bay along the shore. By September most of the larger crabs are in the upper bay region. As winter approaches, the adult population moves down-bay toward the higher salinities. They remain quiet and "bed down" in the soft bay bottom, commonly on the shoal bars in 10 to 40 feet of water.

Crab dredging begins on December 15, and continues until early spring when the crabs move off the bars and begin the up-bay migration. Oyster schooners, party boats, and fish trawlers are outfitted with crab dredges for this work.

Blue crabs are not potted during the fall because of a slack market. This slack market for crabs is generally marked by the advent of the oyster season in September, when the crab-picking houses supplied by the potters temporarily shut down because most of the labor turns to oyster shucking. Market-sized crabs, however, are plentiful and in good condition and are commencing their annual down-bay migration to the mud flats at this time.

Commercial crabbing in Delaware Bay can be a very profitable business. The price that a crabber receives for a bushel of crabs fluctuates with the season and abundance of crabs. During the summer, the price for #1 grade crabs, large males, is $5 to $7 a bushel. Second grade crabs, any medium-sized males and all females, bring $1.50 to $3.50 a bushel. The smaller males and the females, due to their size, are less valuable to the crab picking-house markets. The winter catch of mixed crabs, mostly females, is sold by the barrel for $8 to $18 a barrel -- depending upon the abundance of crabs and the market condition. Many crabbers pot from 20 to 30 bushels of crabs every day of the summer; winter crabbers may dredge from 5 to 15 barrels a day.

The average yearly crab catch in Delaware Bay for the seven-year period studied was 3,143,700 pounds, or 7,869,250 crabs for which crabbers were paid $294,163. On the basis of these averaged figures, Delaware Bay crabs bring ten cents a pound, or, each crab caught was worth 3.3 cents.

TABLE 21

AVERAGE ANNUAL CRAB LANDINGS BY DELAWARE COUNTIES, 1950-1956

County	Pounds	Value
New Castle	213,871	$ 21,295
Kent	2,695,486	248,640
Sussex	234,343	24,228
	3,143,700	$ 294,163

These county harvest records do not reveal exactly where the crabs were caught, but they do indicate that Kent County boats account for 5/6 of the average crab landings in Delaware Bay.

The combined area of the crab pot fishery (85,000) and the crab dredge fishery (44,000) is 129,000 acres. The average yearly harvest records show that 25 pounds of crabs, worth $2.50, are harvested per acre per year. This is an average of one bushel, or 62 crabs, harvested per acre per year.

(5) Summary of Shellfisheries.

The extent of each area given in Table 22 is an approximation. An attempt was made to outline the boundaries of the major areas of shellfisheries harvest, as indicated on Figure 10. An evaluation of the regions of greater harvest within each area was not ascertained. We know that production was not equal throughout the entire area; therefore, crop values per acre computed from the table give an erroneous impression of actual values. The table is useful, however, since it establishes data from which certain inferences can be made more easily. For example, less than one-half of the 45,000 acres outlined as planted oyster grounds are suitable for planting. Actually, the annual oyster crop of over one million dollars has been harvested from about 8,000 of a total of some 20,000 planted acres. On these 8,000 acres the annual harvest is worth some $170. per acre, but this is obviously an average estimate of oyster production per unit of area, since oysters are not uniformly abundant even in the planted areas.

It is certain, therefore, that the total annual shellfish crop harvest value of $13 per acre, derived from the 170,000 acres within which shellfish are taken, is too low an estimate. Assuming that production throughout one-fifth of the total area is equivalent to the average oyster production level, then the bulk of the harvest is being produced upon 43,000 acres. This gives an average shellfish harvest value of $51 per acre, but even this estimate may be only one-tenth or less of the actual production that does occur. Harvest rates and total biological production are widely different, since even for the oyster, large populations capable of restocking the beds must be maintained.

TABLE 22

SUMMARY OF SHELLFISHERIES, 1950-1956

(All values and measurements are recorded in thousands)

AREA DESCRIBED	SIZE OF AREA (in acres)	AVERAGE CROP HARVEST Pounds	AVERAGE CROP HARVEST Value
Western portion of Delaware Bay	197		
Extent of bay bottom including all shellfisheries areas	170		
Extent of planted oyster grounds	45	20,640	$ 1,360
Clam dredge fishery	23	331	112
Clam tong and rake fishery	17	298	424
Crab pot and dredge fishery	129	3,144	294
TOTAL OF SHELLFISHERIES AREAS	214*	24,413	$ 2,190

* This figure is larger than the actual bottom area utilized by the shellfisheries (170,000 acres) because there is some overlap of the individual harvest areas (see Figure 10).

Calculating a 5% return on $2,190,000, the annual harvest of shellfish represents a dividend upon an investment of $43,800,000; or an evaluation of more than $1,000 per each heavily harvested acre.

Commercial and sport fisheries in Delaware waters. An evaluation of the magnitude of the sport fishery has been made by the University of Delaware (Daiber, 1956). This evaluation, with data obtained from "Fishery Statistics of the United States," for the years 1950-1956, has been utilized to determine the major Delaware fishing areas and to assign catch data and the value of catches to these areas.

(1) Sources of information. The first portion of this section is directed toward an evaluation of commercial fisheries in the State of Delaware. The yearly value of the fish catch, in pounds and dollar value, was derived from the "Fishery Statistics of the United States" and compiled into

Table 23.

Areas of the estuary most frequently commercially fished were located by analyzing available catch records and unpublished information. These areas were plotted on U.S.C. & G.S. Chart #1218 and then measured, in acres, using a compensating polar planimeter. The catch value, divided by the acres of fishing grounds, gives a per acre evaluation of the commercial fisheries. This value represents an annual return on a capital investment and indicates the worth of the area of the estuary used for commercial purposes. Commercial fishery methods analyzed include the following: purse seine, haul seine, gill nets--anchor, drift, runaround, and stake, fyke nets, dip nets, and otter trawls. The data for the areas illustrated in Figure 11 are given in Table 24.

