

3.4. INDIAN RIVER INLET

3.4.1. History and Stabilization of Indian River Inlet

Indian River Inlet provides the connection between the waters of the Inland Bays and the Atlantic Ocean. The inlet has a complex history of opening, migration, shoaling, closure, and re-opening, due to natural forces prior to its stabilization by jetties in 1938-40. Dredging activities and disposal of dredge spoil material have also modified the system. The following chronology is compiled from information presented in Thompson and Dalrymple (1976), Lanan and Dalrymple (1976), and Carey (1979). Recent data on bathymetry and dredging were provided by DNREC and the U.S. Army Corps of Engineers, Philadelphia District. A time line depicting the history of the inlet over the past centuries is shown on Figure 3.11.

The earliest record of an inlet in the Rehoboth Bay/Indian River Bay system is shown in a 1670 land survey map, in the vicinity of the present Rehoboth Marsh (Scharf, 1888). Carey (1979) suggests that this inlet had been open (with possible lateral migration) for part or most of the previous 100 to 200 years, based on her analysis of the subsurface stratigraphy of the Rehoboth Marsh (a relict flood tidal delta). Carey's data further indicate that the inlet closed approximately 200-300 years ago (1680-1780), after which much reworking and destruction of the delta/inlet sediments occurred.

By 1800, the inlet was again open, and migrated northward throughout the 19th century. The location of the inlet in 1800, 1843, and 1882 is shown on an 1882 U.S. Army Corps of Engineers chart of Indian River Inlet, Delaware (Figure 3.12). Between 1800 and 1843, the inlet migrated approximately 1.25 miles northward, at an average rate of 153 feet/year. From 1843



to 1882, the inlet continued to migrate northward at an average annual rate of 68 feet/year, so that the inlet was located one-half mile northward of its 1843 position. During the 19th century, the inlet "rarely ever (contained) more than three feet of water" (Vincent, 1870).

In the early 1800's, Burton Island was connected to Long Neck by a narrow marsh, which was ditched by the landowner. These ditches allowed water to flow from Indian River Bay to Rehoboth Bay. Around 1857, an effort was made to dike all but the main channels; there was some improvement, but the dikes were destroyed in a storm about 18 months later. During this time, a flood tidal shoal (the "Bulkhead") formed landward of the inlet, obstructing navigation. This shoal was first dredged in 1876. In 1883, a 4' channel was dredged, but by 1884, the channel shoaled to 2'. Between 1882 and 1912, the channel continued to migrate and shoal; efforts at dredging the channel and diking the bays continued.

During the late 19th-early 20th century, the opening of two artificial waterways with connections to the Inland Bays occurred. In 1891, the pilot channel for the Assawoman Canal, linking Indian River Bay and Little Assawoman Bay, was excavated. In 1913, the Lewes and Rehoboth Canal was opened. Indian River Inlet closed completely in 1911-12, and again in 1915, 1923, and 1925-28. Attempts were made to re-open the inlet during some of these closures. In the summer of 1928, after three years of closure, dredging was initiated to create a channel 60' wide and 4' deep. Several attempts to complete the project failed; work was stopped in November, 1928 due to lack of funds, and the inlet remained closed through the following winter. In April, 1929, local concerns succeeded in cutting a channel which remained open, and was subsequently dredged in late 1929 to a width of 60' and a depth of 8'. However, the inlet shoaled and closed again in 1931. The State Highway Department used dynamite to

blast the inlet open in 1931; the inlet closed again in 1933. The State Highway Department redredged the inlet in 1933, and again in 1937.

On August 26, 1937, a federal project to stabilize Indian River Inlet was approved. The goals of the project were (1) to increase the salinity of the bays and to decrease stagnation; (2) to permit a rise and fall of the tide in their bays to increase the effectiveness of mosquito control measures; and (3) to provide a navigational waterway for commercial purposes. The project called for widening, deepening, and stabilizing the inlet channel. Dredging was completed in 1938; the channel was generally 200' wide and 15' deep. Construction of two parallel rubble-mound jetties, 500' apart, was initiated in 1938 and completed in 1940.

3.4.2. Effects of Inlet Stabilization

Changes to the inlet and vicinity have been extensive and rapid in the years following construction of the jetties:

- The presence of the jetties interrupted the northward flow of sand along the open ocean coast, resulting in accretion of the beach on the south of the inlet, and erosion of the shoreline to the north. An analysis by Galgano (1989) of historic shoreline positions showed that between 1944 and 1977, the southern shore built seaward approximately 250', while the northern shoreline eroded over 300' during the same time interval. Erosion mitigation has included periodic beach renourishment using material obtained from dredging the inlet. In 1990, a permanent sand-bypassing plant using eductors (jet pumps) was constructed to transfer approximately 100,000 to 110,000 cubic yards of sand per year from the south beach across the inlet to the north beach (Clausner and others, 1991; 1992).

- The inlet began to widen rapidly westward of the jetties. Raney and others (1990) attribute the flanking to refraction of waves entering the inlet and striking the channel banks obliquely, and to the formation of eddies due to expansion of the flood currents. In 1938, the State placed 200' of rip-rap west of the jetty to prevent flanking. In 1941, steel sheet pile bulkheads were extended along the widened shoreline to stop bank erosion. In 1963, the bulkheads were extended westward and the steel sheet pile was reinforced with rip-rap.

- Development and enlargement of the flood tidal delta (inner shoal) occurred following opening and stabilization of the inlet. The primary source of sediment for development of the flood tidal delta is material swept into the bay by flood tidal currents. The sand in the flood tidal shoal is typically medium-to fine-grained, well sorted quartz sand, with a general decrease in sediment grain size in landward direction. Carey (1979) documented that previous (pre-inlet stabilization) deposits in the bay consisted of lagoonal muds and silty sands carried through earlier ephemeral inlets. Rapid development of shoal areas occurred from 1938 through 1954. Sand deposition and flood tidal delta growth continued through 1968, due to ample sediment supply from erosion of inlet banks, and deposition of dredge spoil. After 1968, sediment supply decreased, due in part to continued dredging and removal of sand from the system. Perlin and others (1983) calculated that the flood tidal delta accreted 75,000 cubic yards per year, averaged over an 18-year period.

- The ebb tidal delta (outer shoal) has also developed and increased in volume since construction of the jetties. Lanan and Dalrymple (1977) calculated that the ebb tidal delta contained 4,880,000 cubic yards of sand; a subsequent analysis by Collins (1982) indicated that the shoal contained nearly 6,000,000 cubic yards of sand. Perlin and others (1983) determined

that the rate of volumetric increase of the outer shoal has decreased over time, and calculated an 18-year average (1964-1982) accretion rate of 87,000 cubic yards per year.

- Dredging activities have continued after construction of the jetties. Since 1938, over 5.7 million cubic yards have been dredged from the inlet and vicinity. Spoil material from most of the early (pre-1970) dredging projects (a total of approximately 2.5 million cubic yards) was placed in Indian River Bay, west of the inlet and in the Sand Island area (Figure 3.13). Spoil material from dredging projects in 1957, 1963 (post-1962 storm), and all projects since 1973 (a total of approximately 3.2 million cubic yards) has been placed on the eroding beach north of the north jetty.

- Erosion of the channel banks and bottom has continued to enlarge the inlet. Figure 3.14 depicts channel cross sections based bathymetric data from 1936-1991, showing progressive deepening of the inlet along a transect approximately 500' east of the Route One bridge. In 1936 (pre-stabilization), the inlet was approximately 270' wide with a maximum depth of -6' (NGVD). Completion of the jetties in 1940 stabilized the width of the channel at 500', but continued scouring deepened the channel. In 1988, a narrow channel over 50' deep existed near the north jetty; by 1991, the base of this deep channel continued to widen. Figure 3.15 depicts channel cross-sections from 1936-1991 between bulkheading along a transect approximately 600' west of the Route One bridge. In 1936, prior to construction of the bulkheading, the inlet was approximately 270' wide and a maximum of -6' deep (NGVD). By 1939, the unstabilized inlet was over 900' wide, with a maximum depth of 17'. In 1941, steel bulkheads confined the inlet to a width of 800' at this location. However, the channel continued to scour and deepen;

- Increased width and depth have resulted in an increase in the inlet's cross-

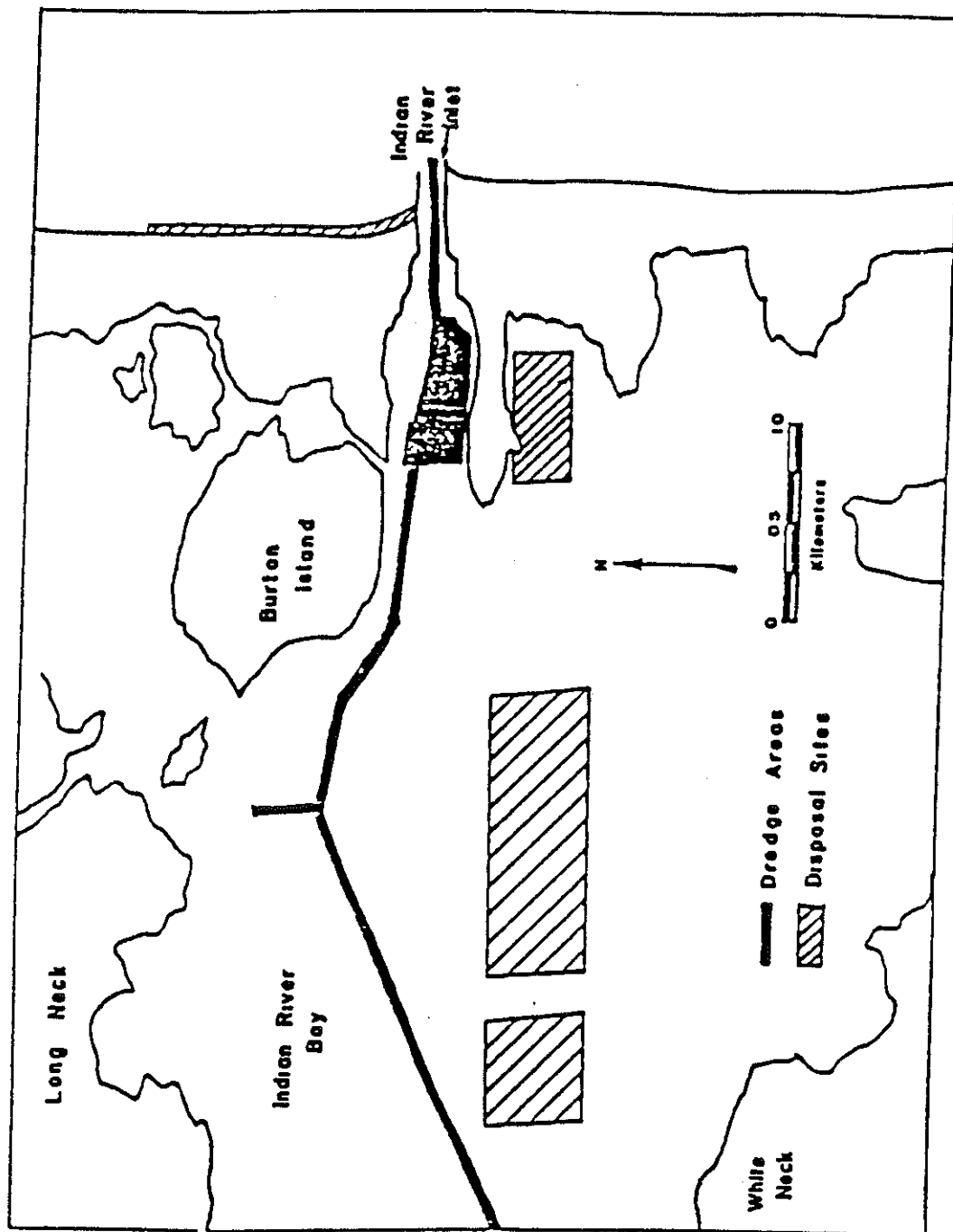
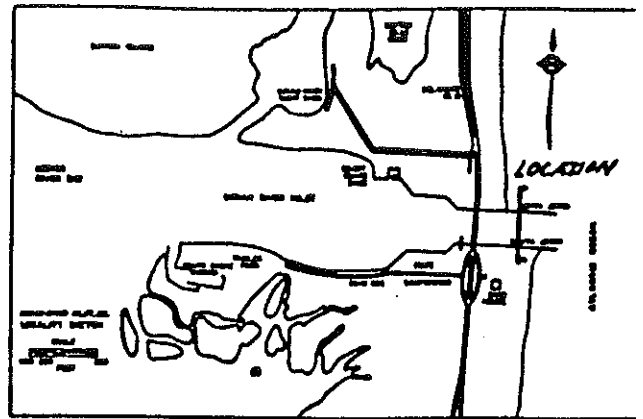


Figure 3.13. Dredge areas and disposal sites, Indian River Inlet and Bay, Delaware (Carey, 1979).



Indian River Inlet, Delmarva, Locality South of Inlet Vented by

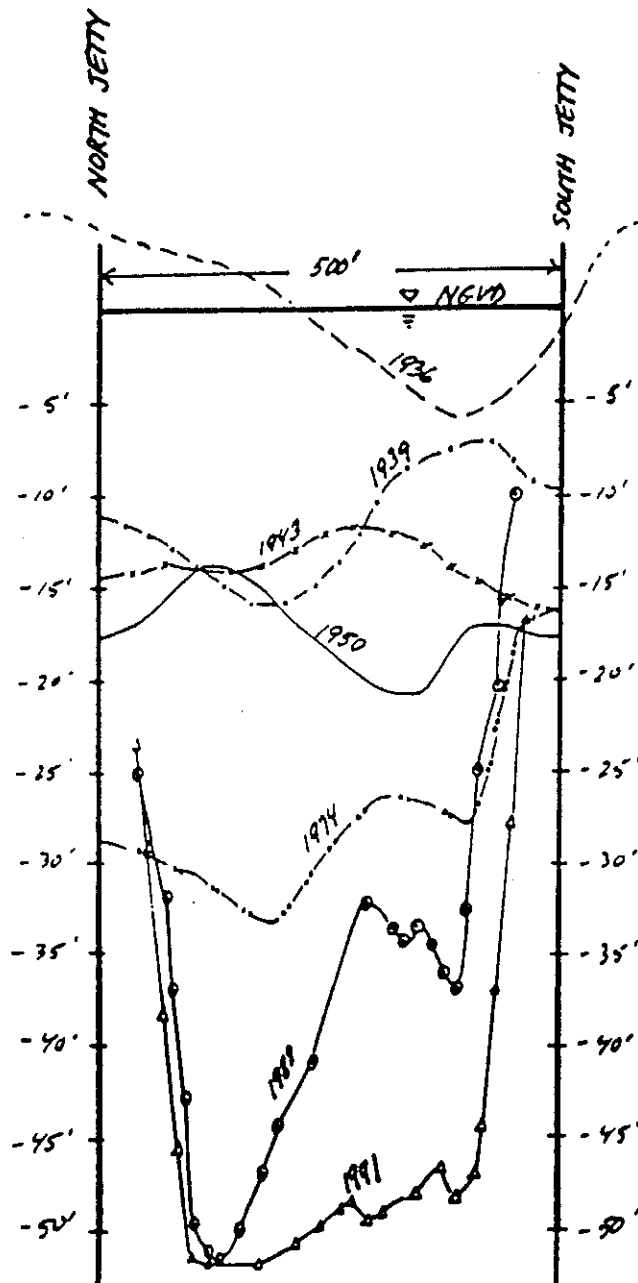


Figure 3.14. Indian River Inlet cross-sections along transect 500' east of Route One bridge, 1936-1991, showing progressive increase in cross-sectional area (data compiled from Lanan and Dalrymple, 1977; U.S. Army Corps of Engineers, Philadelphia District).

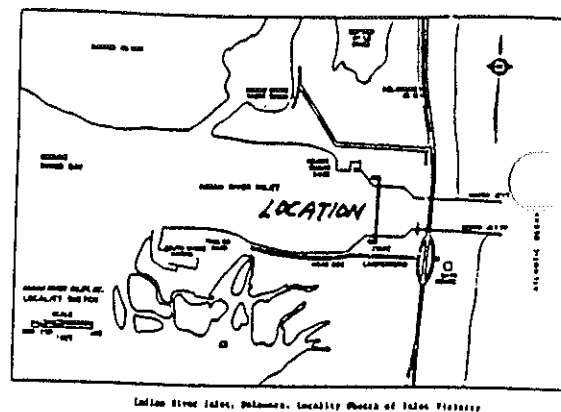
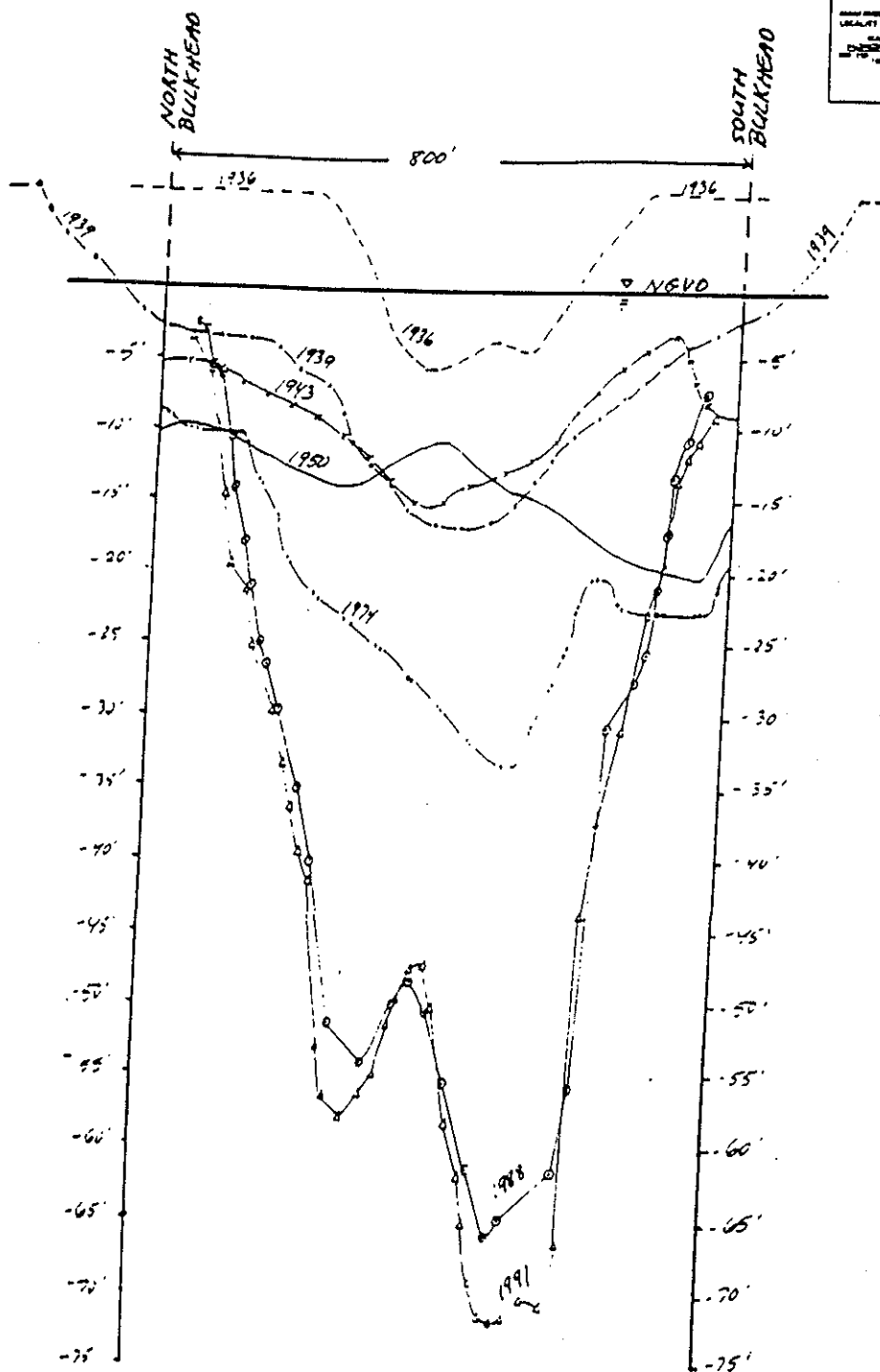


Figure 3.15. Indian River Inlet cross-sections along transect 600' west of Route One bridge, 1936-1991, showing progressive increase in cross-sectional area (data compiled from Lanan and Dalrymple, 1977; U.S. Army Corps of Engineers, Philadelphia District, 1988; 1991).

sectional area. Figure 3.16 shows increases in area for the cross-sections depicted in Figures 3.14 and 3.15. The cross-sectional area of the inlet 500' east of the bridge has increased from approximately 800 ft² in 1936 to nearly 22,000 ft² in 1991; the cross-sectional area of the channel 600' west of the bridge increased from approximately 900 ft² to over 31,000 ft² during the same time period.

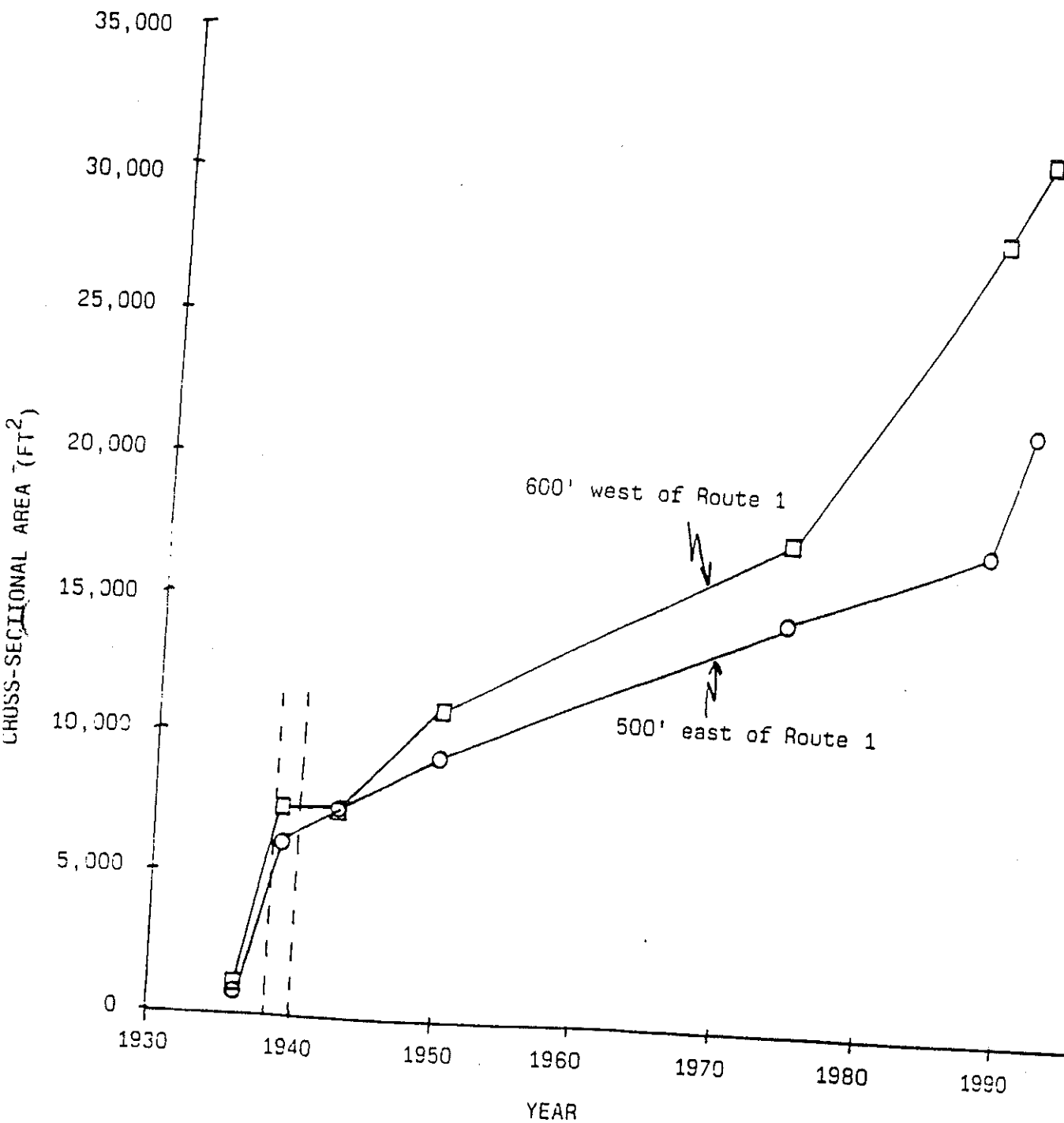


Figure 3.16. Changes in cross-sectional area, Indian River Inlet, 1936-1991, for two transects depicted in Figures 10 and 11.

3.5 ENVIRONMENTAL EVOLUTION AND FUTURE PROJECTIONS

Information about past surficial sediment patterns and environmental changes in the Inland Bays can be inferred through stratigraphic analysis of sediment core data. Extensive research on the subsurface stratigraphy of Delaware's Inland Bays has been conducted and published (Kraft, 1971; Kraft, Biggs, and Halsey, 1973; Kraft and John, 1976; John, 1977; Carey, 1979; Kraft and others, 1979; McDonald, 1981; Chrzastowski, 1986; Kraft and others, 1988). Geologic cross-sections based on vertical sedimentary sequences from cores taken in Rehoboth Bay, Indian River Bay, and the Little Assawoman Bay vicinity show that depositional environments have changed over recent geologic and historic time, primarily in response to factors such as sediment supply, inlet dynamics, storm events, antecedent topography, and sea-level rise.

