COMPARISON OF NATURAL AND ALTERED ESTUARINE SYSTEMS:

Analysis

Center for Coastal and Environmental Studies
Rutgers-The State University of New Jersey

New Jersey Department of Environmental Protection,
Division of Fish, Game, and Shellfisheries, and
Division of Coastal Resources

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Rutgers - The State University of New Jersey

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INTRODUCTION

Purpose

This study was initiated to determine how the community structure and function of a natural salt marsh would be affected by development. We did this by comparing an existing lagoon housing complex and an adjacent, undisturbed salt marsh. The results of that work have been compiled in a two volume set entitled, "Comparison of Natural and Altered Estuarine Systems, The Field Data - Volumes I and II," and it is selected portions of this document which serve as the primary data source for the following analysis.

This analysis which is entitled, "Comparison of Natural and Altered Estuarine Systems, Analysis," consists of three parts. The first part is a description of the general New Jersey salt marsh environment and a delineation of certain physical and chemical aspects of the study area proper. The second part is a food web analysis. The important populations and interactions from a trophic standpoint are reported in this section. Finally, the third part is an assessment of the salt marsh functions and characteristics which are not specifically trophic in nature, such as the providing of habitat, erosion control, etc. Throughout the analysis, the comparison between the natural and developed areas of the salt marsh is emphasized.

Although undeveloped estuarine areas are legislatively defined as valuable (Wetlands Act of 1970), studies are necessary to verify this viewpoint. Such studies are also required to meet New Jersey's obligations under existing environmental regulations. These would include the Rules and Regulations Establishing Surface Water Quality Criteria pursuant to the Federal Water Quality Act of 1965; the provisions for riparian leases and grants approval; and the Coastal Area Facilities Review Act of 1973.

Organization

The project was a cooperative venture between Rutgers University and the New Jersey Department of Environmental Protection (NJDEP). Dr. Norbert P. Psuty administrated the Rutgers University elements. Mr. Paul Hamer served as Dr. Psuty's counterpart for the NJDEP participants and acted as overall project coordinator. The personnel involved were as follows:

I. Rutgers University principal investigators and their associates

  A. Dr. James E. Applegate

    1. Dr. John Blydenburg

    2. Dr. Steven A. Salmore

    3. Mr. Stephen L. Sterner

  B. Dr. James B. Durand

    1. Mr. Teruo Sugihara

    2. Mr. Charles Yearsley

C. Dr. Ralph E. Good

1. Mr. William Brown

2. Mr. Barry Frasco

3. Mrs. Katherine Smith

D. Dr. Harold H. Haskin

1. Mr. Michael Hogan

2. Mr. Bruce Kiesel

3. Mr. Gary Ray

4. Mr. William Ressler

5. Dr. Diana Ward

II. NJDEP - New Jersey Division of Fish, Game, and Shellfisheries (NJDFGS) investigators

A. Bureau of Fisheries Management

1. Mr. Patrick Festa

2. Mr. Peter Himchak

3. Mr. John Makai

4. Mr. John McClain

B. Bureau of Wildlife Management

1. Mr. Fred Ferrigno - Wetlands Ecology section leader

2. Mr. Robert Bosenberg

3. Mr. Joseph Penkala

4. Mr. William Shoemaker

5. Mr. Dennis Slate

6. Mr. Joseph Sweger

7. Mr. Earl Tomlin

8. Dr. J. Richard Trout

9. Mr. Lee Widjeskog

While the length of participation by the individuals varied, the separate lines of investigation were maintained for a minimum of 2 years and as long as 4 years. Throughout this analysis, these years will be referred to as study years I-IV. June 1973 - May 1974, June 1974 - May 1975, June 1975 - May 1976, and June 1976 - May 1977 are termed study years I, II, III, and IV, respectively.

The broad areas of investigation and the principal investigators associated with them were as follows:

I. Hydrography, nutrients, and water quality

A. Dr. James Durand

B. Mr. John Makai

II. Primary production, vegetation, and/or decomposition

A. Dr. James Durand

B. Mr. Fred Ferrigno

C. Dr. Ralph Good

D. Mr. Dennis Slate

E. Mr. Earl Tomlin

F. Mr. Lee Widjeskog

III. Benthic invertebrates and zooplankton

A. Dr. Harold Haskin

IV. Finfish, finfish food web, and/or shellfish

A. Mr. Patrick Festa

B. Mr. John McClain

V. Marsh surface animal populations and/or activity

A. Mr. Robert Bosenberg

B. Mr. Fred Ferrigno

C. Mr. Joseph Penkala

D. Mr. Earl Tomlin

E. Dr. J. Richard Trout

F. Mr. Joseph Sweger

G. Mr. Lee Widjeskog

VI. Use and/or harvest

A. Dr. James Applegate

B. Mr. Fred Ferrigno

C. Mr. Peter Himchak

D. Mr. William Shoemaker

The apparent overlapping of the research areas resulted from a particular study effort being subdivided between different investigators on a geographical or organismal basis.

The editing and compilation of the "Comparison of Natural and Altered Estuarine Systems, Field Data - Volumes I and II" and the examination of the data ("Comparison of Natural and Altered Estuarine Systems, Analysis") were carried out primarily by Teruo Sugihara with supervision by Drs. Durand and Psuty. This portion of the project was done in cooperation with the Division of Fish, Game, and Shellfisheries and the Division of Coastal Resources (in particular the Bureau of Coastal Planning and Development.)

THE SALT MARSH ENVIRONMENT

The Estuarine Zone: An Overview

The estuarine zone encompasses areas both aquatic and terrestrial in nature. It is composed of the waters of an estuary and the tidal wetlands associated with these waters. The aquatic portion of the estuarine zone was initially defined using Pritchard's definition of an estuary, "a semi-enclosed body of water with an unimpaired connection to the open sea and within which seawater is measurably diluted with freshwater derived from land drainage" (Pritchard 1967). The lateral limits of the estuarine zone were defined as the terrestrial areas subject to tidal influence by these waters. Under Pritchard's definition, the upstream limit of the estuary is determined by the inland penetration of seawater. However, to be consistent with the definition of the lateral boundaries, the upper limit of the estuary in this report was also fixed at the limit of tidal influence, including freshwater areas in the extremes of the individual systems. Thus, salt marshes, freshwater wetlands, and former wetlands were encompassed by the terrestrial zone. Under these conditions, New Jersey has approximately 1.6×10^5 ha (3.92×10^5 acres) of estuarine waters (Eisele pers. comm.)[1] and roughly 1.1×10^5 ha (2.63×10^5 acres) of former or existing wetlands (Ferrigno et al. 1973).

Vegetation of New Jersey salt marshes are dominated by two grasses, *Spartina alterniflora* and *Spartina patens*, as is true for all the salt marshes between New England and the Carolinas. In New Jersey, other species include those in Table 1.

Table 1. The vegetation species found in New Jersey salt marshes after Moul (1973).

Submerged flowering plants

1. *Zostera marina* L.
2. *Ruppia marina* L.
3. *Potamogeton pectinatus* L.

Dominant grasses and rushes

1. *Spartina alterniflora* Loisel.
2. *Spartina patens* (Ait.) Muhl.
3. *Distichlis spicata* (L.) Greene
4. *Juncus gerardi* Loisel.
5. *Panicum virgatum* L.

[1] William Eisele is head of the Bureau of Shellfish Control of the New Jersey Department of Environmental Protection. Data as of 1976.

Table 1. Continued.

6. *Phragmites australis* Trin.*
7. *Festuca rubra* L.
8. *Agrostis alba* L. var. *palustris*

Important herbs with dominant grasses and rushes

1. *Limonium carolinianum* (Walt.) Britt.
2. *Solidago sempervirens* L.
3. *Suaeda maritima* (L.) Dumont
4. *Suaeda linearis* (Ell.) Moq.
5. *Salicornia virginica* L.
6. *Salicornia europea* L.
7. *Salicornia bigelovii* Torr.
8. *Aster tenuifolius* L.
9. *Pluchea purpurascens* (SW.) D.C. var. *succulenta* Fern.
10. *Ptilimnium capillaceum* (Michx.) Raf.
11. *Plantago oliganthos* R. and S.
12. *Atriplex patula* L. var. *hastata* (L.) Gray
13. *Spergularia marina* (L.) Griseb.
14. *Triglochin maritima* L.
15. *Eleocharis parvula* (R. & S.) Link

Shrubs

1. *Iva frutescens* L. var. *oraria* (Bartlett.) Fern. and Grisc.
2. *Baccharis halimifolia* L.

Plants of the transition, brackish to freshwater border of the marsh

1. *Hibiscus palustris* L.
2. *Scirpus americanus* Pers.
3. *Elymus virginicus* L. var. *halophilus* (Bickn.) Wieg.
4. *Eleocharis* spp.
5. *Lobelia cardinalis* L.
6. *Lythrum salicaria* L.
7. *Amelanchier* spp.

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* *Phragmites australis* will be used in this report as the proper name for *Phragmites communis* based on Clayton (1968).

While annuals like *Salicornia*, *Suaeda*, and *Atriplex* are present, most of the salt marsh plants are perennials. Large areas of the marsh are generally monotypic in composition. There is a sequence in which these communities are distributed on the marsh. The area nearest the tidal water body is generally occupied by *Spartina alterniflora*, tall form (SAT). Behind this community and dependent on their height above mean low water are found communities dominated by *Spartina alterniflora* short form (SAS), *Spartina patens* (SP), and *Distichlis spicata* (DS) (usually in conjunction with SP). *Juncus gerardi* may be present in areas of even higher elevation. Next to the upland is located a transition zone where *Panicum virgatum* and species of shrubs are found. Note that where drainage pattern or elevation variations exist, disjunct distributions of species do occur.

The major freshwater wetlands are associated with the Delaware River, its tributaries from Salem to Trenton, and the upper ends of the Cohansey, Maurice, Great Egg Harbor, and Mullica rivers. The freshwater wetlands would include areas vegetated by the species listed in Table 2.

Table 2. The vegetation species typical of New Jersey freshwater wetlands after Robichaud and Buell (1973) and Walton and Patrick (1973).

1. *Typha angustifolia*	13. *Iris versicolor*
2. *Typha latifolia*	14. *Polygonum punctatum*
3. *Pontedaria cordata*	15. *Acnida cannabina*
4. *Nuphar advena*	16. *Hibiscus* spp.
5. *Peltandra virginica*	17. *Polygonum sagittatum*
6. *Sagittaria latifolia*	18. *Polygonum arifolium*
7. *Eleocharis* spp.	19. *Phragmites australis*
8. *Sparganium* spp.	20. *Panicum virgatum*
9. *Zizania aquatica*	21. *Rumex verticillatus*
10. *Scirpus* spp.	22. *Lythrum salicaria*
11. Other members of the Cyperaceae family	23. *Ambrosia trifida*
12. *Decoden verticillatus*	24. *Impatiens capensis*

Former wetlands are those tidal areas diked, filled, or developed. Ferrigno et al. (1973) estimated 23% of the wetlands existing as of 1953 were in this category. Estimates of losses over the last 2 centuries range as high as 50% (Robichaud and Buell 1973).

The New Jersey estuarine zone extends from the lower Hudson River south to Cape May and then northwest along the Delaware Bay - River system as far as Trenton. This encompasses 10.6×10^4 ha (263,050 acres) of former or existing wetlands. The Atlantic Ocean division of this zone contains 6.1×10^4 ha (151,188 acres) of this area while the Delaware Bay - River division includes 4.5×10^4

ha (111,862 acres) (Ferrigno et al. 1973). Both divisions have over 200 km (125 miles) of coastline. Parts of Bergen, Hudson, Union, Essex, Monmouth, Ocean, Burlington, Atlantic, and Cape May counties are found in the Atlantic Ocean division. The Delaware Bay - River division counties are Cape May, Cumberland, Salem, Gloucester, Camden, Burlington, and Mercer. Table 3 provides a description of existing and former wetlands for each of the counties within their respective divisions.

Table 3. Tidal marsh parameters for the 1953 - 1973 period after Ferrigno et al. 1973.

County	1953 marsh area (ha)*	1973 marsh area (ha)	Marsh area lost (ha)	% loss
Atlantic Ocean division:				
Bergen	2,018	987	1,031	51
Hudson	1,688	657	1,031	61
Union	979	0	979	100
Essex	248	0	248	100
Middlesex	2,167	1,365	802	37
Monmouth	1,542	818	724	47
Ocean	14,977	10,554	4,423	30
Burlington#	2,979	2,921	58	2
Atlantic	19,482	17,465	2,017	10
Cape May#	15,105	13,280	1,825	12
Delaware Bay - River division:				
Cape May#	5,213	3,685	1,528	29
Cumberland	21,861	17,409	4,452	20
Salem	14,115	9,935	4,180	30
Gloucester	2,881	1,487	1,394	48
Camden	224	120	104	46
Burlington#	656	490	166	25
Mercer	322	322	0	0

*To convert to acres multiply hectares by 2.471.
#Area contained within the relevant division and not the total for the entire county.

We subdivided these two divisions into five smaller regions based on degree of development, geology, and biological considerations. The regions were (Figure 1): (1) Region I, northeastern New Jersey to South Amboy; (2) Region II, South Amboy to Bay Head; (3) Region III, Bay Head to Cape May; (4) Region IV, Cape May to the Delaware Memorial Bridge; and (5) Region V, the Delaware Memorial Bridge to Trenton.

Region I, the northeast New Jersey/New York City sector, is one of the most heavily developed and densely populated areas in the United States. Domestic and industrial discharges provide the major insults to the estuaries which include the lower Hudson, the lower Passaic, the Hackensack, the Elizabeth, the Rahway, and the Raritan rivers, as well as the Arthur Kill, the Kill Van Kull, and the Newark and Upper New York bays. The major terrestrial estuarine feature is the Hackensack Meadowlands. Basically, a *Phragmites* marsh, it has been highly impacted by landfill, industrial activity, and transportation facilities as has the remainder of the estuarine zone in Region I. Geologically, Region I lies mainly within the Piedmont province.

Although not heavily industrialized, much of the shoreline of Region II is residentially developed. Overall population densities exceed 3.6×10^3 people per square kilometer ($p.km^{-2}$) and are indicative of highly utilized areas (Rivkin Assoc. 1976). This region includes the Navesink, Shrewsbury, Shark, and Manasquan Rivers, in addition to parts of Sandy Hook, Raritan, and Barnegat Bays. Much of the pollution originates from Region I sources, although local sewage discharge has been a significant problem in the past. Region II marks where the Inner and Outer Coastal Plains first intersect the Atlantic coastline, and there is a consequent shift in soil types present.

Typical of Region III, Bay Head to Cape May, is the barrier island chain which has allowed the formation of an extensive back bay system connected by channels and creeks and bordered by extensive areas of salt marsh. Ocean County, which forms a large portion of the northern sector of Region III (the Mullica River and north) has been subject to increased residential use. Its population has increased by 91.2% over the 1950-1960 period, 92.6% between 1960 and 1970, and a 50% increase is expected in the 1970-1980 period (Oross Assoc. 1973). Nieswand et al. (1972) reported the construction of 62 lagoon home complexes in Ocean County. Referred to as "one of the fastest growing counties in the United States" (Queale and Lynch 1976). Ocean County certainly is one of the fastest developing in New Jersey. Approximately 30% of the original 14,977 ha (37,007 acres) of wetlands present in 1953 were destroyed in the subsequent 20 year period (Ferrigno et al. 1973). Significantly, lagoon home complexes occupy 3,366 ha (8,317 acres) of altered wetlands (Walton et al. 1976). Associated with development is a degradation of water quality indicated by condemnation of water areas for shellfish harvest. Previously, this was attributable to the use of septic tanks for waste disposal.

The southern part of Region III is more intensely developed than the northern part, especially the barrier islands. Here, population densities range from 4.5×10^3 - 19.5×10^3 $p{\cdot}km^{-2}$ (Rivkin Assoc. 1976). Wetlands losses over the 1953 - 1973 period totalled 3,841 ha (9,492 acres) in Atlantic and Cape May counties (Ferrigno et al. 1973). In the past, sewage outfalls have been responsible for decreased water quality in the area reflected by the condemnation of much of the area waters for shellfish harvest.

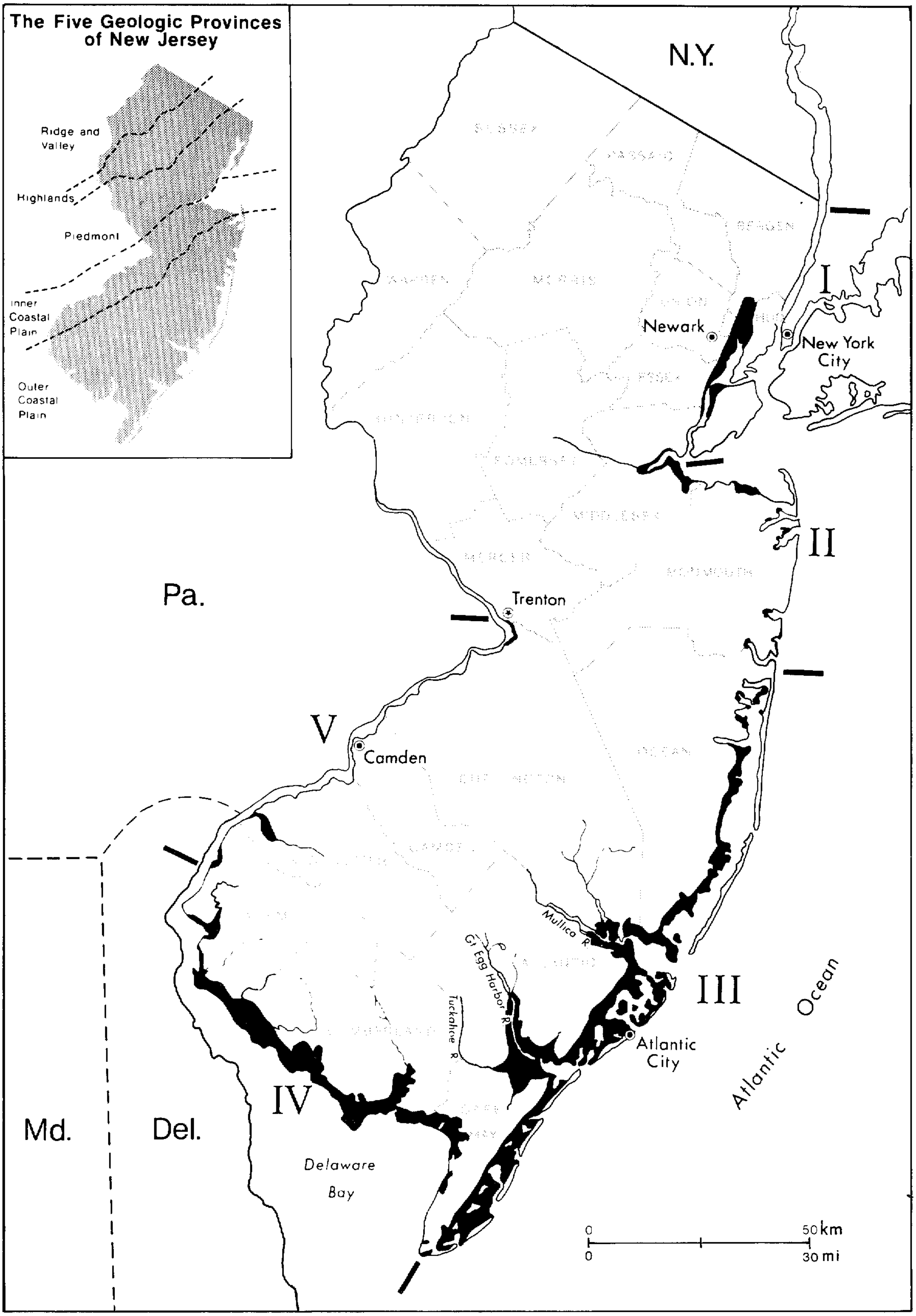

Fig. 1. Map of New Jersey showing Regions I - V. Dark areas represent salt marsh.