TABLE 23

ANNUAL ESTIMATE OF THE FISH CATCH IN THOUSANDS OF POUNDS AND DOLLARS FOR EACH DELAWARE COUNTY (Compiled from U. S. Fish & Wildlife Service "Fishery Statistics," 1950-1956)

	NEW CASTLE		KENT		SUSSEX		DELAWARE Total	
Year	Lbs	$	Lbs	$	Lbs	$	Lbs	$
1950	103	16	301	50	152,848	1,665	153,252	1,731
1951	129	21	326	55	167,355	2,014	167,810	2,090
1952	200	24	154	34	208,243	2,067	208,597	2,125
1953	187	25	156	39	361,798	4,057	362,141	4,121
1954	155	17	194	26	307,111	4,564	307,460	4,607
1955	160	8	1,248	106	308,923	4,221	310,331	4,335
1956	54	4	675	54	353,709	4,678	354,438	4,736
Avg.	141	16	436	52	265,712	3,324	266,289	3,392

TABLE 24

AREAS OF COMMERCIAL TRAWL AND NET FISHERIES (See Figure 11)

TRAWL FISHERY		NET FISHERY	
Area No.	Acres	Area No.	Acres
1	3,200	1	700
2	7,500	2	1,200
3	3,600	3	400
4	14,800	4	10,100
5	2,200	5	400
Total Acres	31,300	Total Acres	12,800

An intensive survey of the salt water sport fisheries, sponsored by Dingell-Johnson funds allocated for marine fisheries research by the Delaware Board of Game and Fish Commissioners, was conducted by the University of Delaware in 1954 and 1955. This survey (Daiber, 1956) included fishing of the following types: (1) party boat, (2) small boat, (3) surf, (4) jetty, and (5) bank, wharf, and bridge fishing. Information on the number of sport fishermen in an average year for each of these types of fishing is summarized in Tables 26 and 27. This average year number of sport fishermen and the average amount of money spent per saltwater fisherman (Circular 44, published in 1956 by the U. S. Department of the Interior on a "National Survey of Fishing and Hunting" conducted in 1955) gives the estimated dollar value of the sport fisheries to the State of Delaware.

(2) Commercial fisheries of Delaware Bay. An average year commercial catch and catch value was computed from the available recent (1950-1956) "Fishery Statistics of the United States." Table 25 records the commercial species of fishes. Table 23 gives an average year catch of 266,289,000 pounds of fish from the Delaware Bay area, with the seven-year average value of $3,392,000. The menhaden fishery contributed the bulk of these averages with 264,821,000 pounds and $3,234,000 yearly. Table 24 and Figure 11 record and show the principal areas available to the net and trawl fisheries; a total of 44,100 acres. The value of the average yearly catch of these two fisheries, $158,000, divided by the acreage gives a per acre value of $3.59. Assuming a 5 percent return, the annual catch then represents a profit on an investment of $3,160,000.

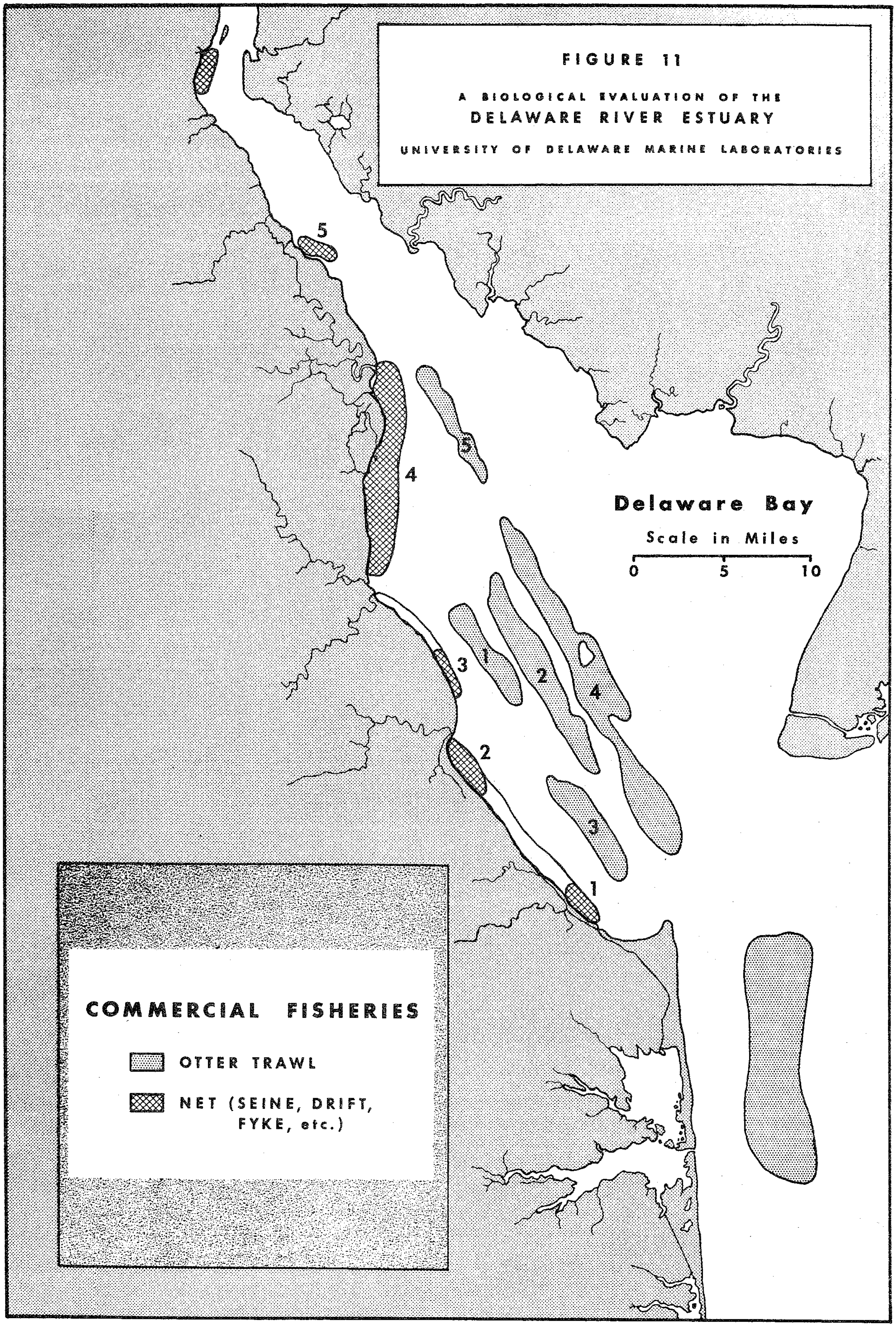


FIGURE 11
A BIOLOGICAL EVALUATION OF THE
DELAWARE RIVER ESTUARY
UNIVERSITY OF DELAWARE MARINE LABORATORIES
Delaware Bay
Scale in Miles
0
5
10
COMMERCIAL FISHERIES
OTTER TRAWL
NET (SEINE, DRIFT, FYKE, etc.)
1
2
3
4
5

TABLE 25

A LIST OF THE FISH AND SHELLFISH HARVESTED FROM DELAWARE BAY
(Based upon "Fishery Statistics of the United States")

FISHES (Common and scientific names)