A geologic cross-section of central Rehoboth Bay, extending from the Atlantic Ocean westward to the Angola Neck area, is shown in Figure 3.17 (Chrzastowski, 1986). The influence of antecedent topography (Herring Creek paleochannel, and topographic highs beneath Marsh Island and present coastal barrier) on thickness, distribution, and geometry of overlying units is illustrated. A geologic cross-section of eastern Indian River Bay, extending from Big Ditch Point southward to near Walter Point is shown in Figure 3.18 (Chrzastowski, 1986). Indian River Bay is associated with a single antecedent valley, the Indian River paleochannel. Studies by Chrzastowski (1986) suggest that the present Rehoboth and Indian River Bays evolved into broad, open-water areas by marine transgression (sea-level rise) and drowning of the interfluves and valleys. The four major sedimentary units are tidal stream mud, marsh mud, lagoonal mud, and flood-tidal delta/barrier sand. Since the earliest transgression into the area at about 11,000 years

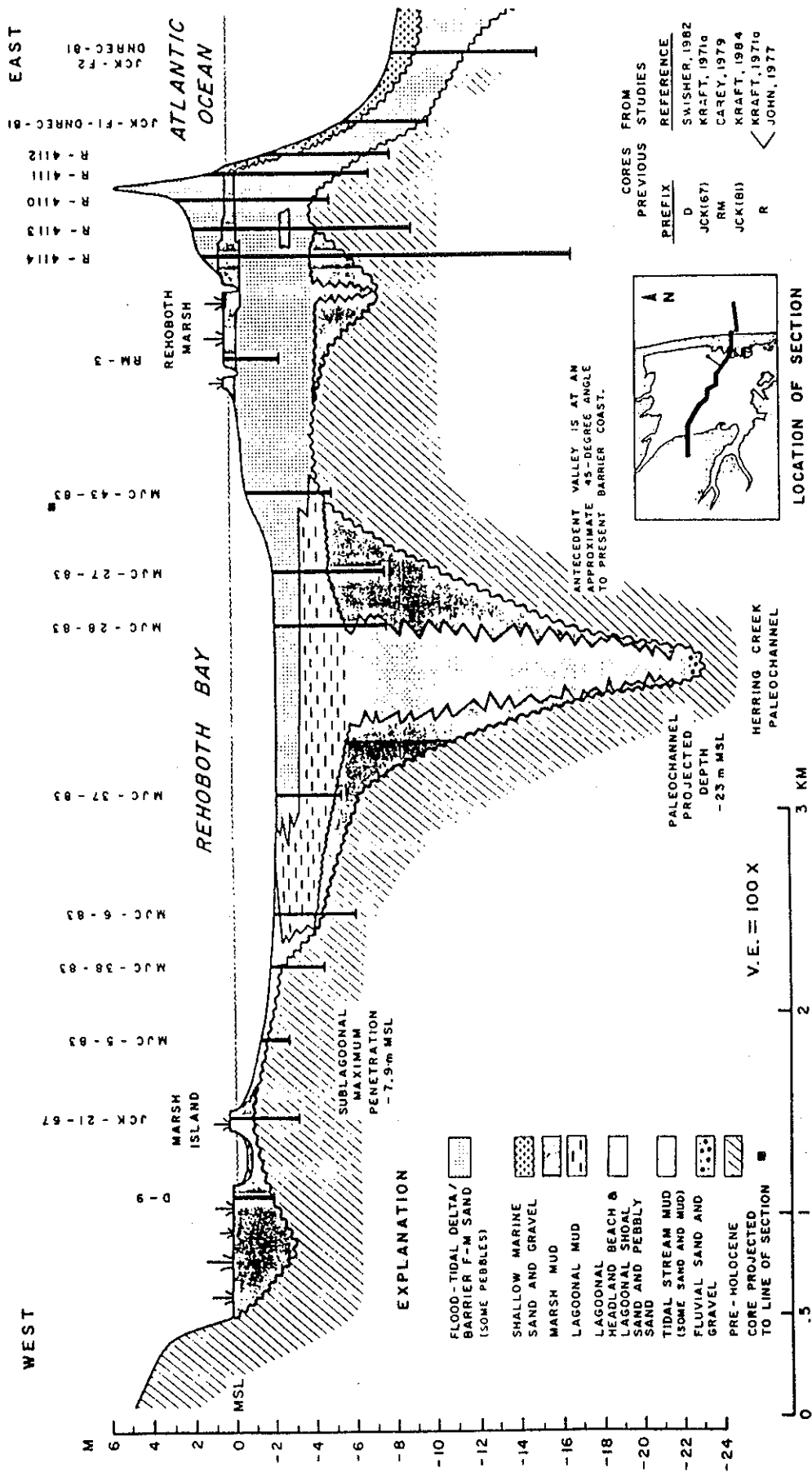


Figure 3.17. Geologic cross-section, central Rehoboth Bay (from Chrastowski, 1986).

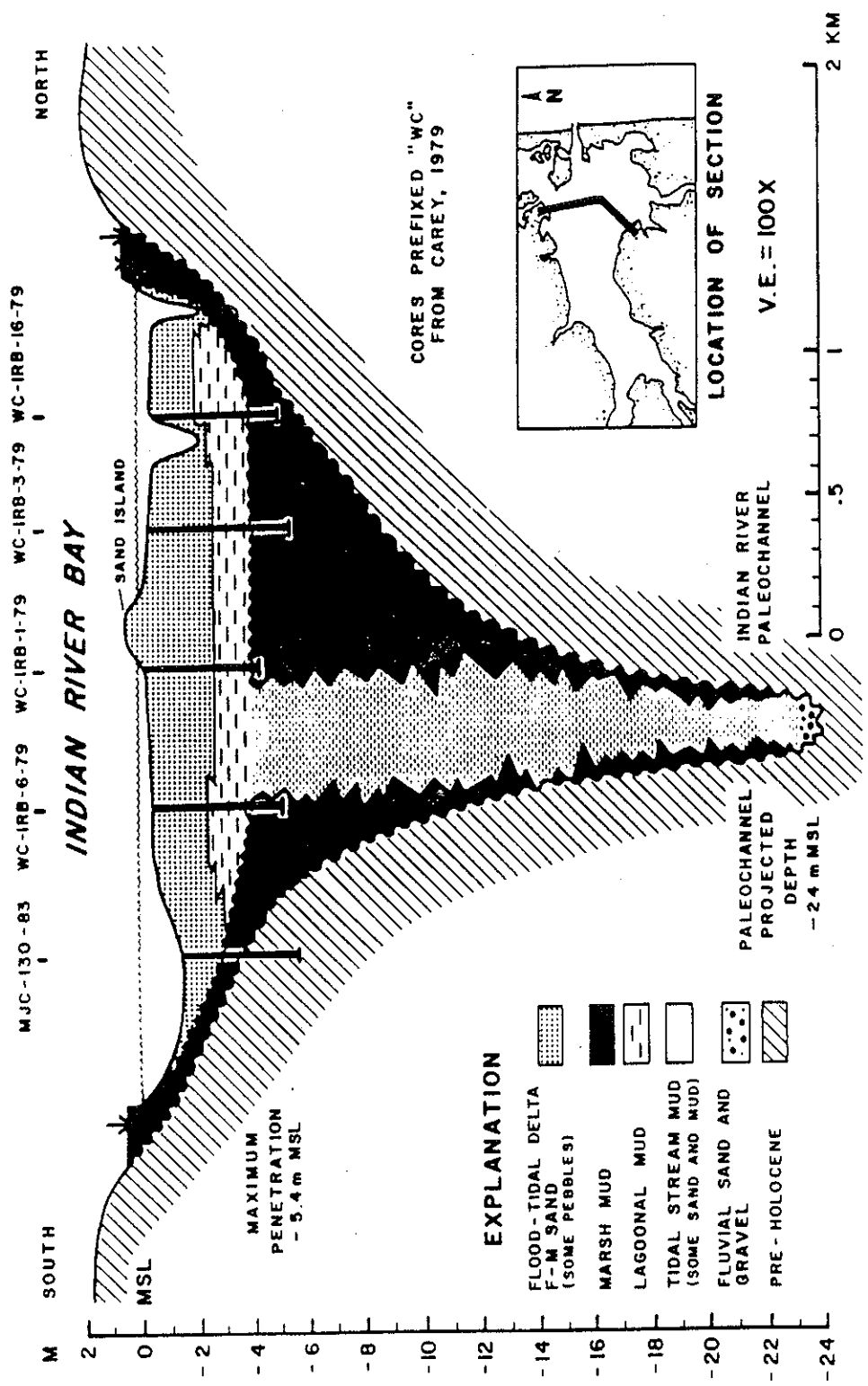


Figure 3.18. Geologic cross-section, central Indian River Bay (from Chrzastowski, 1986).

ago, tidal streams and adjacent salt marshes were the dominant depositional environments of Rehoboth and Indian River Bays, due to the (lateral) restriction of the narrow stream valleys, resulting in deposition of tidal stream mud and marsh mud. With continued sea-level rise across paleointerfluves, an open water area developed, with maximum increase in areal transgression occurring 3,000 to 2,000 years ago, and deposition of lagoonal mud and flood-tidal delta/barrier sand in the eastern section of the bays.

Chrzastowski (1986) speculates that the future geologic evolution of Rehoboth and Indian River Bays will be in response to sea-level change, sediment supply and accumulation rate, and human interaction with these processes. He utilized the information about past trends to develop a projection for the future configuration of Rehoboth Bay and Indian River Bay, for a sea level of +10 feet higher than present (Figure 3.19). Sea level may reach this elevation in less than a century, based on the high-value sea-level rise scenario presented by Hull and Titus (1986). Based on current trends in sea-level rise along coastal Delaware (low-value scenario), it may take as long as 700 to 800 years. The projection presented by Chrzastowski suggests the following evolutionary changes in the Inland Bays:

- Submergence of all areas with an elevation less than 10' above mean sea level (including large sections of Long Neck and White Neck);
- Development of peninsulas and islands at knolls or high points, as paleointerfluves are transgressed;
- Open-water area will advance upstream and laterally from the axes of the tributary tidal stream valleys;

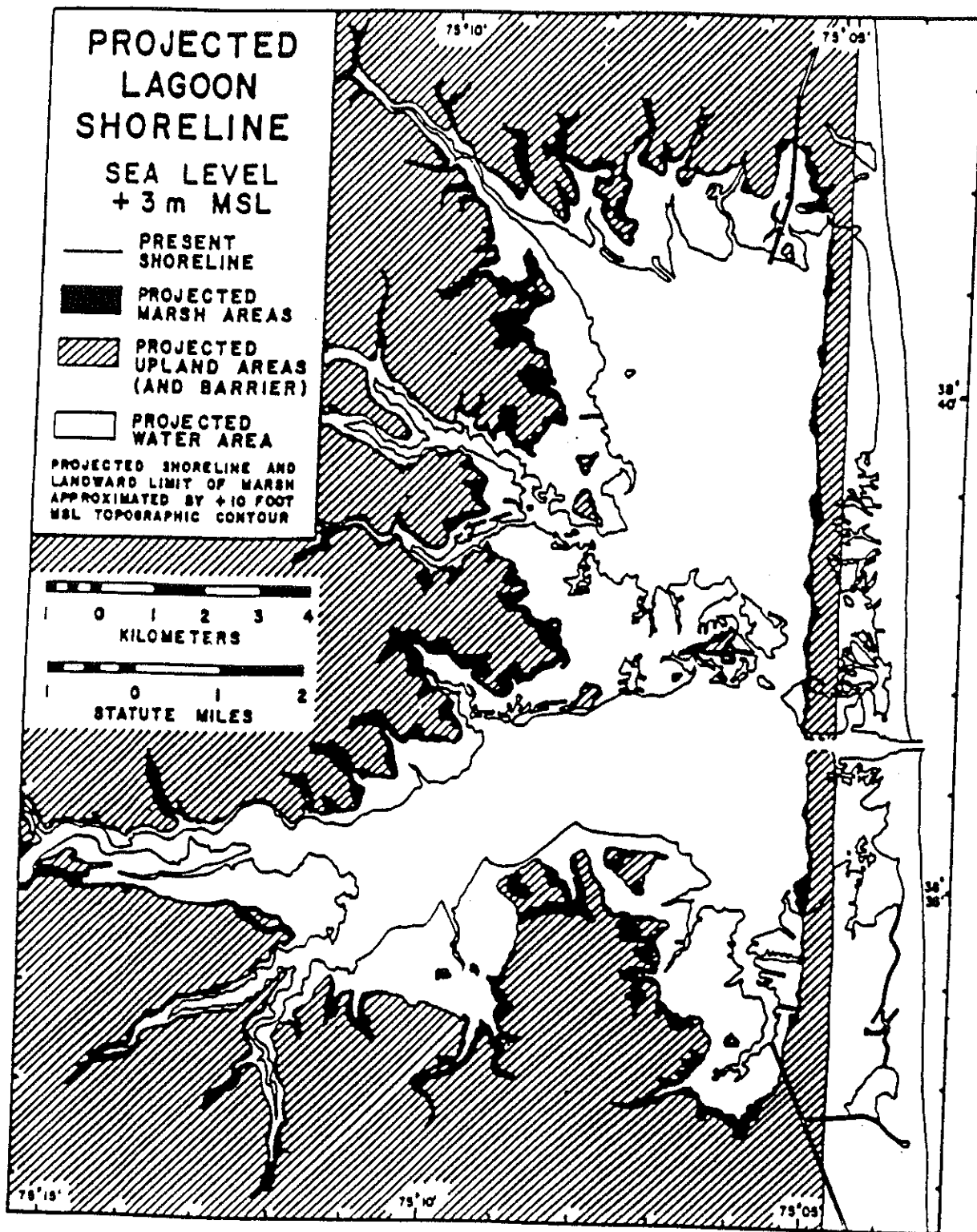


Figure 3.19.

Projected configuration of Rehoboth Bay and Indian River Bay, Delaware at sea level 3 meters (10 feet) above present (Chrzastowski, 1986).

- Continued landward (westward) migration of the fringing marshes along the western shore of the bays;
- Continued shoreline erosion;
- Landward (westward) migration of the coastal barrier located on the eastern margin of the bays, resulting in filling in of the eastern section of the bays to create new land areas in these regions.

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SECTION 4

LIVING RESOURCES

4.1 INTRODUCTION

The biological communities of surface waters, in general, and the Delaware Inland Bays, in particular, are intrinsically linked to the water and sediment quality of those waters and therefore serve as important measures of the "health" of the system. Because they integrate the effects of numerous environmental stressors, including those that are human-induced and those that are naturally-occurring, biological communities provide a "holistic" measure of the aggregate impact of fluctuating environmental conditions (EPA, 1990).

In addition to providing a direct assessment of the state of the Inland Bays, the "status of biological communities" is of direct interest to the public as a measure of a perceived "pollution free" environment. While reductions in chemical pollutant loadings may not be readily understood by the general public as a positive environmental result, an increased catch of recreationally important fish and shellfish is readily recognized as an improvement in the health of the system.

The goal of the characterization process is to provide the resource managers or trustees of the resource, information that will allow a clear definition of the problems affecting the estuary and thereby allow a clearer focus on developing and implementing a strategy by which to address those problems.

With this goal in mind, the "*Living Resource*" characterization addresses three primary objectives:

1. A description of the status of the principal biological communities using the Delaware Inland Bays estuary.

2. Through a review of historical data for each of these communities, an identification of spatial and temporal changes or trends in community structure.
3. For those communities for which "significant" trends have been identified, the integration of living resource data with similar data for physical and chemical characteristics e.g., modifications to habitat.

The purpose of this section, then, is to provide information for addressing the first two objectives, i.e., to present "status and trend" data for subsequent integration with other components of the characterization process. The intergration is performed in Section 5 of the Inland Bays Characterization, *Characterization Integration*.

4.1.1 Development of the Database for Analyses of Current and Historical Status of the Living Resources of the Inland Bays

As previously described in Section 1 of this report, numerous sources were evaluated for information with which to develop the *Living Resources* characterization.

The primary source of available data for the biological communities of the Inland Bays is the *Annotated Bibliography for the Inland Bays* (Maumeyer, 1986, revised 1990). The *Annotated Bibliography* is a reference bibliography of more than 230 technical reports, as well as, public interest articles published in a variety of local journals and magazines, such as *The Delaware Conservationist*. Initially compiled in 1986 for the Delaware Department of Natural Resources and Environmental Control, (DNREC) the bibliography was substantially updated in 1990.

To assist in the development of the "Living Resources" database, an *Annotated Bibliography for Living Resources* was developed within which principal references from the *Annotated Bibliography* were organized for each of the key biological communities evaluated including:

- . Phytoplankton
- . Zooplankton
- . Macroflora
- . Benthos

- . Shellfish
- . Finfish
- . Wildlife/Waterfowl

Figure 4.1-1 describes the relative distribution of studies and technical reports among the key biological communities of the *Living Resources* characterization. As demonstrated, the principal communities investigated include the finfish and shellfish communities which collectively comprise about one-half of all biological studies conducted in the Inland Bays.

Figure 4.1-2 describes the relative distribution of those studies conducted and reports written among the bays. Biological studies conducted in Indian River Bay represent more than half of the studies performed in all three bays. This is due principally to the number of studies that have been performed at Delmarva Power and Lights's (DP&L) Indian River Power Plant (IRPP) in Millsboro, Delaware.

Obvious is the lack of substantive data for the biota of Little Assawoman Bay where very few studies were found. Studies of this embayment represent about 5% of all biological investigations performed in the Inland Bays. Further, we were unable to locate data on coliform bacteria in a format suitable for analysis and interpretation except for the maps discussed in Sec. 4.6.4.

To facilitate the characterization process, each of the technical reports described in the annotated bibliography was evaluated on the basis of several criteria including:

- . The relevance to the perceived problems affecting the Inland Bays.
- . The spatial and temporal distribution of the data.
- . The ease of data access.
- . Cost of data acquisition.

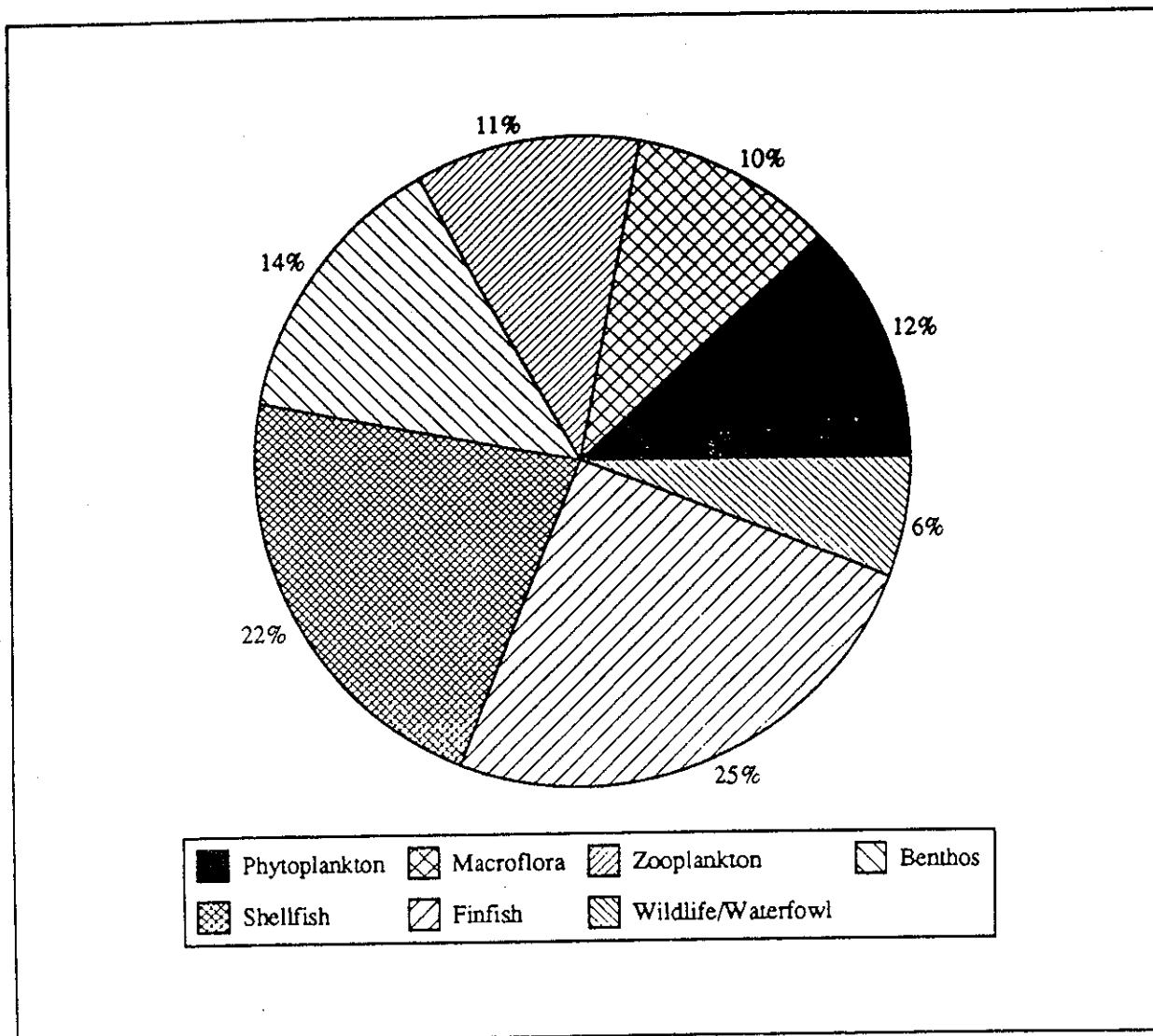


Figure 4.1-1
Relative Distribution of Studies Among Key Biological
Communities Available for
Living Resource Characterization

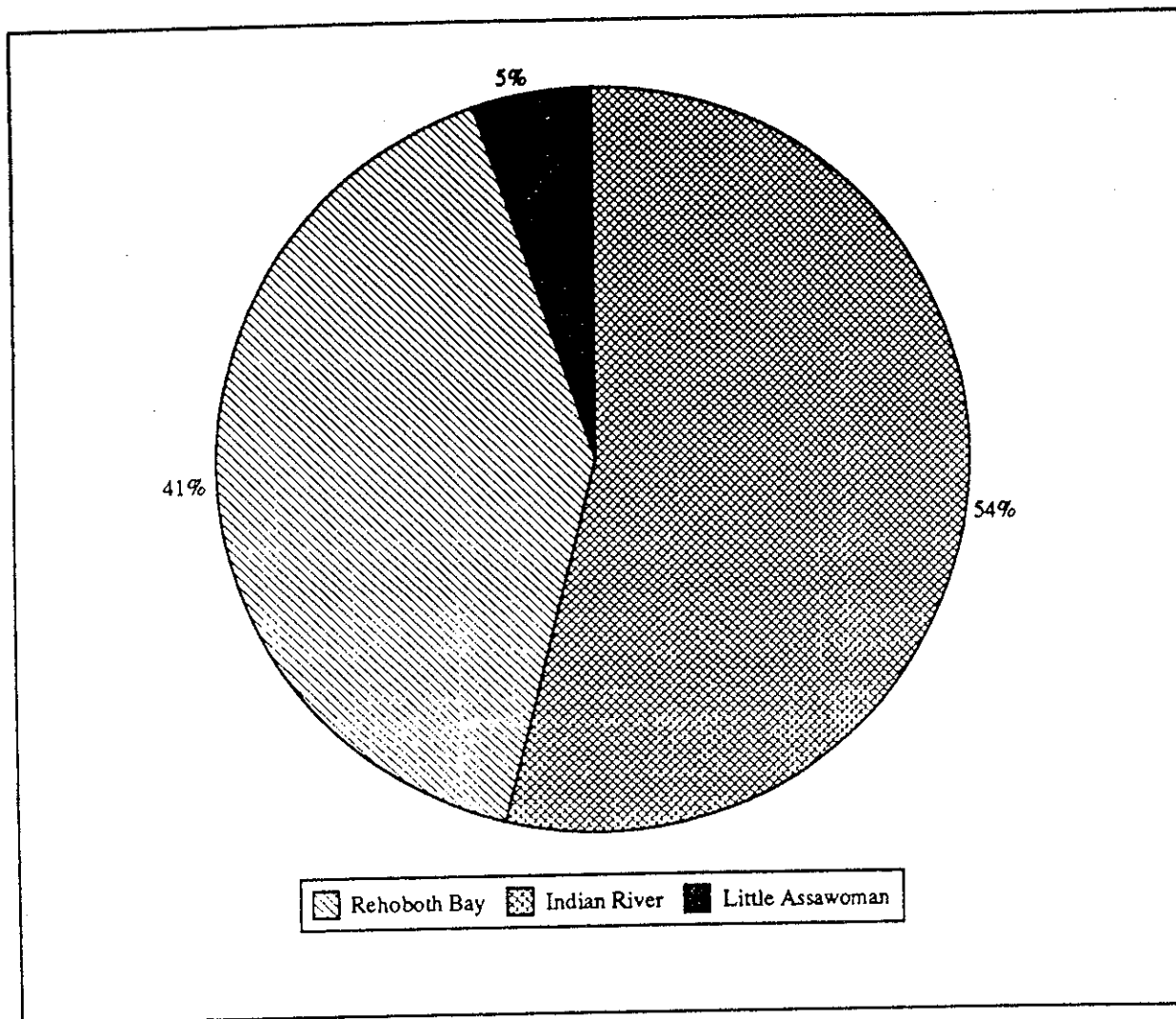


Figure 4.1-2
Relative Distribution of Biological Studies
Among Indian River Bay, Rehoboth Bay,
and Little Assawoman Bay Available for
Living Resource Characterization

Based on these criteria, an individual study was ranked as being of either "high", "medium", or "low" priority for data acquisition and subsequent inclusion in the *Living Resource* database. Those studies that ranked as either of "high" or "medium" priority were obtained and reviewed as part of the characterization for each of the biological communities. These reports represent the sources of information from which the current and historical status of the biological populations inhabiting or supported by the Inland Bays are described.

4.1.2 Organization of the Living Resource Characterization

Characterization of the *Living Resources* is performed for each of the following communities inhabiting or supported by the Inland Bays Estuary.

4.2	Phytoplankton	4.6	Shellfish
4.3	Zooplankton	4.7	Finfish
4.4	Macroflora	4.8	Wildlife/Waterfowl
4.5	Benthos		

For each of these communities, information is presented in the following order. First, a discussion of the sources of all information is presented upon which the subsequent "status" and "trends" analysis are based.

Secondly, the "status" or current condition of the principal populations for each community is discussed where data are available and where data allow. For the most part, data are presented as summary statistics of various community metrics, (e.g., numbers of species, abundance, density, etc.) and are presented in tabular or graphic format with attendant narrative.

Finally, once the status or current condition of the resource has been described, an analysis of "trends" is presented. The "trend" analysis of appropriate populations represents a comparison of data used to define status with data from earlier studies to identify changes or shifts in

population metrics over the period of record. Where possible, quantitative information is provided to support the trends analysis; in the absence of these data, a qualitative discussion based on limited information is presented. Note that where data sets are particularly dated or information is insufficient, a discussion of trend is precluded. As with the discussion on the status of the biological community, data are presented graphically or tabularly with associated narrative.