Creeks draining the Pine Barrens are the usual sources of freshwater for the back bay systems; however, there are larger river systems also present (Toms, Mullica, and Great Egg Harbor rivers). From the Mullica River north, the streams feed into the Barnegat Bay, Manahawkin Bay, and Little Egg Harbor. These are relatively large, open water bodies. South of the Mullica River, the bays are smaller and the salt marsh more extensive per unit area. Reed Bay, Absecon Bay, Lakes Bay, Great Egg Harbor, and Great Sound are some of the larger bodies of water.

Region III lies entirely within the Outer Coastal Plain and represents the largest wetlands system in New Jersey.

Region IV includes the parts of Cape May, Cumberland, and Salem counties bordering Delaware Bay and based on population density is the least developed of all the regions. The existing industries are primarily oriented towards the harvest of the area's natural resources, and the shellfish industries figure prominently in the local economy. The oyster industry annually harvests around 10^6 dollars of oysters, *Crassostrea virginica*. Blue claw crabs, *Callinectes sapidus*, are also important with landings greater than 4×10^5 dollars annually for Cumberland County alone (U.S. Department of Commerce 1974b, 1975b, 1976b). Another natural resource oriented industry is salt hay farming.

The marshes in Region IV are extensive and are associated with three main tributaries of Delaware Bay, the Maurice, Cohansey, and Salem rivers, as well as numerous smaller streams. Water quality in the bay at present is good and is not seriously degraded by local sources because of the lack of heavy industry and major population centers other than Bridgeton and Millville. Sources in Philadelphia and Camden probably provide the major pollution threat. This is indicated in part by the condemnation of all Delaware River waters above the Cohansey River with respect to shellfish harvest.

Region V includes part of Salem, Gloucester, Camden, and Burlington counties which border the Delaware River. Parts of the shoreline are heavily industrialized with many petrochemical and manufacturing plants present. The shipping facilities are also extensive. Associated with these commercial and industrial centers are large populations. As a result, water quality is poor in the Camden/Philadelphia area compared to the rest of Region V.

The estuarine zone in New Jersey can be described as an area undergoing population growth faster than the rest of the state. It is becoming more and more a year-round residential area as opposed to its former seasonal status. Economically, it is oriented towards utilization of its natural resources and surrounding environment. The availability of water related activities has been a prime attraction for the tourism and recreational industries upon which a significant portion of the economy rests. It is estimated recreational finfishing and shellfishing alone generate 217.2×10^6 and 158.6×10^6 dollars of annual income, respectively (Bonsall 1977). The income derived from the commercial fishing industries is another way in which the estuarine zone economy is dependent on natural resources. These industries provided 30.4×10^6 dollars of revenue in 1976. Associated with them is a 60×10^6 dollar fishery products processing industry (Bonsall 1977). Obviously, the preservation of these sources of income are necessary to protect a major part of the local estuarine zone economy. Logically, the maintenance of the biological systems supporting these activities is equally as critical.

Choice of Study Site and Description

Walton et al. (1976) reported lagoon development construction was a consequence of a series of events occurring from 1950 on. The greater highway access by the increasingly affluent populations of New York City and Philadelphia contributed to the creation of a large housing demand in the New Jersey coastal zone. In addition, the post war increase in investable funds combined with favorable tax and housing legislation provided the profit incentive to finance the construction to satisfy this need.

The location of the new construction, however, was contrary to previous trends, probably because of land acquisition costs. Prior to this, Island Beach, Lakewood, and Toms River were the major commercial and population centers. Now development efforts were concentrated in the Garden State Parkway - Route 9 corridor (Oross Assoc. 1973). One of the end results was the creation of 62 lagoon systems in Ocean County with a total of 13,612 houses by the spring of 1970. Nearly 73% of this was a direct result of the housing boom of the 1960's with only 27% being constructed prior to 1960. In comparison, 52% of the permanent residences in the rest of Ocean County were built prior to 1960 and 48% in the 1960's (Nieswand et al. 1973).

The study area is located near Manahawkin, New Jersey at 39°19'N and 74° 13'W (Figure 2). The site consists of three sectors, the undeveloped marsh, a lagoon complex, and the bordering back bay waters. The terrestrial sectors are roughly bounded by Route 72 on the north, Route 9 on the west, and Westecunk Creek on the south. Upland areas are also present within these boundaries, but the tidal areas are the primary focal points of interest. Specifically, we selected Village Harbour (at the time of the study known as Beach Haven West) as the developed salt marsh area to be studied. The adjacent salt marsh to the southwest served as the comparison undeveloped site. The back bay sector extended from Beach Haven Inlet in the south to Sandy Island in the north (roughly the same latitude as Harvey Cedars). We delineated a back bay zone extending beyond the immediate marsh and lagoon complex sites in order to encompass the entire adjacent hydrographic unit.

We divided the undeveloped portion of the study area into "aquatic" and "terrestrial" zones. Those areas associated with the water column proper, the benthic sediments, and the periodically exposed mudflats were included in the aquatic zone. In contrast, the bank and marsh surface were considered as "terrestrial" irrespective of their periodic inundation by tides (Figure 3). In further describing the study area, we adopted certain conventions. The term "system" refers to the terrestrial and aquatic elements composing a hydrographically defined unit. The terms "mouth", "mid", and "upper" refer to portions of the waterway or system located nearest to, intermediately from, and farthest from the bay, respectively.

SALT MARSH SITE -- The salt marsh site extends from the southwestern border of the Village Harbour development to the southwestern boundary of the Dinner Point Creek system. The upland forms the western border while Manahawkin Bay and Little Egg Harbor comprise the eastern border. Because the tidal range is small, there are only limited areas of *Spartina alterniflora* tall form, and these are restricted to the edges of creeks and ponds. Most of the marsh is covered by *Spartina alterniflora* short form and a combination of *Spartina*

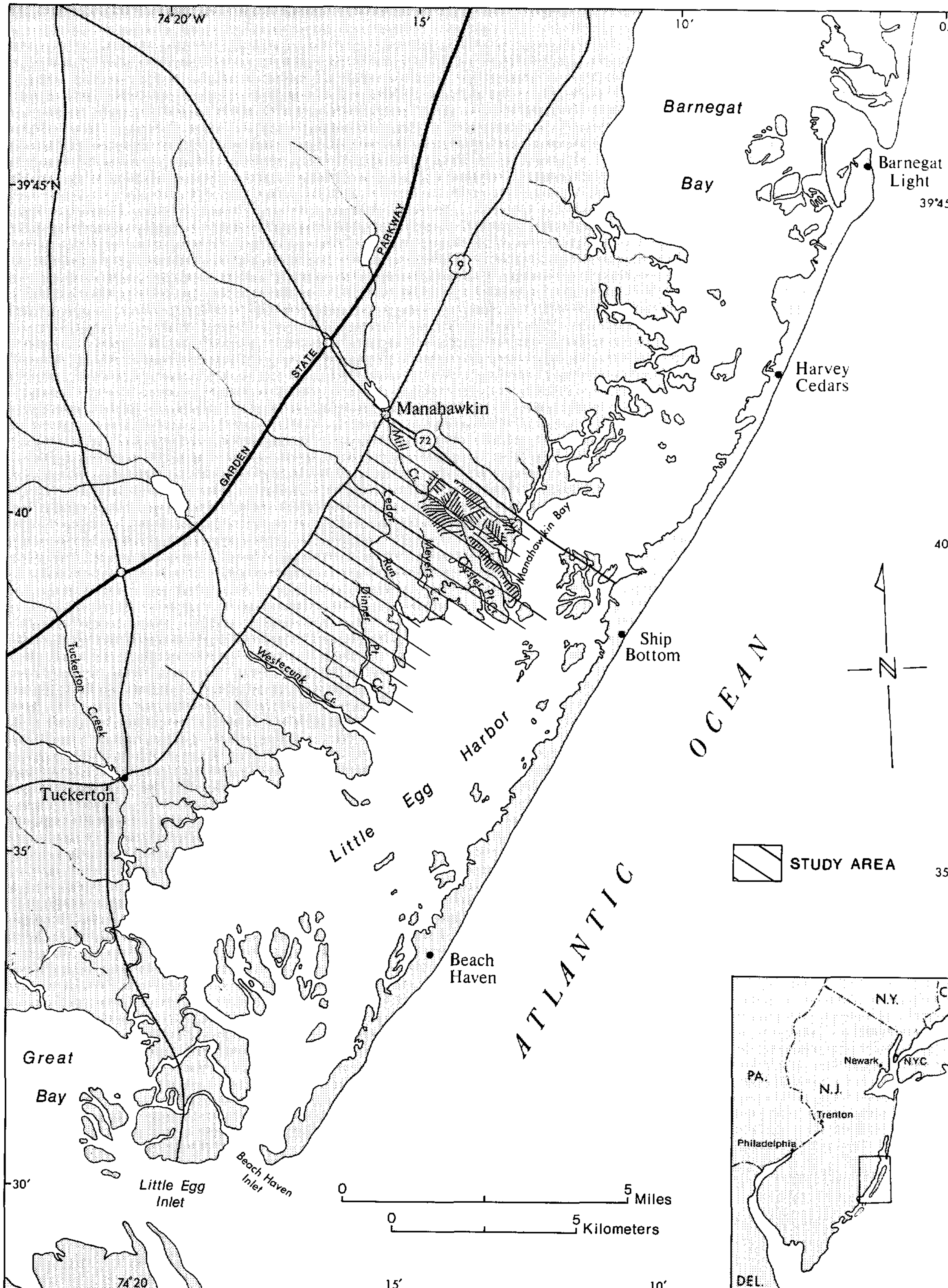

Fig. 2. Study area location.

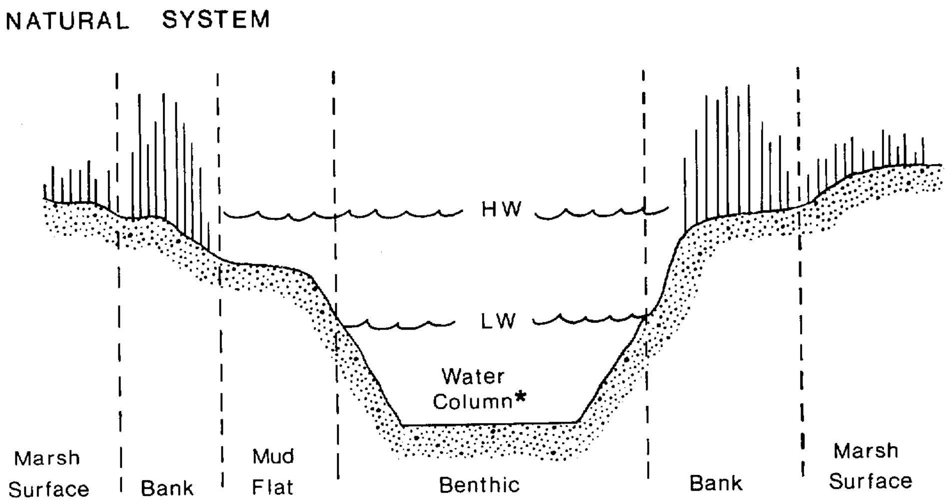

Fig. 3. Cross section of a natural marsh.

patens and *Distichlis spicata*. There is an understory of algal mats over much of the marsh surface. Submerged vegetation is also found in the numerous salt pools, both permanent and temporary, on the marsh.

The marsh itself is relatively undisturbed. Mosquito ditching is the major disturbance. There are a small number of houses on the marsh, and these are generally along the roads that extended to the bay from the upland. The other primary use of the marsh is for hunting. The adjacent bay is extensively used for shellfish harvest and for recreational fishing and boating.

The marsh site includes a number of waterways with varying amounts of upland drainage: (1) Mill Creek system; (2) Oyster Point Creek-Mud Cove system; (3) Meyers Creek system; (4) Cedar Run system; (5) Channel Creek system; and (6) Dinner Point Creek system.

All of these streams were studied except Channel Creek. The Meyers Creek and the Oyster Point Creek - Mud Cove systems received the most extensive investigation. Accordingly, much of the data reported as representative of a salt marsh were derived from these systems. Each stream has features which made it unique. Whether it is degree of tidal influence, freshwater input, configuration, or the types and sizes of the various zones in the system, variability between systems exists. Consequently, no one system was considered as totally representative of a "typical" salt marsh.

Based on the analysis of aerial photographs, the size of the marsh study site is roughly 1,370 ha (3,385 acres) excluding the surface area of the major waterways. Partitioning this into drainage basins yielded the breakdown in Table 4.

If the upland portions of the drainage basins are included (Brush and Flynn 1974), the following increases would occur: (1) Mill Creek system, 6,060 ha (14,974 acres); (2) Cedar Run system, 1,596 ha (3,944 acres); and (3) Dinner Point Creek system, 498 ha (1,231 acres).

Table 4. Marsh surface estimates for the various water systems.*

System	Marsh surface (ha)#
Oyster Point Creek - Mud Cove	312.3
Meyers Creek	95.5
Cedar Run	213.8
Channel Creek	155.7
Dinner Point Creek	591.5
Total marsh surface	1,368.8

*Mill Creek has only minimal marsh drainage which was determined to be negligible for the purposes of this analysis.
#To convert to acres, multiply hectares by 2.471.

Dinner Point Creek system -- The Dinner Point Creek system encompassed the largest amount of salt marsh (Figure 4). The waterway consists of two major tidal tributaries each over 2 km (2.4 miles) long draining into a main channel over 4 km (2.5 miles)

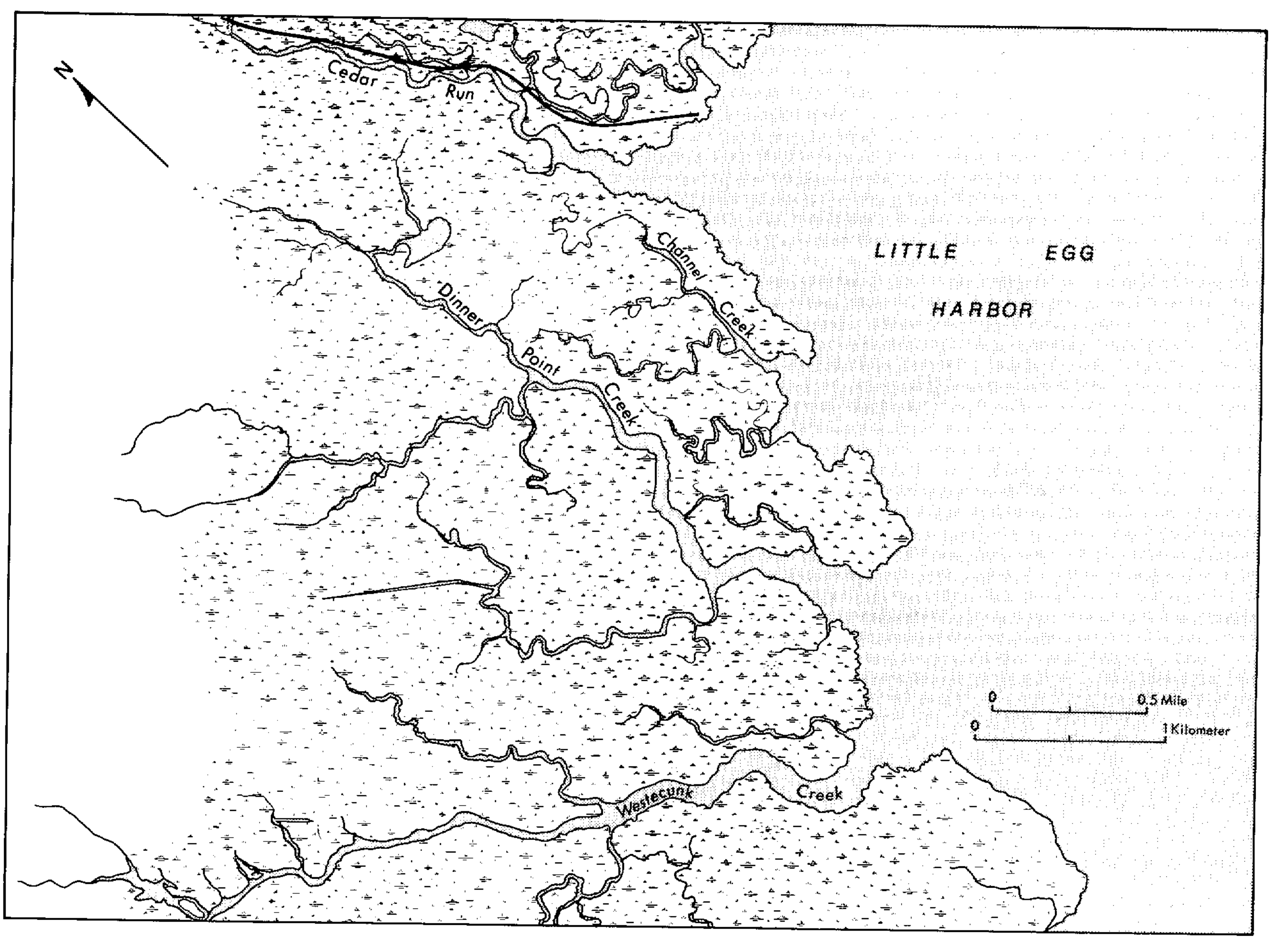

Fig. 4. The Dinner Point Creek system.

in length. The surrounding marsh is primarily composed of *Spartina alterniflora* short form and *Spartina patens*. The marsh is ditched and the drainage network connects to both the tributaries and the main channel. Because the creek is shallow and the drainage basin restricted to the marsh zone, tidal influence is the major hydrographic force present. The large amount of marsh surface associated with the mosquito ditches provides a large tidal prism storage capacity. Other than the ditching, there is not evidence of dredging or filling along the major tributaries or main channel. There are only a few man-made structures present. The Dinner Point Creek system represents a region of minimal disturbance in the study area.