Alewife
Pomolobus pseudoharengus
Bluefish
Pomatomus saltatrix
Bonito
Sarda sarda &
Euthynnus alletteratus
Butterfish
Poronotus triacanthus
Carp
Cyprinus carpio
Catfish
Amerius (Ictalurus) species
Croaker
Micropogon undulatus
Drum (black)
Pogonias cromis
Eels, common
Anguilla rostrata
Flounder
Pseudopleuronectes americanus
Fluke
Paralichthys dentatus
Glut herring
Pomolobus aestivalis
Hake
Urophycis chuss
Herring
Clupea harengus
Ling
Urophycis regius
Kingfish
Menticirrhus species
Mackerel
Scomber scombrus

Menhaden
Brevoortia tyrannus
Mullet
Mugil curema
Mugil cephalus
Porgy
Stenotomus chrysops
Puffer
Spheroides maculatus
Red Drum
Sciaenops ocellata
Sea bass
Centropristes striatus
Shad
Pomolobus sapidissima
Sharks
Carcharodon species,
Mustelus species,
Carcharhinus species,
Sphyrna species,
Lamna species and others
Spot
Leiostomus xanthurus
Striped bass
Morome saxatilis
Sturgeon
Acipenser sturio
Trout
Cynoscion regalis
Cynoscion nebulosus
White perch
Morone americana
Whiting
Merluccius bilinearis
Yellow Perch
Perca flavescens

TABLE 25 continued

SHELLFISH (Common and scientific names)

Blue crab
Callinectes sapidus
Hard clam
Mercenaria mercenaria
Conchs
Busycon canaliculatum
Busycon carica
Maninose
Mya arenaria
Oyster
Crassostrea virginica
Squid
Loligo pealei

TURTLE (Common and scientific names)

Snapper
Chelydra serpentina

(3) Sport fisheries. A summary of a four-year, 1952-1955, survey of marine sport fishing in Delaware waters was reported by Daiber (1956). This investigation was most intensive during the fourteen week period from 29 May through 3 September 1955. The data (Table 26) clearly established a large out-of-state segment of sport fishermen (54% from Pennsylvania, 13% residents of other states). This influx of anglers from other states is an indication of the recreational value of the fishery and the distance anglers will travel to fish for food and/or pleasure.

On the basis of 21 airplane counts, made on randomly selected days of people fishing and knowledge of the probable percentage of people fishing on the day of the counts, as determined by other surveys, a cumulative total of 341,300 anglers during 1955, was estimated. This figure undoubtedly includes persons counted more than once, since Daiber (1956) found that, on the basis of over 1,900 interviews, 4% of the people interviewed were fishing for the first time, 28% had fished occasionally that season, while 68% of the anglers fished frequently. Even if only one-tenth of the estimated total represented different people, then at least 34,000 anglers fished in Delaware waters during the summer of 1955.

The national survey conducted for the Fish and Wildlife Service (Circular 44, *op. cit.*) reported that saltwater anglers spent, on the average, \$91.18 per year, 98% of which included equipment and trip expenditures. This means that the people fishing in Delaware waters spent some \$3,000,000 in pursuit of

TABLE 26

THE STATE RESIDENCE OF PEOPLE

SALTWATER SPORT FISHING IN DELAWARE -- 1955

TYPE OF FISHING	LOCATION	STATE OF RESIDENCE (expressed in %) Delaware	Pennsylvania	Other	NO. OF INTERVIEWS
Party Boat	Bowers Beach	21	70	8	98
	Mispillion	38	50	13	8
	Lewes	0	78	22	32
	Indian River Inlet	4	72	25	57
Small Boat (skiff)	Port Penn	72	20	8	)
	Woodland Beach	37	55	8	)
	Kitts Hummock	63	30	8	)- 361
	Slaughter Beach	57	43	0	)
	Lewes	26	69	5	)
	Indian River and Rehoboth Bays	12	74	14	332
Surf		20	55	25	87
Jetty		19	52	29	435
Bank-Bridge		64	35	1	237
AVERAGE		33	54	13	131

that fishing. The conservativeness of this estimate (given in the University of Delaware Marine Laboratories Biennial Report, 1955-1956, No. 3:11) can be demonstrated by another calculation. The $3 million dollars represents only 1% of the total Atlantic coast sport fishery, from Maine to Florida (according to data in Circular 44, *op. cit.*). We feel confident, therefore, that our estimate is a minimum value.

Referring to Table 27, and using our estimate above, some 34,000 people fished a total of 1,594,100 hours during the summer of 1955, which is an average of 47 hours per angler per year. The table also records the prominent species of fishes, the number caught of each species, and the grand total of 2,618,700 fishes caught. Since edible fish landed by commercial fishermen were valued in 1955, at an average of 12¢ per pound, the sport catch, computed on the basis of one pound per fish, was worth $314,244.

The sport fisheries are not limited to specific areas as are the commercial fisheries. Party boat and small (row) boat fishing areas are shown in Figure 12. A more elaborate, pictorial chart of sport fishing areas was published by Stevenson (1952). Another chart was drafted by Mr. Anthony J. Florio to show the major access routes to inland lakes, primary streams, bay, and oceanside ports (published in January 1955 by the Delaware Board of Game and Fish Commissioners). Practically all of the 197,000 acres in the Delaware or western portion of Delaware Bay (see Table 1), can be designated as a sport fisheries area. This is an oversimplification, however, it suffices for the calculation to follow. Most of the beach areas, jetties, and bridges are readily accessible by good roads. The major small boat ports are on or near major highways. This general accessibility suggests that the $3,314,244 per year value associated with the sport fishery in the above discussion can be equated to the entire 197,000 acres of water available to the anglers, or an evaluation of some $16.80 per acre per year.

The previous discussion has been based on fishes and fishing as a form of outdoor recreation and a self-satisfying means of providing freshly caught food for the table. There is also a considerable sport fishery for the blue crab and the hard clam, principally in the Rehoboth Bay and Indian River Bay areas.