SECTION 4.2

PHYTOPLANKTON

4.2.1 Introduction

The phytoplankton community represents a major component of the living resources of the Inland Bays and form the base of the food chain for the entire system. Most phytoplankton species are autotrophic, that is, they contain the pigment chlorophyll *a*. Chlorophyll *a* can absorb a portion of the visible spectrum and the resulting energy is used within the cells to synthesize all necessary constituents through the uptake of nutrients (nitrogen, phosphorus and silicon in various forms) and carbon. During daylight, the phytoplankton produce oxygen, while in the dark they respire carbon dioxide. Thus, the phytoplankton both control and are subject to the chemical quality of the water in which they are suspended.

Three characteristics of phytoplankton populations will be evaluated in this section. The populations are sometimes characterized by the concentration of chlorophyll *a* contained in a given water volume, by the primary production or the rate of growth of the cells in a given volume for a specific time, and by the species of phytoplankton present in a given volume of water.

4.2.2 Data Sets

The data sets used principally in this analysis are those to be found in Brooks (1974), Ecological Analysts (1976), the Philadelphia Academy of Natural Sciences (1988), and the Delaware Department of Natural Resources and Environmental Control (1989 - present). Characteristics of the data sets can be found in Table 4.2-1.

Table 4.2-1

Phytoplankton Studies of the Inland Bays

Author	Location	Time Period	Parameters
Brooks, et al. (1974)	Indian River, Millsboro to Pepper Creek	May 1969 - Oct. 1971	chlorophyll <i>a</i> , taxonomy, productivity
EA 316(a) (1976)	Indian River, Millsboro to Inlet Rehoboth Bay	June 1974 - June 1976	chlorophyll <i>a</i> , taxonomy, productivity
PANS (1988)	Rehoboth Bay (4 sta) Indian River Bay (5 sta) Assawoman Bay (2 sta)	September 1985 - September 1986	chlorophyll <i>a</i> , taxonomy, productivity, nutrients
DNREC	All bays	1989 - 1991	chlorophyll <i>a</i>

4.2.3 Chlorophyll

Chlorophyll data that form the basis of the status of the Inland Bays have been reported in Smullen (Chapter 2, this report) and are summarized in Table 4.2-2. The geographical distribution of chlorophyll follows a clear pattern. Lowest values are found near the inlet in Lower Indian River Bay and in southern Rehoboth Bay through Masseys Ditch. Middle and Upper Indian River consistently contain the highest concentrations of chlorophyll. Little Assawoman Bay waters have higher concentrations of chlorophyll than Rehoboth, but lower values than found in Middle or Upper Indian River.

In addition to the geographical pattern, there is a pronounced seasonal pattern to the distribution of chlorophyll. Often low annual values are found in the fall and spring, with moderate values occurring during a mid-winter bloom. Highest annual values will be found in summer. As reported in Sec. 2 of this report, Lacoutre and Sellner (1985) report a significant decrease in chlorophyll in upper and middle Indian River between 1974 and 1985.

4.2.4 Primary Productivity

While the chlorophyll concentration represents the standing crop of phytoplankton, the primary productivity is a measure of the ability of the phytoplankton population to produce particulate organic matter in the form of cells. Available seasonal data on primary productivity are limited to the measurements of Brooks, et al (Ecological Analyst, 1976). We have summarized the data in Table 4.2-3. There are no historic data from Little Assawoman Bay, and inadequate data from any of the systems to establish a trend.

Smullen (Chapter 2) has shown that dissolved oxygen concentrations, during daylight, in summer, may reach 200% saturation in the middle and upper Indian River and these same concentrations may sag during summer nights, to 10-20% of saturation. The combination of high standing stocks as indicated by the chlorophyll and high organic production as

Table 4.2-2
Number of Occurrences of Chlorophyll Concentration* in the Inland Bays

Chlorophyll Concentration	Indian River Bay												Massey						Rehoboth Bay						Assawoman Bay											
	Upper			Middle			Lower												North			Central			South			North			Central			South		
	Su	F	S	Su	F	S	Su	F	S	Su	F	S	Su	F	S	Su	F	S	Su	F	S	Su	F	S	Su	F	S	Su	F	S	Su	F	S			
>200	2			1																																
>150	2	1																																		
>100	2																																			
>50	2			1			9			1																										
>20	5	4	2	3	7	2	1	6	1																											
>10	1		2	2	3	1	2			1																										
>5			1	3		1	5	2		1																										
<5	1		4	1	4		10	2	2	1	7																									

*The data in the body of the table represents the number of occurrences of all non-zero chlorophyll values in the database.

Table 4.2-3
Measured Rates of Primary Productivity (mgC/l/hr)*

Segment	1974			1975		
	Su	A	W	Sp	Su	
Millsboro Dam	.146	.106	.014	.001	.090	
Indian River Upper	.226	.127	.033	.015	.252	
Indian River Middle	.198	.064	.046	.042	.148	
Indian River Lower	.134	.028	.062	.036	.080	
Rehoboth Bay Central	.061	.019	.012	.027	.042	

* Ecological Analysis, 1976.

indicated by high primary productivity are both consistent with wide oscillations in dissolved oxygen concentration.

4.2.5 Phytoplankton Community Composition

Phytoplankton taxonomy is an important measure in the characterization of an estuary because there are "desirable and undesirable" phytoplankton as well as phytoplankton that serve as indicators of processes occurring within an estuarine segment.

Brooks et al. found that green and blue-green algae dominated during the summer near the head of Indian River with greater abundance of diatoms and dinoflagellates at higher salinities. During cold seasons, diatoms dominated through all sections of Indian River. Ecological Analysts (1977) expanded the scope of Brooks work to include lower Indian River Bay and one station in Rehoboth Bay. They found that diatoms dominated (both temporally and spatially) during the cold seasons and that nanoplankton were present in the greatest abundance between June and October. EA further found that over 90% of the phytoplankton had a cell diameter less than 20 μm , but that the largest 1% of the phytoplankton contained 35% of the biomass (that is, 35% of the potential food supply for zooplankton, ichthyoplankton and other organisms). In summary, in terms of numbers, the nanoplankton and small diatoms dominate the system, while, in terms of biomass, the large plankton dominate.

Lacoutre and Sellner (1988) conducted a study similar to those of Brooks and Ecological Analysts and they included community composition at several stations in Indian River, Rehoboth, and Little Assawoman Bays. They found that picoplankton dominated the assemblage during summer and further, they identified *Microsystis* sp. as a major component of the picoplankton. *Microsystis* is a blue-green algae often associated with eutrophic or hypereutrophic conditions and was found in all three Bays during the summer. Lacoutre and Sellner note that *Microsystis* is a freshwater organism and that, although it is very abundant, it does not seem to bloom in the higher salinities found in most of the Inland Bays.

Tyler (1989) conducted a taxonomic study of the phytoplankton in upper Indian River

during the summer of 1988. During the summers of 1986 and 1987, there had been extensive fish kills in the upper Indian River associated with red tides. The purpose of the study was to identify the algae responsible for the red tide and to determine whether the algae were toxic. Tyler found that the ... "cause of the red water to be a number of diatom species..." (mostly *Skeletonema* and *Rhizosolenia*) that were intruded from offshore and probably reached bloom proportions because of the favorable, high nutrient conditions found in middle and upper Indian River. Phytoplankton diversity and dominance in Indian River Bay is similar to middle Chesapeake Bay except for the presence of blue green algae in upper and middle Indian River during summer.

Beasley (1987) separated and identified the diatoms preserved in a sediment core from central Rehoboth Bay. Her goal was to infer the historic environmental conditions in the Bay from the autecology of the preserved diatoms. A summary of the results of her work is presented in Table 4.2-4. Beasley was able to trace the environment of the Bay from 1700 to 1987. Nutrient favoring forms increased in abundance from 1890 to the 1970's, probably in response to the application of fertilizers. They may have decreased in the last decade due to increased flushing caused by an enlarging inlet. Turbidity tolerant diatoms have increased in abundance probably because land clearing activities increased erosion. The findings of Beasley are generally consistent with the historic development of the watershed and the movement and stabilization of the inlet.

Table 4.2-4

Summary of Environmental Trends Inferred from
Diatom Assemblages in Central Rehoboth Bay
from 1670-1987
Beasley, 1987

	Nutrient Favoring Forms	Environment	Turbidity Tolerance	Productivity	Comments
1990 --	D	S	I		
70 --	I	F			
50 --	I	B	I	D	Inlet closed or restricted
30 --	I	S			
10 --	I	SE		I+	
1890 --	D		I		
70 --		FM			Inlet to Rehoboth Bay
50 --			D	I	
30 --	D	S			
10 --	I	F	D	I	Inlet closed or restricted
1790 --	D	S	I	D	
70 --					
50 --					
30 --					
10 --					
1690 --	I	F	I		
70 --					

S = Stressful, F = Favorable, M = Marine, B = Brackish, E = Eutrophic
I = Increasing, D = Decreasing

APPENDIX 4.2-A
PHYTOPLANKTON
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SECTION 4.3

ZOOPLANKTON

4.3.1 Introduction

As members of the plankton community, zooplankton are free-floating or drifting organisms that are readily transported by water currents. Zooplankton typically range in size from microscopic ($<10\text{-}200\text{ }\mu\text{m}$), such as the copepods and invertebrate larvae, to macroscopic ($>200\text{ }\mu\text{m}$), such as the chaetognaths and jellyfishes. The zooplankton serve as an integral link between the phytoplankton of the estuary and estuarine carnivores, including many commercial fish. They also serve to regulate the phytoplankton populations in estuaries with grazing efficiencies ranging from 5% to more than 50% of phytoplankton production (Fulton, 1984; Carlson 1978; Williams et al., 1968; Heinle, 1966).

Components of the zooplankton community can be categorized in three classes, namely, holoplankton, meroplankton, and tychoplankton. The holoplankton represent those organisms that spend their entire life cycle in the water column. In most of mid-latitude estuaries the holoplankton are composed principally of the calanoid copepods especially *Acartia spp.* The meroplankton spend only a portion of their life cycle in the water column, and are typically composed of the invertebrate larval stages such as the polychaete trochophore or the molluscan veliger. In addition to invertebrate larvae the vertebrate ichthyoplankton larvae also comprise a substantial portion of the meroplankton of the estuary. A third class of plankton, the tychoplankton represent those organisms whose swimming ability is intermediate to the plankton and nekton and may live on the bottom from which they may be accidentally swept. Members of the tychoplankton include such organisms as the mysids, such as *Neomysis spp.* and the cumaceans.

This discussion of zooplankton occurrence in the Inland Bays deals principally with the holoplankton and meroplankton in these waters.

The principal objectives of the zooplankton community section of the "*Living Resource*" characterization are several and include:

- . The identification of studies that have been conducted of the zooplankton community of the bays and selection of those studies most appropriate to characterization.
- . The definition of the status of the zooplankton community, as defined by such measures as species composition and relative abundance, and
- . A description of the historical record and the identification of changes in the zooplankton community over time, where data allow.

4.3.2 Previous Research

Several studies have examined the zooplankton of the Delaware Inland Bays, however, coverage has been poor with a gap in published data of almost twenty years. Moreover, of the few studies conducted, several were designed to evaluate specific problems, e.g., entrainment in the Indian River Power Plant, and as such, these data are limited spatially and temporally and are of little value in describing the status of zooplankton community of the Inland Bays. All studies to date have focused on zooplankton in the Indian River estuary. With the exception of limited ichthyoplankton information (Scotton, 1970), no data were found for either Rehoboth Bay or Little Assawoman Bay.

The earliest study of zooplankton in the Indian River estuary was conducted by Hopkins (1958). In this study, Hopkins examined the transport of zooplankton through Indian River Inlet from 1955 to 1958 and focused chiefly on mysid distribution, principally *Neomysis*, and seasonal abundance.

In a second study of zooplankton in 1970 and 1971, Davies and Jensen (1974) looked at the effect of entrainment and exposure of zooplankton to elevated temperatures during transport

through the cooling water system of the Indian River Power Plant (IRPP). This study was primarily experimental and directed at detecting mortality due to entrainment.

To date, the most comprehensive study of the zooplankton in the Inland Bays was a three-year study conducted by Delmarva Power and Light Company (DP&L 1976) from 1974 through 1976, in the Indian River estuary. The study, "Ecological Studies in the Vicinity of the Indian River Power Plant: a 316(a) Demonstration," was designed to address several objectives including:

- "[a definition] of the distribution and relative abundance of the zooplankton population in Indian River,
- an assessment of the seasonal variation in these distribution and abundance patterns, and
- [an attempt to define] any thermal discharge effects on the zooplankton."

No subsequent study of the zooplankton community of the Delaware Inland Bays was found.

4.3.3 Status of the Resource

It has been nearly twenty years since the last study of the zooplankton community of the Inland Bays was conducted (DP&L, 1976). Moreover, no studies were found of the zooplankton of Rehoboth Bay or Little Assawoman Bay. Consequently, the status of the zooplankton community of the Delaware Inland Bays is not known.

4.3.4 Historical Record of the Zooplankton Community

Research of the zooplankton community in the Inland Bays is severely limited both temporally and spatially. The following discussion presents what little is known of the zooplankton community of the Indian River estuary based on the results of the DP&L study conducted from 1974 to 1976. No data from which to identify temporal trends were available.

A study of the zooplankton community of the Indian River estuary was conducted by Ecological Analysts for DP&L during the period of June 1974 through August 1976. Microzooplankton and macrozooplankton were collected twice a month from June 1974 through May 1975 at eight stations (Figure 4.3-1) in Indian River estuary. Sampling of microzooplankton from June 1975 to August 1976 was performed once a month. Microzooplankton samples were collected with a 0.5 meter diameter, 153 mesh, conical plankton net. Macrozooplankton were collected with a 505 um mesh net. Samples were collected with oblique tows at variable depths depending on the depth of water column at the time of the sampling.

• Microzooplankton

During its two-year monitoring study, DP&L found the mean annual density of microzooplankton was similar for both years. During the first year (1974-1975), the mean annual density measured 5,200 organisms per cubic meter (m^3). Similarly, in 1975-1976, an average of 6,300 organisms/ m^3 were collected. These densities are comparable to figures reported for other estuaries in the mid-Atlantic (Table 4.3-1).

The seasonal pattern displayed in the microzooplankton in the Indian River estuary from 1974-1976 was typical of estuaries in the mid-Atlantic region. Major peaks in mean zooplankton density occurred in August-September and March-April in both years (Figure 4.3-2). Maximum mean monthly densities in the August-September period were about 11,000/ m^3 for both years. During March-April, the mean microzooplankton density measured about 10,000/ m^3 in 1974/1975 and 18,000 in 1975/1976-numbers that are not significantly different in terms of zooplankton abundance where densities within a factor of two are considered similar (Williams et al., 1986).

The seasonal variation in microzooplankton generally reflected the seasonal increase and decrease of the copepod population, especially *Acartia* spp. Microzooplankton attained a peak abundance in March and April following the winter-spring phytoplankton bloom, with a second peak developing during late summer. The August/September peak reflected a large increase in the number of immature *Acartia* (Figure 4.3-3).

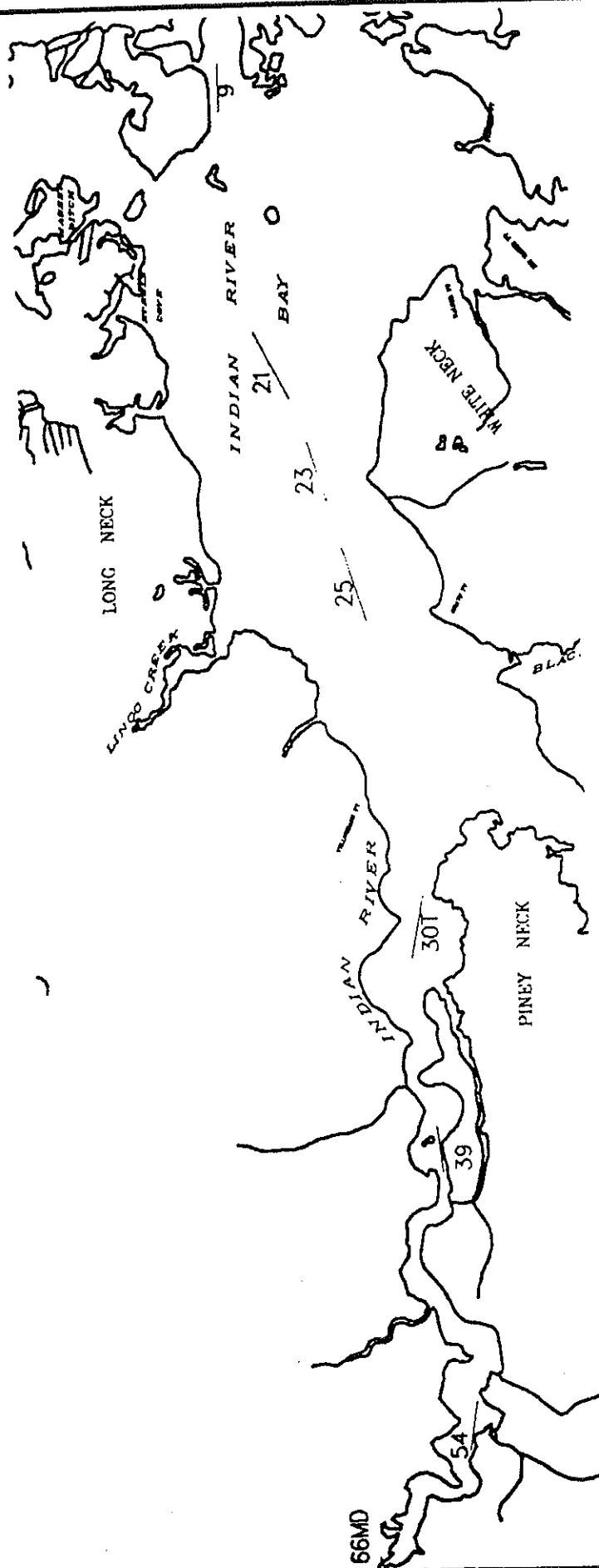


Figure 4.3-1
Locations of Zooplankton
Sampling Stations
DP & L (1976)

Scale 1 Inch = 4000 Feet
 2000 0 2000 4000

Table 4.3-1

Zooplankton Composition in Six Different Estuaries*

Estuary	Indian River Delaware(1)*	Patuxent River Maryland(2)*	North Inlet South Carolina(3)*	Sandy Hook New Jersey(4)*	Cord Sound, Florida(5)*	Potomac River, Virginia(6)*	Barnegat Bay, New Jersey(7)*
Net mesh size/ μm	153	370	153	203	200	150	80
Average annual density/ m^3	5,750	1,425	9,258	8,052	3,765	20,191	68,500
Percent Composition							
Acartia adults	38	61	19.7	32	75	13.4	21
Immature copepods			17.8	28.6		66.6	42
Other copepods		36.3	29.8	17.4	15.8	7	
Meroplankton		1.2	24.2	8.8	7.9	11.2	
Other		1.5	8.2	16.2	1.9	2	

* (1) DP&L (1976); (2) Herman et al. (1968); (3) Lonsdale and Coull (1977); (4) Sage and Herman (1972); (5) Reeve (1975); (6) Sage et al. (1976); (7) Sandine (1984).

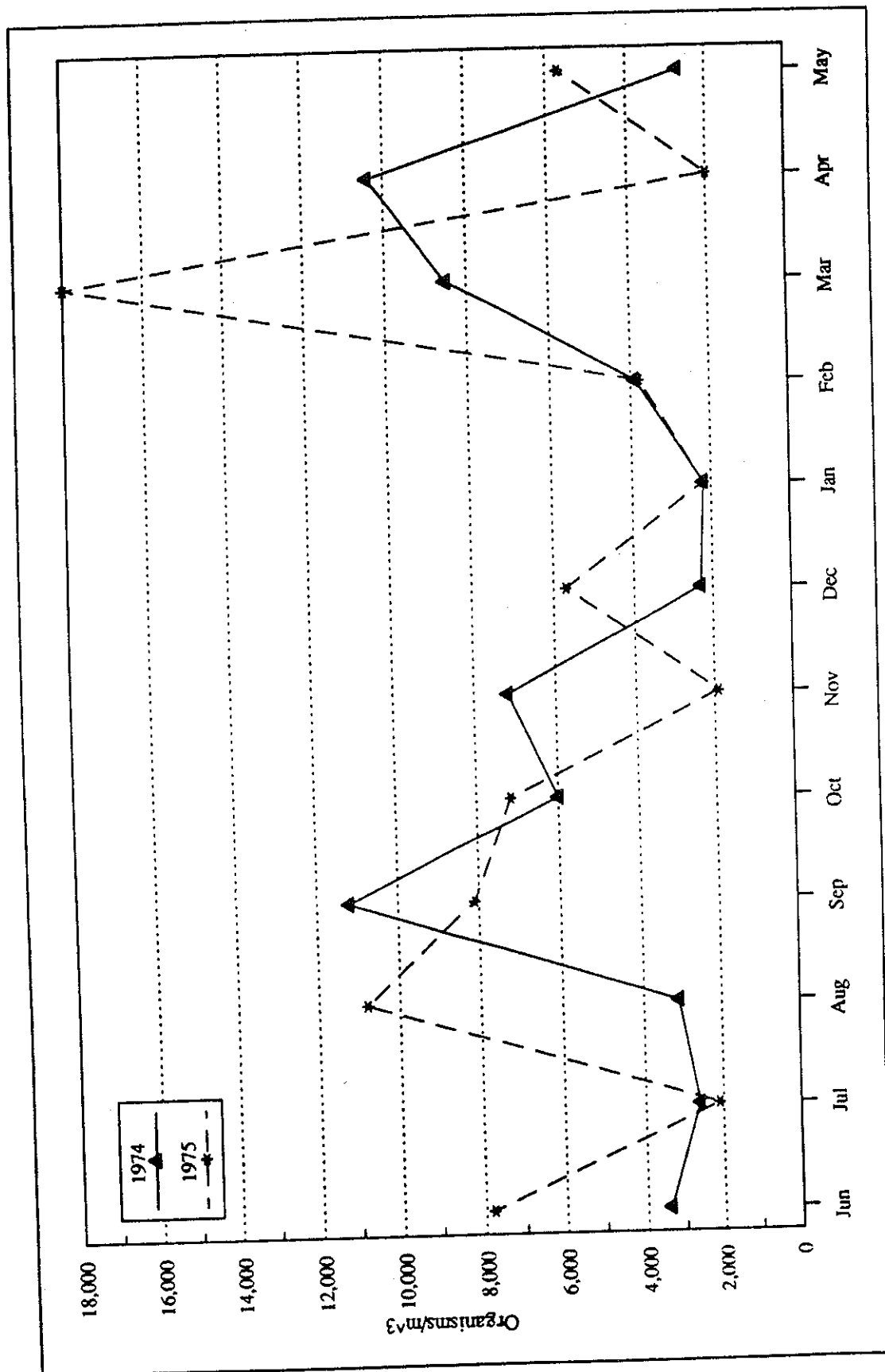


Figure 4.3-2
Mean Abundance of the Microzooplankton Population in the Indian River
 Source of Data: DP&L, 1976

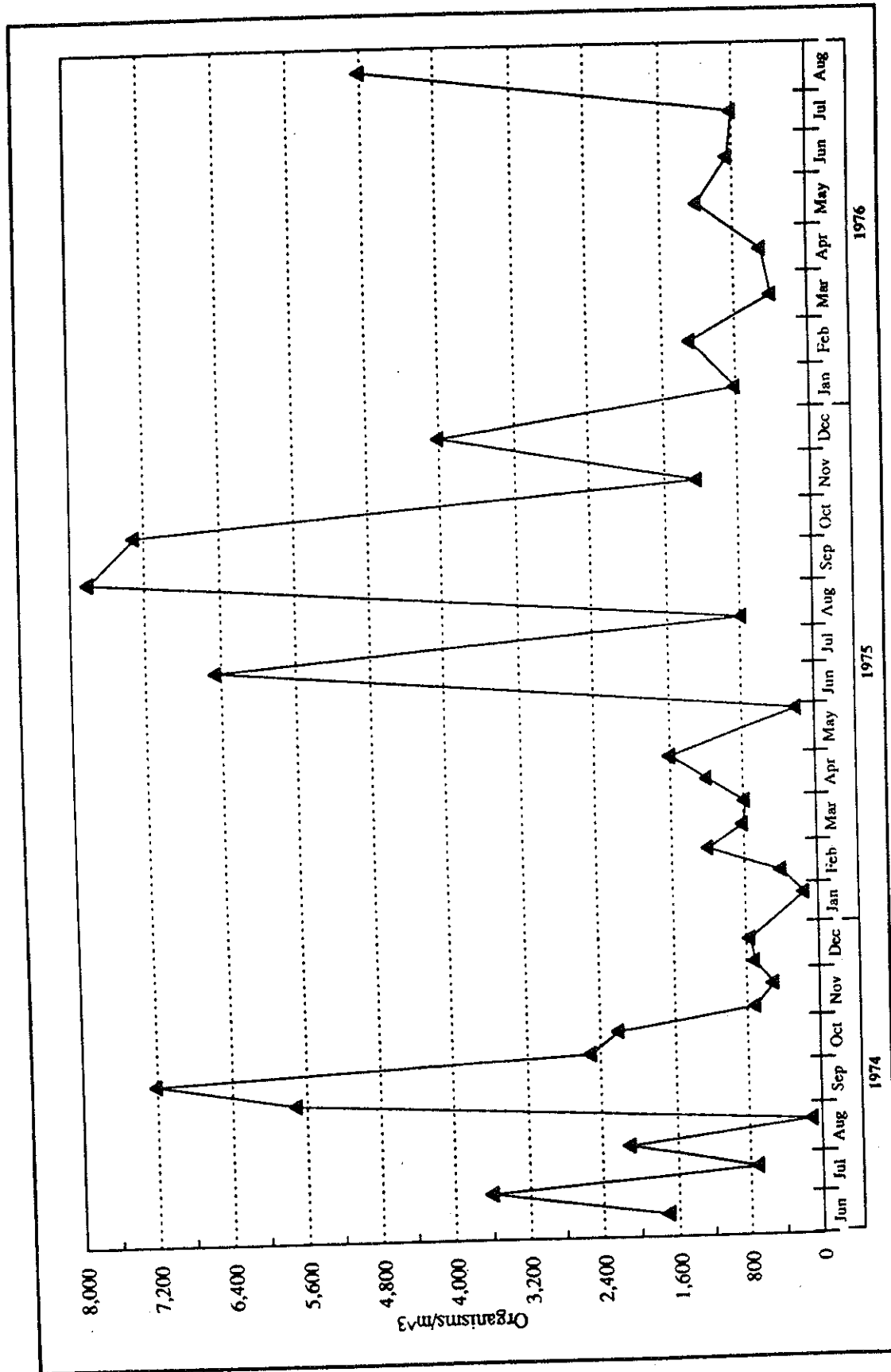


Figure 4.3-3
Mean Abundance of *Acartia* spp.
Source of Data: DP&L, 1976

While zooplankton abundance in spring and late summer reflected seasonal blooms of phytoplankton, the decrease in mid-summer was most likely due to predation by the ctenophore, *Mnemiopsis leidyi*, an opportunistic species that feeds on a variety of zooplankton. A peak ctenophore density in July 1975 of nearly 50 m³ correlates well with a sharp decline in zooplankton (Figure 4.3-4). A number of researchers have reported a decrease in zooplankton numbers accompanied by an increase in tentaculate ctenophores. This has been reported in Narragansett Bay (Deason and Smayda, 1982); Delaware Bay (Cronin et al., 1962), Long Island Sound (Barlow, 1955), Barnegat Bay (Mountford, 1980), and the Patuxent River (Herman et al., 1968). Deason and Smayda (1982) found that in Narragansett Bay a pulse in ctenophore abundance was accompanied by a rapid decline in zooplankton density and a resultant phytoplankton bloom again followed by a sharp increase in zooplankters especially the copepods. This led Deason and Smayda to conclude that in temperate estuarine systems ctenophores may be a primary regulator of zooplankton and phytoplankton density.