Meyers Creek System -- The Meyers Creek system is a large pond connected to the bay by a winding channel approximately 1.4 km (0.9 miles) in length (Figure 5). The marsh vegetation consists of roughly 55.0 ha (136 acres) of *S. alterniflora* short form, 0.8 ha (2 acres) of *S. alterniflora* tall form, and 34.6 ha (85 acres) of *S. patens*. It is the smallest of the natural marsh systems studied. Like Dinner Point Creek, Meyers Creek is undeveloped, tidal in nature, restricted primarily to the marsh zone, and ditched. Additional bathymetric and physical data are listed in Table 5.

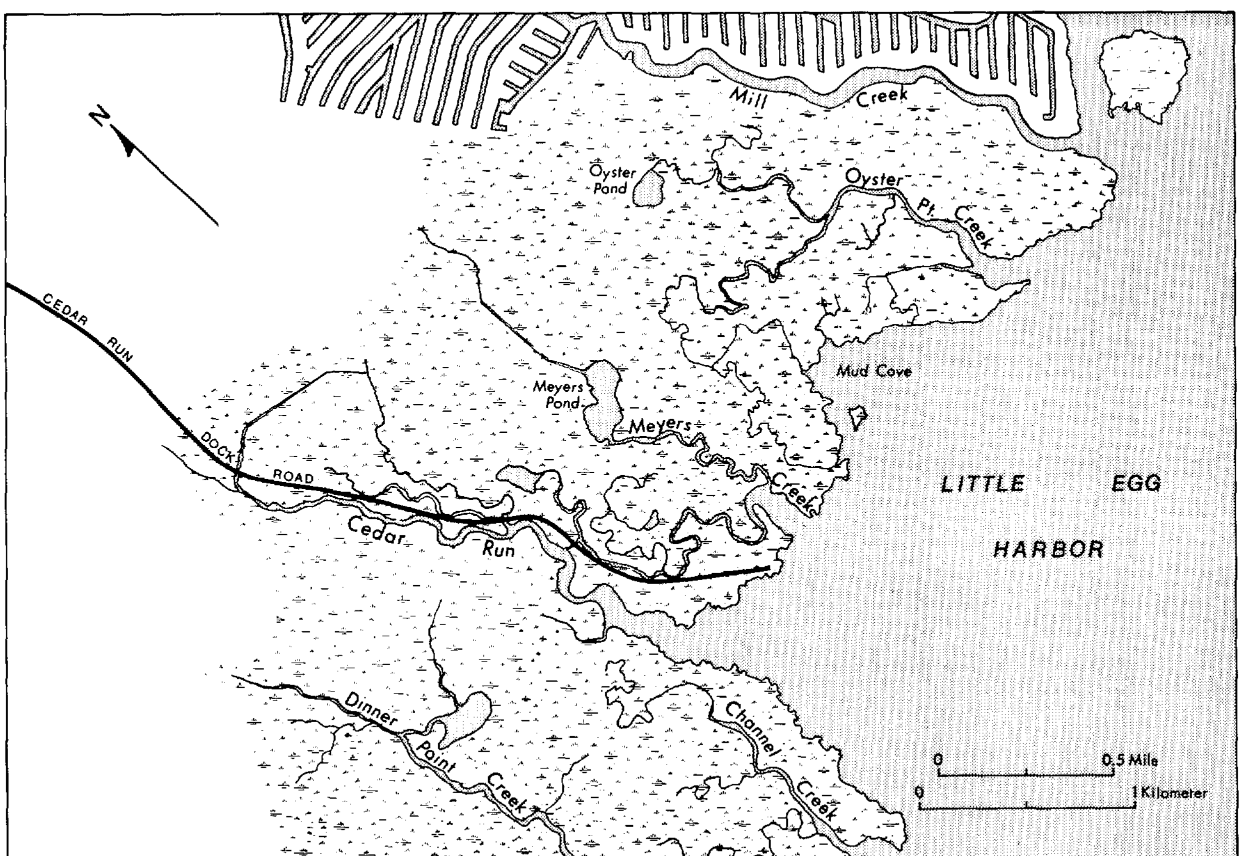

Fig. 5. The Meyers Creek, Oyster Point Creek - Mud Cove, and Cedar Run systems.

Table 5. Bathymetry and other features of the Meyers Creek system (after Durand et al. 1977).

Parameter	Meyers Creek	Meyers Pond
Mean depth (m)*	1.2	0.42
Perimeter (m)	2,348	1,255
Tide range (m)	0.46	0.46
Water surface area (m^2)	23,000	43,000
Volume (m^3):		
High water	22,000	18,000
Low water	12,600	7,500
Tidal prism	9,400	10,500
(Tidal prism · High water^{-1})	0.43	0.58

*To convert to feet, multiply meters by 3.281.

Oyster Point Creek - Mud Cove System -- The second largest natural marsh system, the Oyster Point Creek - Mud Cove system, is similar in nature to the Meyers Creek system (Figure 5). Ditch drainage is directed into Little Egg Harbor as well as Oyster Point Creek. The area between Oyster Point Creek and Mill Creek showed evidence of lagoon construction at the time of the study. The Popular Point area has since been converted into a low level tidal impoundment for mosquito control purposes by the Ocean County Mosquito Control Commission.

The creeks and waterways of the study area were placed in three different categories or types which reflected their degree of development. These types were: (1) natural or undisturbed creeks; (2) partially disturbed waterways; and (3) fully lagooned waterways. The three systems just described, Dinner Point Creek, Meyers Creek, and Oyster Point Creek - Mud Cove, belong to the natural or undisturbed type.

Cedar Run System -- Of the natural marsh sites, Cedar Run is the most disturbed system (Figure 5). Situated on the northern shore of the stream are a number of small homes, docks, and an access road. Most of the surrounding drainage basin, however, is typical of the other marsh sites. The system is approximately 2.5 km (1.6 miles) in length and has no major branches. Its tidal marsh drainage area is intermediate in size; however, a significant portion of its drainage is derived from the upland. Cedar Run would be considered a partially disturbed waterway.

LAGOON HOME COMPLEX SITE -- Village Harbour was chosen as a study site for a number of reasons. It was constructed using the same techniques and basic design as most other lagoon systems in New Jersey. It also is the largest of its type. It is located in a rapidly developing area of New Jersey, Ocean County. Finally, it is situated on a back bay salt marsh system which is the most prevalent New Jersey wetland type.

The basic design of Village Harbour and the other Ocean County systems is a network of dead-end canals branching off a main channel. These channels and canals were created by the dredging of salt marshes to provide navigable waterways and spoil which was used to elevate the home sites surrounding the waterways. The canals were often dredged deeper than was necessary for navigability by small water craft. Generally, this depth exceeds that of the parent water body. Bulkheading frequently was constructed to retard the effects of bank erosion and secondarily to allow convenient boat anchorage.

Single-family homes are the usual structures in the complexes. As of 1973, septic tanks and/or sewers were utilized for waste handling in these developments. Although sewers are preferable because of the high soil porosity and water table conditions, septic tank systems were present in many Ocean County complexes. Village Harbour is now completely sewered and regionalization of the area's sewage disposal systems is in progress. Nonpoint source pollution occurs in these complexes as road and surface runoff.

Village Harbour is composed of five separate housing systems of varying age and configuration. We designated these as Lagoon Systems A, B, C, D, and E (Figure 6). We also applied a numerical code to each lagoon (Figure 6). Each lagoon is identifiable by a letter and number combination representing the system it belongs to and the individual lagoon itself. For example, the number 08 lagoon in Lagoon System A was called Lagoon A08.

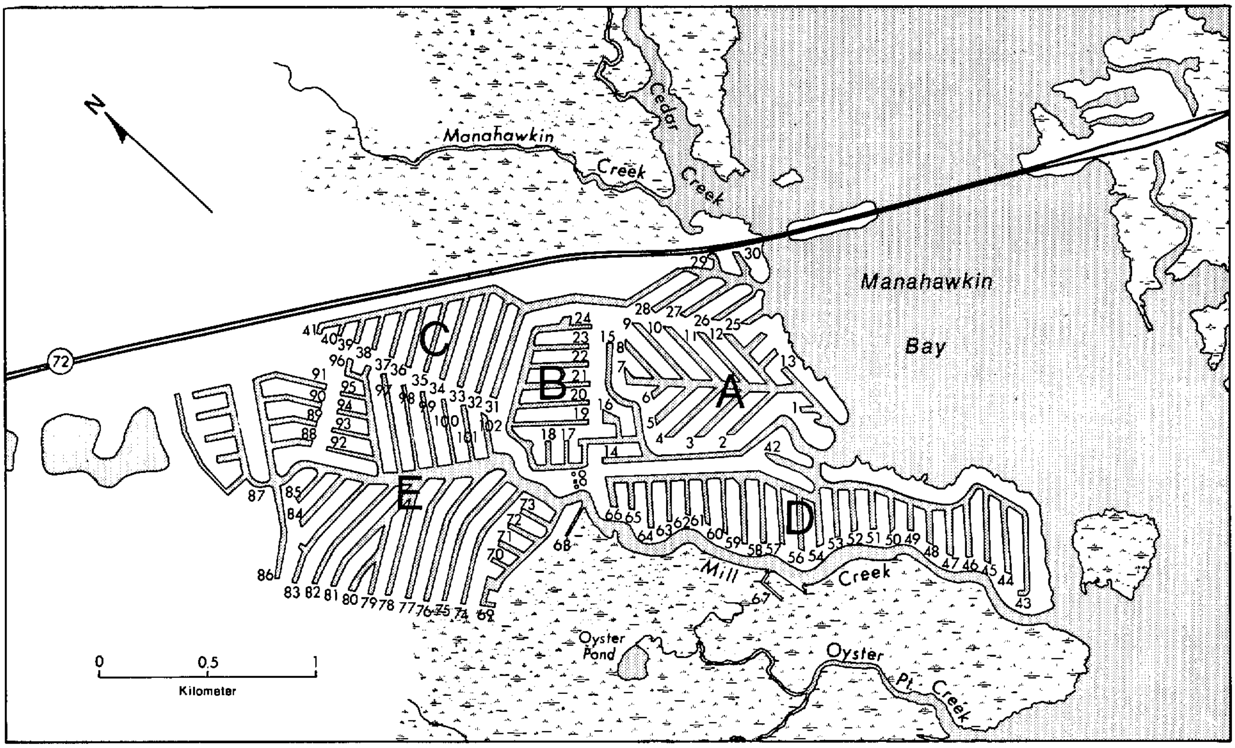

Fig. 6. Village Harbour complex.

The lagoon systems are variable with respect to their configuration. The most compact of Lagoon Systems A, B, C, and D is Lagoon System A which has 13 lagoons radiating off a relatively straight and short main axis at regular intervals. At the other extreme is Lagoon System B with one of the longest and most convoluted main axes in the entire complex. In addition, there are 14 lagoons branching off the main channel and these are primarily located in the distal half of the system. The last system in the development, Lagoon System E, is unique because it separates the main portion of Village Harbour from the adjacent salt marsh control sites. Because the system is not entirely developed and marsh areas adjoined the system, it has characteristics of both areas. Lagoon System E contains the greatest number of canals. With Mill Creek as its central axis, it has a significant and continuous freshwater input not present in the rest of Village Harbour. In addition, Lagoon System E extends into the upland and has the greatest remote point distance from the bay in the complex. Another distinguishing feature is the discharge into Mill Creek of all Village Harbour sewage by the local treatment plant. Lagoon Systems A, B, C, and D would be classified as fully lagooned waterways; whereas, Lagoon System E because of its dual nature would be categorized as a partially disturbed creek or waterway.

Lagoon Systems A, B, and C are fully developed whereas D and E are partially developed with construction ongoing. As of January 1978, much of this activity was centered on the southwest side of Mill Creek. There were 10 lagoons still undeveloped in this general area. There were also 8.5 lagoons undeveloped in the lower part of Lagoon System D. Altogether there are 3,100 (plus or minus 100) homes already constructed (Slavin, pers. comm.).[2] Of the 455 homes built in Stafford Township during 1977, around 300 were in Village Harbour (Weller, pers. comm.)[3]

The conventions used to describe the parts of the lagoon system are similar to those used for the undeveloped marsh. The area was divided into "aquatic" and "terrestrial" zones. Again the water column proper and the benthic sediments were considered part of the aquatic zone. The terrestrial zone was composed of the bulkhead and bank areas adjacent to the waterways and the elevated spoil areas upon which houses and roads were constructed. Because of the nonbiological nature of this latter area, most of the terrestrial zone research was restricted to the bulkhead and bank area. Specifically, the productivity of the algal community on the pilings and bulkheading was studied. This community is considered as the equivalent to the algal community of the creek bank and *Spartina alterniflora* tall form areas. An idealized cross section of a lagoon is depicted in Figure 7. The aquatic zone investigations comprise the bulk of the research in the developed area. Particularly extensive work was done with phytoplankton productivity, the benthic invertebrate populations, and the physical and chemical factors of the lagoon water columns.

Lagoon Systems A, B, and E were the focal points of the study in the developed area. The variations between these systems provided a range of conditions representative of most New Jersey lagoon systems. Physical characteristics of Lagoon Systems A and B are listed in Table 6.

BACK BAY ZONE -- The bay section of the study area includes Little Egg Harbor, Manahawkin Bay, and the southern part of Barnegat Bay. Extending from Beach Haven Inlet to the Harvey Cedars area (Sandy Island), its length is approximately 25.6 km

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[2]This data is from the Stafford Township Municipal Sewage Authority and is based on the number of sewer hook-ups as of January 1978.

[3]This data is from the Building Inspector and Zoning Office of Stafford Township and is based on the number of building permits.

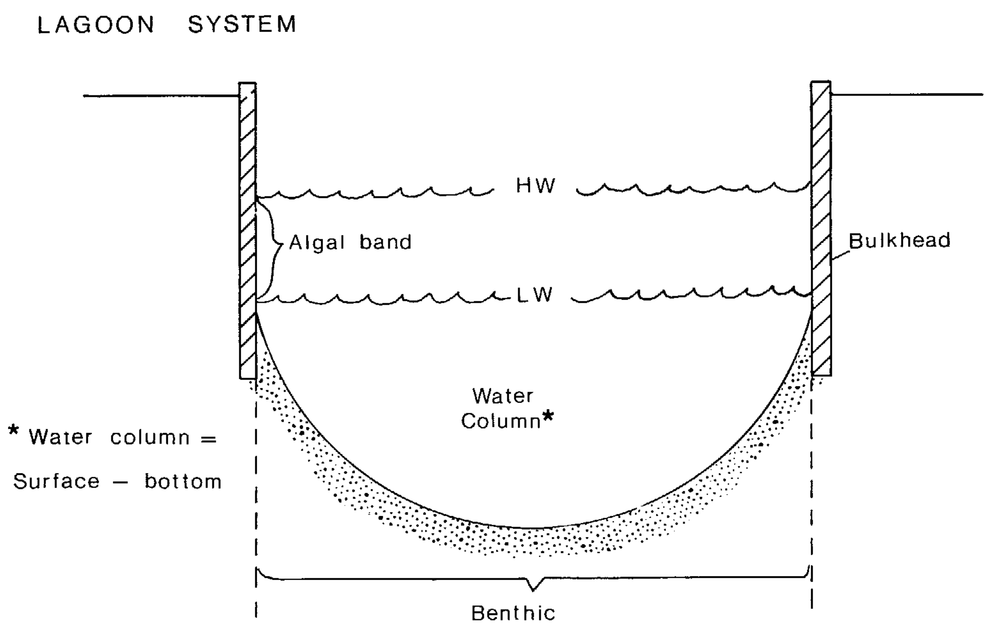

Fig. 7. Cross section of a lagoon.

Table 6. Physical characteristics of Lagoon Systems A and B.

Characteristic	Lagoon System A	Lagoon System B
Mean depth (m)*	3.06	3.06
Length of waterways in the system (m)	4,370	5,452
Perimeter (m)	8,287	11,526
Lagoon surface area (m^2)	148,566	160,063
Drainage surface area (m^2)	284,720	339,400 #
Total surface area (m^2)	433,286	499,463
Volume ($m^3 \cdot 10^3$)	263.0	272.5

*To convert meters to feet, multiply by 3.281.
#This figure was calculated using a different method. Total surface area equals the sum of the lagoon and drainage surface areas and ignores the discrepancy in methods.

(15.9 miles). Other parameters are as follows: (1) maximum width, 7.4 km (4.6 miles); (2) surface area, 10,345 ha (25,563 acres); (3) volume, 1.1 x 10^8 m^3 (28.9 x 10^9 gal); and (4) mean depth, 1.1 m (3.5 ft.) (McClain et al. 1976). Figure 8 shows the depth profiles for five bay transects.

The tides are semidiurnal with two flood and two ebb tides occurring over a 24.8 hour period. Near the study area, the tidal amplitude is not large. Little Egg Inlet has the greatest mean tide range at 1.1 m. Moving northward, the mean tide range progressively decreases to 0.2 m at Harvey Cedars and then increased to 0.9 m as Barnegat Inlet is approached (U.S. Dept. of Commerce 1977).

Weather

New Jersey's climate is classified as humid continental warm summer (Critchfield 1966). Temperature variations exist or occur on seasonal, diel, and day to day bases. Minimum air temperatures are generally detected during the January period. Maximum air temperatures are generally attained in July. The seasonal temperature changes are generally greater than 20°C (36°F). Biel (1958), citing the mean daily extremes for a 37 year record at New Brunswick, New Jersey, verified differences in daily extremes normally were 9 - 13°C (16 - 23°F).

One manifestation of the climatic variability is the occurrence of rapidly moving rain and thunderstorms. Yearly precipitation between 50 and 130 cm (20 - 50 in) is normal for this type of climate. The 1976 total precipitation varied from 75.8 to 135.7 cm (29.85 - 53.42 in) statewide. It was somewhat unusual that the precipitation was distributed uniformly over the entire year. A monsoonal regime is normally expected in humid continental climates in interior areas.