Stevenson (1952) and Daiber (1954) reported upon sport crabbing and clamming in these bays for the summers of 1952 and 1953, respectively. The exact number of people enjoying this sport is not known, but an estimate is included with the other data combined from Stevenson (1952) and Daiber (1954) in Table 28. During two 12-week periods, the summers of 1952 and 1953, an estimated 252,040 blue crabs and 614,600 hard clams were obtained. The commercial value of this harvest averaged $15,692 per year, calculating the value of crabs at 3.3¢ apiece and

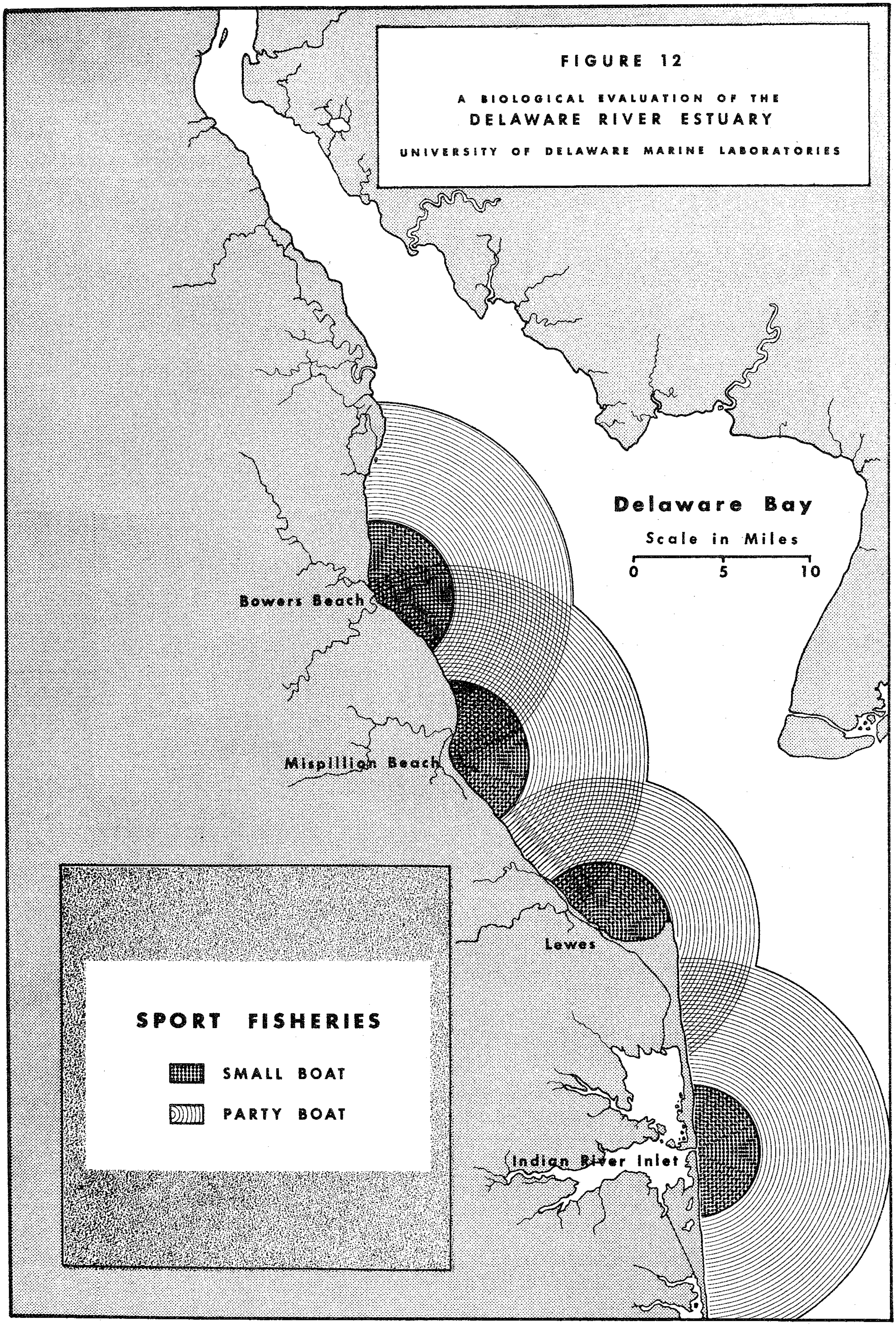


FIGURE 12
A BIOLOGICAL EVALUATION OF THE
DELAWARE RIVER ESTUARY
UNIVERSITY OF DELAWARE MARINE LABORATORIES
Delaware Bay
Scale in Miles
0 5 10
Bowers Beach
Mispillion Beach
Lewes
Indian River Inlet
SPORT FISHERIES
SMALL BOAT
PARTY BOAT

TABLE 27

THE ESTIMATED TOTAL NUMBER OF PEOPLE SPORT FISHING IN DELAWARE SALTWATERS, THE TOTAL MAN-HOURS OF FISHING, AND THE TOTAL FISH CAUGHT -- 1955 (All numbers and values are given in thousands)

TYPE OF FISHING	NO. OF PEOPLE	MAN-HOURS	TOTAL FISHES	Croaker	Weakfish (Trout)
Party Boat	62	459	1,292	225	121
Small Boat					
Delaware Bay	71	344	744	608	110
Indian River & Rehoboth Bays	76	379	423	-	130
Surf	39	148	76	9	35
Jetty	89	247	67	2	7
Bank-Bridge	4	17	16	4	1
TOTALS	341	1,594	2,618	848	404

TYPE OF FISHING	Flounder	Spot	Sea Bass	Blue Fish	Other
Party Boat	-	-	892	54	-
Small Boat					
Delaware Bay	15	4	-	-	7
Indian River & Rehoboth Bays	285	-	2	-	6
Surf	-	-	-	-	33
Jetty	46	-	10	-	2
Bank-Bridge	1	-	-	-	10
TOTALS	347	4	904	54	58

TABLE 28

SUMMARY OF A SURVEY OF SPORT CRABBING AND CLAMMING IN INDIAN RIVER AND REHOBOTH BAYS DURING THE SUMMER OF 1952 (Based upon data obtained by Stevenson (1952), with an estimate of the harvest in 1953 from Daiber (1954))

SPECIES	NUMBER OF SHELLFISH CAUGHT	ESTIMATED NUMBER OF FISHERMEN	HOURS SPENT FISHING	AVERAGE CATCH PER HR.	RESIDENCE OF FISHERMAN Del.	O-S*
Blue Crab	166,000 86,040**	10,350	45,500	4	30%	70%
Hard Clam	300,800 313,800**	11,325	43,000	7	30%	70%

* Out-of-State residents ** 1953 estimates

assuming an average of 250 clams per bushel. Although of low economic value, this quantity of seafood provided 88,500 hours of recreation to several thousand sport crab and clam fishermen in 1952.

A spot check conducted in Rehoboth and Indian River Bays by wardens of the Delaware Commission of Shell Fisheries during the summer of 1957, revealed that an average of 250 persons clammed on week days, while 400 clammed on week-ends and on holidays. The average harvest was found to be 100 clams per person. Assuming that these data are fully applicable over the four-month period commencing in mid-May, then over one million clams could have been harvested by sport clammers in 1957.