The microzooplankton community of the Indian River estuary from 1974 to 1976 was dominated by a number of species of copepods. Table 4.3-2 presents the rank order of abundance of the top fifteen species of microzooplankton collected in the estuary from 1974 to 1976. These fifteen species comprised 85 percent of the total number of zooplankton collected during this study. Adult and juvenile copepods were the major numerical constituents in sample collections comprising about 40 percent of zooplankton abundance and were represented by at least 48 species (Figure 4.3-5). Copepod species that were numerically dominant in overall microzooplankton abundance included:

Acartia tonsa
Acartia spp.
Eurytemora affinis
Oithona spp.
Paracalanus spp.

The density of *Acartia tonsa*, the most abundant species collected, fluctuated seasonally with changes in water temperature. Summer populations were characterized by an increase density in June (25,000/m³) interrupted by a decline in July, followed by another increase towards the end of summer (30,000/m³). Late summer peaks were due principally to an abundance of

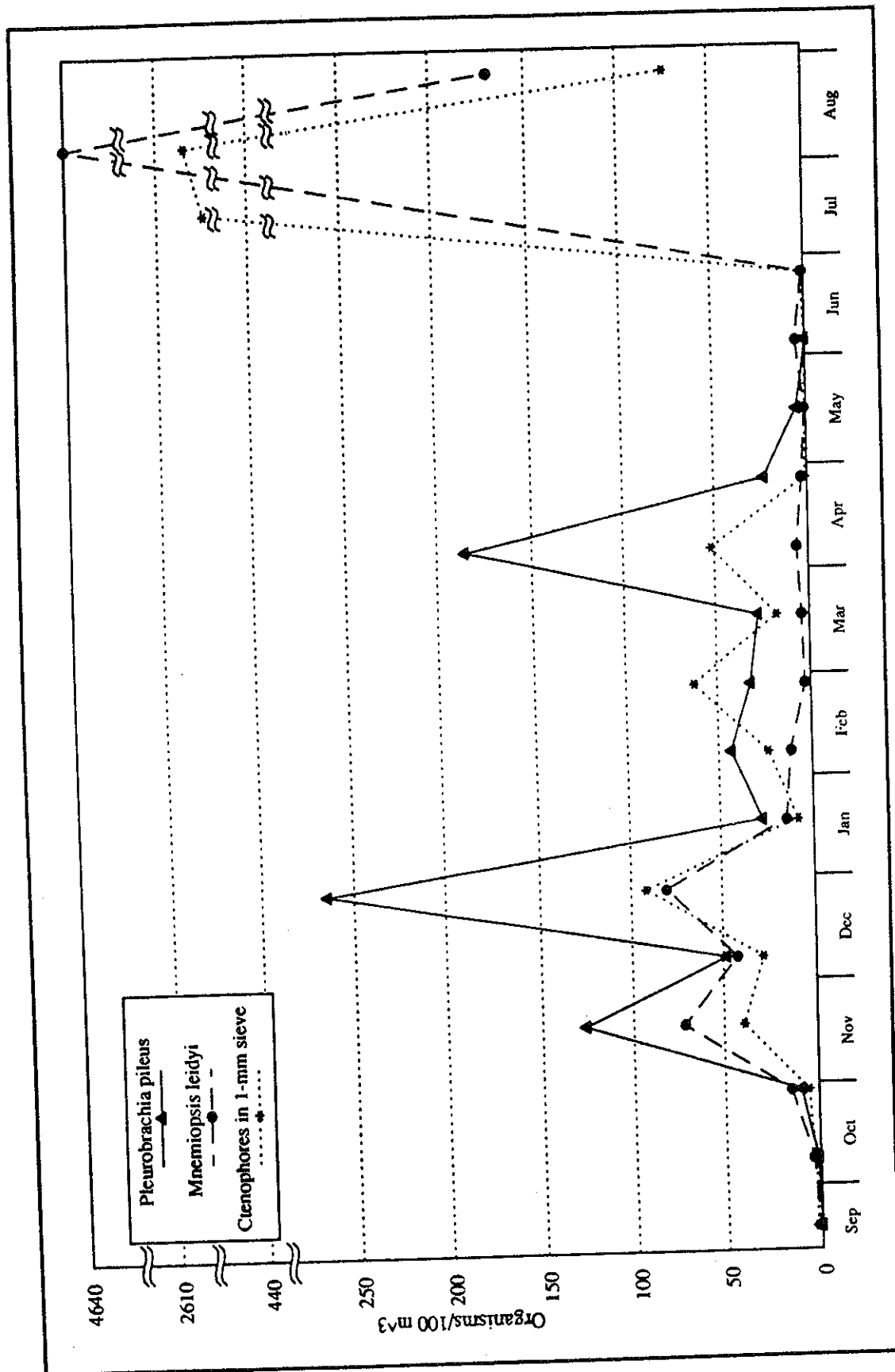


Figure 4.3-4
Mean Abundance of Ctenophores for All Stations Sampled in
the Indian River, September 1974 - May 1975

Source of Data: DP&I, 1976

Table 4.3-2

**Rank and Percent Numerical Composition of the
Fifteen Most Abundant Microzooplankton and Macrozooplankton Species
Collected Between 1974 and 1976**

Microzooplankton			Macrozooplankton		
Species	Rank	Percent	Species	Rank	Percent
<i>Acartia spp.</i>	1	24.7	<i>Neomysis americana</i>	1	23.4
<i>Acartia tonsa</i>	2	12.8	<i>Sagitta spp.</i>	2	19.5
<i>Noctiluca spp.</i>	3	8.8	<i>Palaemonetes spp.</i>	3	18.5
<i>Unid. polychaete larvae</i>	4	8.6	<i>Neomysis juv.</i>	4	8.1
<i>Eurytemora spp.</i>	5	6.0	<i>Crangon septimespinosa</i>	5	6.8
<i>Paracalanus crassirostra</i>	6	5.1	<i>Lyriope tetraphylla</i>	6	6.7
<i>Oithona spp.</i>	7	4.8	<i>Sarsia tubulosa</i>	7	5.7
<i>Paronychocamptus hunts</i>	8	4.5	<i>Ampelisca spp.</i>	8	1.4
<i>Centropages spp.</i>	9	4.3	<i>Bougainvillia carolinen</i>	9	0.9
<i>Unid. cirripedia spp.</i>	10	2.2	<i>Argulus bicolor</i>	10	0.9
<i>Paracalanus spp.</i>	11	1.6	<i>Rathkea octopunctata</i>	11	0.7
<i>Euterpina actifrons</i>	12	1.1	<i>Neomysis</i>	12	0.7
<i>Pseudocalanus minutus</i>	13	1.1	<i>Edotea triloba</i>	13	0.6
<i>Temora spp.</i>	14	1.1	<i>Scolecoplepides viridis</i>	14	0.5
<i>Oithona colcarva</i>	15	1.1	<i>Mysidopsis bigelowi</i>	15	0.5

Source: DP&L, 1976

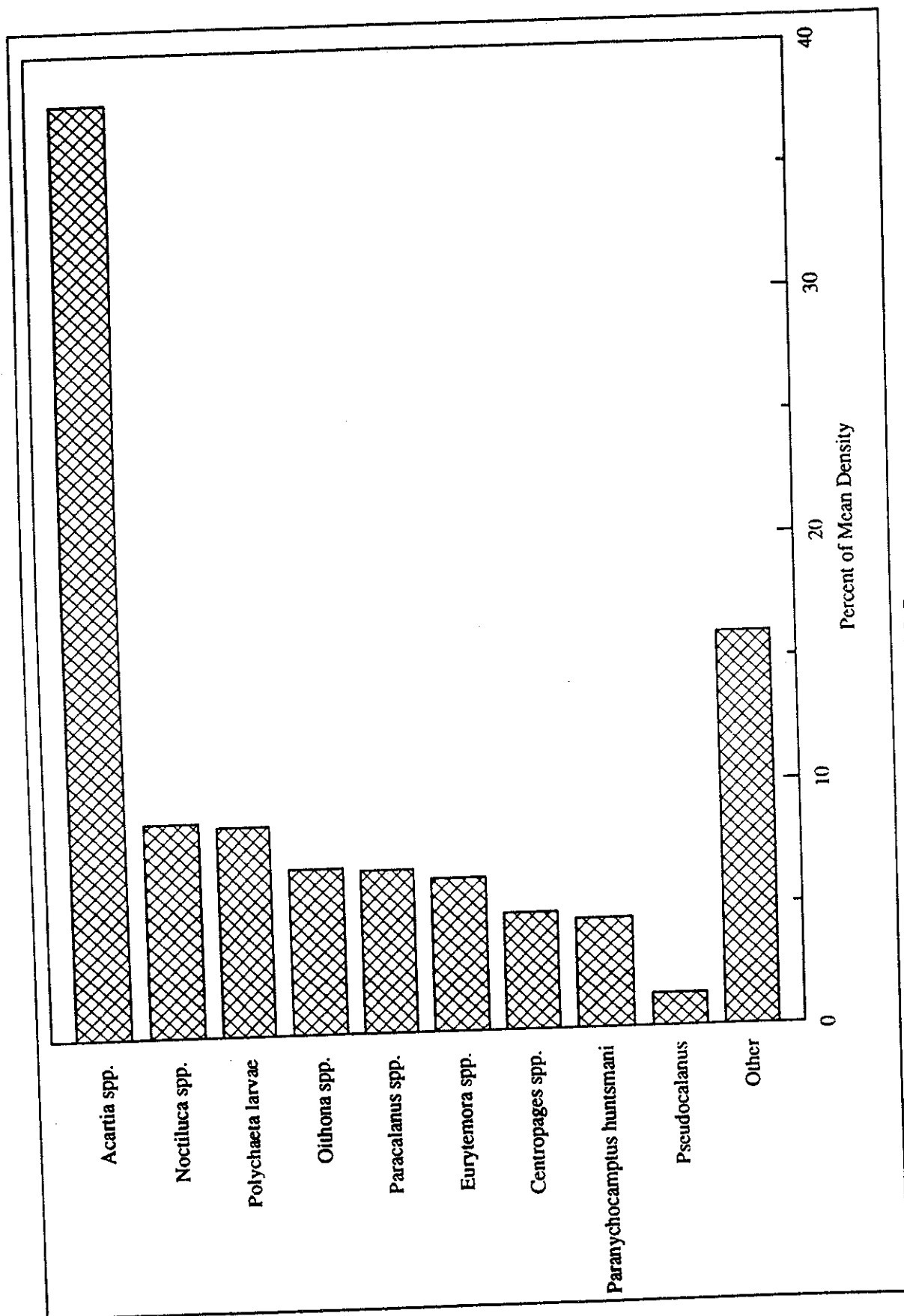


Figure 4.3-5
Percent Mean Density of Principal Microzooplankton Taxa
Collected in Indian River Estuary from 1974 - 1976
 Source of Data: DPAI, 1976

copepodites in August/September. As previously noted for the microzooplankton as a whole, the decline in July was thought to reflect predation by a seasonally abundant ctenophore population. *Acartia* density declined in fall and maintained a lower density throughout winter. In studies of the Delaware Bay, *A. tonsa* was found to be the single most important holoplanktonic copepod species (Deevey, 1960 and Cronin et al., 1962). Similar findings were made in the Patuxent River by Heinle (1966) and Herman et al., (1968). *A. tonsa* alternates in abundance with its congeneric associate *A. clausi*. This is particularly true of colder waters than those found in Indian River where *A. clausi* may become the dominant species. Although *A. clausi* was observed to increase in relative abundance in the colder winter months in Indian River, it never exceeded the densities of *A. tonsa* (DP&L, 1976). Findings made relative to the copepod, *Acartia*, in the Indian River survey led DP&L to conclude that "due to the fact that *Acartia* is the most numerous zooplankton species [it] is an indication that the estuary, although smaller in scale than most well-studied estuaries in the mid-Atlantic coast, is typical of the physical and biotic environment in which *Acartia* tends to flourish".

In addition to *Acartia*, DP&L found that the polyhaline segment of the estuary also included significant populations of typical coastal copepod species including *Centropages typicus* and *Centropages hamatus*. Moreover, the zooplankton of the oligohaline reach supported several freshwater species of copepods including *Cyclops sp* and *Eucyclops sp*.

After *Acartia spp.*, *Noctiluca spp.* ranked second in numerical abundance accounting for 8.8 percent of the total microzooplankton density. DP&L included *Noctiluca* a dinoflagellate, as part of the zooplankton because of its heterotrophic feeding habits and relatively large size. Maximum densities in excess of 36,000/m³ were observed in fall.

Unidentified polychaete larvae represented the third most abundant taxon accounting for 8.6 percent of the total microzooplankton collected. Maximum densities of 11,800/m³ and 26,700/m³ were recorded in April 1975 and March 1976, respectively, in the mesohaline reach at station 30T.

Accounting for 6.8 percent of the total collection of microzooplankton, *Oithona* spp. were the next most numerically dominant zooplankton. The maximum density of *Oithona* was measured in the polyhaline segment (Station 9) at a density of 8,050/m³.

• Macrozooplankton

During 1974-1976, nearly 100 different taxa and life stages of macrozooplankton were collected. Table 4.3-2 presents the rank order of abundance of the top fifteen species of macrozooplankton collected in the estuary from 1974 to 1976. These fifteen species comprised 95 percent of the macrozooplankton abundance during this period. The macrozooplankton community was dominated by both holoplankton and meroplankton. Holoplanktonic forms were dominated by the mysid shrimp *Neomysis americana* and the carnivorous chaetognath, *Sagitta* (Figure 4.3-6). During the period of study, *Neomysis americana* comprised about 23 percent of the macrozooplankton. Other holoplanktonic forms of note included the trachymedusan, *Liriope tetraphylla*, and the hydromedusan, *Sarsia tubulosa*, also were numerically dominant holoplanktonic forms of the macrozooplankton community.

Immature decapods were the most abundant meroplanktonic form of the macrozooplankton community. While crab megalopae and zoeae of the mud crab *Rithropanopeus harrasi* were numerically dominant, the zoeal forms of the caridean shrimp, *Palaemonetes* spp., and *Crangon septemspinosa* made up a major portion of the meromacroplankton of Indian River

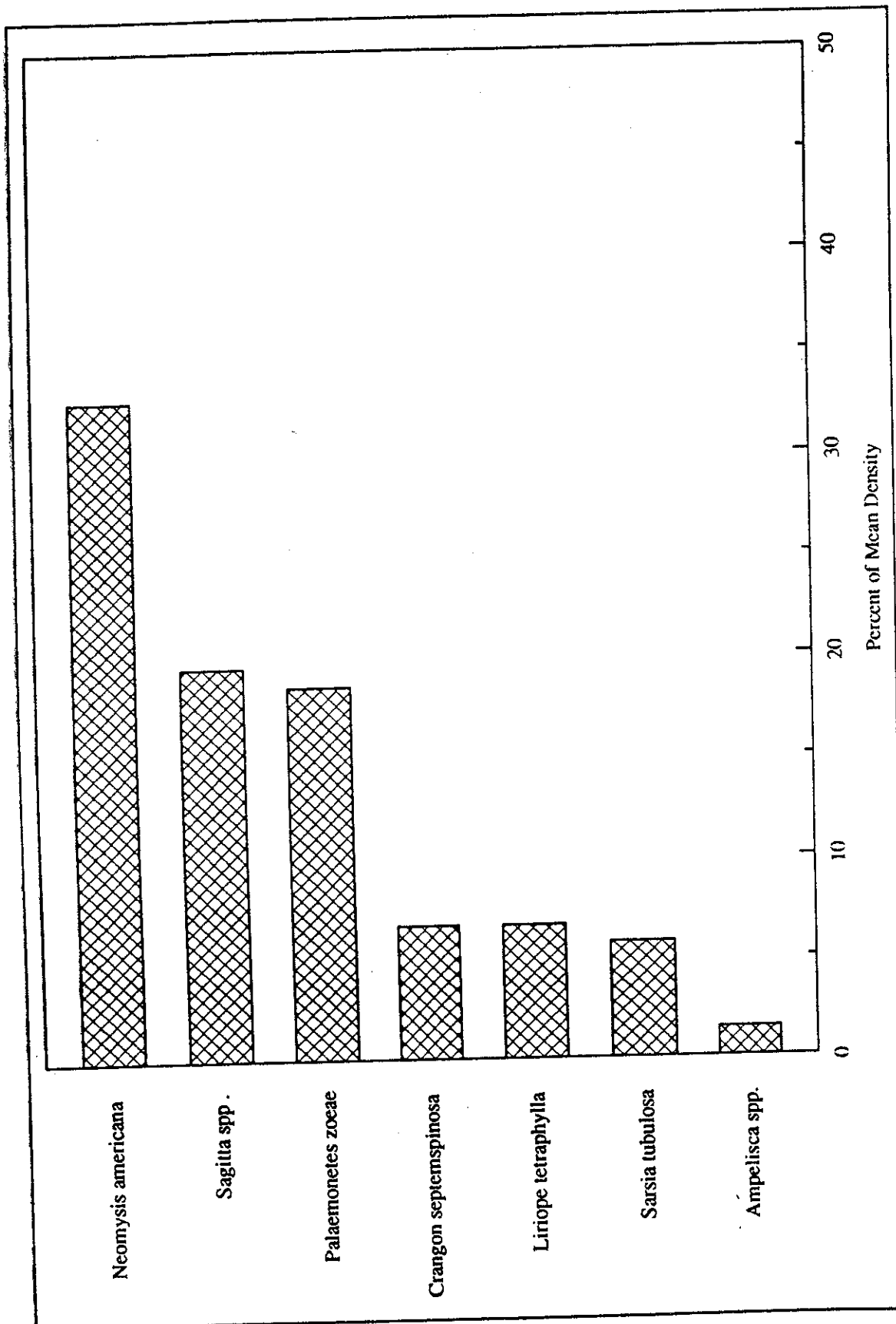


Figure 4.3-6
Percent Mean Density of Major Macrozooplankton Species Collected in
Indian River Estuary from 1974 - 1976
 Source of data: DP&R, 1976

from 1974 to 1976. The seasonal distribution of macrozooplankton abundance in Indian River between 1974 and 1976 is presented in Figure 4.3-7.

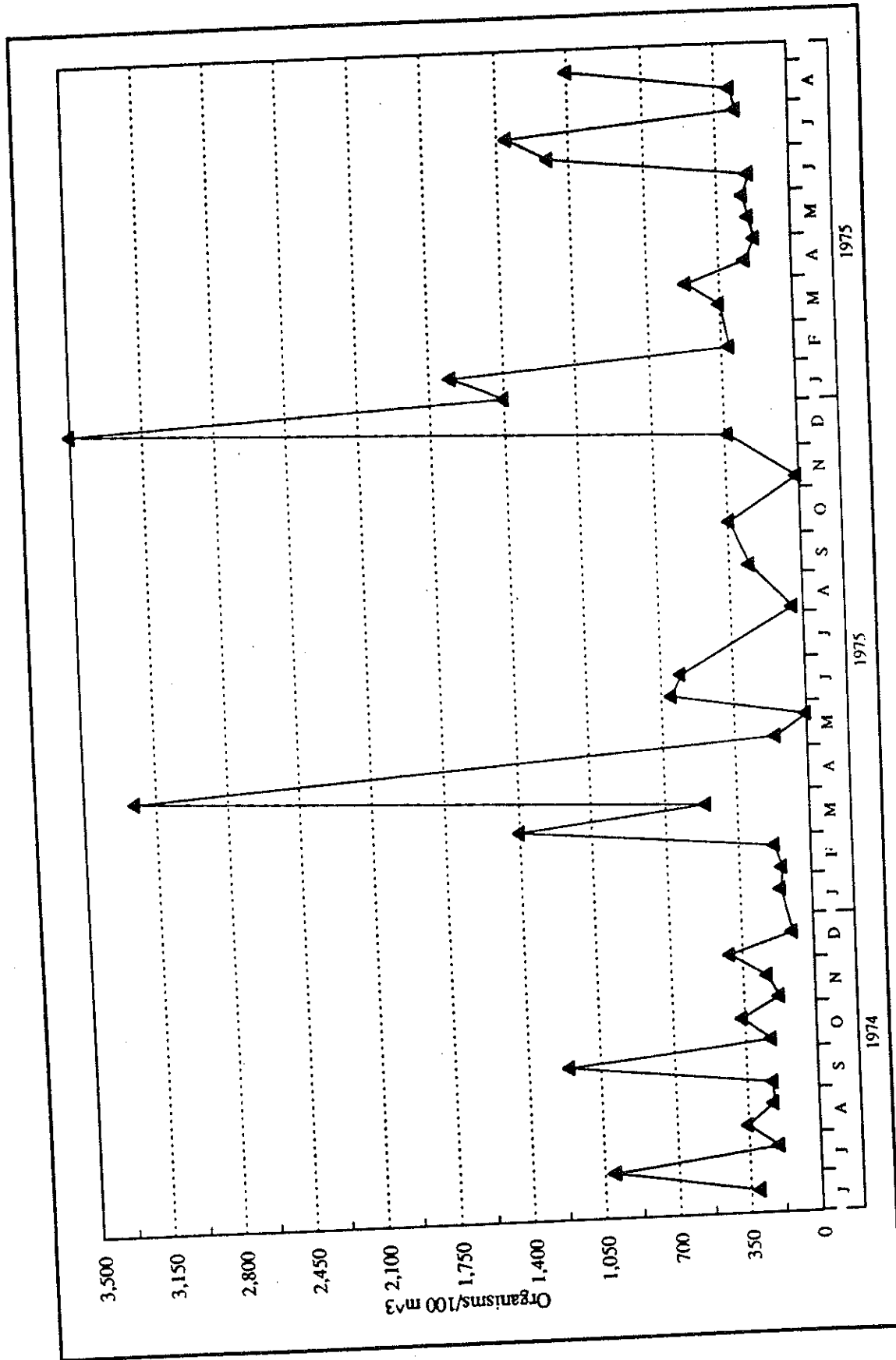


Figure 4.3-7
Mean Abundance of Macrozooplankton Population in the Indian River

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APPENDIX 4.3-A (Continued)
ZOOPLANKTON
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C



SECTION 4.4

MACROFLORA

4.4.1 Introduction

The macroflora that comprise the benthic floral community of the Delaware Inland Bays represent an important element of the estuarine system. Represented by both the macroalgae, such as sea lettuce (*Ulva lactuca*), and the submerged aquatic vegetation (SAV), such as eelgrass (*Zostera marina*), the macroflora provide a substantial contribution to the production of primary organic matter in the bays. Serving as habitat for infauna, epibiota, and juvenile and adult nekton, the macroflora contribute to vital spawning, nursery and feeding grounds for numerous species in the bays. (Rozas and Odum, 1987; Orth et al., 1984; Thayer et al., 1984, Loveland et al., 1984; Phillips, 1974).

The principal objectives of the macroflora section of the "*Living Resource*" characterization are several and include:

- . The identification of studies that have been conducted of the macroflora of the bays and selection of those studies most appropriate to characterization.
- . The definition of the status of the macrofloral community, as defined by such measures as species composition, relative abundance, and biomass.
- . The description of the historical record and the identification of changes in the macrofloral community over time, where data allow.

For the purpose of this discussion, macroalgae and SAV are discussed separately in the following narrative.

4.4.2 Macroalgae

4.4.2.1 Previous Research

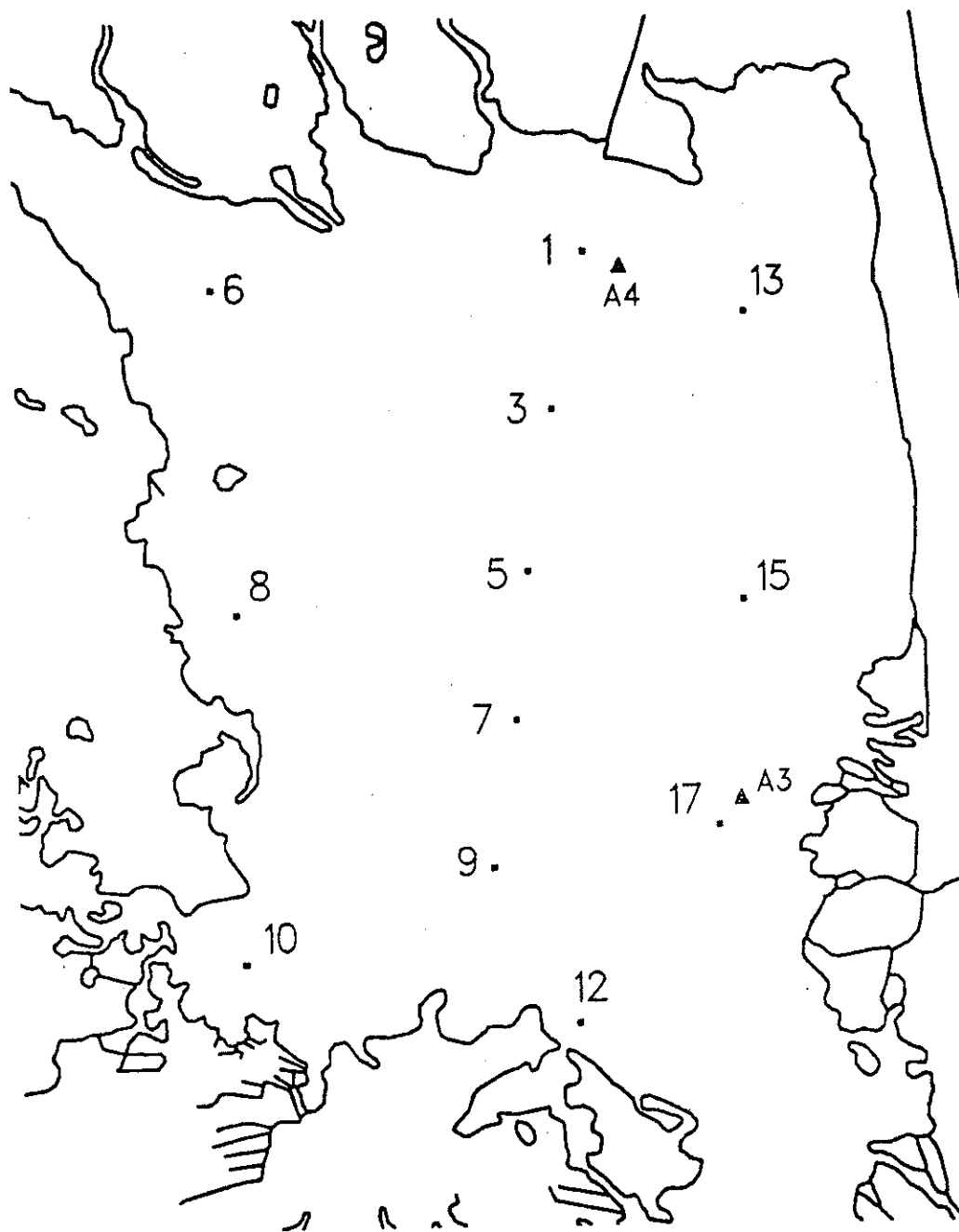
Only two studies were found that investigated the macroalgal community of the Delaware Inland Bays. They include:

- Orris, Patricia, 1972, *A Floristic and Ecological Survey of the Benthic Macroalgae of Rehoboth Bay, Delaware*.
- Heck, K.L, and K.G. Sellner, 1988, *Macroalgae in Delaware's Inland Bays*.