The climate varies within the state and to obtain a weather picture more representative of the study area, we selected three stations near the study site

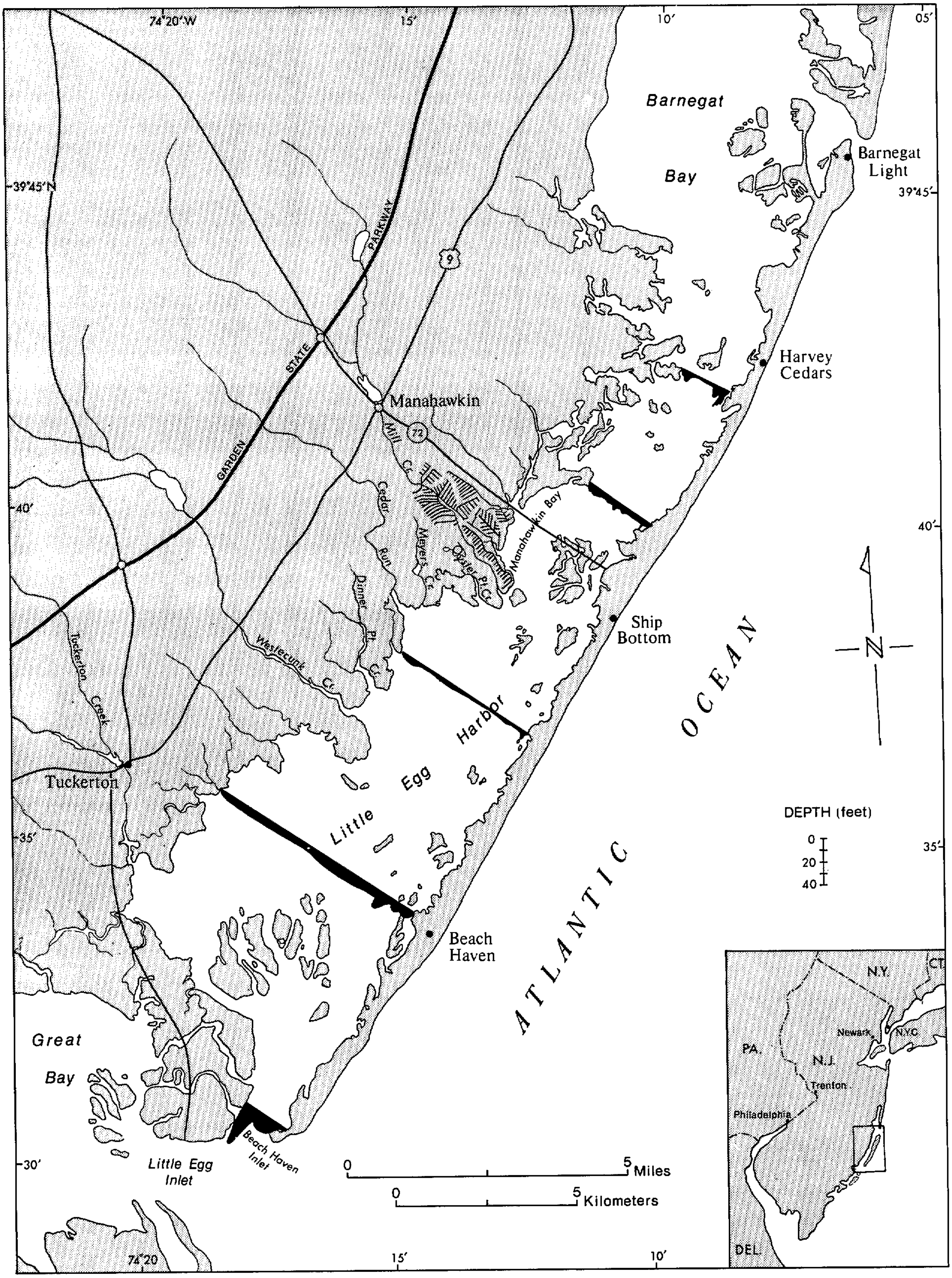

Fig. 8. Depth profiles of the Little Egg Harbor - Manahawkin Bay system.

for further analysis. The three were Toms River to the north, Tuckerton to the west, and Atlantic City to the south. These three stations were chosen for their nearness and their coastal zone location and provided the most complete weather picture for the study area. They exhibited continental weather characteristics, however, there was some station variation (Table 7).

Table 7. Weather characteristics for the stations surrounding the study area during the period 1973 - 1976. Data source was the U.S. Dept. of Commerce, NOAA, Environmental Data Service (1973, 1974a, 1975a, 1976a)

Variable		Toms River	Tuckerton	Atlantic City
Maximum temperature				
(°C)		37.8	37.8	35.6
(°F)		100.0	100.0	96.0
Date		8/3/75	8/3/75	8/28/73
Minimum temperature				
(°C)		-17.8	-16.7	-12.2
(°F)		0.0	2.0	10.0
Date		2/18/74	1/19/76	1/19/76
Maximum monthly mean temperature				
(°C)		24.2	24.3	24.2
(°F)		75.6	75.8	75.6
Date		7/73	8/73	7/74
Minimum monthly mean temperature				
(°C)		-1.9	-1.7	0.4
(°F)		28.5	29.0	32.7
Date		1/76	1/76	1/76
Difference between maximum and minimum				
(°C)		26.1	26.0	23.8
(°F)		47.1	46.8	42.9
Average rainfall 1941 - 1970				
(cm)		117.3		104.4
(in)		46.18		41.11
Rainfall				
1973	(cm)	135.3	123.1	98.4
	(in)	53.26	48.45	38.75
1974	(cm)	106.8	100.9	83.8
	(in)	42.04	39.74	33.00
1975	(cm)	143.9	117.8	101.3
	(in)	56.64	46.39	39.89
1976	(cm)	96.1	90.5	76.9
	(in)	37.83	35.62	30.29

Physical and Chemical Characteristics of the Study Site: Salinity in the Aquatic Zone

The salinity (S^{o}/oo) or salinity gradients observed at any particular station are the result of several factors which modify the initial seawater input. These include land drainage, precipitation, evaporation, and tidal circulation. The freshwater input is via the creek systems which drain the bordering upland areas. Creeks which drain only the marsh also serve to collect and channel any precipitation into the system, but their contributions are smaller. Although groundwater input occurs, its significance at the study site is unknown.

Salinity studies in the Manahawkin system provide information on: (1) input of drainage via the creeks; (2) the vertical circulation patterns in natural and altered waterways; and (3) the horizontal circulation patterns in the bay.

MATERIALS AND METHODS -- Salinity was measured using a silver nitrate titration after Harvey (1957). The data sets used in this analysis were selected because of their completeness (spatially or temporally), compatibility (methodology, sampling, or purpose), and/or connection with data used in other sections of this report.

The Durand group provided the core of the natural marsh and lagoon complex data while the back bay data were derived from the work of Makai (NJDFGS). Study year II (1974-1975) was chosen as the focal point of the evaluation whenever possible because of the amount and types of sampling done. Additional information was also incorporated from other years (particularly study year I) to account for factors such as yearly variation and alteration of vertical profiles and/or to provide a data base when none was available in study year II.

The sampling routine employed by the Durand group varied over the 3 years of the investigation. Initially, the sampling was twice a month with more intensive sampling in the summer and less in the winter. During study year II, selected major stations were sampled twice a month and selected minor stations monthly. The last year, the Meyers Creek system, the Lagoon System A, and Marker 21 were the main experimental sites. Monthly testing was generally employed for the standard physical and chemical measures at this time. Sampling stations are shown in Figure 9.

Diel studies were performed in the two system types which permitted analysis of the variations occurring over a 24 hour period. System-wide surveys were also conducted in the lagoon system at different times of the year to establish a frame of reference for the more frequently sampled stations.

The NJDFGS sampled at least monthly for part of the study year I and all of study year II in an effort which encompassed the entire study area (Figure 10). The back bay sampling program involved data collection at nine major stations. When possible these sites were sampled on at least a monthly basis. Surface and bottom measurements provided the bulk of the data; however, long term continuous temperature records were also made. The data selected was primarily from study year II.

More detailed information on methods and materials are in the reports of Durand et al. (1974, 1975, 1976, 1977) and McClain et al. (1976).

RESULTS AND DISCUSSION -- Dinner Point Creek -- During study year II, Dinner Point Creek had a limited freshwater flow for most of the year. Differences in the

Fig. 9. Sampling stations in the natural marsh and lagoon systems.

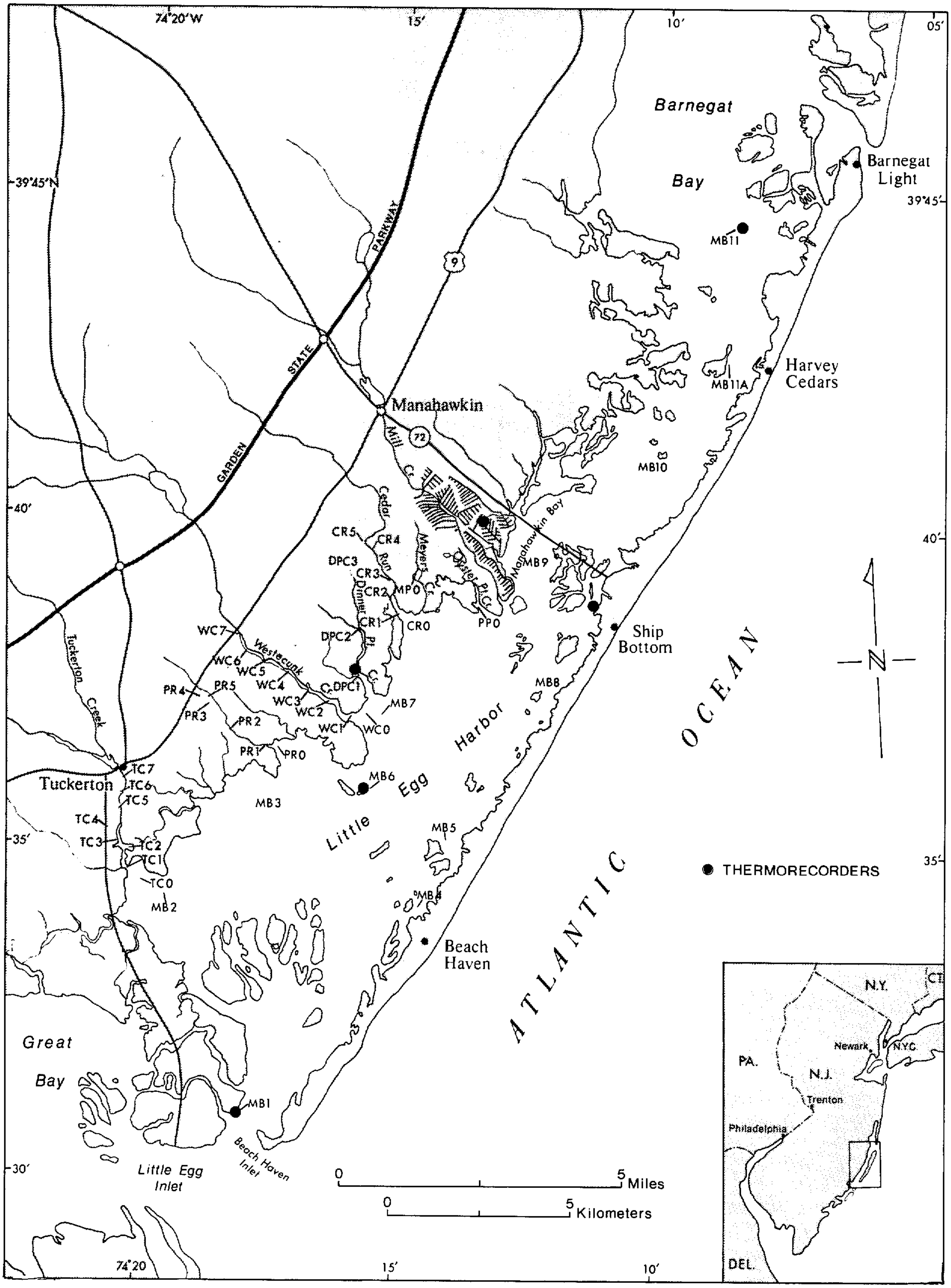

Fig. 10. Bay sampling stations

monthly mean surface salinities of the creek mouth and upper end stations amounted to as much as 11.75 parts per thousand (ppt or $^{o}/oo$). In all cases, the monthly means at the mouth station exceeded the corresponding values at the upper end station.

At the creek mouth, the monthly mean surface salinities ranged from 20.35 (March 1975) to 26.08 $^{o}/oo$ (September 1974) with an annual monthly mean of 24.15 $^{o}/oo$ (an annual monthly mean refers to an average of all the available monthly means). The upper end station exhibited a monthly mean range of 9.16 (January 1975) - 23.56 $^{o}/oo$ (December 1974) with an annual monthly mean of 16.69 $^{o}/oo$. The upper end was more variable than the lower regions of the system because the upper station was influenced more by transient hydrologic and climatic factors.

The water column was well mixed in the lower and middle regions of the creek. However, there was a salt wedge at the upper end which resulted from the freshwater input offsetting the local mixing forces. The remote location of this salt wedge and its rate of incorporation with the bay water within the creek system suggest the freshwater flow is limited and the halocline weak and of relatively small consequence.

The salinity data from study year I are also consistent with the above interpretation. The creek mouth station demonstrated a relatively stable surface salinity level approximating the study year II values. Not unexpectedly, the upper end location deviated from the trends and values of study year II. While there is yearly variation in the salinity differences between the creek mouth and upper end, the creek mouth salinities still exceeded the upper end values in study year I.

Diel studies at Dinner Point Creek in August 1973, October 1973, December 1973, and May 1974 revealed a cyclic variation in the salinity concentrations over a 24 hour period (Figure 11). Maximum salinities were reached during high tide stages and minimums during low tide stages. For studies run in August, October, December, and May, the salinity variation over the 24 hour test period was 3.5, 4.8, 5.9, and 8.3 ppt, respectively. There was essentially no difference between the surface and bottom values, confirming the lack of salinity stratification in the lower portion of the system.

Meyers Creek -- Surface salinities at Meyers Creek mouth exceed those in Meyers Pond (Figure 12), however, the differences did not approach those between the Dinner Point Creek mouth and upper stations. In study year II, monthly means at the two stations differed by less than 5 $^{o}/oo$. Despite an extensive drainage ditch network, the freshwater input is limited relative to the tidal influence. This is consistent with the bathymetry data which shows the tidal prism of the Meyers Creek system to be about 0.5 of the high tide volume. Monthly means ranged from 14.76 to 24.10 $^{o}/oo$ and 10.81 to 24.21 $^{o}/oo$ for the creek mouth and pond, respectively. The annual monthly mean of the mouth station (21.63 $^{o}/oo$) exceeded the upper end site (19.41 $^{o}/oo$).

Vertical salinity data are not available for Meyers Creek. However, salinity stratification was considered unlikely to occur because of the high ratio of tidal prism to high tide volume, the relatively shallow nature of the majority of the system, and the lack of a significant freshwater input.

Like Dinner Point Creek, Meyers Creek salinity data for study years I and II indicated more annual variation at the upper end than at the mouth station. There

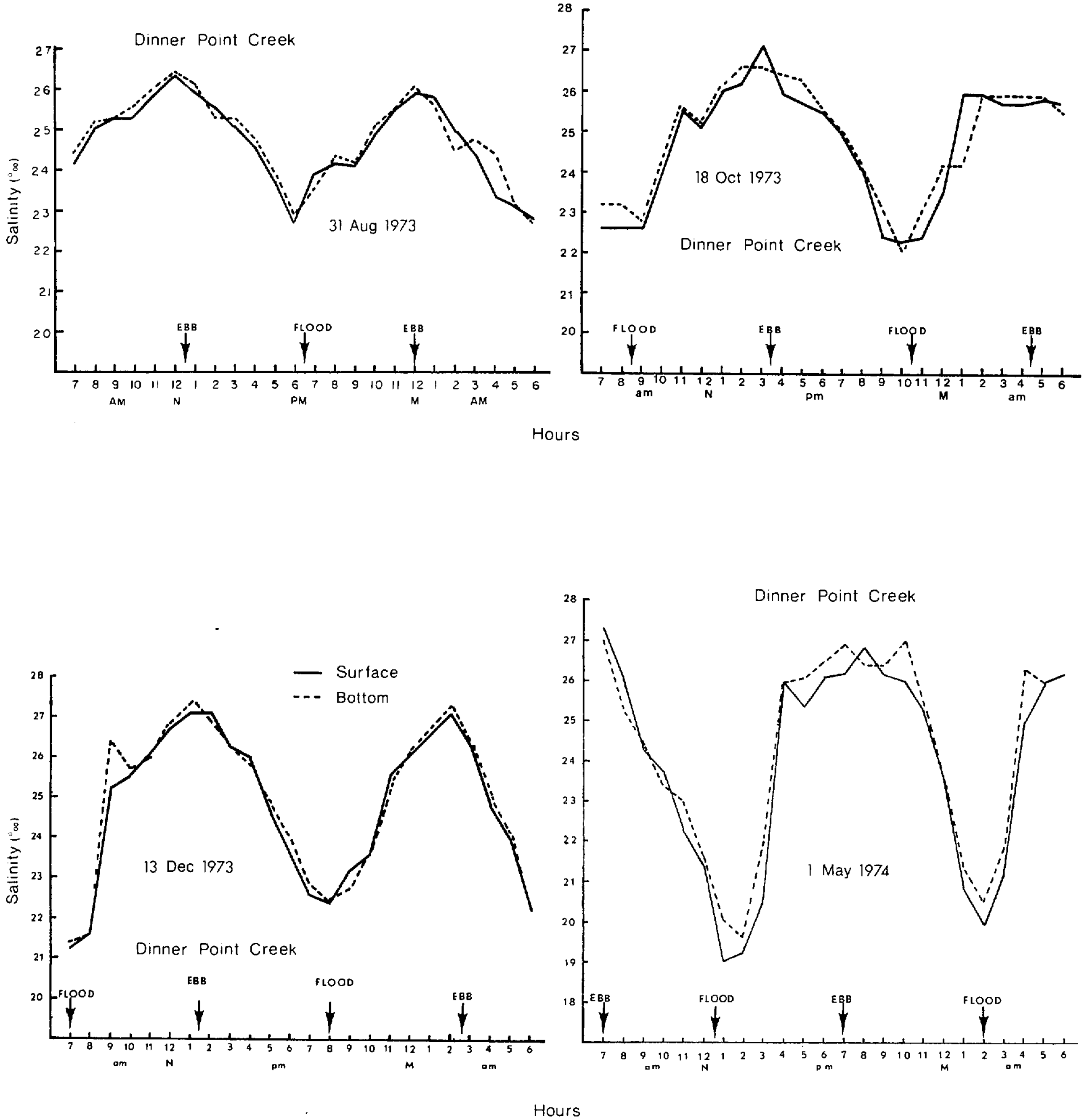

Fig. 11. Diel salinity patterns.