A comparison of the results of the 1957 spot check with those obtained during the 1952-1953 surveys does not reveal if there was an actual three-fold increase in the harvest or whether there was a difference in the methods employed to survey the clammers. There also could have been an increased popularity of the sport, with more people doing more clamming than in the previous years. It can be easily confirmed on any summer week-end, however, that sport clamming and sport crabbing too, are real recreational activities enjoyed by entire families.

Ocean fisheries off Delaware Bay. The coastal region off Delaware Bay is one of the most productive ocean fisheries areas in North America according to June and Reintjes (1957). They estimated that during 1953, a total yield of fish and shellfish from this region amounted to over 662 million pounds, valued at $11.5 million to the fishermen. This production could be much higher because many millions of pounds of trash (not utilized) species of fish are discarded annually.

June and Reintjes (1957) surveyed the ocean fisheries in an area of some 11,236 square miles (statute) along the Atlantic coast between Barnegat Lightship and Winter Quarter Lightship, seaward to the 100 fathom contour. They stressed the large number of commercial and other species occurring off Delaware Bay. This area is more or less the geographical center of migratory fishes, as weakfish (trout), croaker, sea bass, and porgy, which range in abundant numbers principally between Cape Cod and Cape Hatteras. It is the southernmost extent of many northern species, such as cod, haddock, lobster, pollock, sea scallops, red hake, sea herring, wolffish, and others. During the warmer water months the Delaware Bay and offshore area is the northern limit of some southern species, as black and red drum, cabio, and spot.

This offshore ocean fishery exists, as explained earlier, entirely within the region influenced by river discharge. Much of the area surveyed by June and Reintjes (1957) is within the boundaries of the Delaware River estuary. It is for this reason that the fisheries off Delaware Bay represent an integral part of any economic evaluation of the Delaware River estuary. This is further demonstrated by the close relationship between the offshore fishery and the bay proper, as seen in the movement of migratory fishes into Delaware Bay for spawning and feeding. Indeed, the young of many species, such as the menhaden, begin their life within the bay and its tidemarsh streams. A comparison of Tables 3, 25, and 29 shows that several species of commercially harvested fishes occur on each list. These species, ranked in order of increasing commercial importance to the Atlantic coast fisheries (see McHugh, 1958) -- common eel, black drum, white perch, bluefish, weakfish, striped bass, croaker, and menhaden -- are found in the shore zone when young, and at later stages are harvested from the bay and are caught in the ocean fisheries.

TABLE 29

A LIST OF THE FISHES AND SHELLFISH HARVESTED IN THE OCEAN FISHERIES OFF DELAWARE BAY (From June and Reintjes, 1957)

FISHES (Common and scientific names)

- Anglerfish
  - *Lophius piscatorius*
- Black Drum
  - *Pogonias cromis*
- Bluefin Tuna
  - *Thunnus thynnus*
- Bluefish
  - *Pomatomus saltatrix*
- Bonito
  - *Sarda sarda*
- Butterfish
  - *Poronotus triacanthus*
- Cabio
  - *Rachycentron canadus*
- Cod
  - *Gadus morhua*
- Common Eel
  - *Anguilla rostrata*
- Conger Eel
  - *Leptocephalus conger*
- Croaker
  - *Micropogon undulatus*
- Dolphin
  - *Coryphaena hippurus*
- Fluke
  - *Paralichthys dentatus*
- Grunt
  - *Haemulon* species
- Haddock
  - *Melanogrammus aeglefinus*
- King Whiting
  - *Menticirrhus saxatilus*
- Little Tuna
  - *Euthynnus alletteratus*
- Mackerel
  - *Scomber scombrus*
- Mackerel Shark
  - *Isurus nasus*
- Menhaden
  - *Brevoortia tyrannus*
- Pollock
  - *Pollachius virens*
- Porgy
  - *Stenotomus chrysops*
- Red Drum
  - *Sciaenops ocellata*
- Red Hake
  - *Urophycis chuss*
- Sand Perch
  - *Bairdiella chrysura*
- Sea Bass
  - *Centropristes striatus*
- Sea Herring
  - *Clupea harengus*
- Sea Robin
  - *Prionotus* species
- Skates
  - *Raja* species
- Spot
  - *Leiostomus xanthurus*
- Striped Bass
  - *Roccus saxatilus*
- Tautog
  - *Tautoga onitis*
- Tilefish
  - *Lopholatilus chameleonticeps*
- Weakfish (Trout)
  - *Cynoscion regalis*
- White Hake
  - *Urophycis tenuis*
- White Marlin
  - *Makaira albida*
- White Perch
  - *Roccus* (*Morone*) *americana*
- Whiting
  - *Merluccius bilinearis*
- Windowpane
  - *Lophopsetta maculata*
- Wolffish
  - *Anarhichus lupas*

TABLE 29 continued

SHELLFISH (Common and scientific names)

Blue Crab *Callinectes sapidus*	Sea Scallop *Placopecten magellanicus*
Conchs *Busycon* species	Squid *Loligo pealei*
Lobster *Homarus americanus*	Surf Clam *Spisula solidissima*

The menhaden fishery is the largest in the region, producing over 622 million pounds, or 94 percent of the total catch in 1953, while the otter trawl fishery for food fish amounted to nearly 21 million pounds, and the surf clam harvest was 7.7 million pounds of meats. Although sport fishing accounted for a small portion of the total landings, some 3 to 5 million pounds, it does contribute substantially to the economy of the area, particularly to recreational interests. An economic summary of these and the other fisheries of the area is given in Table 30.

TABLE 30

FLEET SIZE, REPLACEMENT VALUE, NUMBER OF FISHERMEN EMPLOYED, AND VALUE OF CATCH FOR 1957 (from June and Reintjes, 1957)

FISHERY	NO. OF VESSELS	REPLACEMENT VALUE OF VESSELS & GEAR	NUMBER OF FISHERMEN EMPLOYED	VALUE OF CATCH
Menhaden	33	$ 6,300,000	957	$ 7,100,000
Otter trawl	86	2,850,000	285	2,000,000
Surf clam	46	920,000	130	963,000
Purse seine for foodfish	3	200,000	24	150,000
Pot	20	200,000	40	190,000
Miscellaneous	20	100,000	40	200,000
Sport	250	1,875,000	500	900,000

The national economic inflationary trend and the improvement in gear is apparent in the menhaden fishery. While the replacement value of an average menhaden vessel and gear in 1953 (Table 30) was around $200,000, it is now $300,000. An electronically equipped steel-hulled vessel costs about one-half million dollars. The modern menhaden factory is a $4,000,000 establishment, furnishing substances from which hundreds of products are made (Tressler and Lemon, 1951; Higgins, 1958).