As her masters thesis, Orris (1972) investigated the macroalgae of Rehoboth Bay from June 1969 through July 1970. Monthly samples were collected at 12 stations widely distributed throughout the bay (Figure 4.4-1). Samples were analyzed for species composition, relative abundance, and biomass.

A second study of the macroalgal community was conducted for DNREC by Heck and Sellner (1988) of the Academy of Natural Sciences of Philadelphia who investigated the macroalgae in both Rehoboth and Indian River Bays. This qualitative study involved approximately monthly collections of macroalgae at two stations in Rehoboth Bay (Figure 4.4-1) and two stations in Indian River Bay from September 1985 through September 1986. This study was designed to provide qualitative information on the composition, relative abundance and seasonality of macroalgae in Rehoboth and Indian River Bays.

As is often the case in biological characterization, caution should be judiciously exercised when attempting to compare results of various studies. Differing objectives lead to the varying sampling methods including sampling gear and monitoring frequency, among others. To facilitate this discussion for the macroalgal community, Table 4.4-1 presents a comparison of the methods employed in both of these studies.



- Location of Orris' Stations
- ▲ Location of Heck & Sellner Stations

Figure 4.4-1
Location of Sampling Stations in
Rehoboth Bay for Studies of
Macroalgae by Orris (1972),
Heck & Sellner (1988)



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Table 4.4-1 Comparison of Methods used by Orris (1972) and Heck & Sellner (1988) to Investigate the Macroalgal Community of Rehoboth Bay				
Study	Period of Study	No. of Stations	Sampling Frequency	Collection Method
Orris, 1972	Jun 1969-July 1970	12	Monthly	Benthic dredge
Heck & Sellner, 1988	Sept. 1985-Sept. 1986	2	Approx. monthly	Otter trawl

4.4.2.2 Status of the Resource

The most recent study of the macroalgal community of the Inland Bays was conducted between 1985 and 1986 by Heck and Sellner (1988). Although more recent anecdotal information exists, no formal study of the macroalga community has been conducted since 1986. Consequently, the status of macroalgae in the Inland Bays is unknown. The following narrative discusses the historical record of macroalgae in the Delaware Inland Bays based on the previous studies noted.

4.4.2.3 Historical Record of Macroalgae in the Inland Bays

By way of background, in shallow estuarine lagoonal systems like that of the Inland Bays, the macroalgal community generally exists in two forms. One form, the macroalgal bed community, occurs where stands of algae are attached to small shell fragments, large sand grains and pebbles, and even other plants (Conover, 1964). Large bed communities of macroalgae have been noted throughout Rehoboth Bay. One noteworthy stand of *Ulva lactuca* occurs in the vicinity of the mouth of Herring Creek (Tinsman, personal communication). Other stands of *Ulva*, or cabbage grass, have also been noted in Indian River Bay between Quillens Point and Gull Island, an area previously inhabited by sparse beds of eelgrass. In a review of aerial photography from the 1970's and 1980's, Klemas observed what was believed to be patches of macroalgae along the shorelines of Indian River and Rehoboth Bays (Heck and Sellner, 1988).

These macroalgal beds give rise to a second form of macroalgal community known as the "drift community" (Conover, 1958, 1964). Chapman (1964) suggests that the drift community is derived from attached forms that become detached with an increase in size in combination with tide and wave action. These "loose lying" or "drift" algal flora have been observed in a variety of other estuaries including Tampa Bay, (Hooks et al., 1976) the Long Island Bays (Conover, 1960), the Texas Coastal lagoons (Conover, 1964), Charlestown and Green Hill Ponds, Rhode Island (Conover, 1961), and Barnegat Bay (Moeller, 1964 and Loveland et al. 1984). The community consists of plants that drift along the bottom being unattached to any substrate.

At the time of her study, Orris observed that the macroalgae of Rehoboth Bay in 1969-1970 was largely of the "unattached" or "drift community" type. Her conclusion was based on verifications from boat and diving observations that she made while conducting the study. Moreover, she observed that many of the algae collected were not attached to any solid substrate at the time of collection.

During the period of the Orris study (1969-1970), the macroalgal community included 59 taxa of algae dominated by 28 species of red algae (*Rhodophyta*), in addition to 17 species of green algae (*Chlorophyta*) and 14 species of brown algae (*Phaeophyta*). Table 1 of Appendix 4.4-B lists the algal species observed during that period. Although the overall composition and seasonal associations varied temporally throughout the bay, the algal community was consistently dominated by three species including:

- . *Agardiella tenera*
- . *Gracilaria verrucosa*
- . *Ulva lactuca*

Collectively, these three species comprised more than 95% of the algal community, by volume, of Rehoboth Bay in 1969-1970.

Temporal changes in the number of algal species were shown to reflect seasonal conditions. Benthic macroflora are responsive to changes in water temperature, solar radiation and nutrient

supply. Because these three factors have distinct periodicities, the species composition varies substantially over an annual cycle. Figure 4.4-2 presents the seasonal distribution of numbers of algal taxa collected in Rehoboth Bay from June 1969 through July 1970. In evaluating taxa diversity in the algal community, Orris observed that maximum taxa richness occurred in early winter (27 taxa in December 1969) and in mid-summer (25 taxa in July 1969). The most noticeable decline in numbers of taxa occurred mid- to late winter (February 1970), when only nine taxa were identified.

Although the number of taxa for any given macroalgal class remained relatively constant throughout the year, numbers of total taxa increased as seasonal associations developed and overlapped. For example, in mid-spring (April), the number of species of *Chlorophyta* increased as water temperature and solar radiation (and possibly nutrient availability) increased. The peak in total species abundance during this period resulted not only from the appearance of spring ephemerals of both the *Chlorophyta* and *Rhodophyta*, but also from the persistence and increase of a number of *Phaeophyta*, particularly *Fucus* sp. in early spring (Orris, 1972). Similarly, the seasonal peak in December 1969 reflected an increased taxa richness of all three classes of macroalgae. In contrast, the mid-winter (February) decline in total algal taxa reflected a depression in taxa richness for the three algal classes.

A second study of the macroalgae of Rehoboth Bay was conducted in 1985 and 1986 by Heck and Sellner (1988). This study was conducted to obtain qualitative information on the composition, relative abundance and seasonality of macroalgae in Rehoboth and Indian River Bays. These data were collected to provide additional information on the possible eutrophication of the Inland Bays.

In contrast to the 59 taxa collected by Orris fifteen years earlier, only 5 taxa were noted in the Inland Bays during the 1985-1986 study. It should be noted, however, that Heck and Sellner provided identification to species level for only those taxa of major abundance. In addition no species level identifications were made for epiphytic species and filamentous green algae. Both epiphytes and filamentous green algae, e.g., *Enteromorpha* spp. contributed

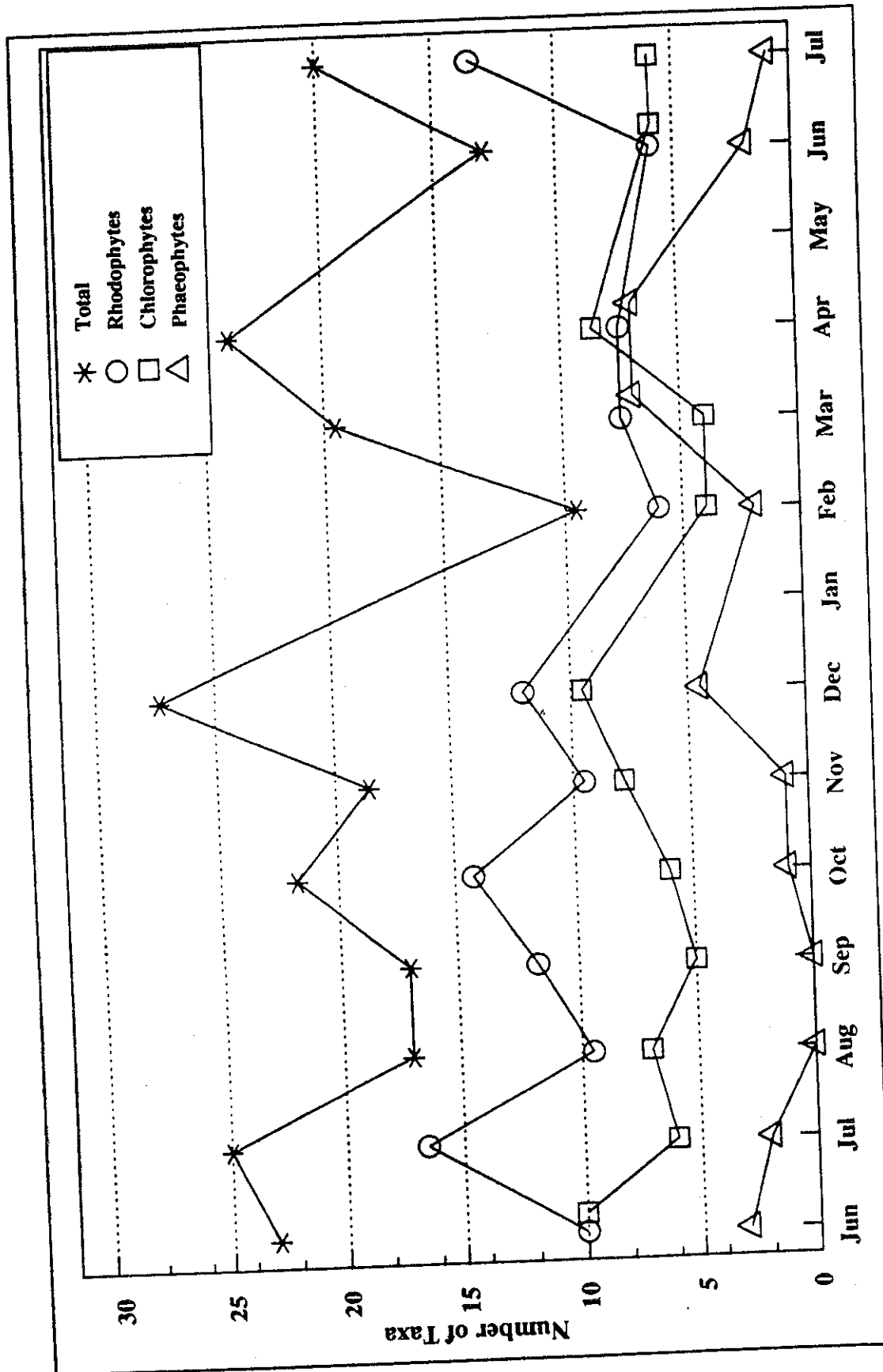


Figure 4.4-2
Seasonal Distribution of Numbers of
Algal Taxa in Rehoboth Bay (1969 - 1970)
(Source of Data: Orris, 1972)

substantially to the list of algal taxa collected by Orris. Consequently, the significance of these findings is uncertain. Although the number of taxa may have been reduced from that of the previous study, similar taxa dominance was observed. As with Orris' study, the principal taxa dominating the macroalgal community were *Gracilaria* sp., *Agardhiella tenera*, *Ulva lactuca* and unidentified filamentous green algae.

As previously noted, the macroalgal community of the Inland Bays is an important source of primary production in the Inland Bays. Temporal variation in algal abundance and biomass is conspicuous and for the most part reflects seasonal changes in incident light, temperature and nutrient availability (Loveland et al., 1984). Figure 4.4-3 provides a comparison of the monthly average biomass of macroalgae measured in Rehoboth Bay from 1969 to 1970. To provide a subsequent comparison with data collected by Heck and Sellner in 1985 and 1986, standing crop data from Orris, reported as liters of algae collected per minute of tow, was roughly converted to a dry weight of algae(g)/m². Calculations and supporting information for this conversion are presented in Appendix 4.4-C.

In 1969 and 1970, the maximum monthly average biomass of macroalgae was observed in summer (July-August) when biomass estimates reached approximately 48 g dry wt/m². A minimum monthly average biomass estimate of about 3.0 g dry wt/m² was measured in early spring (March 1970). The annual average biomass for Rehoboth Bay for the study period was estimated as approximately 18.0 g dry/m².

In addition to evaluating community composition, Heck and Sellner also measured macroalgal biomass. Figure 4.4-3 also provides a comparison of the monthly average biomass of macroalgae collected in Rehoboth Bay in 1985 and 1986 with that observed in 1969 and 1970. The annual average biomass reported by Heck and Sellner for Rehoboth Bay was nearly 1.0 g dry/m² or about 18-fold less than that found in 1969-1970.

The difference in biomass between the two studies is suspected to be a function of the differing collection methods, as well as the limited sample size by comparison. Because of the disparate sample size of the two studies, a comparison of those stations similar to both studies was made.

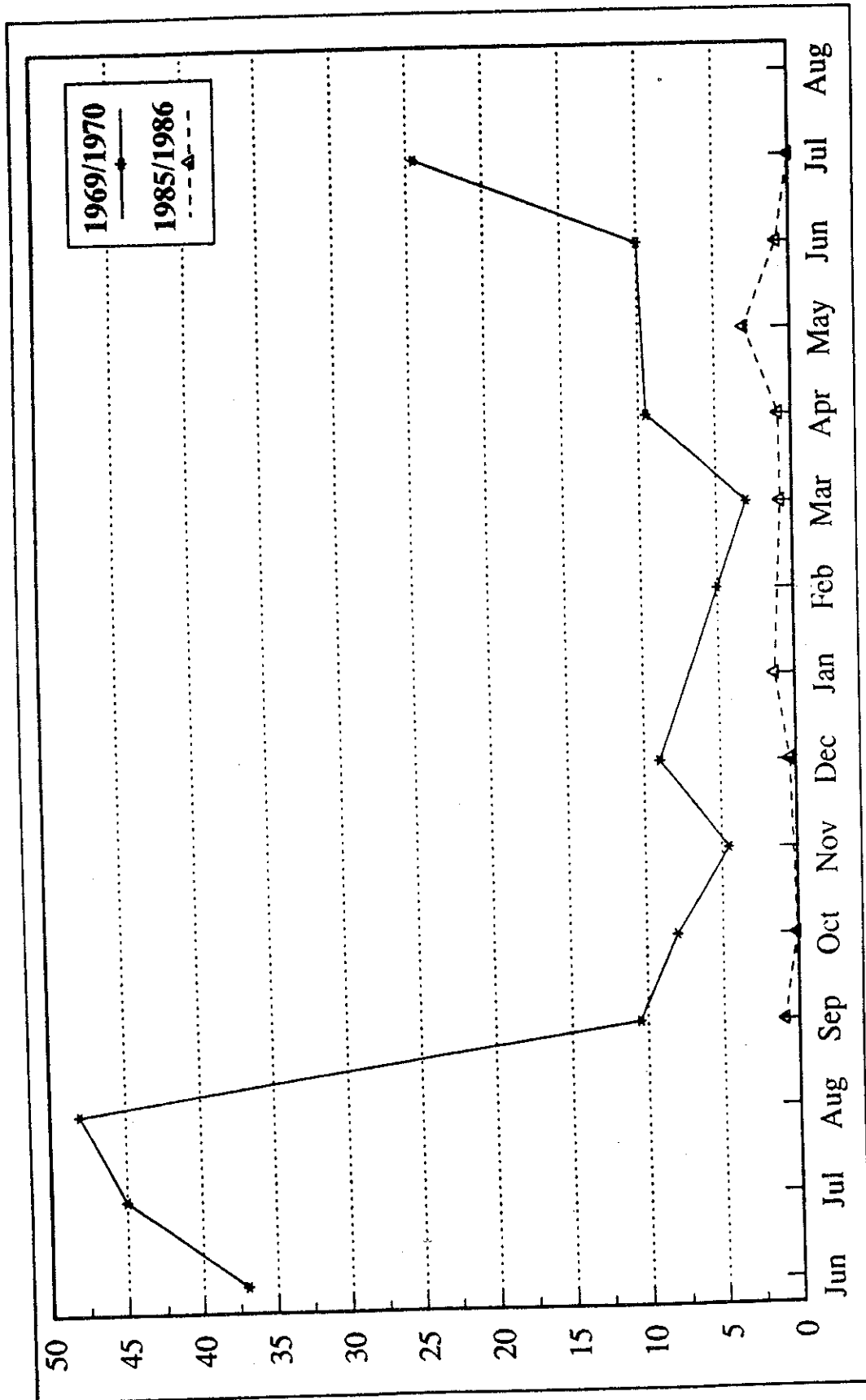


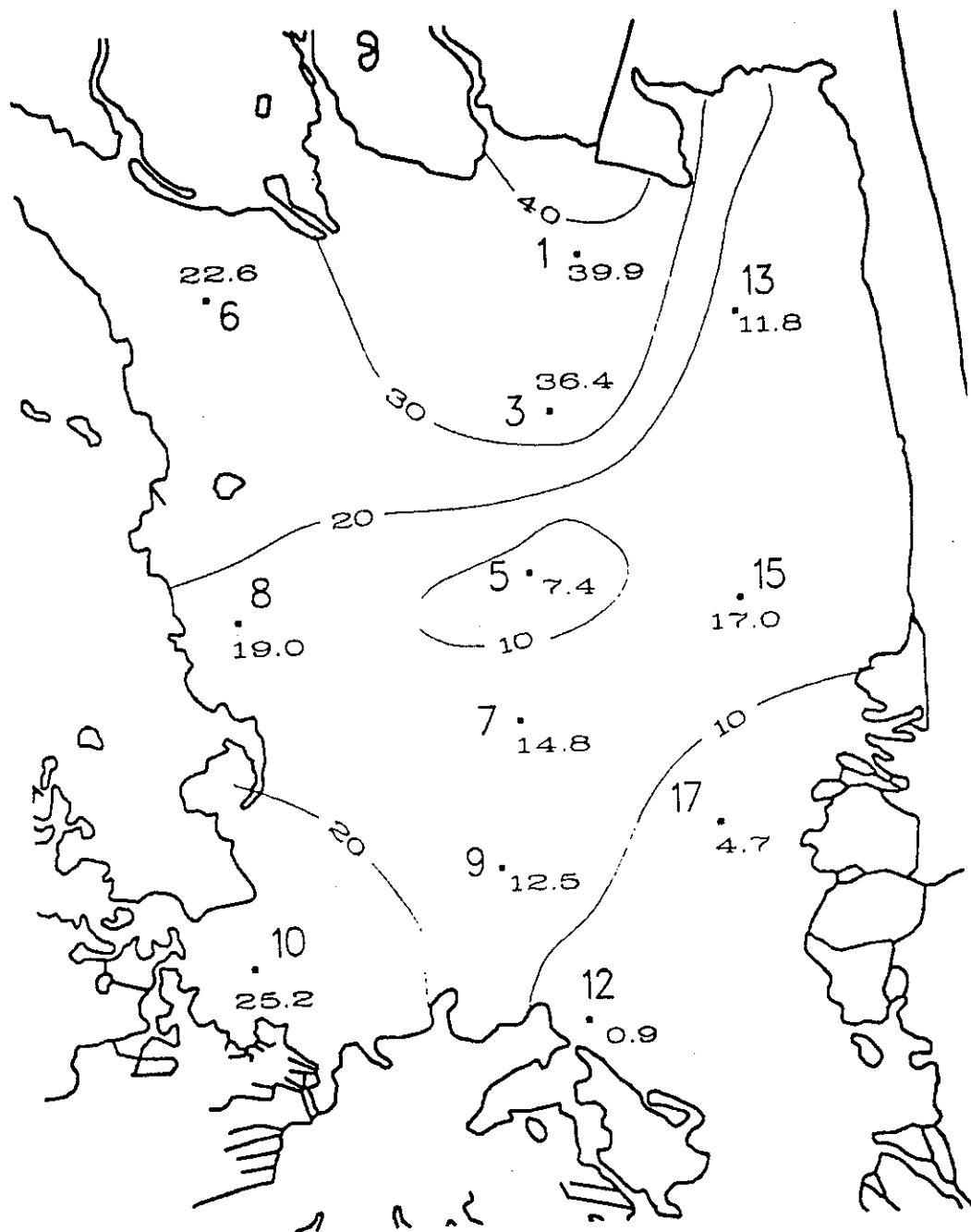
Figure 4.4-3
Comparison of Monthly Average
Biomass of Macroalgae in Rehoboth Bay in
1969/1970 (Orris, 1972) and 1985/1986 (Heck & Sellner, 1988)
(Grams Dry Weight/Meter²)

A comparison of the average annual biomass was made for comparable stations near the mouth of the Lewes and Rehoboth canal (i.e., Orris's Station 1 and Heck and Sellner's Station A4) and in the vicinity of Rehoboth Marsh (i.e., Orris' Station 17 and Heck and Sellner's Station A3) the comparison of biomass data near the mouth of the Lewes and Rehoboth Canal shows about a thirty-fold decrease (39.9 g dry/m^2 in 1969-1970 versus 1.2 g dry/m^2 in 1985-1986) in macroalgal biomass over the sixteen-year interval of the two studies. A seven-fold decrease (4.7 g dry/m^2 versus 0.7 g dry/m^2) was found in a similar comparison for comparable stations located in the vicinity of Rehoboth Marsh.

In addition to the differences in sample size (i.e. number of stations), the absence of biomass data in August 1985, a period of high algal production in 1969, further complicates the comparison of studies based on differences in annual average biomass. A comparison of average annual biomass for similar stations during comparable months (i.e, excluding August as well as other months when data for both studies were not collected) showed that at Station 1 (A4), 29.0 g dry/m^2 were collected in 1969/1970 while only 1.0 g/m^2 was collected in 1985/1986. Likewise at Station 17 (A3) 4.2 g dry/m^2 were sampled in 1969/1970 in contrast to 0.55 g dry/m^2 in 1985/1986. Summary data for these analyses are provided in Appendix 4.4-1 of this subsection.

Heck and Sellner point out in their report, that the use of an otter trawl to collect macroalgae probably grossly underestimates the available algal material. For a number of reasons, then, results from Heck and Sellner's study should be used with caution in making any substantive conclusions.

In addition to the seasonal aspect of macroalgal distribution Orris examined the spatial or geographic distribution of the macroalgae. Figure 4.4-4 describes the annual average distribution of macroalgal biomass from data generated in 1969/1970. A higher distribution of biomass in the northern portion of the bay may be the result of several factors including an increase in nutrient availability resulting from discharges of the Rehoboth Wastewater Treatment Plant through the Rehoboth-Lewes Canal and into Rehoboth Bay at the time of the study. A



Source of Data: Orris, 1972

Figure 4.4-4
Distribution of Mean Annual
Macroalgal Biomass in
Rehoboth Bay 1969-1970 (g dry / m²)



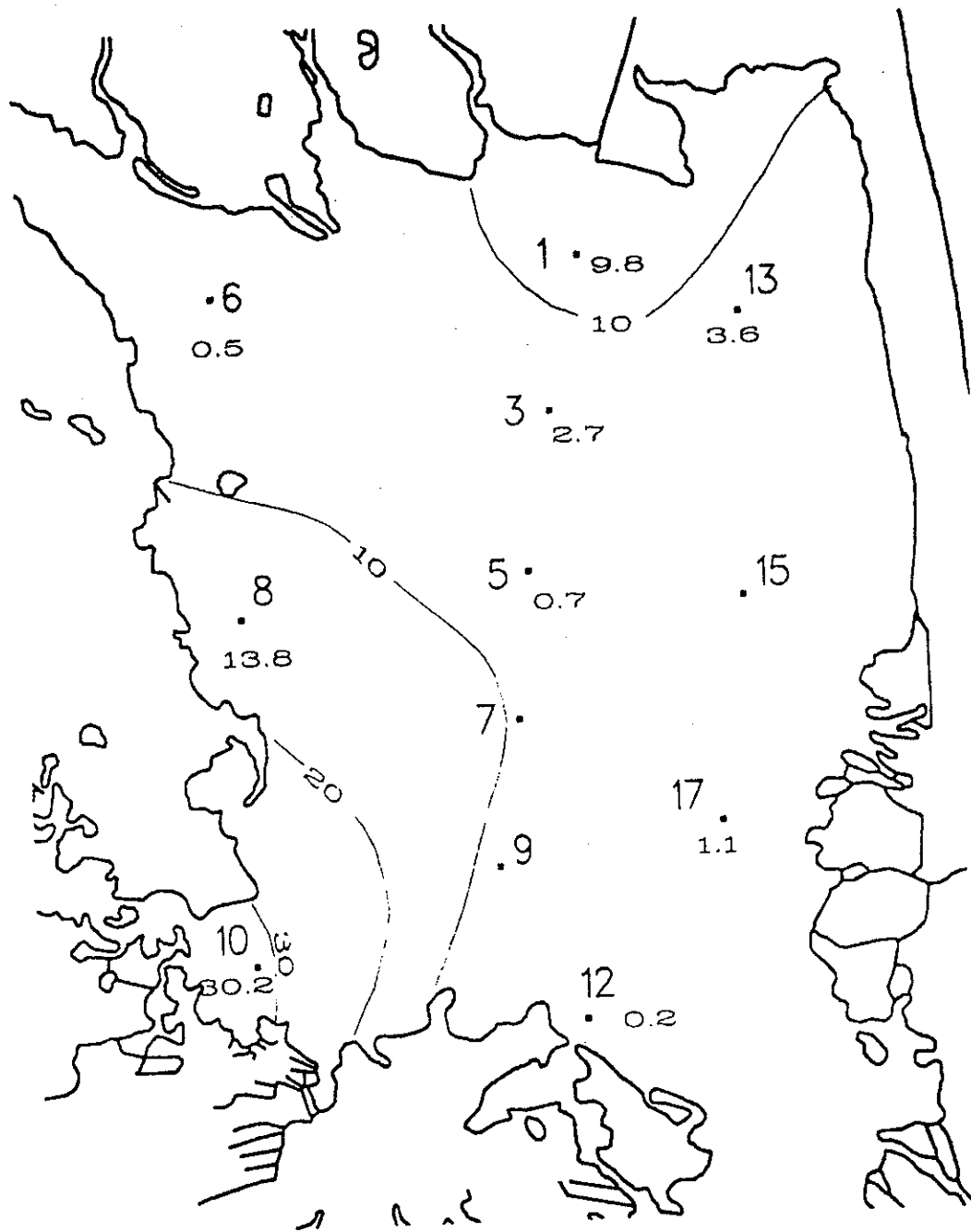
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comparison of the seasonal distribution of macroalgal densities shows the highest alga density occurring in the northern sections of the bay during summer, as reflected in the mean annual biomass distribution, and in the northern and southwestern portion of the bay in winter (Figure 4.4-5). Again, peak density in the northern segment of Rehoboth Bay in summer was thought to reflect higher nutrient levels proximate to the treatment plant. Figure 4.4-6 describes the distribution of inorganic nitrates in August 1969, the period of peak algal production. The levels of nitrates generally show a positive correlation with algal biomass. Maximum concentrations of both nitrates and algal biomass occur along the northern portion of the Bay. In addition, the algal distribution may also be affected by the seasonal circulation of Rehoboth Bay. The circulation patterns in Rehoboth Bay are currently under investigation.