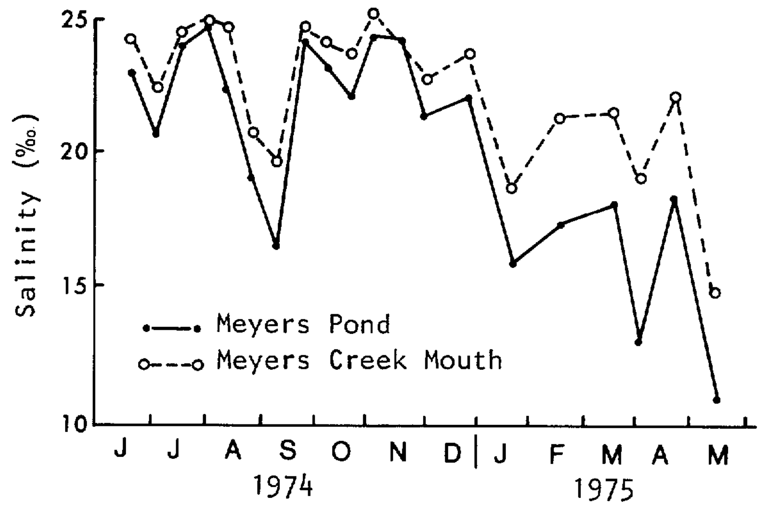

Fig. 12. Meyers Pond and Meyers Creek mouth salinity curves.

is a tendency for summer and fall salinities to exceed winter and spring values. This pattern is related to the evapotranspiration pattern for the Manahawkin area. Using the Thornthwaite method (1948) of estimating potential evapotranspiration (PE), we find, despite ample precipitation throughout the year, there are relative dry and wet seasons (Figure 13). These seasons correspond to the periods of high and low salinity.

The occurrence and duration of these dry and wet seasons are determined by rainfall and other climatic factors which vary annually. This, in turn, contributes to the year-to-year changes in the salinity patterns. For example, the failure for monthly mean salinities to decline in the last half of study year III as expected based on data from study year I and II coincided with below average rainfall.

Oyster Point Creek -- The data for Oyster Point Creek was from study year I. The Oyster Point Creek salinity pattern was similar to that of Meyers Creek. The portions of each creek near the bay had monthly mean salinities differing by no more than 2 $^{o}/oo$. The two upper end stations exhibited comparable values as well, although the largest difference was around 5 $^{o}/oo$. Considering this, Meyers Creek and Oyster Point Creek probably are alike in being primarily influenced by tidal forces.

Cedar Run -- Although the data for Cedar Run are limited, certain trends are suggested. During study year II, the surface salinity range was 1.5 - 24.8 $^{o}/oo$ with a gradient of decreasing salinity from the creek mouth to the upper regions. Bottom values ranged from 1.7 to 25.8 $^{o}/oo$. Annual monthly means for lower, mid, and upper portions of the stream were 20.46, 12.48, and 8.99 $^{o}/oo$, respectively. The corresponding values for the bottom of the water column were 22.09, 15.69, and 11.53 $^{o}/oo$. This decreasing progression of values in an upstream direction indicates a continuous freshwater flow. Despite the shallow nature of the creek (less than 2 m (6.6 ft) deep), a salt wedge was present periodically. Surface and bottom salinities differed by as much as 10 $^{o}/oo$ at the upper station. However, these large differences were usually not observed at the creek mouth.

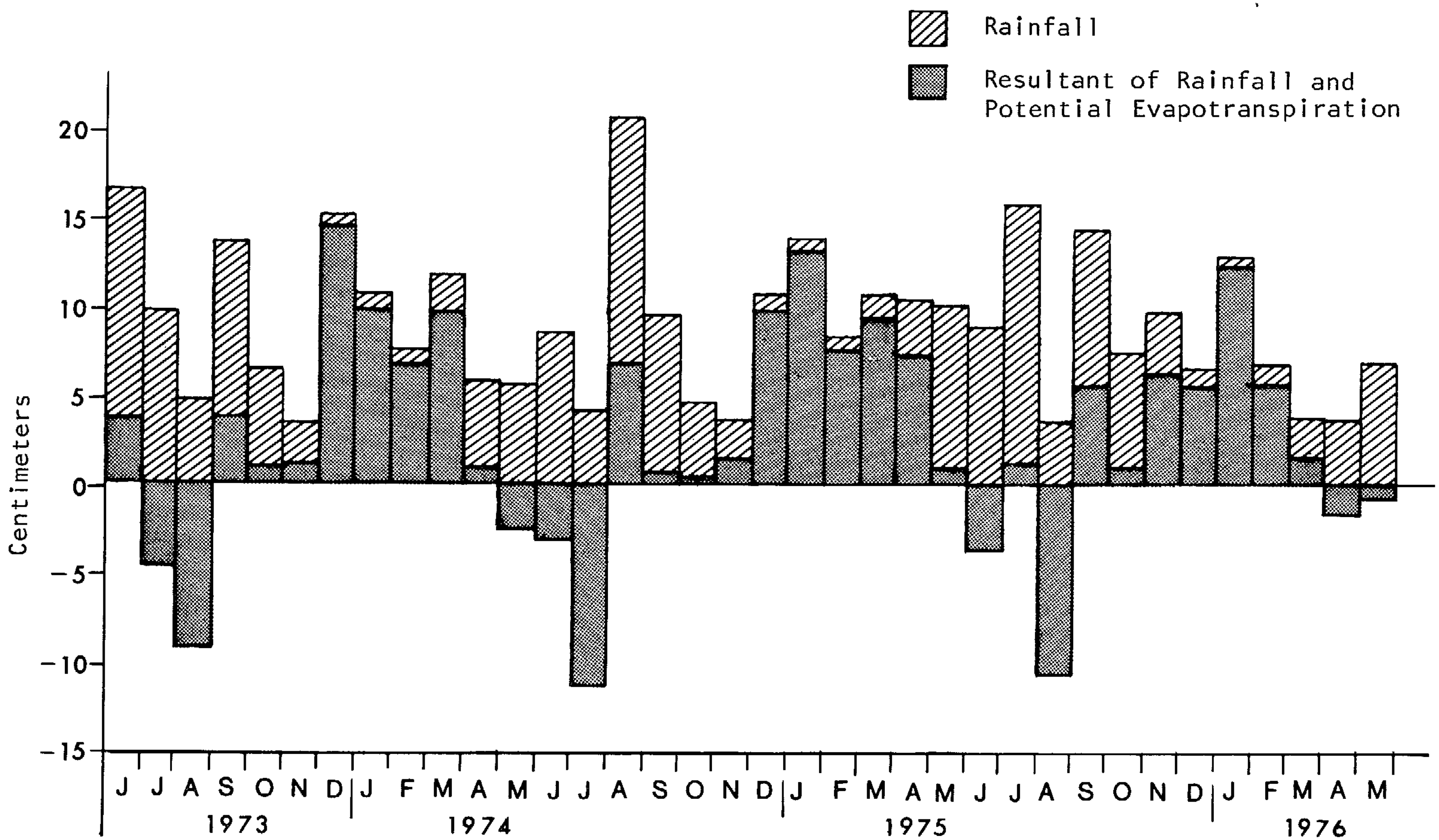

Fig. 13. Monthly rainfall data and the difference between rainfall and potential evapotranspiration in cm.

Mill Creek -- The three stations on the Mill Creek main axis (Lagoon System E mouth, Lagoon E68, and Lagoon E87) had a surface salinity range of 0.2 - 26.35 $^{o}/oo$. The most remote station, Lagoon E87, ranged from 0.02 to 6.14 $^{o}/oo$ during study years I and II. The mid creek and creek mouth stations had values of 4.28 - 19.10 $^{o}/oo$ and 8.05 - 26.35 $^{o}/oo$, respectively for the same period.

Based on the monthly means, there is a general tendency for higher salinities in the summer and fall followed by a decline. However, the data at times also reflects the increased importance of freshwater flow in the system which results in a more irregular seasonal pattern.

Between stations, the seasonal trends are consistent for a given time period if the freshwater influence is considered. The major difference between the stations are increases in salinity and in the range of values as the bay is approached (Figure 14). Of course, the effect of the large freshwater input at Lagoon E87 is to eliminate most seasonal salinity shifts and maintain a relatively constant, low salinity regime.

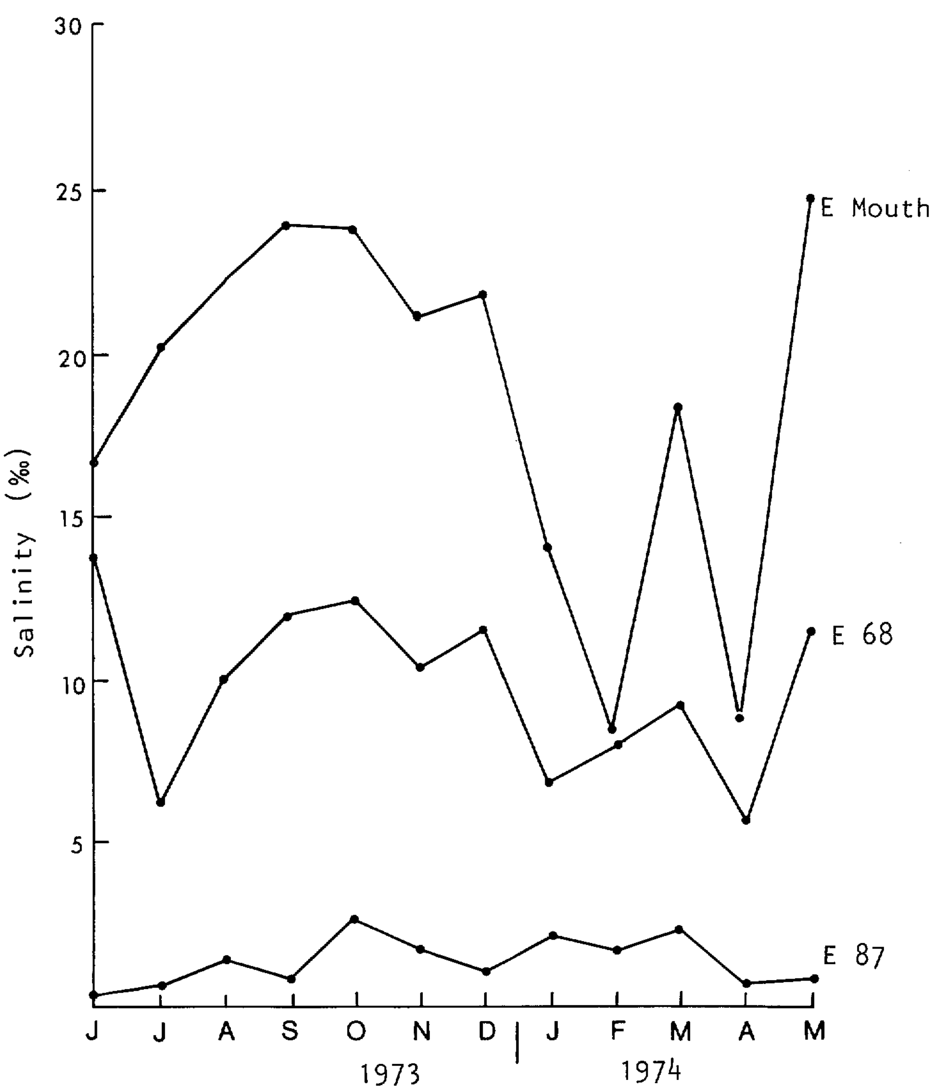

Fig. 14. Monthly mean salinities for Mill Creek in study year I.

Bottom monthly mean salinities at Mill Creek mouth were generally 23 - 24 $^{o}/oo$ during July - November of study year II and approximately 21 $^{o}/oo$ during the following January - April. This pattern is probably a reflection of the bay water influence which would be particularly strong at this station and depth. Bottom monthly mean salinities at Lagoon E68 (the mid creek station) were generally around 17 - 18 $^{o}/oo$ reaching a maximum of 20.81 $^{o}/oo$ in December.

Table 8 provides a summary of the Lagoon System E (Mill Creek) data.

Table 8. The Mill Creek salinity data summary. Means are expressed in parts per thousands.

Mill Creek location	Depth	Study year	Range of the monthly means	Annual monthly mean	No. of observations
Lower end or mouth (Lagoon System E mouth)	Surface	I	8.79-24.68	19.05	12
		II	12.11-24.09	18.33	11
	Bottom	II	20.05-23.70	22.01	8
Mid (Lagoon E68)	Surface	I	5.57-15.64	10.13	12
		II	4.28-14.29	9.28	11
	Bottom	II	15.70-20.81	17.64	10
Lagoon E81 (NJDFGS)	Surface	II	4.80-14.80	10.39	12
	Bottom	II	9.90-19.75		
Lagoon E98 (NJDFGS)	Surface	II	2.55-11.20	7.65	12
	Bottom	II	10.40-17.20	13.69	12
Upper end (Lagoon E87)	Surface	I	0.43- 2.69	1.36	12
		II	0.52- 6.14	2.06	10

The surface and bottom salinity levels indicate an appreciable halocline is present during most of the year. The upper and mid creek stations demonstrate the most persistant gradients. Of all the systems discussed so far, the most sharply defined halocline is found in Mill Creek.

The vertical and upstream gradients suggest a large freshwater input is present throughout the year, unlike in the other waterways. This is supported by Brush and Flynn (1974) who estimated the Mill Creek freshwater flow (1.02 $m^3 \cdot sec^{-1}$) to be several times that of Cedar Run (0.28 $m^3 \cdot sec^{-1}$) or Dinner Point Creek (0.16 $m^3 \cdot sec^{-1}$). The large salinity shifts at the Mill Creek mouth confirm the influence of the freshwater input on Mill Creek (Figure 15). The large upland drainage area of Mill Creek is probably responsible for the size of the freshwater flow.

Brush and Flynn (1974) estimated the average tidal discharge for Mill Creek (12.8 $m^3 \cdot sec^{-1}$), Cedar Run (7.0 $m^3 \cdot sec^{-1}$), and Dinner Point Creek (9.8 $m^3 \cdot sec^{-1}$). Their estimates for tidal flow exceed their estimates of freshwater flow by more than a factor of 10. Therefore, despite Mill Creek having the largest freshwater input, it, like the other creeks, is dominated by tidal forces.

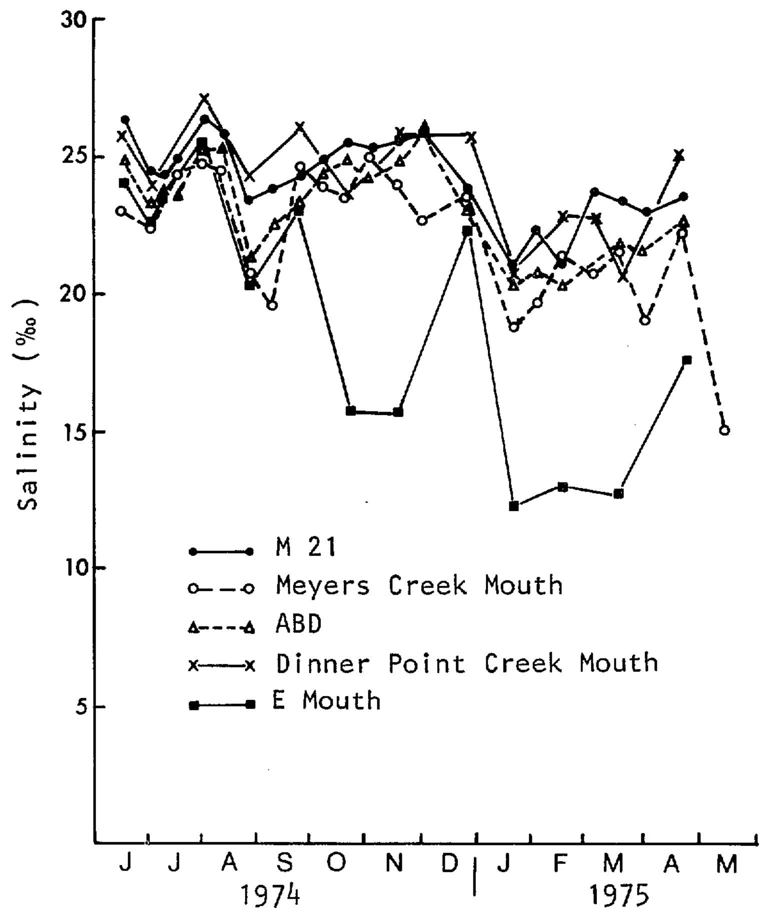

Fig. 15. Surface salinity levels at the mouths of the major systems and at Marker 21 (M 21) during study year II.

Fully Lagooned Waterways -- The remaining systems within the Village Harbour complex were created entirely by dredging. The stations studied in these systems differ primarily in depth and distance from the bay which affects their hydrographic features.

ABD is under the greatest bay influence whereas Lagoon B24 is least affected because of its remoteness from the bay and its depth (deepest site in the complex). Lagoons A02 and A08 are intermediate in terms of bay influence to these two and are probably more typical of New Jersey lagoon communities.

At the ABD station, the mean monthly surface salinity ranged from 20.34 to 26.00 $^{o}/oo$ with an annual monthly mean of 23.17 $^{o}/oo$ during study year II. Again, there is a tendency for higher levels to occur in the summer and extend through the fall with minimum values occurring around January. In fact, all the surface waters in Lagoon Systems A and B had seasonal salinity patterns nearly identical to ABD.

Of the lagoon stations, the mouth of Lagoon A02 is nearest to the bay. During study year III, Lagoon A02 mouth had a surface salinity range (monthly means) of 20.99 - 27.12 $^{o}/oo$ and an annual monthly mean of 22.84 $^{o}/oo$. The bottom of the water column had a similar monthly mean salinity range of 21.50 - 27.61

^{o}/oo and an annual monthly mean of 23.86 ^{o}/oo. Surface and bottom monthly mean salinities normally differed by no more than 0.8 ^{o}/oo. Vertical salinity profiles based on 1 m (3.3 ft) interval sampling confirmed the absence of a halocline. With a depth of over 6.0 m (20 ft), the salinity gradient was usually less than 1.0 ^{o}/oo for the entire water column.