Construction and operation of food processing plants are expensive. An oyster shucking house, equipped with mechanical means for moving oysters in and shells out and providing work for 50 to 60 shuckers, costs $25,000. To build a quick-freeze shellfish processing plant and a warehouse with a holding capacity of 300,000 pounds would require an investment of not less than $100,000.

Conservatively estimated, the commercial fisheries vessels, gear, and factories and the food processing plants of Delaware represent well over 15 million dollars of investments.

It is obvious -- when encompassing the combined value of the marine fishery resources, of charter boats and sport fishing business, of fishery vessels, of commercial non-food product factories and food processing plants -- that Delaware River estuary-dependent activities represent a ~~modest~~ sum of over 60 million dollars. This estimate is low because the fisheries harvest is not as high as it should be. We have already cited (page 46) the decline of just one fishery, the oyster industry, to about one-half of its former volume. A second example is even more striking. In former years there was an abundant shad fishery in the bay and river. Throughout the 19th century the annual shad catch weighed between 10 and 19 million pounds. Shortly after the turn of the century there was a precipitous drop in the fishery and after 1920 the catch has rarely exceeded 500,000 pounds according to various statistical publications of the United States Government. Pollution control and abatement is required before the shad populations of former years can be expected to survive the upstream spawning migration and the downstream run of the young shad to the estuary and open ocean. Large numbers of young shad, 4 to 6 inches in length, are now common along the shores in the upper portion of the estuary (compare with Table 3). We could witness a noticeable return of the shad within a few years, if pollution abatement and control continues.

Fish kills in the lower Delaware River are a yearly occurrence, generally in early June, and although there has not been a study made of the cause or causes, the lack of oxygen or the presence of toxic substances are suspected. Data on oxygen-lack within the lower River has been amply supplied by Cronin

(1954a) and by Kaplovsky (1956). The causes of this lack can be due to a single factor or a complex of physical, chemical or biological phenomena; further studies are required to solve the annually recurring fish kills.

CONCLUDING REMARKS

State-wide interest in marine biology and a recognition of the value of the aquatic resources of Delaware led to the inception of a marine science program at the University of Delaware in 1951. This program, of education and conservation advisement based upon research findings, has been aided further by grants from federal, state, and private sources. The central research interest of this program is the Delaware River estuary: the environment, the organisms, the inter-relationships between environment and organisms, and the production of renewable harvestable resources.

This scientific investigation of the Delaware River estuary has provided intellectual enrichment, exciting experiences, and self-rewarding achievement for our researchers. Our growing understanding of the estuary and its resources has contributed to intrastate programs and has enabled representatives of the State of Delaware to better participate in matters of interstate concern, as on the Interstate Commission on the Delaware River, the Atlantic States Marine Fisheries Commission, and the Water Resources Association. The marine program, no less than any other academic pursuit, has furnished cultural and recreational as well as practical advantages to the people of Delaware. We extend these advantages to all who wish to learn and to share with us our increasing knowledge about the Delaware River estuary -- its wonderful world of life, its bountiful harvests, and its present and potential value to the rapidly developing industrialized coastal area.

We commend to your attention, as a rewarding intellectual experience, the fruits of learning being produced by the newly developing field of estuarine research. If, however, you are concerned only about an economic evaluation of the river basin we urge you to look at the entire freshwater-affected and dependent area and to make a full appraisal of the present and potential role of the Delaware River estuary in the overall economy of the river basin. Three publications can be cited as particularly suited for the purpose of obtaining the perspective necessary for this appraisal. It is of interest to note that these publications are reports from separate symposia and committee undertakings resulting from the combined efforts of many specialists.

The first, a book that all persons engaged in resources research and in administration of the public welfare should consult, resulted from a desire of anthropologists

> "to keep abreast of all the means at man's disposal to affect deliberately or unconsciously the course of his own evolution; in this case, what man has done, and is doing, to change his physical-biological environment on the earth."

This volume, "Man's Role in Changing the Face of the Earth," edited by Thomas (1956), resulted from an international symposium held to consider in retrospect, process, and prospect three interrelated factors: (1) the earth's resources, (2) the numerical pressure of population upon, and sustained by, the resources, and (3) man's differing cultures, or ways of life. Thomas (1956) writes,

> "Within the last century man has developed the idea that change is continuous and includes himself. Conceptions of fossil man (prior to present man), of biological evolution (in which man is included with all other living phenomena), and of the vast duration of earth history are but a few examples of ideas developed by science and become part of the public consciousness since the mid-nineteenth century. Can the uniqueness of the present be made clearer for those within it by focusing on the role of man in altering the earth's surface, keeping in mind the longevity of the period in which he has been doing so? This Symposium is intended to contribute to such an understanding."

From the start the "Treatise on Marine Ecology and Paleoecology" was planned as

> "an appraisal of accomplishments in the fields of marine ecology and paleoecology, particularly those ecological investigations related directly or indirectly to paleontology."

Volume one of the Treatise, "Ecology," edited by Hedgpeth (1957), contains a wealth of information that is applicable to estuarine ecology. Among the many topics discussed by specialists are: concepts of marine ecology; solar radiation, submarine daylight, and photosynthesis; salinity; temperature; oxygen in the ocean; nutrient elements; organic detritus; interrelations of organisms; plankton; bottom communities; and estuaries and lagoons.

The "Proceedings, Salt Marsh Conference, 1958" edited by Ragotzkie (1959), resulted from geologists, hydrographers, botanists, and zoologists meeting for a common purpose, to learn what the others had and might contribute to the study of salt marshes. The major categories of topics included in the conference were the land structure, vegetation, and ecology of salt marshes and historical records obtainable from salt marshes.

It has been the objective of the writer to outline what is known about the boundaries of the Delaware River estuary, some of the man-caused changes that affect the environment of estuarine organisms, and the productivity of the estuary. This estuary is the tidal portion of the Delaware River basin, including the tidal marshes along its shores and a vast area of over 3,000 square miles off its mouth. Man-caused changes in river flow, although influential in the distribution of estuarine organisms, are not as damaging as pollutants. Both changes, river flow and pollutants, are engineering problems that must be better solved than they are today if biological productivity of the estuary is to remain high or to be improved.

We should be ever critical of man-made changes of naturally occurring factors affecting the estuary, particularly of the river flow characteristics, until it can be demonstrated that these will not be detrimental to estuarine life, especially to commercially valuable species. For example, the ability of aquatic organisms to conserve water in their tissues under varying salinity and associated environmental conditions is what determines where those organisms can exist within the estuary. Variations in the freshwater flow that bring about changes in the pattern of water circulation of the upper estuary can markedly affect the distribution of planktonic species and those bottom-dwelling species, such as the oyster, that spend their larval stages carried by the currents.