Timmons and Price (1993) have recently revisited the Orris sites and have found the same 5 dominant species. They were also able to determine that about 50% of the algae were attached and 50% were drift community in Rehoboth Bay. In addition Timmons and Price found correlations between species of microalgae and ammonium, as well as particulate and dissolved phosphorous.

The absence of a long-term monitoring program of the macroalgal community in Rehoboth Bay makes any analysis of trends difficult. Data are limited to three studies which represent snapshots of the macroalgal community taken years apart. In as much as their comparison provides discrete pictures in time, and notwithstanding the difficulty in comparing two greatly different sampling programs, a comparison of the principal similarities and differences of their findings can be summarized as follows:

Taxa richness has been reduced from 59 species collected in 1969-1970 to five species collected in 1985-1986. As previously noted, classifications of algal species were made only for those taxa of major abundance. In addition, no species identifications were made for epiphytic species or filamentous green algae-taxa that were abundant in the 1969-1970 study. Consequently, the importance of the difference in taxa richness is not known. Differences in macroalgal biomass between 1969-1970 and 1985-1986 were found to be on the order of a thirty-fold reduction in

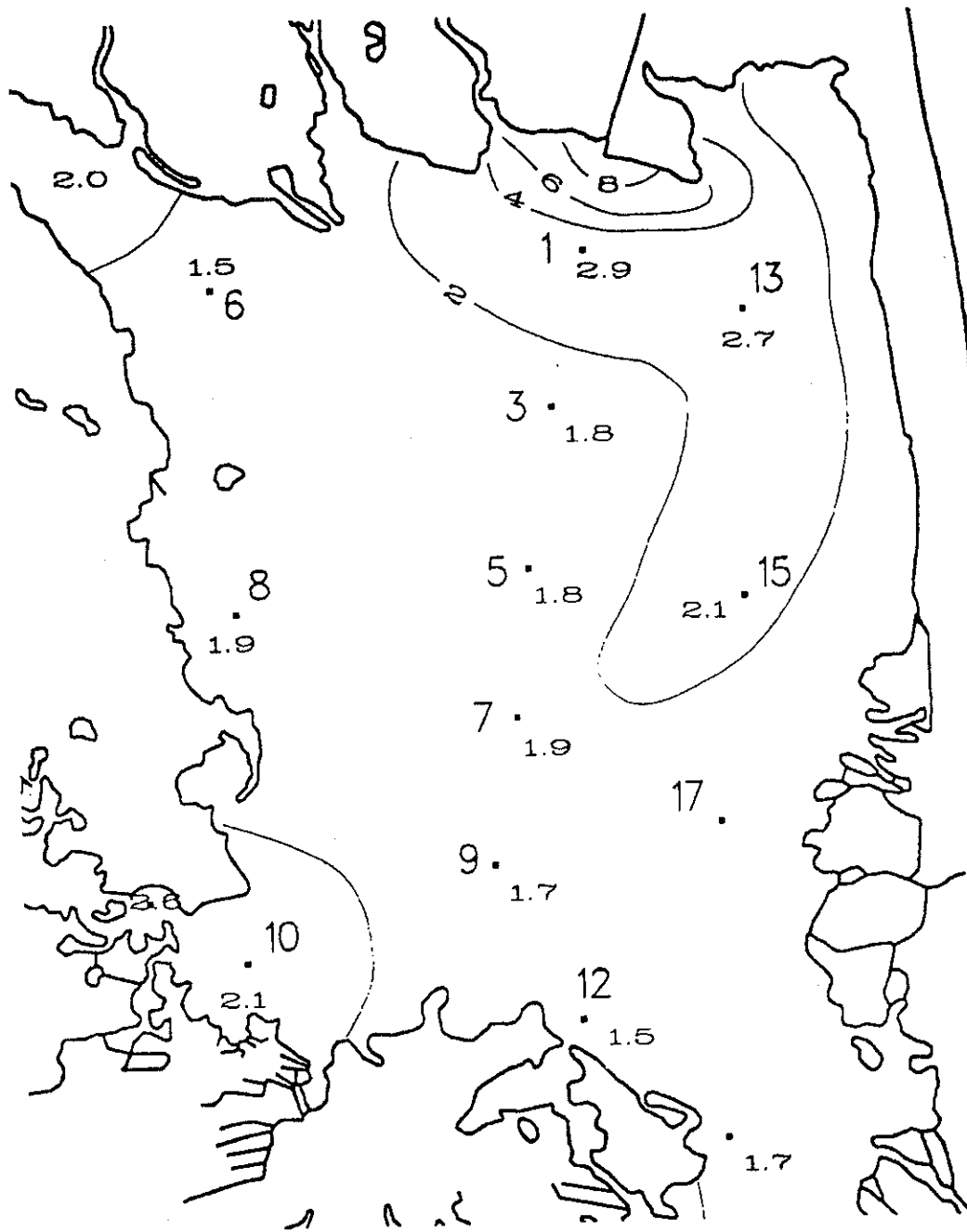


Source of Data: Orris, 1972

Figure 4.4-5
Distribution of
Average Biomass for
Rehoboth Bay
Winter 1969-1970



Scale 1 Inch = 4000 Feet
 2000 0 2000 4000



Source of Data: Orris, 1972

Figure 4.4-6
Distribution of
Annual Mean Nitrogen
Concentrations ug - at/L TN
Rehoboth Bay, 1969-1970



Scale 1 Inch = 4000 Feet
 2000 0 2000 4000

the annual average algal biomass for Rehoboth Bay during the sixteen year interval. Comparisons meant to normalize the sample size and frequency between the studies could not account for the differences. The difference in the sampling gear was thought to account for a great deal of the biomass reduction; however, it is not known if this can account for the full difference. The 1993 study showed the same five dominant species as the 1969-70 study showed and, as far as we can tell, there appears to be no measurable trend.

4.4.3 Submerged Aquatic Vegetation (SAV)

4.4.3.1 Previous Research

To date only three studies of the SAV community of the Inland Bays have been conducted. These studies include:

- Orth and Moore. 1988. *Submerged Aquatic Vegetation in Delaware's Inland Bays (1985-1986)*.
- Delmarva Power and Light, 1976. *Ecological Studies in the Vicinity of the Indian River Power Plant, a 316(a) Demonstration*.
- Cottam and Munro. 1954. *Eelgrass Status and Environmental Relations*.

In addition to these studies, much of the information about SAV in the Inland Bays is anecdotal. Recently, Tracy Bryant (1992) of the University of Delaware's College of Marine Studies Marine Communications Office, conducted interviews with a number of long-time residents of the Inland Bays area. As part of the interview process, individuals were asked among other things to recall when and where they may have seen eelgrass in the bays. To the extent possible this narrative incorporates some of this information although compilation of the interviews notes is not yet complete.

4.4.3.2 Status of the Resource

By way of introduction, two species dominate the SAV community of coastal lagoonal systems like the Delaware Inland Bays. They include eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*). Recognized for their habitat value by numerous researchers (Munro and Perry, 1982; Stevenson and Confer, 1978; Martin and Uhler, 1951 Gutsell, 1930), these species are also noted for their sensitivity to changes in water quality (Forney & Davis, 1981; Kemp et al., 1983; Twilley et al., 1985).

As previously noted, the most recent study of SAV in the Inland Bays was conducted in 1985 and 1986. In that study, Orth and Moore (1988) searched Rehoboth, Indian River, and Little Assawoman Bays for the presence of SAV. The results of that search indicated that neither eelgrass (*Zostera marina*) nor widgeon grass (*Ruppia maritima*) existed in the Inland Bays at that time. In addition, they also concluded that no eelgrass or other SAV species had been observed in these bays since the early 1970's.

In 1990, DNREC attempted to re-introduce eelgrass in locations where SAV was thought to have occurred historically. Preliminary results of plant growth and rhizome production were promising; unfortunately these beds were destroyed before conclusive findings could be made (Anderson, personal communication).

While no active reconnaissance of the Inland Bays for SAV has occurred since 1986, it is generally believed that no significant beds of SAV currently exist in the Indian Bays. In the continental United States, seagrasses are present in every coastal state except Delaware, Georgia and South Carolina (Orth and Nowak, 1990).

4.4.3.3 Historical Record of SAV in the Inland Bays

The following is an account of what is known historically about the presence of SAV in the Inland Bays. It draws on information from the studies previously noted as well as anecdotal accounts.

References to the early occurrence of seagrass in the Inland Bays is limited to anecdotal information available from some of the earliest accounts of the Inland Bays. In *Delaware: a Guide to the First State* (Eckman, 1938 rev. 1955), a description of Millsboro and its commerce describes the town as a center for shipping a variety of products including seafood. As late as 1915, dozens of crabbers brought in thousands of soft-shell crabs from Rehoboth and Indian River Bays to Millsboro for shipment. A discussion of Burton's Island provides an account of how "the shallow flats nearby were famous for the great numbers of softshell crabs found in the grass that used to grow on the bottom but had since disappeared." The account goes on to suggest that because of the loss of vegetation in the 1930's, the area had lost its value in supporting a reliable supply of soft crabs for market.

In the early 1930's a catastrophic eelgrass decline occurred worldwide. On the Atlantic seaboard from New Jersey to Virginia the abnormal dying of eelgrass occurred from about 1928 to 1932 (Lewis, 1932). Moffit and Cottam (1941) reported that along most of the Atlantic Coast of the United States, 99 percent of the standing stocks of eelgrass were destroyed. The disease was termed "wasting disease" and the symptoms of the "wasting disease" were noted as follows:

"[dying plant] showed black areas of considerable size on the leaves, at first near their tips, subsequently nearer the leaf-bases. Eventually each leaf affected dies turns brown, and decays. Death of the leaf, with accompanying disintegration, is progressive from the tip to the base. The rootstock dies and turns black, the death of the rootstock apparently coincides with the loss of the leaves or following it very closely." (Lewis, 1932).

The effect of the "wasting disease" on whatever SAV populations existed in the Inland Bays is not clear. The loss of eelgrass in the inland bays due to the disease is complicated by the chronology of openings and closings of Indian River inlet and the consequent change in the salinity regime during the time of the outbreak. During the eelgrass "wasting" pandemic, it was observed in the Chesapeake Bay that eelgrass growing where the sea-water was greatly diluted with freshwater was still healthy and normal suggesting that salinity played a role in determining

the tolerance threshold of the seagrass to the disease. (Orth and Moore, 1981, Anderson and Macomber, 1980).

During the period of the eelgrass pandemic in the Inland Bays a particularly dry spell had closed the inlet from 1925 to 1930, opening for a brief period in 1930 before closing again in 1931 (see Section 3 for history of Indian River Inlet). Although the extent to which this prolonged closing affected the SAV community is unknown, one might speculate that a significant reduction in the salinity regime could have either stressed the reproductive capacity and maintenance of the population, or conversely, enhanced the tolerance of the existing eelgrass stands to the disease because of reduced salinity. So it is not clear whether the primary reason for the loss of eelgrass early on in the inland bays system was due to alteration of the salinity regime, the wasting disease, or some other unknown cause.

Little factual data exists for the recovery of eelgrass in the Inland Bays following the pandemic and the stabilization of the inlet in 1939. The earliest reported study of SAV population in the Inland Bays was conducted by Cottam and Munro (1954) in the early 1950's. In the wake of the eelgrass pandemic the purpose of this study was to define the distribution and abundance of eelgrass in United States coastal waters including Delaware Bay and the inland bays.

In this study, Cottam and Munro conducted the first full scale reconnaissance of eelgrass status in the coastal U.S. since 1935 (Lewis and Cottam, 1936). In the 1935 study, however, no specific reference was made to Delaware waters. In 1953, Cottam and Munro petitioned state game departments, among others, to provide information on the status of eelgrass in their respective states. Information from Delaware state personnel led Cottam and Munro to conclude that at the time of the survey, "no known stands of eelgrass occur in the state." In addition, they mention that the state was engaged in planting eelgrass in areas of Delaware and Indian River Bay where the plant "formerly" occurred. No indication as to where that might have been is given in their account.

Based on their account, the condition of the SAV community in the Inland Bays was not unlike that occurring in neighboring states. To the south in Chincoteague Bay, where the plant was formerly abundant, the bay was almost totally devoid of plant growth in the early 1950's. It was also reported that the bays appeared to be more turbid and tidal flats were covered with more "ooze" than had been found previously. In New Jersey, specifically Barnegat Bay, excellent recovery had occurred in the twenty year interval from 1930 to 1950 in the northern part of the bay. However, in coastal embayments from Little Egg Harbor south to Cape May, eelgrass was found to be absent (or nearly so) in areas where it was once abundant. It was also noted that sites which were formerly excellent eelgrass beds were now characterized by shifting sands supporting masses of macroalgae, principally *Ulva* and *Enteromorpha*.

More recently, in a review of historic aerial photography, Orth and Moore (1988) observed what appeared to be a fairly dense stand of SAV, possibly eelgrass, in Indian River Bay in the early 1940's. An aerial photograph from 1942 indicated a possible stand of SAV at a location just south of Indian River Inlet. Similarly, in a 1954 photograph, a fairly large bed of what was believed to be SAV was also noted in the vicinity of Pasture Point above White Creek. This latter finding contradicts the earlier observations of Cottam and Munro who reported that no eelgrass was known to exist in the Inland Bays in the early 1950's. Anecdotal information collected by Orth and Moore (1988) and more recently by Bryant (1992) from long-time residents of the area adds confusion to the interpretation of the aerial photographs. Although some residents recall SAV located in the bay around Pasture Point in the 1950's and attest to the value of these beds as habitat, especially for crabs and clams, others recall the area being covered with cabbage grass (*Ulva*). Both may be true, however, since co-occurrence of eelgrass with macroalgae in eelgrass beds has been widely demonstrated (Thorne-Miller et al., 1983; Thayer et al., 1984; and Conover, 1964). In Rhode Island coastal lagoons Thorne-Miller et al., 1983 observed that macroalgae were usually entangled among the rooted seagrass. The algae was dominated by species of chlorophytes, *Ulva* in particular, and rhodophytes which reached maximum biomass of 1,200 and 853 g dry wt/m², respectively.

Several reasons exist for the possible contradiction and include:

- 1) Difficulty in interpreting historical aerial photography i.e., distinguishing between eelgrass and macroalgae.

- Guidelines for remote sensing of SAV have been established only recently for photography to ensure optimal conditions for accurate photo interpretation of SAV and include such factors as sun angle, SAV growth stage, turbidity, etc. (Orth et al., 1990). The lack of these elements as well as ground truthing, for historical aerial photographs available to Orth and Moore made interpretation difficult, at best (Orth and Moore, 1988; 1986, Orth, personal communication).

- 2) Reliability of information collected by Cottam and Munro (1954).

- As previously noted, their study enlisted the aid of individual state personnel in the form of solicited responses to questionnaires. The extent to which the state was aware of the full condition of SAV in the Inland Bays or the thoroughness of its response at the time is unknown.

- 3) Revegetation efforts.

- In their report, Cottam and Munro describe state efforts to transplant eelgrass in the Inland Bays. Orth and Moore (1988) suggest the possibility that eelgrass observed in the 1950's was a result of that effort.

The possibility also exists that some of these areas, especially those proximate to the inlet, may have been covered during the dredging of Indian River Inlet and the channel in 1951 (Lanan and Dalrymple, 1977). These authors describe the dredge spoils as being placed on the flood tide shoals adding to the formation of several of the islands, e.g. Gull Island. In addition, interviews with several long-term residents have also suggested that the "storm of '62" had resulted in the loss of eelgrass that had existed between Gull Island and the south shore of Indian River Inlet (Bryant, 1992).

Nevertheless, there does appear to be some indication that there was some recovery of the SAV community in the Inland Bays between the 1950's and 1970's. Although the extent of the recovery is not known, SAV was noted in several areas of the Inland Bays during this period. While conducting a survey of the benthic macroalgae of the Rehoboth Bay in 1972, Orris observed sparse beds of widgeon grass (*Ruppia maritima*) in the mouths of tidal creeks along the eastern shore of Rehoboth Bay, especially in the vicinity of Big Bacon Island in Rehoboth Marsh.

In a study of the shore zone fishes of Rehoboth and Indian River Bays between 1968 and 1970, Derickson and Price (1973) reported the presence of widgeon grass, *Ruppia sp.* in Rehoboth Bay in Rehoboth Marsh and in the vicinity of Nats Cove on Long Neck. No other SAV was reported at any of the other sixteen stations sampled, including Gull Island where only *Enteromorpha sp.* was noted. In addition and by way of anecdote, Biggs and Kraft observed the presence of scattered SAV beds along the same marshes in lower Rehoboth Bay also in the late 1960's (Orth and Moore, 1988).

In 1974 and 1975, Ecological Analysts, Inc. conducted field studies for Delmarva Power and Light in Indian River Bay in support of a 316(a) demonstration for its Indian River Power Plant. As part of those studies, the potential impact of heated effluent to possible SAV communities was evaluated. Although there appeared to be "ample suitable substrate for colonization of SAV," field observations during all seasons failed to demonstrate the occurrence of SAV in the upper brackish portions of the Indian River estuary. However, "beds of eelgrass", *Zostera marina*, were observed near the inlet and represented the only SAV observed in those studies (DP&L, 1976).

Between 1971 and 1974, Orth et al., (1990) observed a rapid decline of SAV in the Chesapeake Bay that was more severe than that of the 1930's pandemic. Since the 1970's die off, revegetation in the Chesapeake has occurred only in the less saline waters of the mid-bay and at the mouths of tributaries. No revegetation has occurred in the more saline open areas of the bay. The effect of this die-off on the Inland Bays of Delaware is not known although we do know that an eelgrass bed was intact in the vicinity of the inlet in 1975 (DP&L, 1976).

Consequently, the decline in the Chesapeake may have been a local phenomenon. Nevertheless, and as previously mentioned, a search of the Inland Bays in 1985 and 1986 failed to locate the SAV beds south of the inlet or in any other area of the bays. Assuming that SAV, particularly eelgrass was present, although in a somewhat limited extent from 1950 through 1975, its complete disappearance from the bays is puzzling.

Numerous reasons have been suggested for periodic declines in eelgrass communities. Prior to the 1930's and since the period of recovery, eelgrass and other SAV have exhibited oscillations in abundance, possibly in response to environmental changes both natural and man-made. Periodic fluctuations in eelgrass populations have been recorded since the mid-19th century. To put the general history of eelgrass decline on the Atlantic Coast in perspective so that it may aid in the interpretation of the eelgrass condition of the Delaware inland bays, the following chronology of eelgrass status along the Atlantic coast is presented (Cottam & Munro, 1954).

- 1720-1880 - seed records indicate fairly stable abundance of eelgrass in the Chesapeake Bay.
- 1854; 1889; 1894; 1908; 1913; 1915; 1917; and 1920-1922 - dates of former disappearance of eelgrass (prior to 1931) in coastal United States.
- 1931-1932 - catastrophic disappearance-eelgrass wasting pandemic - note that the disappearance of eelgrass from New Jersey waters was thought to have started as early as 1928 (Lewis & Cottam, 1936).
- 1933-1940 - Rather slight and temporary local recovery indicated along the Atlantic coast.
- 1940-1944 - Period characterized by fluctuations involving local recovery often followed by abrupt partial die-out.
- 1944-1950 - marked improvement generally; in some areas first noticeable recovery since 1931. SAV still absent in many localities.
- 1951-1953 - greatest improvement noted.
- 1954-1970 - recolonization of eelgrass in Chesapeake, primarily in mesohaline areas (Thayer et al. 1984).

- 1971-1974 - Rapid decline of *Zostera* and *Ruppia* in lower segment of Chesapeake Bay (Orth et al., 1990).
- 1974-Present - general recovery of previous eelgrass beds in Chesapeake continued absence in high salinity areas of the bay.

Numerous reasons have been offered for the periodic decline of SAV both globally and locally. Because of the cyclic nature of SAV die-offs early observers (Setchell, 1929, Lewis, 1932,) suggested that SAV decline may be attributed to natural population cycles or weather events such as droughts. More recently, Rasmussen (1973; 1977) presented evidence that the decline of eelgrass in Europe (and possible elsewhere) was associated with a period of warm summers and mild winters. This theory is supported in part by the observation that the eelgrass life cycle is largely a function of water temperature and salinity. Reduced salinities have been shown to greatly enhance seed germination and that germination is lowest at high salinities. Dry years with low annual freshwater discharge would tend, therefore, to inhibit germination (Churchill et al, 1978; Keddy and Patriquin, 1978; and Phillips et al 1983).

In addition, eelgrass has been shown to be susceptible to heat stress which effects vegetative reproduction. Fonseca et al, (1984) observed that vegetative reproduction is important in maintaining eelgrass meadows. During summer, when growth slows dramatically, vegetative shoot mortality may be substantial. These researchers have shown that in shallow eelgrass meadows i.e., <1-2 m, mortalities of transplants, as well as natural plant stocks coincide with the onset of excessive warm summer temperatures and periodic low tides. Thayer et al., (1975) suggested that the combined effects of temperature and dessication in shallow waters may be largely responsible for die-off but their individual effects are difficult to separate.

More recently, a consensus of scientists evaluating SAV loss in the Chesapeake Bay suggests that the recent loss of SAV in the bay and possibly in other temperate estuaries of the Atlantic Coast is probably due primarily to an increase in light attenuation in the water column and biofouling of plant surfaces with epiphytes caused by excessive loadings of nutrients and sediments (Hurley, 1991).

4.4.3.4 Comparison of Habitat Requirements for SAV with Sediment Water Quality of the Inland Bays

As previously noted, numerous reasons have been offered for both the initial decline of SAV in estuaries and its failure to recolonize. Initial loss may be due to regional effects such as disease or climatic change, or more localized effects including winter kill, high temperature, high salinity, destruction by cownose rays or waterfowl, turbidity and epiphytism, among others.

The following narrative discusses some of the physical and chemical requirements of SAV and how those requirements relate to known conditions in the Inland Bays. Because historical and anecdotal information has suggested the presence of SAV in the lower reaches of Indian River estuary and along the fringe marshes of eastern and southern Rehoboth Bay (e.g. Rehoboth Marsh), habitat requirements are compared with water quality data for the polyhaline (18% - 35‰) segment of Indian River estuary and the southern segment of Rehoboth Bay.

Habitat requirements for key parameters were taken largely from "Habitat Requirements for Chesapeake Bay Living Resources" (Chesapeake Bay Program (CBP), 1991). Additional data were obtained from "Chesapeake Bay: A Framework for Action" (EPA, 1983). The habitat requirements presented in these documents were based on numerous laboratory, field and mesocosm studies from the four segments of the Chesapeake Bay, as well as reviews of historical and recent literature.

Figures 4.4-7 through 4.4-13 present temporal plots of long-term conditions of key habitat parameters from 1970 to 1990 where available. These plots are benchmarked with the individual habitat requirement so that, where data allow, a 20-year comparison can be made and the extent to which conditions are improving or worsening relative to the habitat requirement can be evaluated.