The annual monthly means at the surface of Lagoon A08 were 22.72, 23.23, and 23.10 ^{o}/oo for study years I, II, and III, respectively, while corresponding bottom values were 23.76, 24.50, and 24.03 ^{o}/oo. Based on the monthly means, surface-bottom salinity differences were less than 3.5 ^{o}/oo with most of these differences less than 1.0 ^{o}/oo. However, during the winter (January in particular), there was a sharp halocline located at 3-4 m (10-13 ft). In study year II, when surface bottom differences of 3.39 (January) and 3.50 (February) ^{o}/oo occurred, the sharpest gradient existed in the 1 m (3.3 ft) directly above the bottom.

Lagoon B24 exceeded 8.0 m (26 ft) in depth in areas and was sampled down to 6.0 m in this study. The salinity gradient was very pronounced most of the year (Figure 16). Differences between the surface and bottom monthly mean salinities reached 6.68 ^{o}/oo. Only around the June and the October-November period were they less than 1.0 ^{o}/oo. The annual monthly means at the surface were 21.51 (study year I) and 21.94 ^{o}/oo (study year II). The corresponding bottom (6.0 m) values were 23.99 and 24.73 ^{o}/oo. The monthly mean bottom salinities were typically confined to a narrow range between 23 and 25 ^{o}/oo. Corresponding surface values varied over a much wider range, 19 - 24 ^{o}/oo.

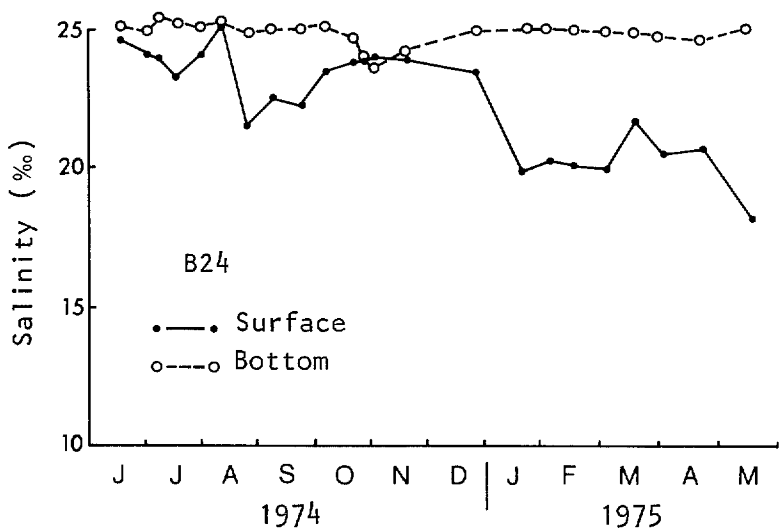

Fig. 16. Salinity levels at the surface and bottom of Lagoon B24 during study year II.

Diel studies were also done at Lagoon A08 in August 1973, October 1973, December 1973, and May 1974. In contrast to Dinner Point Creek, there was almost no variation in the salinity during any of the 24 hour test periods (Figure 17). This reflects low flow and limited circulation.

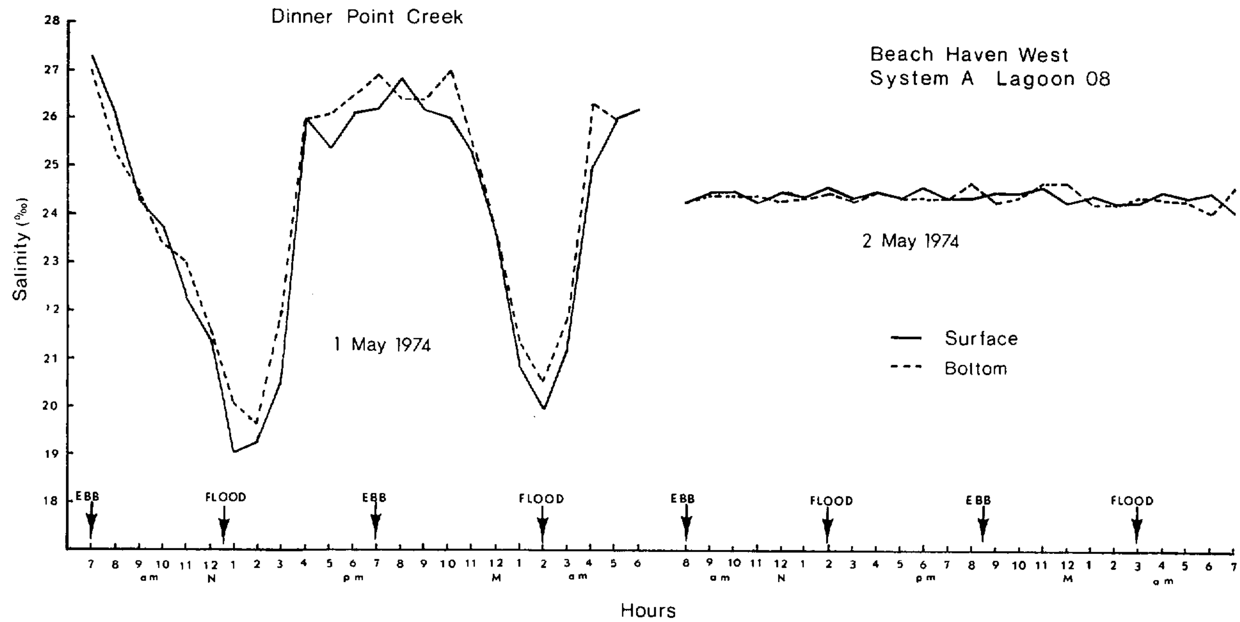

Fig. 17. Diel salinity variation at Dinner Point Creek and Lagoon A08, May 1974.

Surveys throughout the Village Harbour system on 9 July 1974 and 8 February 1975 indicate salinity stratification is particularly strong in the Mill Creek system (Lagoon System E) and the more remote stations (Figure 18).

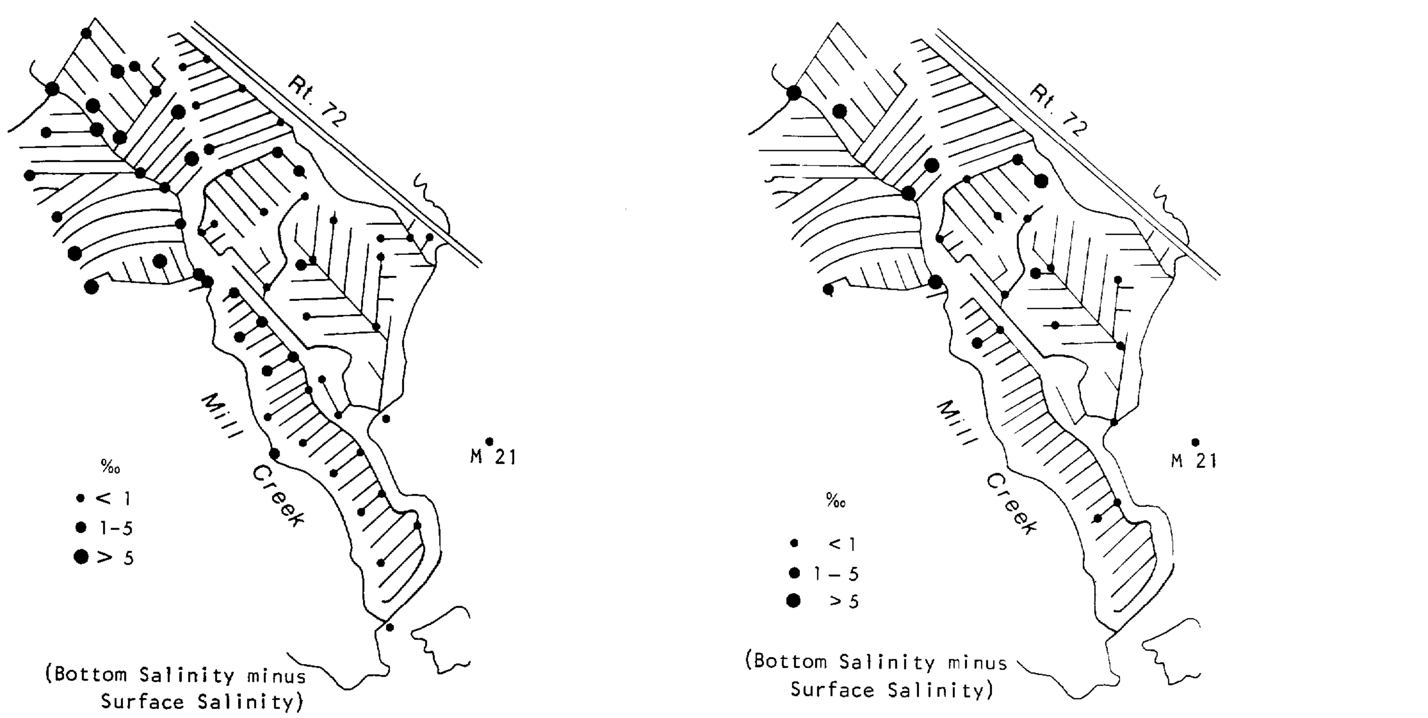

Fig. 18. Surface minus bottom salinity differences in Village Harbour, study year II.

Bay -- In the bay, there were nine stations (MB 1, MB 2, MB 5, MB 6, MB 7, MB 8, MB 9, MB 10, and MB 11A) which are shown in Figure 19. A summary of the salinity data for each station is given in Table 9. Although the salinity varied, the seasonal patterns at all the stations were similar. The salinities were higher in the summer and fall than in the winter and spring (Figure 20). This again coincided with the dry and wet season regime established by rainfall and evapotranspiration.

No steep haloclines were observed; however, horizontal gradients were present. Along the main axis, salinities increased as the distance to Beach Haven Inlet (MB 1) decreased. Monthly mean salinity at the sites along Long Beach Island, MB 8, MB 5, and MB 1 increased 2 - 3 $^{o}/oo$ between each station proceeding in a southerly direction. Salinities at stations MB 9, MB 7, MB 6, MB 2, and MB 1 along the western margin of the bay exhibited the same trend. This indicates the principal source of saline water for the entire back bay study area was Beach Haven Inlet. In a cross-bay direction, salinity values were relatively uniform. MB 5 and the parallel MB 6 station showed relatively small differences in salinity levels. On this basis, the bay is considered well-mixed. However, data from stations MB 7 and northward indicated the areas adjacent to the streams and western shore are subject to greater freshwater inputs.

The influence of tidal forces was emphasized by surveys made on flood (June 1975) and ebb (July 1975) tides (Figure 21). Salinities at a station varied 4 - 5 $^{o}/oo$ and isohaline were displaced several km with a change in tides. These surveys also reinforced the concept of strong freshwater influence along the western bay margin, particularly around Mill Creek.

Overall, the stations MB 11A, MB 10, MB 9, and MB 8 represent the region of low salinity in the study area. MB 1 represents the region of high salinity water. Other sites are transitional between these two extremes. The freshwater drainage mixed with the bay water adjacent to its point of entry into the bay. Through tidal action, the water is eventually transported out of the inlet. The net effect is a gradient with the less saline water temporarily retained in the remote end of the study area or near its point of entry. Note that a similar situation could be expected in the region between Barnegat Inlet and Sandy Island and would impede any rapid northward movement of the accumulated freshwater.

Physical and Chemical Characteristics of the Study Area: Soil Salinity

Soil salinity is a product of tidal flooding, precipitation, and evapotranspiration among other factors. It has been implicated along with tidal inundation (Adams 1963; Good 1965, 1972) as a possible cause for the growth height differences in *Spartina alterniflora*. The potential exists then for salinity to exert influence on the productivity of the emergent macrophyte community.

The purpose of this study is to: (1) examine the soil salinity levels and their seasonal patterns in the major vegetation types present, and (2) evaluate the differences in soil salinity between the vegetation types.

METHODS AND MATERIALS -- During the period October 1973 - April 1976 in the general area of Mud Cove, soil salinities within five major vegetation types were measured. These types were *Spartina patens* (SP), *Spartina alterniflora* short form (SAS),

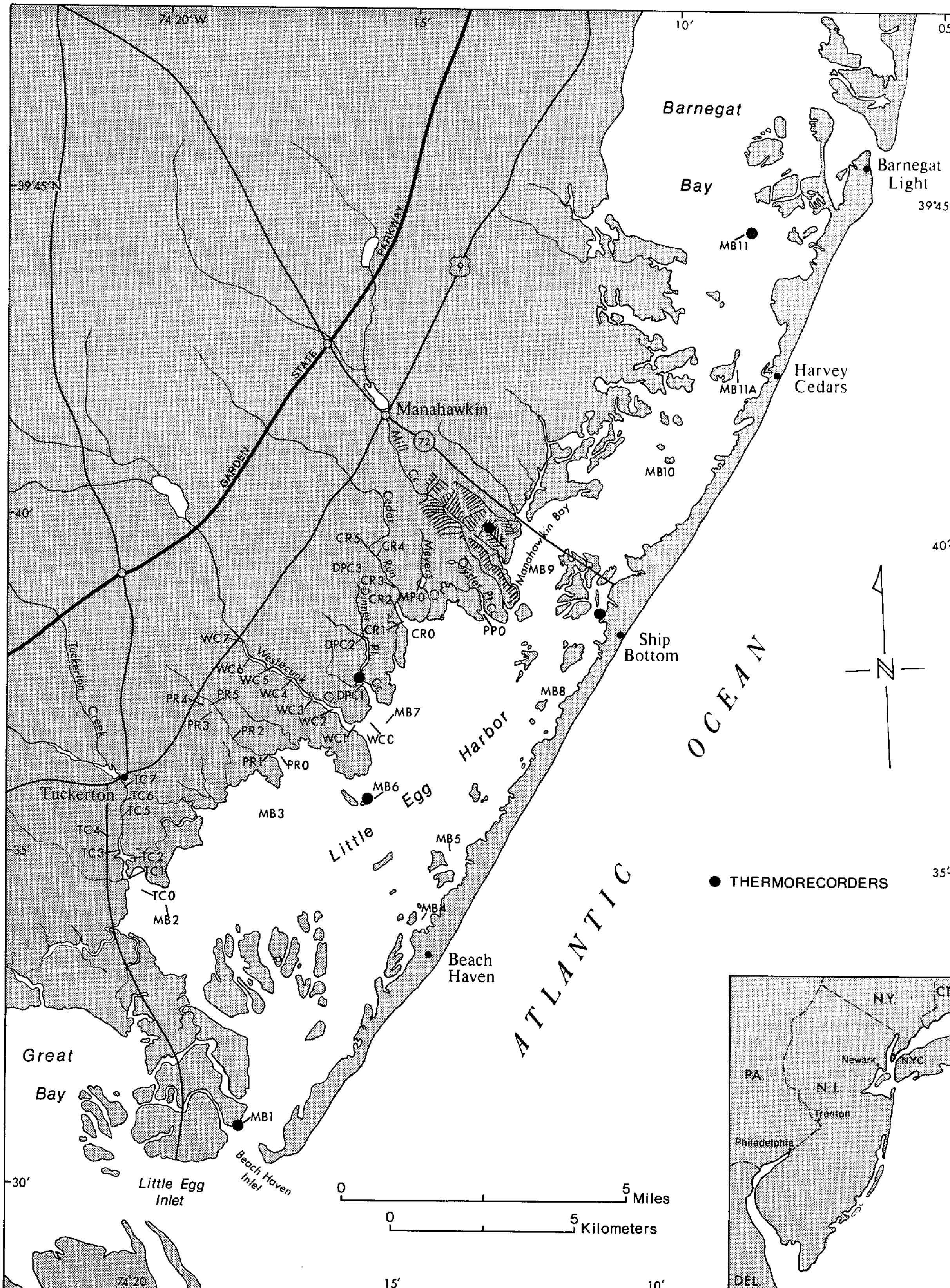

Fig. 19. Sampling stations in the Little Egg Harbor - Manahawkin Bay system.

Table 9. Summary of the salinity data for the bay sites during study year II.

Site	Depth	Monthly mean range ($^{o}/oo$)	Annual monthly mean ($^{o}/oo$)	No. of observations (months)
MB 1	Surface	31.80-28.35	30.44	12
	Bottom	31.80-29.40	30.60	12
MB 2	Surface	30.80-26.60	28.73	12
	Bottom	30.30-26.45	28.62	12
MB 5	Surface	29.20-25.10	27.39	12
	Bottom	29.00-25.30	27.56	12
MB 6	Surface	28.70-23.60	27.06	12
	Bottom	29.60-24.30	27.28	12
MB 7	Surface	27.63-23.58	26.07	12
	Bottom	27.93-23.78	26.26	12
MB 8	Surface	26.80-22.85	24.96	12
	Bottom	26.90-22.95	25.23	12
MB 9	Surface	26.80-21.83	24.38	12
	Bottom	26.73-22.00	24.53	12
MB 10	Surface	26.50-21.90	24.74	11
	Bottom	26.40-21.90	24.75	11
MB 11A	Surface	26.15-21.90	24.66	11
	Bottom	26.70-21.50	24.72	11

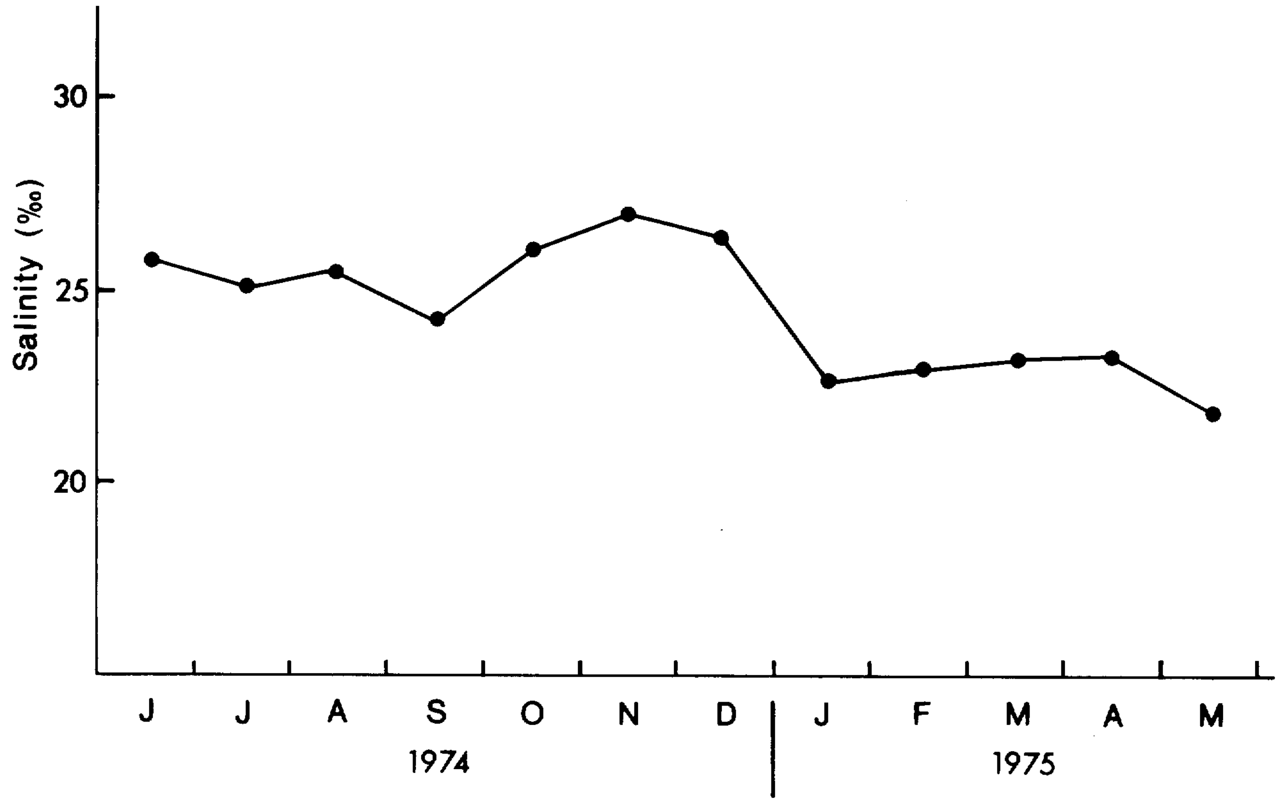

Fig. 20. Monthly mean salinities at MB 9 (Marker 21) for study year II.