In addition to the "old-fashioned type" of soil, sewage, and industrial pollutants, a new, more deadly series -- detergents, insecticides, and radioactive substances -- poses an even more critical problem than does fluctuation in the freshwater flow. Essentially, the challenge is to achieve better management of our natural resources to counteract a century of decrease due largely to inadequate solution of pollution problems.

The freshwater flow from the Delaware River basin and all its contained minerals, nutrients, and pollutants, has an effect upon some 4,000 square miles of coastal waters bordering the states of New Jersey, Delaware, and Maryland. The value of marine resources harvested yearly from this area, added to the investment in vessels, equipment, and factories processing the harvest, is in excess of 60 million dollars. To this can be added another type of resources -- seawater, which includes extraction of metals from seawater, as at the Northwest Magnesite Company plant at Cape May, New Jersey, and the probable future source of large volumes of freshwater from the sea. Utilization and management of these mineral and water resources, the food and commercial products crops, and the recreational aspects of the natural resources is an expanding frontier of man's activities.

Tidal marshes have been found to be highly productive of estuarine life, particularly plants, and they contribute much to estuaries. Delaware marshes are essential to the production and maintenance of water fowl and fur bearer populations. These marshes, particularly tidal ones, are valuable also to the fisheries of the Delaware River estuary. Indeed, if all tidal marshes were lost from the productivity of the estuary, our fisheries harvest might well drop to less than half of their present volume. A positive program of marsh utilization must be adopted so that industry, agriculture, and recreation, with effective control of mosquitoes, can coexist with fisheries. Impoundment and flooding of marshes for the dual purpose of mosquito control and water fowl and/or fur bearer management are contrary to the best interest of fisheries. A suitable number of tidal marshes must be managed for maximum benefit to the fisheries. On the other hand, if a marsh must be lost from estuarine production, the Little Creek area can be listed as a good choice for use as an impoundment-dredge spoil area on the basis of our present knowledge.

This report upon the biological productivity of the Delaware River estuary provides sufficient information on its value to appeal to every conservation-thinking citizen of the United States. The need is to achieve better utilization of our rapidly diminishing per capita natural resources. Wanton destruction of renewable natural resources -- instead of seeking opportunities of increasing this renewable production afforded by our accumulating scientific and engineering abilities -- is not only a crime today, it penalizes future generations with a severe handicap. This line of reasoning is obviously stimulated by ominous forecasts of what lies ahead for worldwide increasing populations, as reported, for instance, in a recent issue of Newsweek (April 27, 1959) on "The avalanche of babies." Locally, as applies to this report, the problem is to provide for our future population by developing the ability to engineer changes that will have a beneficial effect upon the biological productivity of the Delaware River estuary. This difficult problem may be solved by future generations in their search for living space, food to eat, and water to drink. Although each of these essential items in the environment of living creatures is seemingly in plentiful supply today, it is not too soon to recognize the probability of their decreasing abundance and to provide the proper background of information for future action. This can be done by initiating research upon the feasibility of manipulating estuarine productivity as a part of the overall consideration of the use of our water resources.

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APPENDIX: HYPOTHESIS ON TIDEMARSH PRODUCTIVITY

Although the broad pattern of events outlined in the following hypothesis on the role of tidemarshes in the productivity of the Delaware River estuary are substantiated by data, certain of the statements may be modified as data accumulates. It is for this reason that the topics on which future research should be undertaken are underlined. Figure 13 graphically supplements Kalber's (1959) hypothesis.

(1) The bulk of nitrogen and phosphorus in the river runoff is probably inorganic.

(2) Both inorganic and organic levels of <u>phosphorus</u> and and nitrogen are built up in the lower river area.

(3) <u>Presumably, due to</u> high BOD (Biological Oxygen Demand) and a narrow light penetration zone, <u>inorganic nutrients entering the "nutrient build-up" area are not bound there by autotrophic activity and thereby largely lost to the estuary at this point</u>.

(4) Much of the added organic material is broken down under anaerobic conditions in the downstream end of the "build-up" area. <u>Inorganic phosphorus and nitrogen are not bound here because of anaerobic and other conditions</u>.

(5) Reaeration at the extreme downstream end of the "build-up" area is apparently rapid, allowing a sudden utilization of inorganic nutrients. <u>The same general phenomenon may occur in the rest of the bay, probably in the sediments. Some of the inorganic substances are passed directly to the marshes for regenerative breakdown</u>.

(6) Due to the shallowness of the bay, mixing is apparently good at all seasons. Mixing allows regenerated inorganic nutrients to be brought to the surface, <u>but a narrow light penetration zone prevents rapid depletion by phytoplankton</u>.

(7) <u>Inorganics released from the bottom, but not utilized in the photic zone, are brought to the marshes for binding in rooted aquatics</u>.

(8) <u>Inorganics are made available again through</u>:

(a) regeneration in marshes from free organics;
(b) <u>breakdown in marshes from rooted aquatics</u>.

(9) These ordinarily limiting inorganics (phosphate and nitrate) <u>are, therefore, steadily fed out into the bay in a form available to organisms. A productive "steady state" in</u>

A. ESTUARINE PRODUCTIVITY -- SUMMARY OF NUTRIENT FLOW:

NUTRIENTS COMING FROM AND THROUGH THE NUTRIENT BUILD-UP AREA (1) ARE IN A FORM USABLE BY MICROSCOPIC FLOATING PLANTS IN THE BAY REGION (2). UNUSED NUTRIENTS ARE BOUND INTO MARSH PLANT TISSUES (3) AND ARE "FED BACK" REGULARLY INTO THE BAY WATER BY BACTERIAL ACTIVITY AFTER THE DEATH OF THE PLANTS (4). THE RESULT OF THESE PHENOMENA IS A RELATIVELY EVEN CONCENTRATION OF NUTRIENTS IN THE BAY WATER (5).