The following discusses the findings for each requirement:

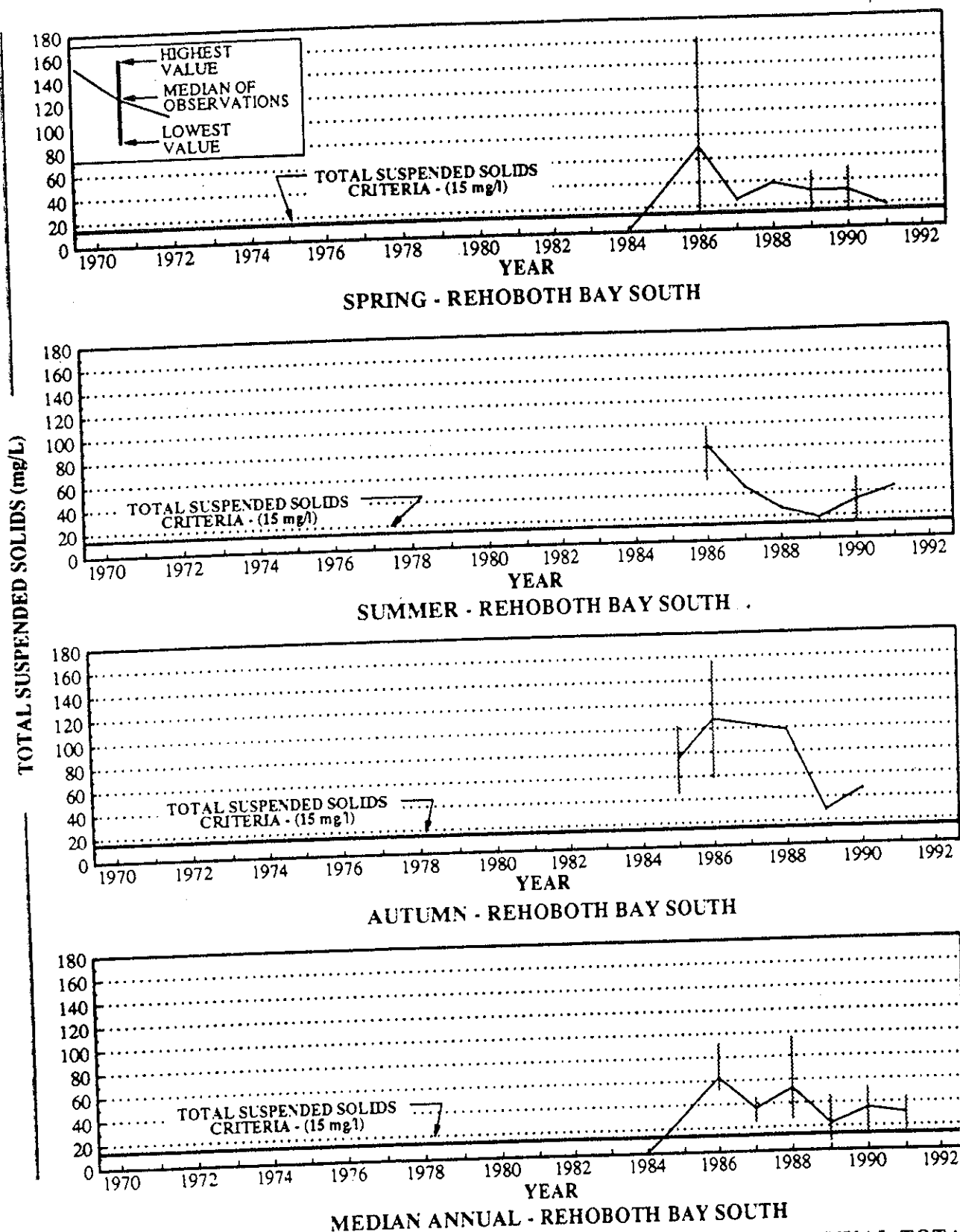


FIGURE 4.4-7 COMPARISON OF MEDIAN SEASONAL AND MEDIAN ANNUAL TOTAL SUSPENDED SOLIDS RECORDED IN REHOBOTH BAY SOUTH SINCE 1970 WITH TOTAL SUSPENDED SOLIDS CRITERIA FOR SAV

RES DALLR-G/DM-1092

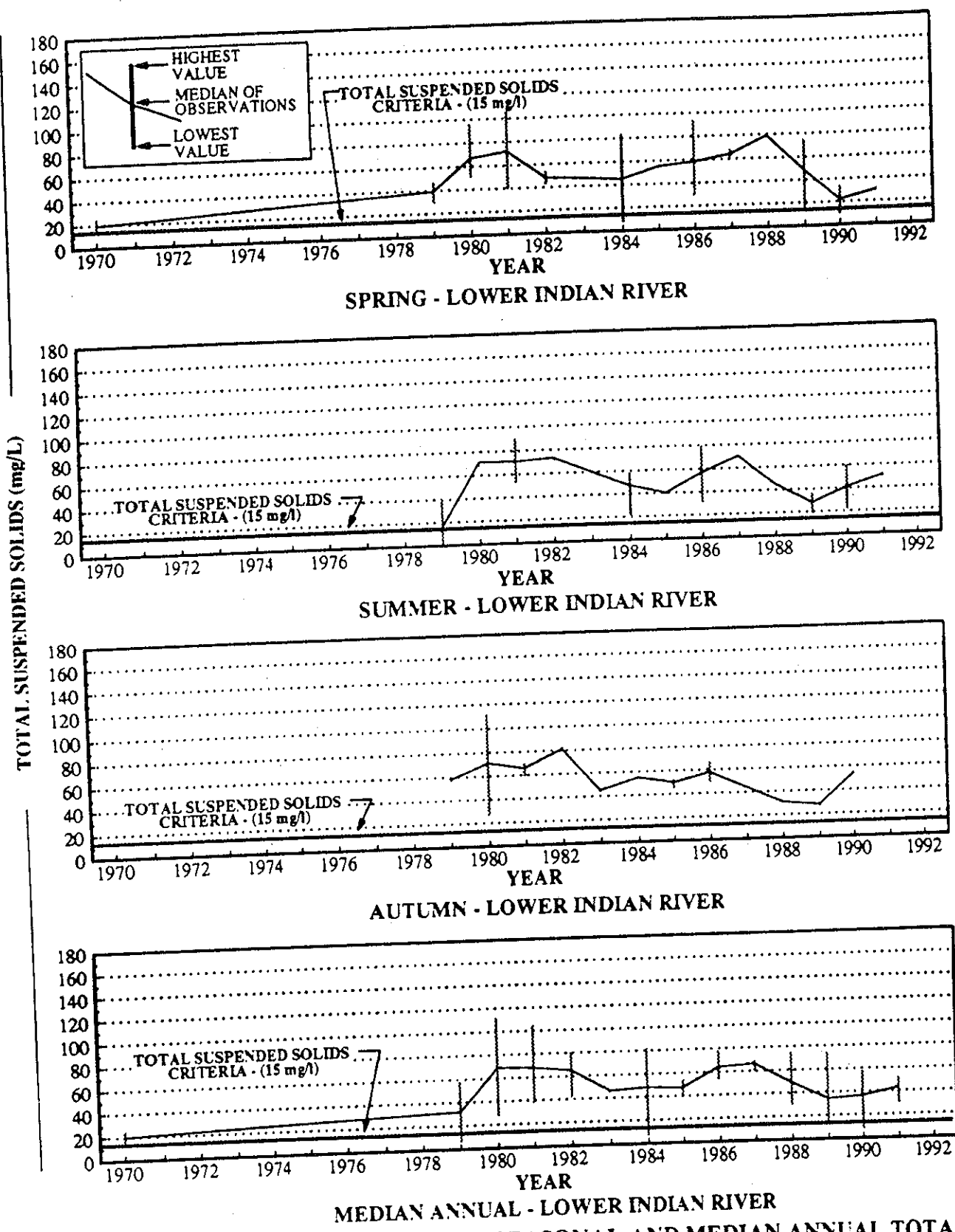


FIGURE 4.4-8 COMPARISON OF MEDIAN SEASONAL AND MEDIAN ANNUAL TOTAL SUSPENDED SOLIDS RECORDED IN LOWER INDIAN RIVER SINCE 1970 WITH TOTAL SUSPENDED SOLIDS CRITERIA FOR SAV

RES DALLR-G/DM-10/92

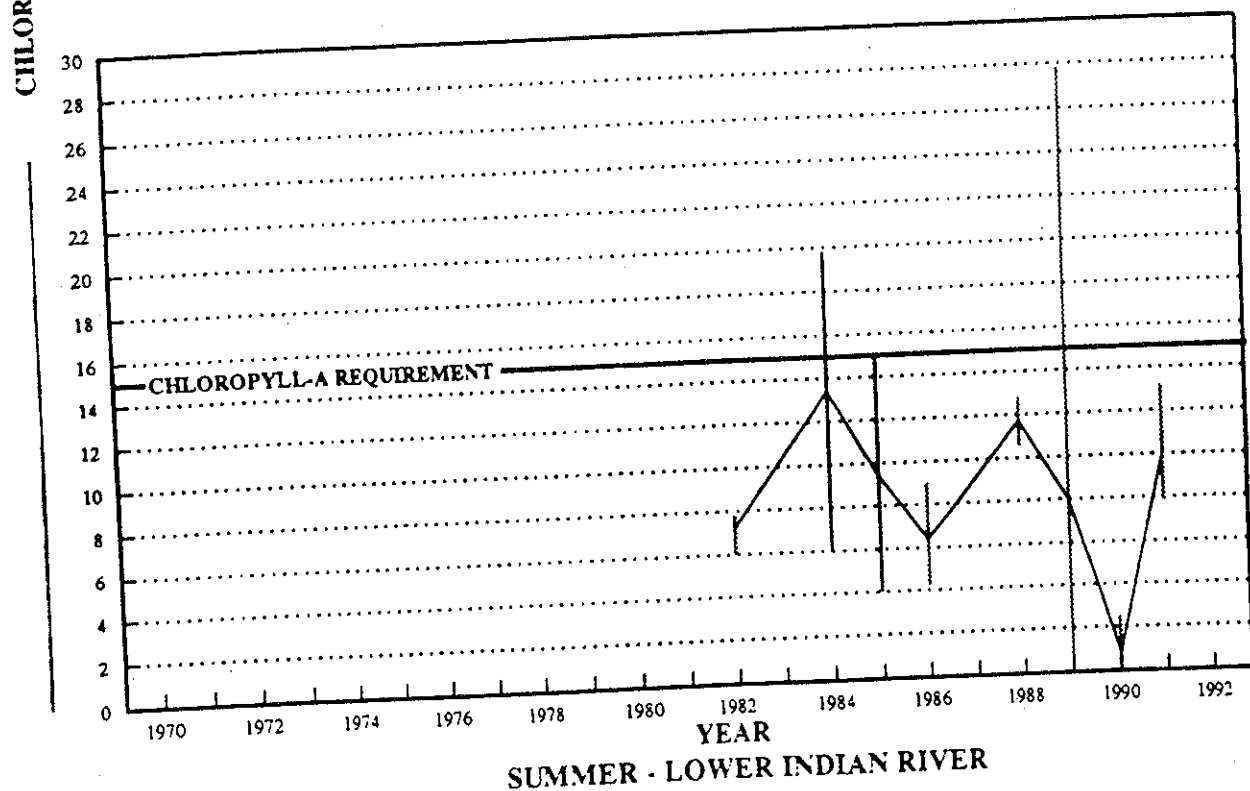
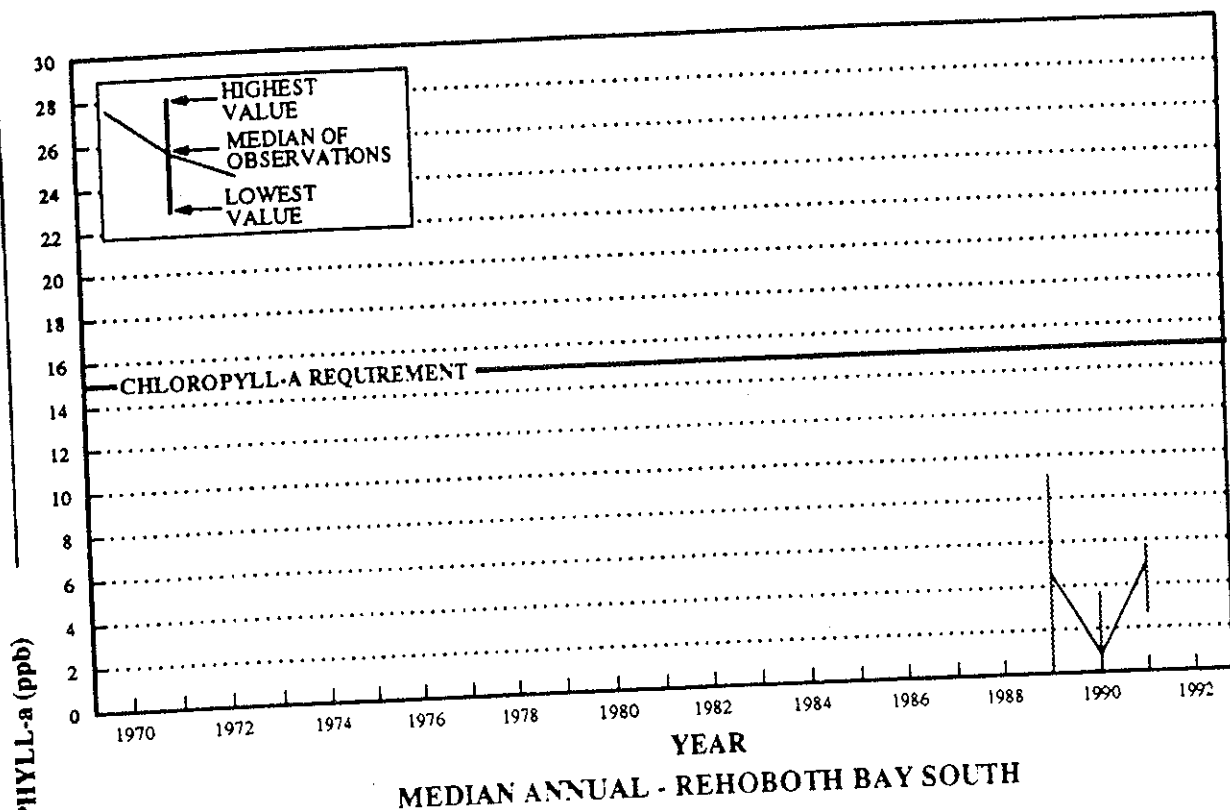


FIGURE 4.4-9 COMPARISON OF MEDIAN ANNUAL CHLOROPHYLL-A RECORDED IN REHOBOTH BAY SOUTH AND LOWER INDIAN RIVER SINCE 1970

CHLORALL-G/OM-10/92

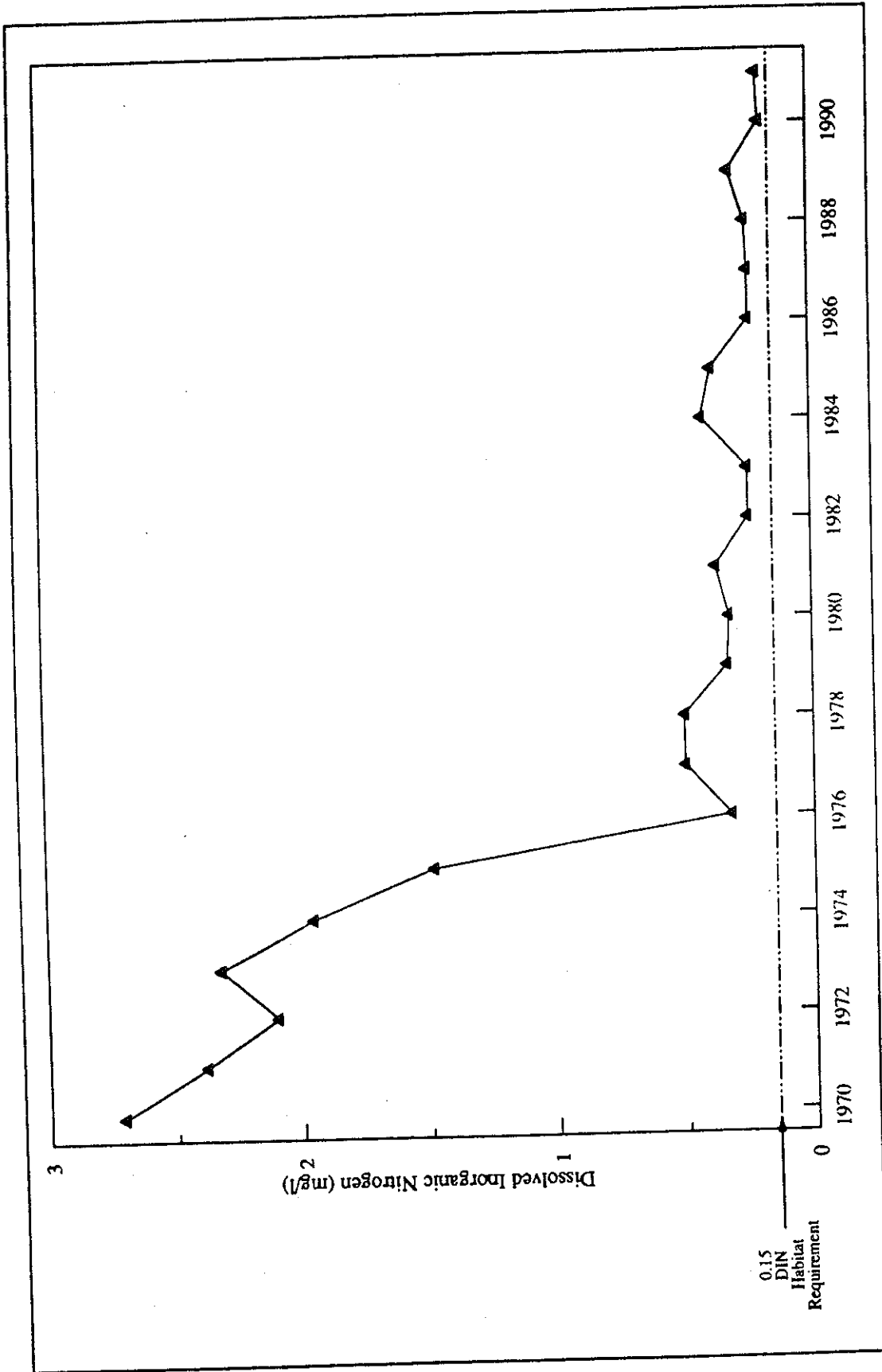


Figure 4.4-10
Inland Bays Annual Water Quality Analysis
Comparison of Annual Median Dissolved Inorganic Nitrogen (DIN) Concentrations in
South Rehoboth Bay with DIN Requirement for SAV

Flab09-D18

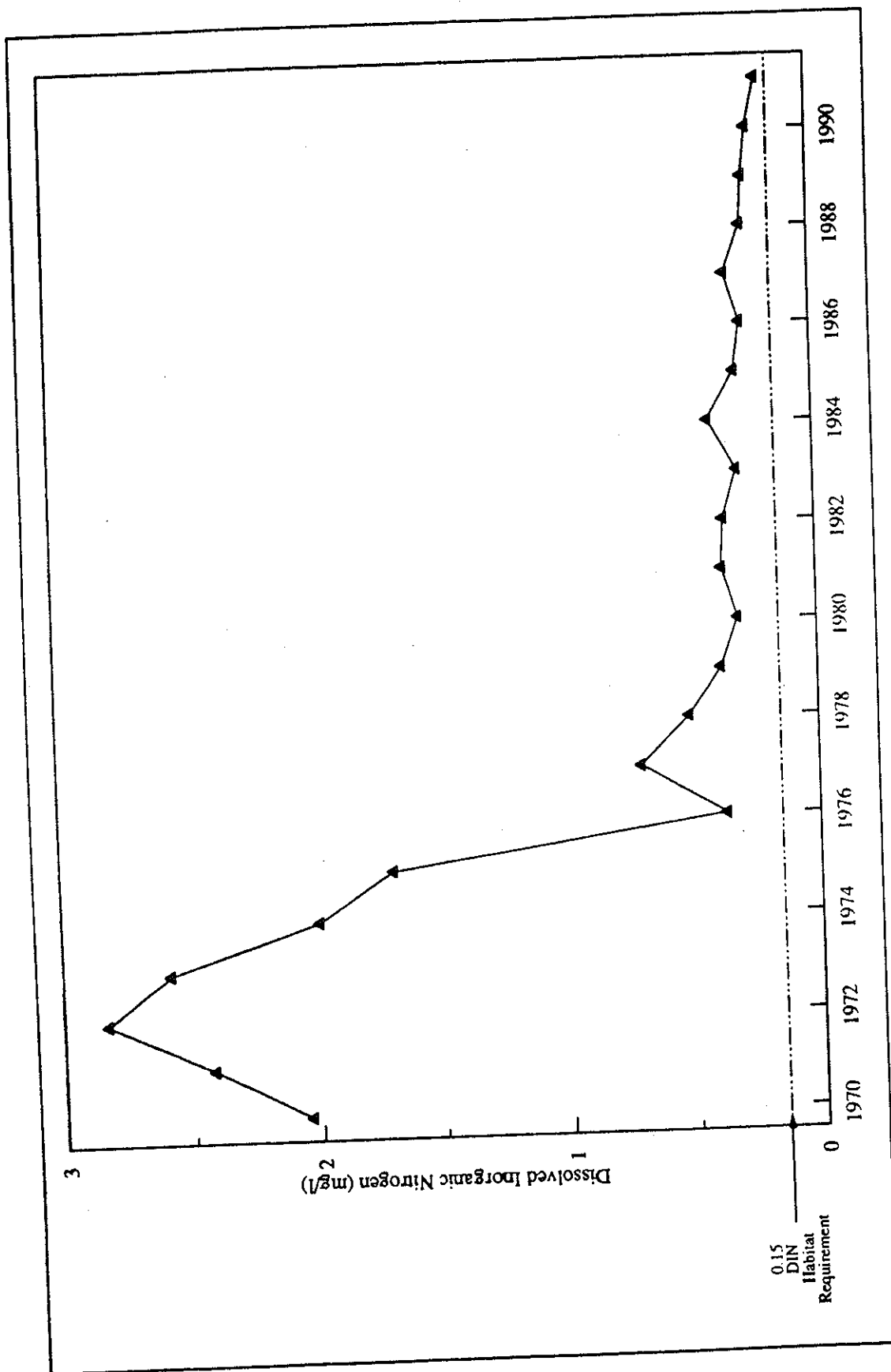


Figure 4.4-11
Inland Bays Annual Water Quality Analysis
Comparison of Annual Median Dissolved Inorganic Nitrogen (DIN) in Lower
Indian River Bay with DIN Requirement for SAV

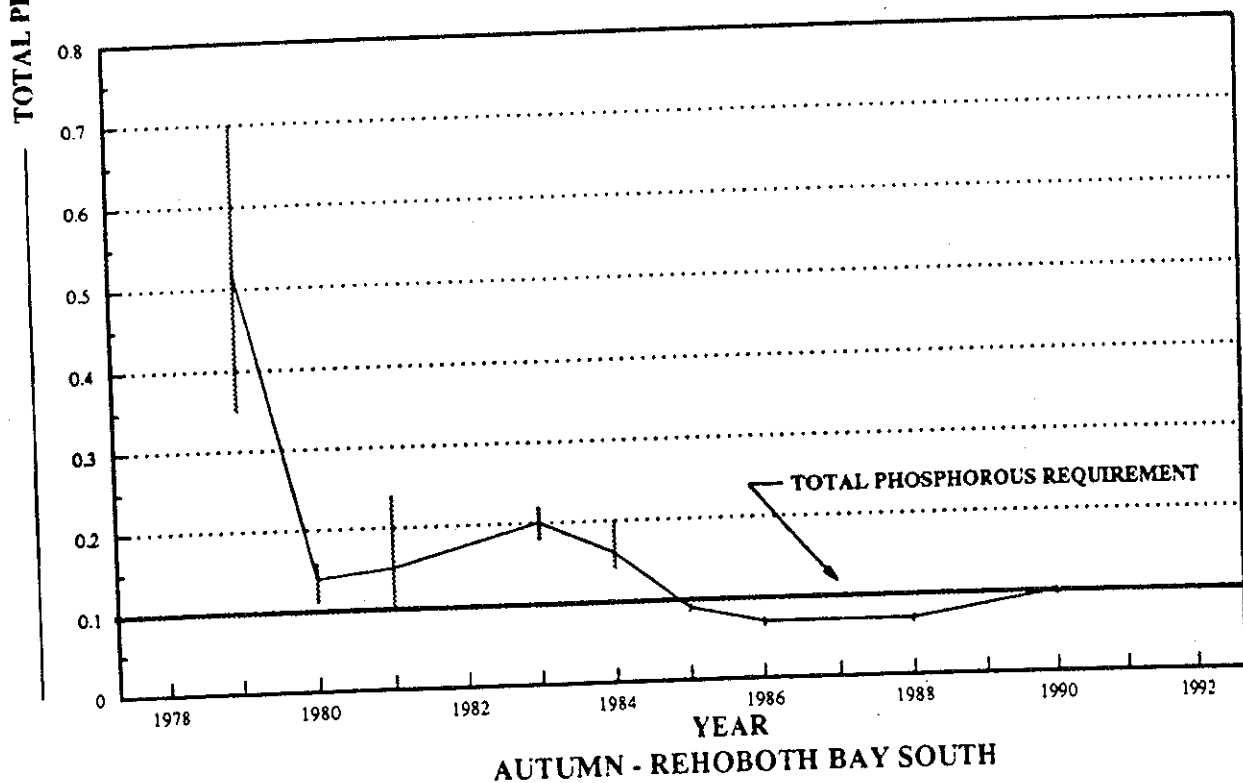
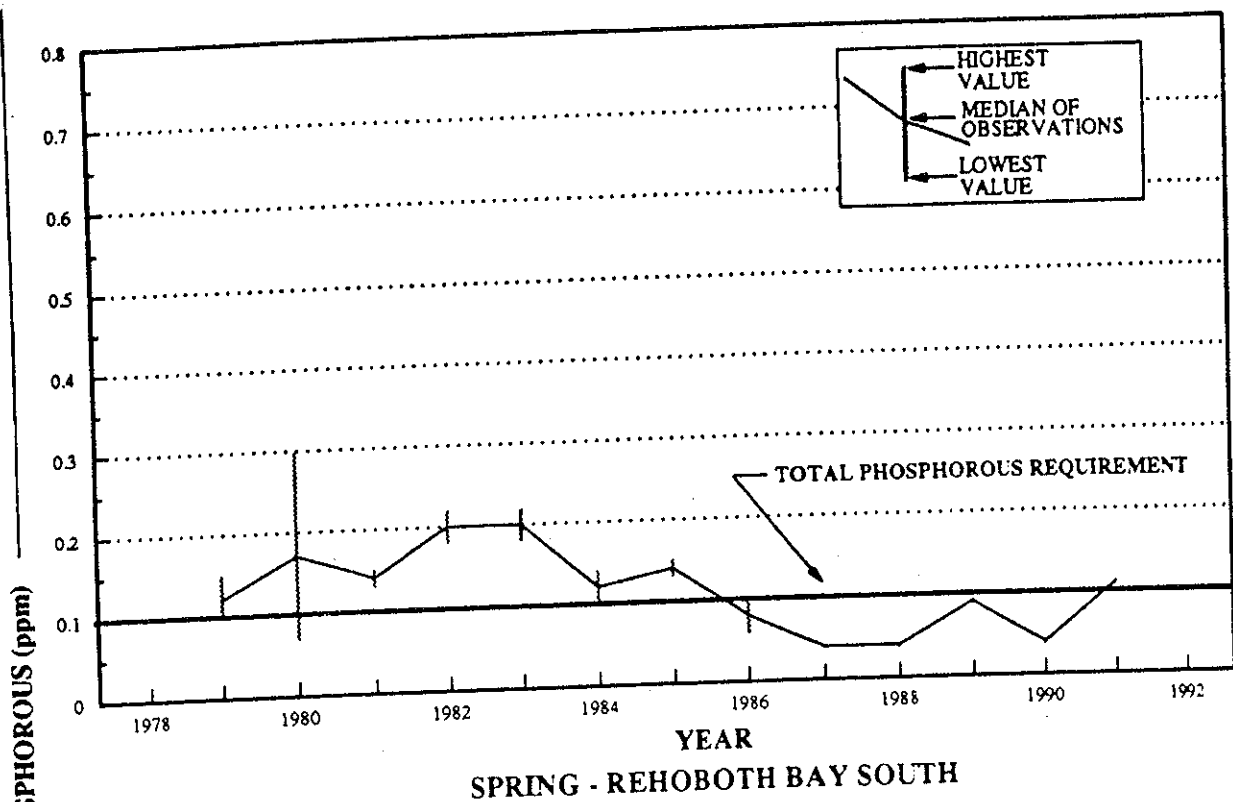