Spartina alterniflora tall form (SAT), *Distichlis spicata* (DS), and *Distichlis spicata - Juncus gerardi* (DS-JG). The method used was after Good (1965) and employed a RB4-250 Beckman Solubridge conductivity meter. Surface samples were taken throughout this time. During 13 October 1975 - 26 April 1976, samples at the surface and at 10 cm depth were taken. Precipitation and tidal inundation data were also collected.

RESULTS AND DISCUSSION -- Mean surface salinities for five major vegetation types are given in Table 10. Large short-term variations occurred. These changes reflect the influence of precipitation and tidal flooding. However, there is an overall seasonal pattern. The summer and fall seasons were the periods of maximum values and the winter and spring the seasons of minimal values. As with the aquatic salinities, this pattern of annual variation correlates with the potential evapotranspiration rainfall cycle for the Manahawkin area.

Mean salinity for the entire study period was greatest at the SAT stations followed by SAS, DS, DS-JG, and SP stations. These data are consistent with the flooding patterns of the various areas. Less frequent flooding and dilution effects by precipitation would favor lower soil salinities at the stations of higher elevation. Height above mean low water for the SAT, SAS, and SP stations was 0 - 15, 35 - 37, and 44 cm, respectively. Consequently, the SAT stations flooded more frequently than the SAS and SP.

Salinities varied most in the SAT area (coefficient of variation = CV = 49) followed by SAS (CV = 43), DS (CV = 43), SP (CV = 35), and DS-JG (CV = 29). The variability at the SAT stations is somewhat unexpected considering the moderating

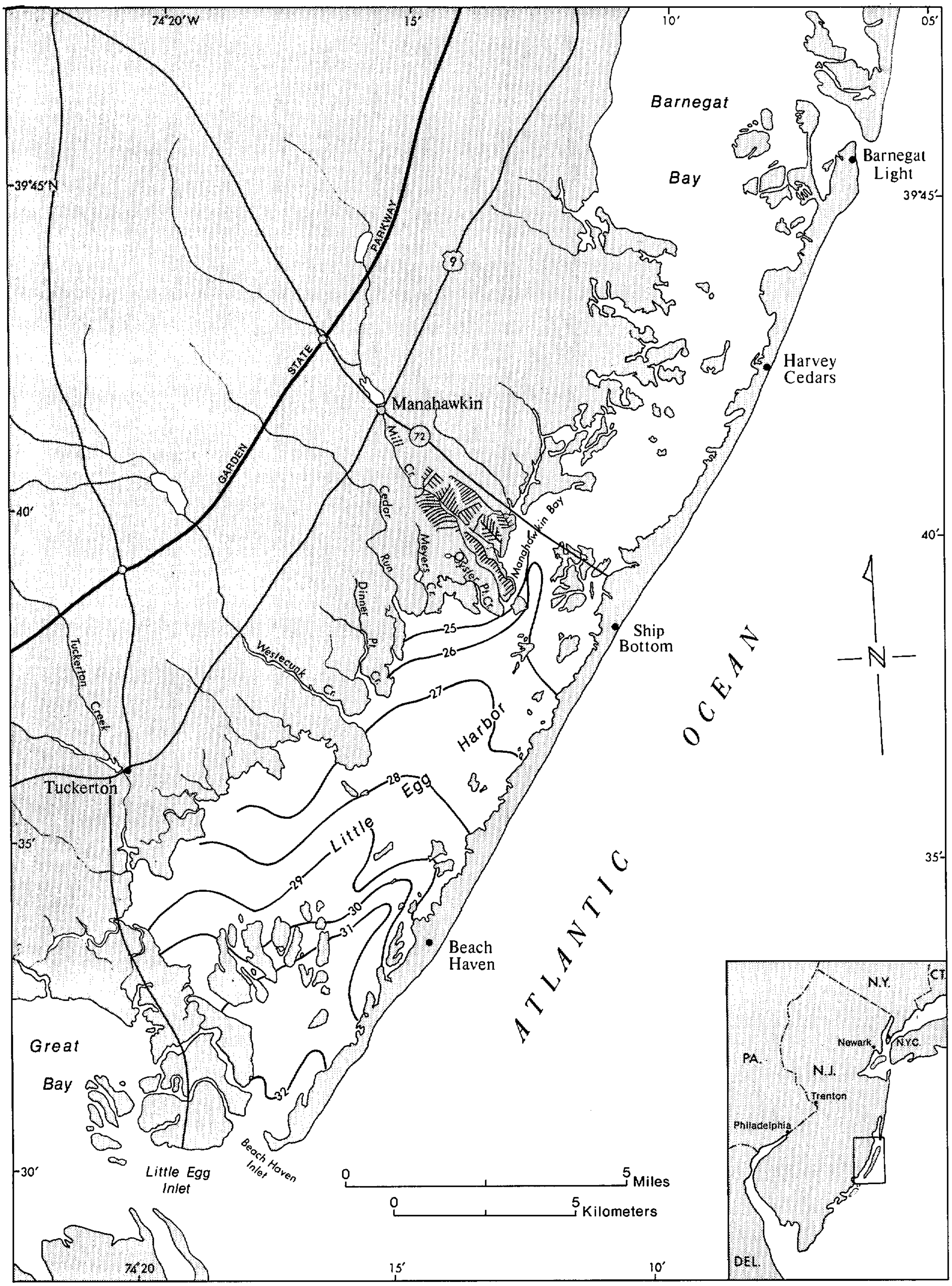

Fig. 21. Isohalines on a flood tide, June 1975 and on an ebb tide, July 1975.

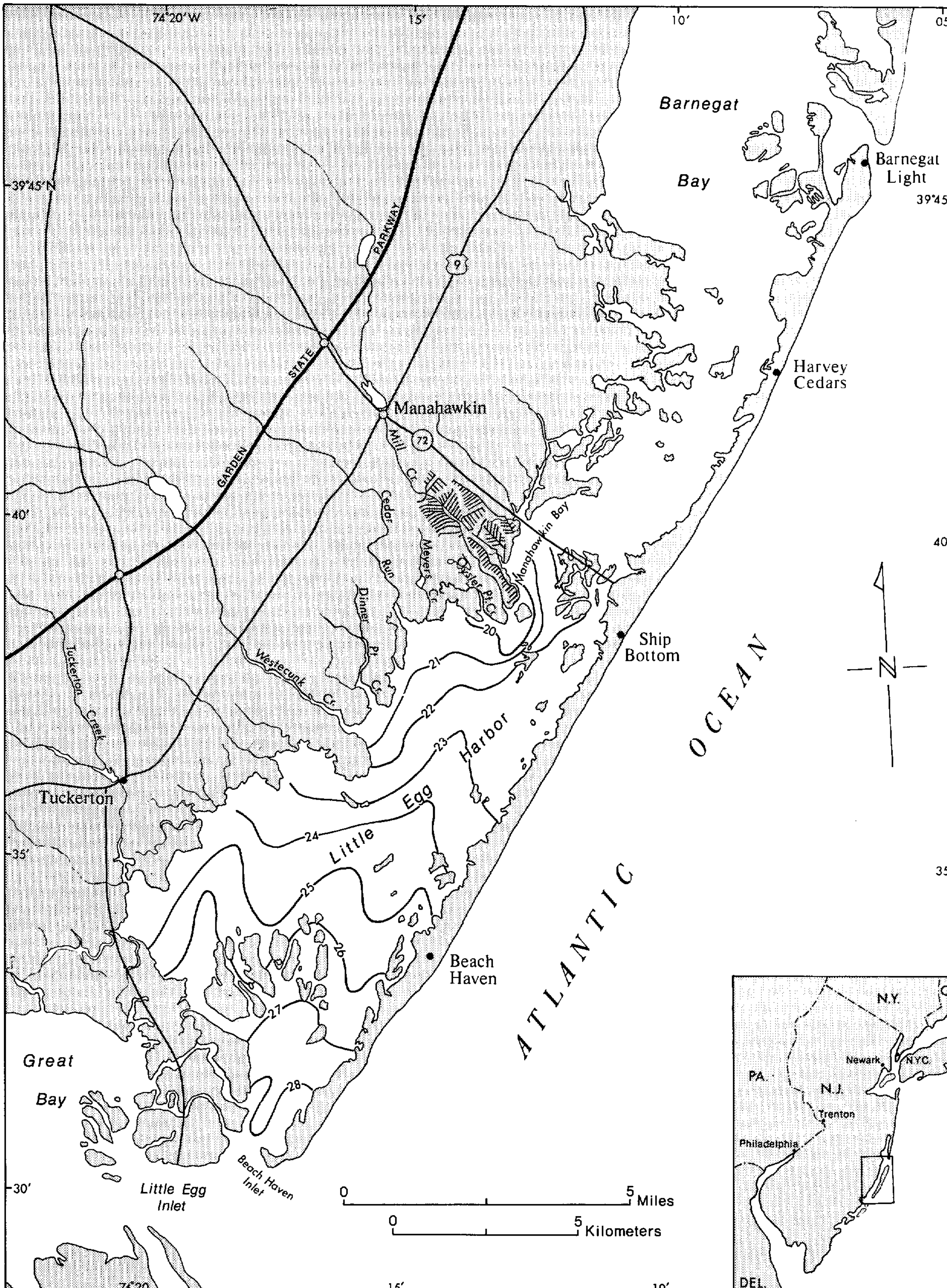

Fig. 21. Continued.

Table 10. Mean mud salinity values ($^{o}/oo$) for the five major vegetation types from 3 August 1973 to 21 April 1975.

Date	*S. patens*	*S. alterniflora* short	*S. alterniflora* tall	*Distichlis spicata*	*D. spicata/ Juncus*
8-3-73	16.6	26.2	37.5		22.1
8-9-73	25.1	49.9	53.6		18.5
8-16-73	12.6	23.0	22.1	21.4	13.9
8-23-73	18.0	18.4	24.0	9.5	19.7
8-30-73	18.7	24.9	36.0	24.4	21.2
9-7-73	32.6	36.0	93.3	46.4	22.9
9-12-73	30.7	38.5	61.2	58.4	26.3
9-19-73	14.9	18.7	24.0	23.4	18.1
9-26-73	13.1	19.7	20.3	22.0	18.8
10-3-73	14.8	19.8	30.6	24.1	21.3
10-20-73	25.6	43.6	67.0	31.5	35.1
10-27-73	18.6	22.3	28.8	35.7	21.3
11-3-73	19.4	25.0	30.4	26.2	18.4
11-7-73	23.1	28.0	25.3	26.4	25.8
11-14-73	15.0	21.5	31.7	22.1	17.3
11-21-73	26.0	37.3	21.9	21.3	20.0
11-28-73	16.5	20.5	24.4	19.3	18.8
12-8-73	18.6	21.5	27.1	13.7	18.5
12-12-73	15.7	20.6	22.5	33.1	20.5
12-26-73	11.6	15.4	18.2	17.3	11.5
1-17-74	9.7	14.2	12.8	15.1	10.7
1-23-74	8.9	11.1	12.5	12.7	10.4
2-20-74	10.3	13.9	15.4	14.3	13.5
3-6-74	13.5	16.9	19.5	15.2	14.3
3-27-74	11.1	23.6	33.0	10.5	15.0
4-3-74	11.2	17.2	15.7	17.1	13.2
4-17-74	10.3	24.6	33.2	18.7	15.4
4-24-74	14.9	24.7	32.5	14.4	29.1
5-7-74	20.8	25.3	29.7	11.5	16.4
5-16-74	14.5	42.5	36.7	19.4	29.3
5-23-74	16.3	48.6	27.9	18.9	20.1
5-30-74	15.1	25.9	30.5	22.7	23.0
6-5-74	14.2	26.6	23.4	21.7	
6-11-74	19.1	43.5	28.1	13.8	
6-17-74	29.2	58.7	55.1	31.8	
6-25-74	16.1	23.4	25.7	18.0	
7-1-74	15.2	19.0	28.7	23.3	
7-8-74	18.1	40.7	33.3	58.7	
7-15-74	20.1	56.9	56.3	22.7	
7-22-74	22.3	34.9	68.3	27.4	
7-29-74	28.3	52.5	61.7	29.7	
8-5-74	34.3	58.3	69.8	31.5	
8-14-74	15.7	29.5	24.8	23.6	
8-25-74	15.9	21.4	25.6	21.8	
9-9-74	11.7	18.6	17.6	23.4	
10-2-74	16.6	32.3	31.5	34.5	

Table 10. Continued.

Date	*S. patens*	*S. alterniflora* short	*S. alterniflora* tall	*Distichlis spicata*	*D. spicata/ Juncus*
10-20-74	16.7	24.9	28.8	32.8	
11-6-74	11.3	25.5	20.9	27.6	
11-27-74	18.7	27.5	27.6	24.6	
12-30-74	18.2	21.7	23.0	25.7	
1-28-75	6.8	12.7	14.9	12.0	
3-5-75	11.0	21.1	22.3		
4-21-75	13.3	24.1	27.7	22.2	
Mean $\pm$ 1 SD	17.3$\pm$6.1	28.2$\pm$12.2	32.3$\pm$15.8	23.9$\pm$10.2	19.4$\pm$5.6

influence of the creek waters. This apparent discrepancy was largely due to the inclusion of data from a single aberrant station.

Soil salinity at 10 cm exceeded surface values at the SAS stations, but were only slightly higher at the more flooded stations.

Physical and Chemical Characteristics of the Study Area: Temperature in the Aquatic Zone

Like salinity, water temperature is an important environmental component. We are primarily interested in temperature's role in relation to stratification.

The purpose of the study is to determine: (1) seasonal water temperature patterns; (2) site differences; (3) diel variation; and (4) the vertical gradients present.

METHODS AND MATERIALS -- Yellow Springs Instrument thermistors, FT_3 Marine Hydrographic thermometers, and modified Model D Ryan thermographs were the devices used in the study. Sampling was done concurrently with the salinity determinations except for the thermographs which provided long-term continuous monitoring. Waterway, vertical gradient, diel, and general survey studies were done. The selection of the data sets used in this analysis paralleled those used in the salinity analysis. Additional information on methods and materials are available in Durand et al. (1974, 1975, 1976, 1977) for the marsh and lagoon systems and McClain et. al. (1976) for the bay.

RESULTS AND DISCUSSION -- Listed in Table 11 are water temperature ranges for a number of stations. All surface values followed the same seasonal pattern. Maximum values were measured during the July - August period, and minimum values were detected during January or February. The seasonal temperature pattern at MB 9, a bay station, is typical (Figure 22).

Local climate influenced the water temperature values, particularly in shallow areas or in areas of the bay where tidal influences were reduced. Creeks because

Table 11. Monthly mean water temperature ranges for study year II.

Site	Depth	Ranges (°C)	Ranges (°F)
Natural Creek:			
Dinner Point Creek mouth	Surface	<0.0 - 25.6	<32.0 - 78.1
	Bottom	0.1 - 24.2	32.2 - 75.6
Meyers Creek mouth	Surface	<0.0 - 24.8	<32.0 - 76.6
	Bottom	2.2 - 24.8	36.0 - 76.6
Meyers Pond	Surface	<0.0 - 24.2	<32.0 - 75.6
Partially Disturbed Creeks:			
Mill Creek mouth	Surface	0.0 - 25.6	32.0 - 78.1
	Bottom	0.0 - 25.4	32.0 - 77.7
Upper Mill Creek	Surface	1.0 - 25.7	33.8 - 78.3
Fully Lagooned Waterways:			
Lagoon A08	Surface	0.5 - 26.8	32.9 - 80.2
	Bottom	3.5 - 23.0	38.3 - 73.4
Lagoon B24	Surface	1.2 - 26.2	34.2 - 79.2
	Bottom	6.5 - 15.4	43.7 - 59.7
Bay:			
Beach Haven Inlet (MB 1)	Surface	4.0 - 21.7	39.2 - 71.1
	Bottom	4.0 - 21.8	39.2 - 71.2
Marshelder Island (MB 5)	Surface	3.5 - 25.9	38.3 - 78.6
	Bottom	3.5 - 25.5	38.3 - 77.9
Marker 21 (MB 9)	Surface	3.2 - 26.1	37.8 - 79.0
	Bottom	3.0 - 25.8	37.4 - 78.4
Sandy Island (MB 11A)	Surface	3.0 - 27.7	37.4 - 81.9
	Bottom	3.0 - 27.3	37.4 - 81.1

of their shallow depth and well mixed nature could rapidly reach equilibrium with the air temperature.