Nutrient build-up area

Tidemarshes

Nutrient pathways (width of arrows indicates relative concentration)

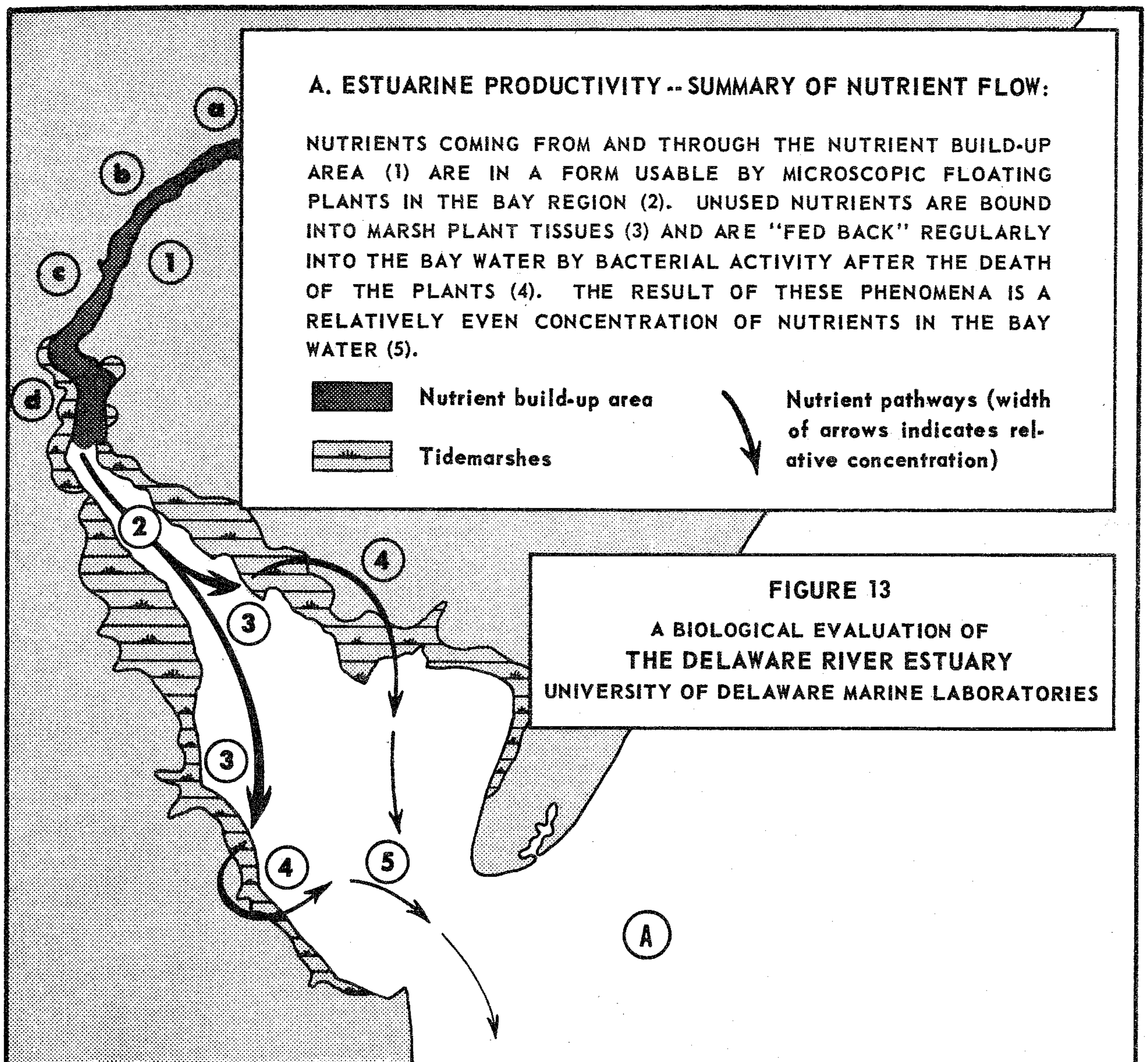
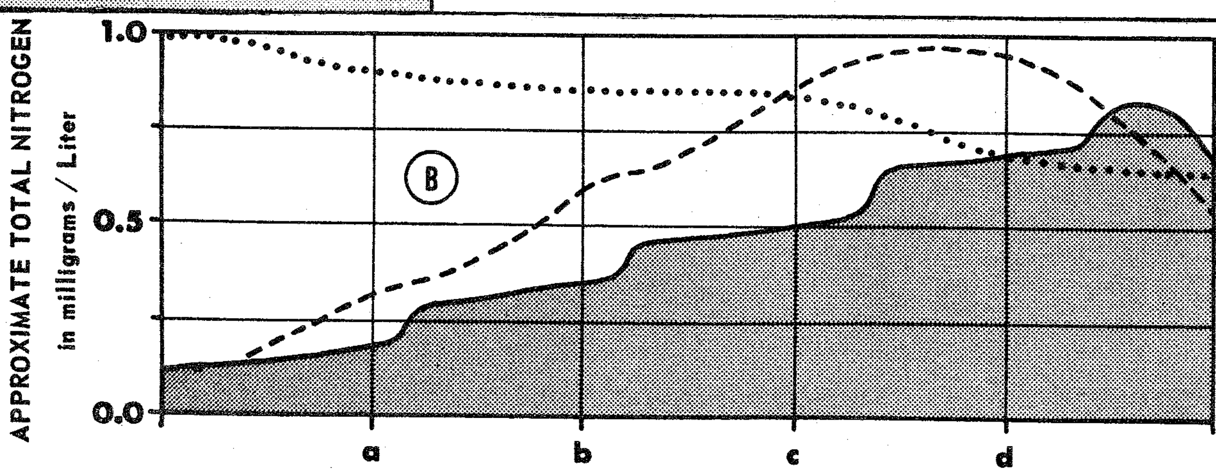


FIGURE 13

A BIOLOGICAL EVALUATION OF

THE DELAWARE RIVER ESTUARY

UNIVERSITY OF DELAWARE MARINE LABORATORIES



B. THESE CURVES SHOW THE TREND IN AMOUNT OF NUTRIENTS IN THE DELAWARE RIVER AT LOCATIONS **a, b, c,** AND **d** IN RELATION TO BIOLOGICAL OXYGEN DEMAND (---) AND LIGHT PENETRATION. TOTAL NITROGEN (——) INCREASES STEP-WISE DOWNSTREAM AND TOTAL PHOSPHORUS (NOT SHOWN) PROBABLY HAS A LESS PRONOUNCED, BUT SIMILAR BUILD-UP. IF LIGHT PENETRATION INTO THE RIVER WATER WERE GREATER, THE AMOUNT OF THESE NUTRIENTS WOULD DECREASE DOWNSTREAM (.....).

nutrient stores thus would be maintained, instead of alternate periods of "feast and famine."

Summary. Two major concepts are introduced by this hypothesis:

(1) A "nutrient build-up" area prevents loss of upstream nutrient contribution, and contributes substrates from which nutrients can be obtained.

(2) The fate of the nutrients can be characterized by the large proportion of organic breakdown that occurs in the bay, and by the uptake of these nutrients by the marshes, where they are "stored" in rooted aquatics and fed back at relatively even rates through the seasonal decomposition of the plants.

The result of these phenomena is relatively even concentration of nutrients in the bay water.