FIGURE 4.4-12 COMPARISON OF ANNUAL TOTAL PHOSPHOROUS RECORDED IN REHOBOTH BAY SOUTH SINCE 1978 WITH TOTAL PHOSPHOROUS REQUIREMENT FOR SAV

PHOSALLR-G/OM-11/92

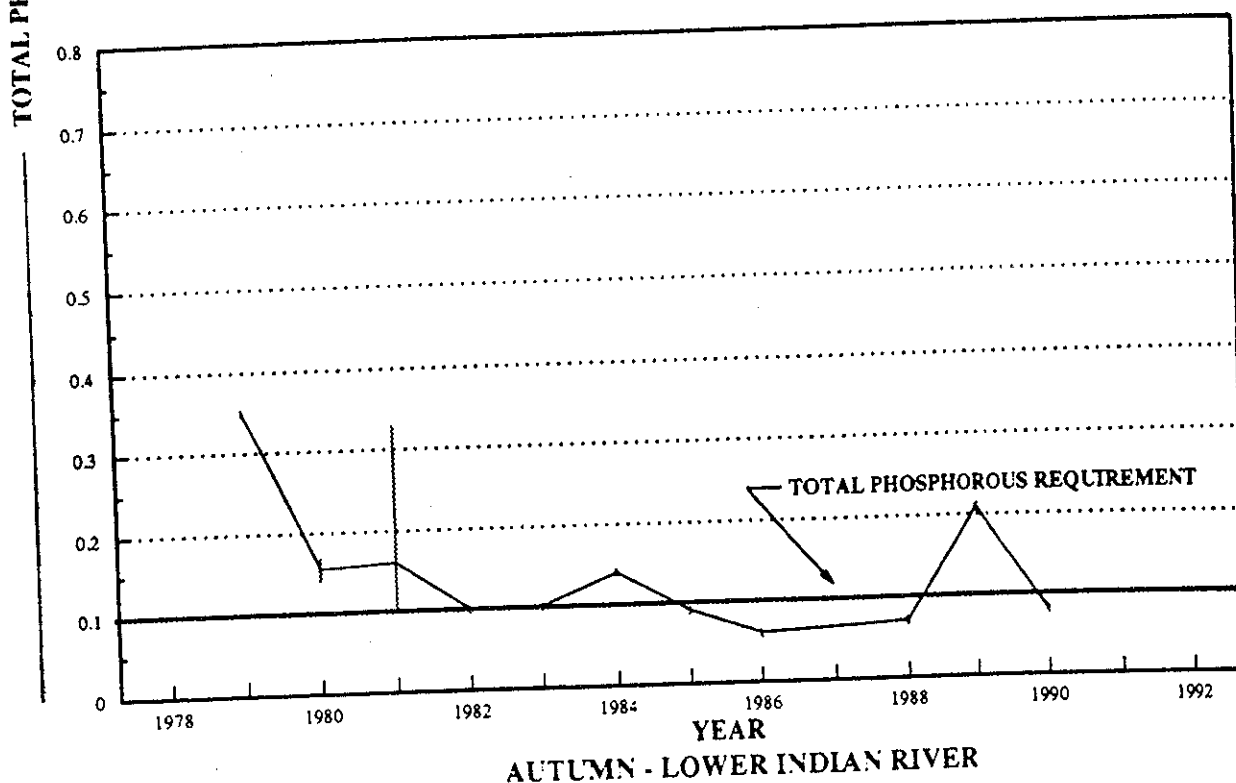
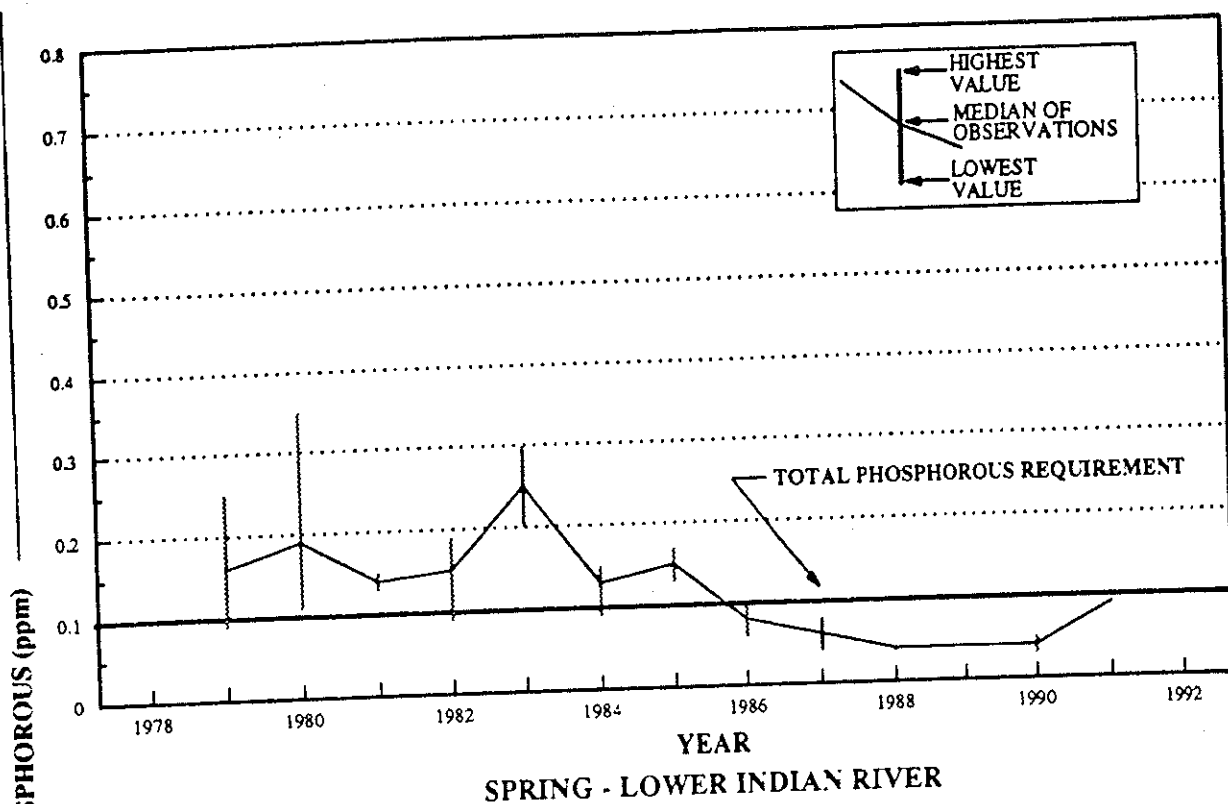


FIGURE 4.4-13 COMPARISON OF ANNUAL TOTAL PHOSPHOROUS RECORDED IN LOWER INDIAN RIVER SINCE 1978 WITH TOTAL PHOSPHOROUS REQUIREMENT FOR SAV

PHOSALL-G/DM-11/92

Substrate

In the mid-Atlantic region, eelgrass has been found associated primarily with sandy to sandy-silt sediments at depths ranging from one to three meters in areas generally protected from wave action (Hurley, 1991). In Barnegat Bay, eelgrass is particularly prominent along the perimeter of the estuary at water depths less than one meter (Loveland et al., 1984). The largest beds of eelgrass are found along the eastern side of the bay where, similar to Rehoboth Bay, the substrate is predominantly sand. Similar findings have been observed in Chincoteague Bay, where eelgrass is found on the western margins of Assateague Island (Orth, personal communication).

Based on a comparison of substrate type found in these bays with that in the inland bays, particularly Rehoboth Bay, there appears to be ample suitable substrate habitat for eelgrass to occur in the inland bays.

Widgeon grass has been reported to occur in the polyhaline segment of the Chesapeake Bay on sandy substrate as well as on softer muds. A preferred habitat occurs in the mosquito ditches of the lower Chesapeake Bay where rich organic muds have accumulated, hence the name "ditch grass" (Stevenson et al., 1978). Orris (1972), and Derickson and Price (1973), and Biggs and Kraft, observed sparse beds of widgeon grass in similar locations in tidal ditches of Rehoboth Marsh in the late 1960's and early 1970's. As with eelgrass, there appears to be ample substrate habitat available in the Inland Bays to support widgeon grass.

Light

Light or reduction in light has been offered as the most important parameter controlling the distribution of SAV in temperate estuaries (Hurley, 1991; Dennison, 1987; Kemp et al., 1983). Light attenuation, or reduction in light intensity in the water column, is largely the result of absorption of light by water and biotic and abiotic particulate concentrations in the water column. Measures of light intensity can be directly recorded as light attenuation coefficients (k_D) and

secchi depth. Indirectly, reductions in light can be inferred from suspended solid concentrations and turbidity.

Light Attenuation

In polyhaline habitats for the Chesapeake Bay, the threshold of light attenuation (k_D) was estimated for both eelgrass and widgeon grass to be $< 1.5/\text{m}$. This value represents a seasonal median at known vegetated sites in the lower segment of the Chesapeake Bay.

To estimate k_D from secchi depth readings, the following conversion factor was used based on simultaneous measurements of both secchi depth and k_D (Hurley, 1991).

$$k_D = 1.45/\text{secchi depth}$$

Using this relationship, median spring, summer and fall light attenuation coefficients were estimated from secchi data collected in Rehoboth and Indian River Bays by Loucuture and Sellner (1988) in 1985-1986. Secchi depth data for Rehoboth Bay was taken from a mid-bay station. Seasonal median secchi depths for middle Rehoboth Bay were 1.2 m for spring, 0.5 m for summer, and 1.0 m for autumn. Consequently, the estimated k_D s are 1.2 m for spring, 2.9 m for summer, and 1.4 m for autumn.

Secchi depth data for lower Indian River was taken from a station below Burton's Island in Indian River Bay. Seasonal median secchi depths for lower Indian River Bay were 1.4 m for spring, 1.2 m for summer, and 1.2 m for autumn. The estimated k_D s are 1.0 m for spring, and 1.2 m for summer and autumn.

Based on these limited data, light attenuation in lowest Indian River Bay does not appear to be a limiting factor in SAV growth. In Rehoboth Bay, light attenuation in summer waters significantly exceeds the $1.5/\text{m}$ criterion. It should be noted, however, that unlike any other SAV, eelgrass generally exhibits senescence in summer. Critical growth occurs in spring and

fall, at which time the light attenuation criterion was not exceeded (Stevenson & Confer, 1978; Thayer, et.al., 1984).

Secchi depth

No secchi depth requirements were noted for the polyhaline segment of the Chesapeake Bay. However, secchi depth measurements made in the tidal fresh segment of the Chesapeake found that a seasonal median secchi depth of 1.0 m was associated with the presence of SAV at most sites. It was also shown that in protected areas, SAV could tolerate a slightly reduced light penetration with a seasonal median secchi depth of 0.8 m. This value has been adopted for the polyhaline segments of the Chesapeake and is used here for the Inland Bays.

As noted previously, the median secchi depth measured in 1986 in the center of Rehoboth Bay during periods of critical growth was 1.2 m in spring, and 1.0 m in autumn. In Indian River Bay, the median secchi depths for spring, and fall were 1.4 m, and 1.2 m, respectively. Based on a comparison of the threshold secchi depth of 0.8 m, with the limited data available, light attenuation during the critical growth period of SAV would not appear to limit SAV production.

Total Suspended Solids (TSS)

The seasonal TSS habitat requirement for polyhaline segments in the Chesapeake is < 15 mg/l. TSS concentrations measured at locations where SAV was no longer present in the Chesapeake significantly exceeded 15 mg/l (Hurley, 1991).

Seasonal data for the Inland Bays were available from 1984 through the present. Figure 4.4-7 presents the seasonal distribution of TSS data recorded in the lower segment of Rehoboth Bay since 1984. Based on these data, the median TSS concentration recorded during the spring for the last five years, 1987 to 1991, in the southern segment of Rehoboth Bay is about 29 mg/l, or about twice the suspended solid requirement for both eelgrass and widgeon grass. For the period of record for the lower segment of Rehoboth Bay (1984-1991), only 1984 (2.0 mg/l - one data

point only) met the TSS requirement in spring. A similar analysis conducted for autumn showed that the median TSS concentration in lower Rehoboth Bay for the last five years of record (1985-1990), which represents the complete period of record, was 72 mg/l. Over the period of record for autumn, no year ever met the TSS requirement.

Figure 4.4-8 presents the seasonal distribution of TSS recorded in the lower segment of Indian River estuary since 1979. The median TSS concentration measured in the lower segment of Indian River in spring for the last five years of recorded data (1987-1991) was 47 mg/l TSS. For the effective period of record, 1979 through 1991, TSS concentrations significantly exceeded the habitat requirement of 15 mg/l TSS (Figure 4.4-8). A similar comparison conducted for Indian River in autumn demonstrated an autumn median TSS concentration from 1985 through 1990 of about 44 mg/l. As with all other findings, none of the years of record met the proposed TSS requirement.

On the basis of available data and the proposed habitat requirement, high levels of total suspended solids during critical periods of vegetative and non-vegetative reproduction and growth for eelgrass may limit the recolonization and successful propagation of *Zostera* in areas historically believed to have contained SAV.

Chlorophyll *a*

The habitat requirement for chlorophyll *a* associated with successful SAV growth in the polyhaline region of the Chesapeake Bay and assumed for Rehoboth Bay and the lower segment of Indian River estuary is 15 µg/l. This threshold is based on seasonal median levels of chlorophyll *a* at vegetated sites in the Chesapeake Bay from 1987 to 1989 (Hurley, 1991).

Data for chlorophyll *a* is severely limited in the south segment of Rehoboth Bay, where only seven measurements since 1989 have been recorded (Figure 4.4-9). Insufficient season-specific data are available from which to quantify seasonal medial levels. A median chlorophyll *a* level

of 3.2 µg/l is well below the 15 µg/l limit. In addition, no single measurement for the period of record has exceeded this requirement.

Figure 4.4-9 also provides a comparison of median levels of chlorophyll *a* measured in the lower Indian River Bay from 1982 to 1991, as with Rehoboth Bay. Insufficient season-specific data are available from which to quantify seasonal median levels. Comparison of the 15 µg/l limit with yearly data collected from 1982 indicate that the median from no single year exceeded the threshold requirement. However, a single chlorophyll *a* concentration (28 µg/l) measured in spring 1989 was about twice the threshold for that season.

Based on the data available, chlorophyll *a* levels would not appear to limit successful SAV growth in either southern Rehoboth Bay or lower Indian River.

Dissolved Inorganic Nitrogen

The dissolved inorganic nitrogen requirement for eelgrass and widgeongrass in polyhaline waters of the Chesapeake Bay is <0.15 mg/l and the DIN for water quality in the Inland Bays is 0.15 mg/l. This threshold value is based on combined spring/fall growing season median observed at vegetated sites in the York River between 1984 and 1989. The DIN threshold was compared with combined annual median concentrations $\text{NO}_3 + \text{NO}_2$ and NH_4 recorded in lower Rehoboth Bay (Figure 4.4-10) and lower Indian River estuary (Figure 4.4-11). Although the DIN levels of waters in each of these areas have improved markedly since 1972, dissolved inorganic nitrogen concentrations in both waterbodies nevertheless exceeds the habitat requirement of 0.15 mg/l and, therefore, may inhibit the successful growth of eelgrass and widgeongrass in lower Rehoboth Bay and lower Indian River estuary.

Total Phosphorus

The mean total phosphorus (TP) requirement for SAV in polyhaline waters is <0.10 mg/l and the dissolved inorganic phosphorous for water quality in the Inland Bays is 0.01 mg/l. This threshold

is based on data collected from polyhaline segments of the Chesapeake Bay in the vicinity of SAV beds. The TP threshold was compared with seasonal averages of TP concentrations in the lower segments of Rehoboth and Indian River Bays.

Seasonal data for the Inland Bays were available from 1979 to the present. Figure 4.4-12 presents the spring distribution of TP concentrations recorded in the lower segment of Rehoboth Bay since 1979. Based on these data, the mean TP concentration recorded in the lower segment of Rehoboth Bay for the last five years of record (1986-1991) is 0.06 mg/l. With the exception of 1991 when a TP of 0.11 mg/l was recorded, all spring TP levels have been at or below the 0.10 criterion since 1986 in lower Rehoboth Bay.

A similar analysis conducted for autumn showed that the mean TP concentration in lower Rehoboth Bay for the last five years of record (1984-1990) was 0.10 mg/l. Since 1985, all concentrations of TP in lower Rehoboth Bay in autumn have been at or below the TP requirement for SAV.

Figure 4.4-13 presents the spring distribution of TP recorded in the lower segment of Indian River for the period of record. Based on these data, the mean TP concentration recorded during spring for the last five years is 0.06 mg/l, well below the criterion of 0.10 mg/l.

A similar analysis conducted for autumn showed that the average TP concentration in Indian River Bay is 0.10 mg/l. Note, however, that with the exception of 1989 when an autumn TP of 0.21 mg/l was recorded, the TP level for the last five years have been below the criterion (Figure 4.4-13).

On the basis of available data in comparison with the proposed habitat requirement, recent levels of TP in the lower Rehoboth Bay and Indian River Bay do not appear significant in limiting SAV colonization in those areas historically believed to have contained SAV.

APPENDIX 4.4-A
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C



**APPENDIX 4.4-A
MACROFLORA
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APPENDIX 4.4-B
LIST OF ALGAL COLLECTED IN
REHOBOTH BAY, DELAWARE BY
ORRIS IN 1969-1970

APPENDIX 4.4-B

Table 1

List of Algae Collected in Rehoboth Bay, Delaware
(June, 1969 to July 1970)

CHLOROPHYTA

Ulothrix implexa
Entocladia viridis
Enteromorpha spp.
Enteromorpha clathrata
Enteromorpha compressa
Enteromorpha erecta
Enteromorpha intestinalis
Enteromorpha linza
Enteromorpha plumosa
Enteromorpha prolifera
Ulva lactuca
Chaetomorpha ilinum
Cladophora expansa
Cladophora flavescens
Cladophora gracilis
Spongomorpha sp.
Bryopsis plumosa

PHAEOPHYTA

Ectocarpus spp.
Ectocarpus confervoides
Ectocarpus siliculosus
Giffordia spp.
Giffordia mitchellae
Pylaiella littoralis
Sorocarpus micromorus
Ralfesia verrucosa
Leathesia difformis
Asperococcus echinatus
Desmotrichum undulatum
Petalonia fascia
Punctaria latifolia
Punctaria plantaginea

RHODOPHYTA

Bangia ciliaris
Goniotrichum alsidii
Porphyra leucosticta
Porphyra umbilicalis
Acrochaetium spp.
Acrochaetium intermedium
Agardhiella tenera
Gracilaria foliifera
Gracilaria verrucosa
Champia parvula
Lomentaria baileyana
Antithamnion cruciatum
Callithamnion spp.
Callithamnion byssoides
Ceramium spp.
Ceramium diaphanum
Ceramium fastigiatum
Ceramium rubriforme
Ceramium rubrum
Ceramium strictum
Grinnellia americana
Chondria spp.
Chondria baileyana
Polysiphonia spp.
Polysiphonia denudata
Polysiphonia harveyi
Polysiphonia nigrescens
Polysiphonia subtilissima



APPENDIX 4.4-C
CALCULATION OF MACROALGAL BIOMASS ESTIMATES
FROM ORRIS, 1972

APPENDIX 4.4-C

MACROFLORA

Calculation of Macroalgal Biomass Estimate from Orris, 1972

BACKGROUND

As previously described, Orris estimated the average monthly biomass collected at 12 stations in Rehoboth Bay between June 1969 and July 1970. These data were presented as average volume of algae collected in a discrete dredging period (liters per minute of tow). To compare the biomass estimates of this study with those of Heck & Sellner (ANSP, 1988) presented in mass of algae collected for a given area (g dry weight algae/m²) a rough conversion of the Orris data was made.

The following provides the methodology used to make that conversion.

Table 4.4-C-1 presents the average volume of algae/minute collected by Orris at each station for each month sampled between June 1969 and July 1970. In addition, the average monthly volumes for all stations sampled are presented.

.Calculation of Area Sampled - Orris reports using a modified Caribbean-type dredge with a mouth measuring 81 cm (0.81m) across. Average dredge time during these monthly surveys was two minutes. The speed of dredge and distance sampled was assumed to be constant with an average dredging time for 100 meters of about two minutes (1 minute, 54 seconds) based on 60 measured samples.

Consequently, one minute of dredging sampled an average area of 40.5m², i.e., (50m/min x 0.81m). Accordingly, the average volume of algae per minute was converted to volume per average area by:

Appendix 4.4-1

Table 4.4C-1

Average Volume of Algae (g dry/in²) for Rehoboth Bay Stations from June 1969 to July 1970.
(N Indicates Negligible Amount of Algae Present)

NOTE: Data converted from (l/min) to g dry/m² as previously described

Station	JUN	JUL	AUG	SEP	OCT	NOV	DEC	FEB	MAR	APR	JUN	JUL
6		51.8 (64.0)	94.0 (118.5)		15.5 (19.1)	0.5 (6)	0.3 (0.4)		0.3 (0.4)	0.5 (0.6)	0.5 (0.6)	N (N)
8		24.5 (32.7)	6.0 (7.4)	45.0 (56.4)	22.5 (27.8)	4.0 (4.9)	18.5 (22.8)		2.5 (3.1)	1.0 (1.3)	3.0 (4.7)	24.0 (30.6)
10		N (N)	41.0 (50.6)	5.1 (6.5)	1.6 (2.0)	22.1 (27.3)	26.9 (33.7)		1.0 (6.2)	42.5 (51.9)	27.5 (34.8)	31.3 (39.6)
1	125.0 (154.3)	128.5 (158.6)	60.0 (74.1)	5.8 (7.2)	3.7 (4.6)	11.4 (14.1)	1.1 (1.4)	11.2 (13.8)	2.5 (3.1)	12.8 (15.8)	7.5 (9.3)	14.3 (18.1)
3	30.0 (37.0)	179.3 (222.0)	128.0 (158.0)	13.5 (16.7)	2.4 (3.0)	0.5 (0.6)	0.3 (0.4)	5.7 (7.0)	1.3 (1.6)	6.0 (7.4)	14.5 (18.1)	8.8 (10.9)
5	5.9 (7.3)	17.0 (21.0)	2.0 (2.5)	N (N)	0.5 (0.6)	0.1 (0.1)	0.3 (0.4)	1.4 (1.7)	0.5 (0.6)	2.8 (3.5)	5.3 (6.5)	36.0 (44.0)
7	9.5 (11.7)	30.8 (37.9)	5.7 (7.0)	1.8 (2.2)	8.9 (11.0)	0.1 (0.1)	22.5 (27.8)	0.5 (0.6)	5.0 (6.2)	1.5 (1.9)	12.0 (14.8)	37.0 (45.7)
9	0.0 (0.0)	13.5 (16.7)	71.0 (87.7)	1.3 (1.6)	0.5 (0.6)	0.2 (0.2)	4.0 (4.9)	5.6 (6.9)	7.5 (9.3)	3.8 (4.7)	4.5 (5.6)	1.3 (1.6)
12	0.2 (0.2)	0.1 (0.1)	0.7 (0.9)		3.6 (4.4)	0.2 (0.2)	0.2 (0.2)	0.4 (0.5)	0.2 (0.2)	0.8 (1.0)	0.5 (0.6)	1.3 (1.6)
13		4.7 (5.8)	40.5 (50.5)	0.5 (0.6)	2.8 (3.5)		2.9 (3.6)		0.3 (0.4)	15.0 (18.5)	9.8 (12.1)	1.3 (1.6)
15		17.0 (21.0)	0.5 (0.6)		7.7 (9.5)	N (N)			0.2 (0.2)	0.5 (0.6)	4.0 (4.9)	80.0 (98.8)
17		2.0 (2.5)	8.5 (10.5)	2.5 (3.1)	7.2 (8.9)		1.1 (1.4)		2.5 (3.1)	5.0 (6.2)	3.8 (4.7)	1.5 (1.9)

$$\frac{\text{Avg volume (L)/time (min)}}{\text{Avg area dredged (m}^2\text{)/time (min)}} = \frac{\text{vol algae(L)}}{\text{m}^2}$$

.Conversion of Algal Volume to Algal Mass - The total wet volume of algae collected for each dredge haul was measured in a 10-liter bucket and measuring water volume displacement.

To convert this wet weight volume of algae to dry weight in grams, it was assumed that the principal algal species, i.e., *Ulva lactuca*, *Agardiella tenera* and *Gracilaria verrucosa* consisted of about 95% water. Note that in order to make a conservative comparison with that of Heck and Sellner, i.e., to develop a conservative estimate of the Orris data, a dry weight to wet weight ratio of 0.05 was used. (Gallagher, personal communication, 1992).

Accordingly, the following calculation was used to adjust liters of algae/m² to grams dry weight/m².

$$\frac{\text{volume (l)}}{\text{m}^2} \times \frac{1000\text{g H}_2\text{O}}{1\text{L H}_2\text{O}} \times \frac{0.05\text{g dry weight algae}}{1.0\text{g wet weight algae}} = \frac{\text{g dry weight}}{\text{m}^2}$$

Example (June, 1969).

$$\frac{0.74 \text{ l}}{\text{m}^2} \times \frac{1000\text{g H}_2\text{O}}{1\text{L H}_2\text{O}} \times \frac{0.05 \text{ g dry}}{1.0\text{g wet}} = 37\text{g dry weight/m}^2$$