This explained why the creek water temperature ranges were among the largest. The surface layers of the lagoons exhibited similar ranges, although there was a tendency for the lagoons to be warmer than the creeks. Increased retention time of the water in the lagoon systems and the consequent prolonged exposure with minimum circulation would account for this.

Near the inlet, the bay water temperature range was minimized reflecting the ocean water input. With increasing distance from the inlet, prevailing air temperatures exerted more influence and wider temperature ranges were observed.

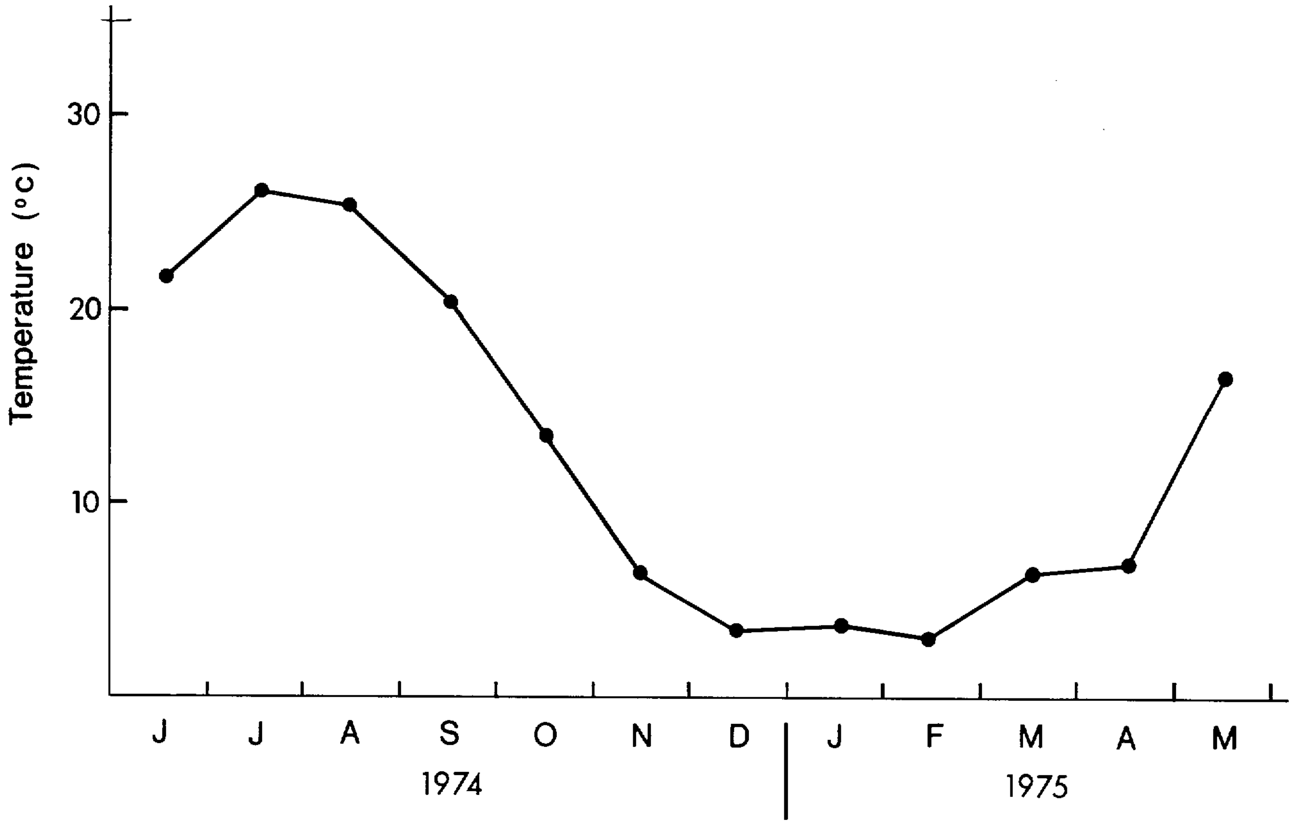

Fig. 22. Monthly mean temperatures at MB 9 (Marker 21) for study year II.

The majority of the study stations did not demonstrate a steep vertical temperature gradient because wind and tidal action kept their water columns relatively well mixed. This was the case for the bay, creek, and Mill Creek stations; however, there existed a much different situation in the lagoon systems. Here, strong thermoclines were detected primarily in the summer and to a lesser extent during the winter. This was confirmed by lagoon system surveys on 26 June 1973, 7 March 1974, 9 July 1974, 8 February 1975 (Figure 23). The development and persistence of these gradients seemed to be a function of the station depth and remoteness from the bay. Table 12 lists examples of vertical gradient data found at the fully lagooned waterway stations. Figure 24 shows the temperature contours at Lagoons A02 and A08 for comparison.

The data supports the contention Lagoon A02 has the weakest thermocline of the three and Lagoon B24 the strongest. Only in the spring did a steep vertical gradient exist in Lagoon A02. Except for periods in the fall and spring, a very strong thermocline was present at Lagoon B24. This gradient was particularly strong in the summer and during the winter took the form of an inverse thermocline. Typically, the steepest part of the thermal gradient was located at depths around 2 m (6.6 ft.) or greater and achieved surface bottom differences between monthly means in excess of 14 and 5 ^{o}C (25.2 and 9 ^{o}F) during the summer and winter, respectively. Lagoon A08 also had a strong thermocline in the summer and exhibited an inverse thermocline in the winter; however, it was not as steep or persistent a gradient as at Lagoon B24.

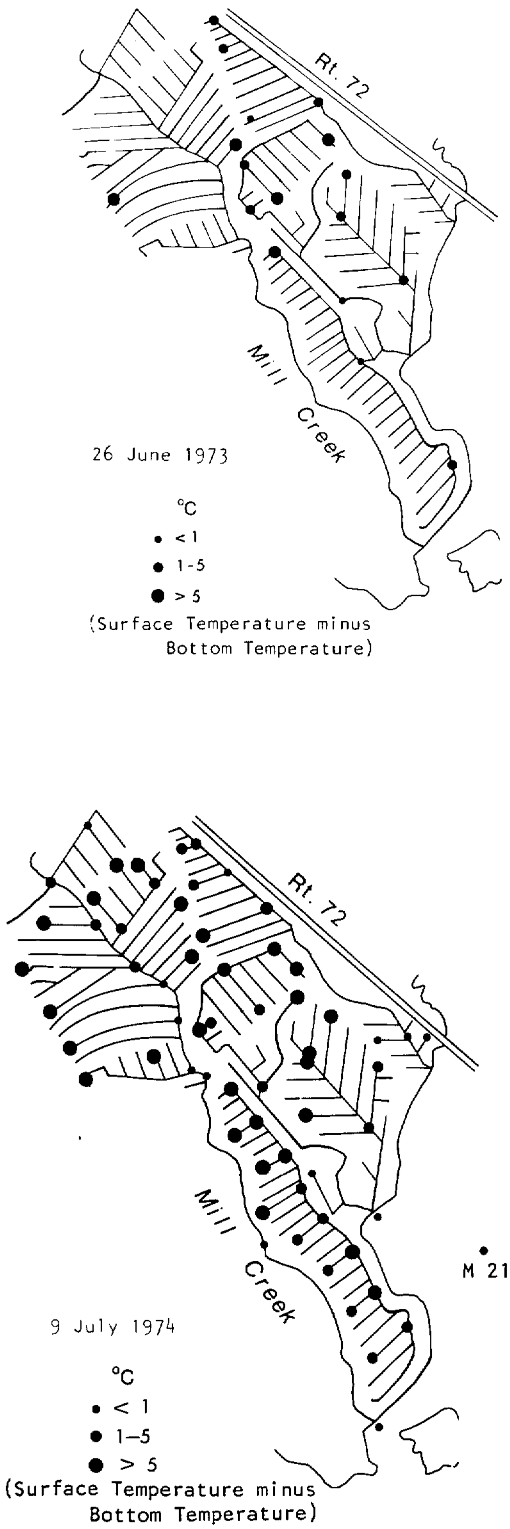

Fig. 23. Surface minus bottom temperature differences in Village Harbour, study years I and II.

Table 12. Vertical temperature gradients for lagoons with different total depths and remote point distances.

Date	Depth (m)	Lagoon A08 (°C)	Lagoon A08 (°F)	Lagoon B24 (°C)	Lagoon B24 (°F)
20 July 1974	0.2	27.0	80.6	25.8	78.4
	1.0	26.5	79.7	25.6	78.1
	2.0	26.0	78.8	25.2	77.4
	3.0	24.5	76.1	22.0	71.6
	4.0	20.0	68.0	19.1	66.4
	5.0	17.8	64.0	16.9	62.4
	6.0			14.5	58.1
	7.0			13.0	55.4
	8.0			12.0	53.6
22 October 1974	0.2	11.2	52.2	12.2	54.0
	1.0	11.1	52.0	12.2	54.0
	2.0	10.8	51.4	11.9	53.4
	3.0	10.5	50.9	11.9	53.4
	4.0	10.1	50.2	11.8	53.2
	5.0			11.8	53.2
	6.0			11.7	53.1
21 January 1975	0.2	0.5	32.9	1.2	34.2
	1.0	0.6	33.1	2.0	35.6
	2.0	2.0	35.6	4.2	39.6
	3.0	2.8	37.0	6.0	42.8
	4.0	5.5	41.9	6.2	43.2
	5.0	7.2	45.0	6.2	43.2
	6.0			6.5	43.7
22 April 1975	0.2	10.4	50.7	9.8	49.6
	1.0	10.2	50.4	10.1	50.2
	2.0	10.2	50.4	10.3	50.5
	3.0	10.2	50.4	9.0	48.2
	4.0	10.2	50.4	8.0	46.4
	5.0	9.8	49.6	8.0	46.4
	6.0			8.2	46.8
	7.0			8.4	47.1

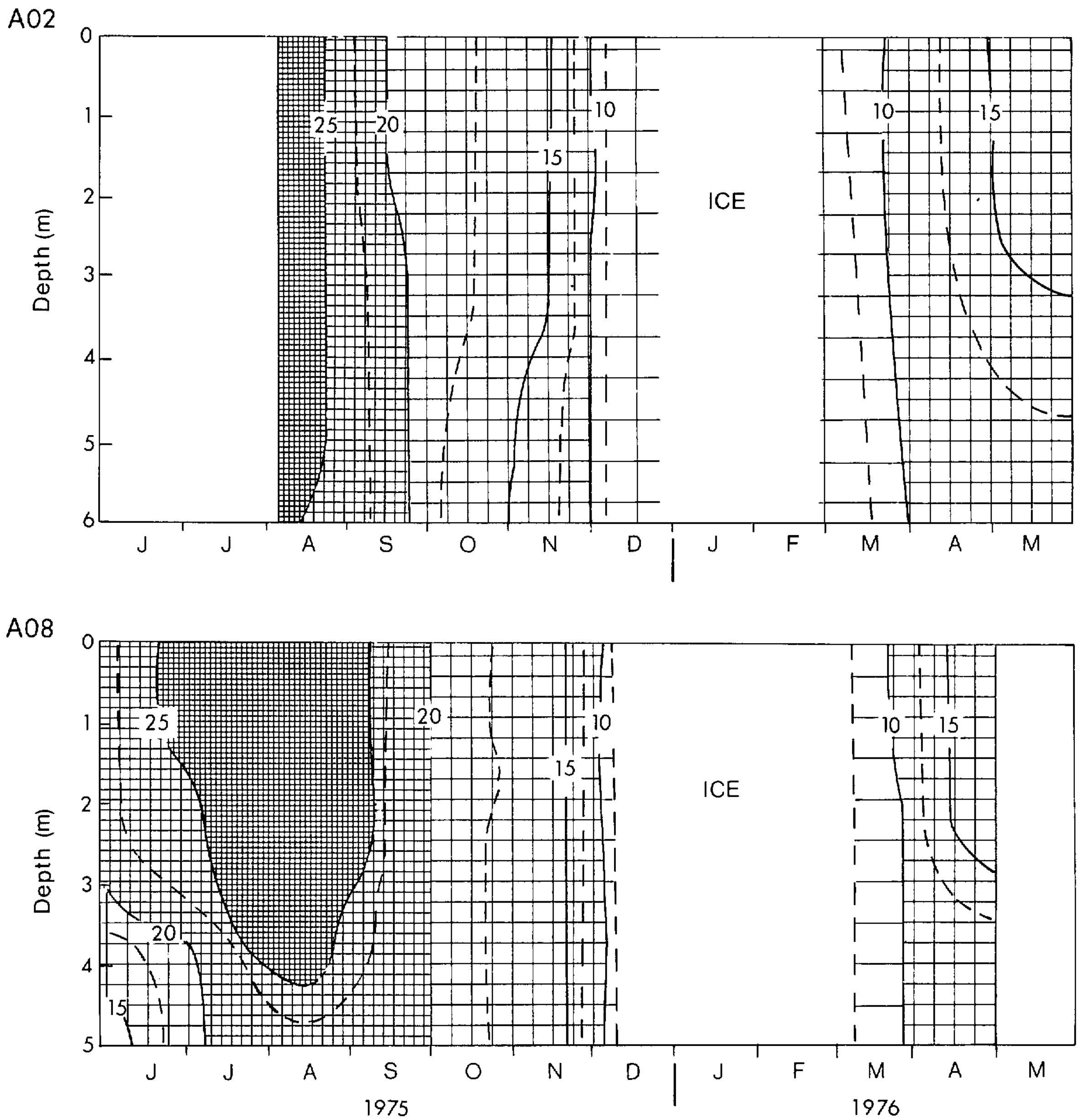

Fig. 24. Contoured water temperature plots for Lagoons A02 and A08 in °C.

Physical and Chemical Characteristics of the Study Area: Soil Temperature

METHODS -- Soil temperatures were studied in the SAT, SAS, SP, and mudflat areas during study year IV.

RESULTS AND DISCUSSION -- Surface soil temperatures are given in Table 13. Such results reflect the seasonal pattern occurring in the adjacent Meyers Creek, with maximum temperatures recorded in July and lowest temperatures in November. The average temperatures recorded for the mudflat and the SAT area most closely approximated that of the creek, with occasionally higher temperatures observed in the SAS and lower temperatures under the densely matted SP.

Table 13. Surface soil temperatures. Source of data: Durand (pers. comm.).

Date	SAT (°C)	SAT (°F)	SAS (°C)	SAS (°F)	SP (°C)	SP (°F)	Mudflat (°C)	Mudflat (°F)
20 May 1976	14.4	57.9	16.9	62.4	11.4	52.5	14.7	58.5
15 July 1976	24.7	76.5	25.7	78.3	21.7	71.1	23.0	73.4
13 September 1976	18.7	65.7	20.5	68.9	19.9	67.8	19.3	66.7
24 November 1976	0.4	32.7	0.0	32.0	0.4	32.7	0.0	32.0
12 May 1977	11.8	53.2	11.7	53.1	9.5	49.1	13.2	55.8

Physical and Chemical Characteristics of the Study Area: Dissolved Oxygen in the Aquatic Zone

Dissolved oxygen is an important factor because of its requirement in the metabolism of most biological life forms. Its study here serves a dual purpose as an indicator of poor circulation as well as high respiratory demand.

The purpose of the study is to determine: (1) seasonal trends; (2) site differences; (3) diel variations; and (4) vertical gradients.

METHODS -- Oxygen determinations were done using a modified Winkler titration. Sampling was done concurrently with the salinity and temperature work already discussed. Additional methods and materials information is available in Durand et al. (1974, 1975, 1976, 1977) for the marsh and lagoon systems and McClain et al. (1976) for the bay.

RESULTS AND DISCUSSION -- The solubility of oxygen in the water column is a function of temperature and salinity. Temperature is the most critical factor affecting potential oxygen levels in this study, particularly in the case of the surface waters. Oxygen concentrations were found to be inversely related to the temperature. Generally, dissolved oxygen levels in the surface waters ranged between 4 and 6 ml $O_2 \cdot l^{-1}$ (5.7 and 8.6 ppm) in the summer and fall. Higher levels, 7 - 8 ml $O_2 \cdot l^{-1}$ (10.0 - 11.5 ppm) occurred during the winter and spring. The bay pattern in Figure 25 is typical of lagoon stations as well as natural and modified creeks. One exception to this is Meyers Pond. The Meyers Pond summer values were much less than expected based on the bay station data. Apparently, the high production of the area and the benthic oxygen demand placed a large respiration drain on the oxygen concentrations in the pond. Dissolved oxygen levels did not drop to zero because the tidal exchange was sufficient to transport oxygen-rich bay water into the pond on the flood tide. During the cooler portions of the year, respiration was reduced and the drain on the oxygen stocks decreased.

The diel variation study at Dinner Point supported this explanation. Increased oxygen levels were associated more with high tide situations. This phenomenon was not observed in diel studies at Lagoon A08 (Figure 26).

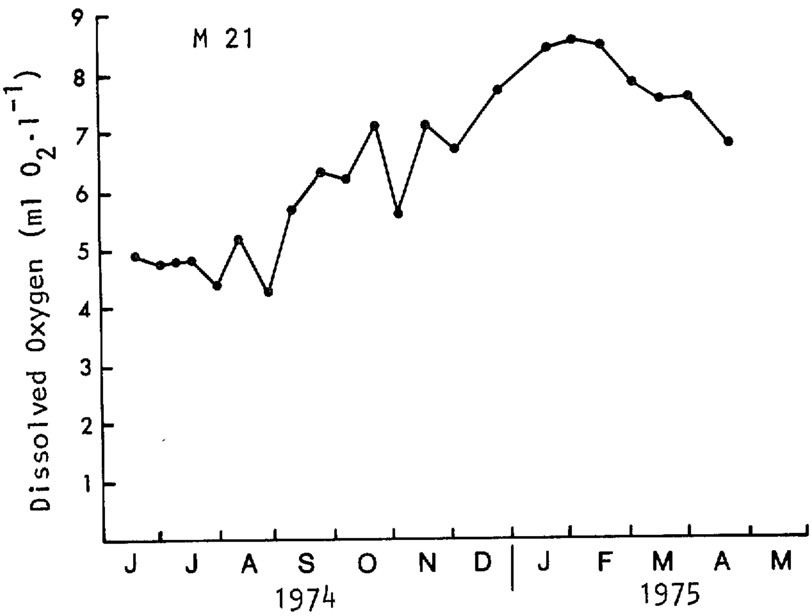

Fig. 25. Dissolved oxygen concentrations at Marker 21 in (ml $O_2 \cdot l^{-1}$).

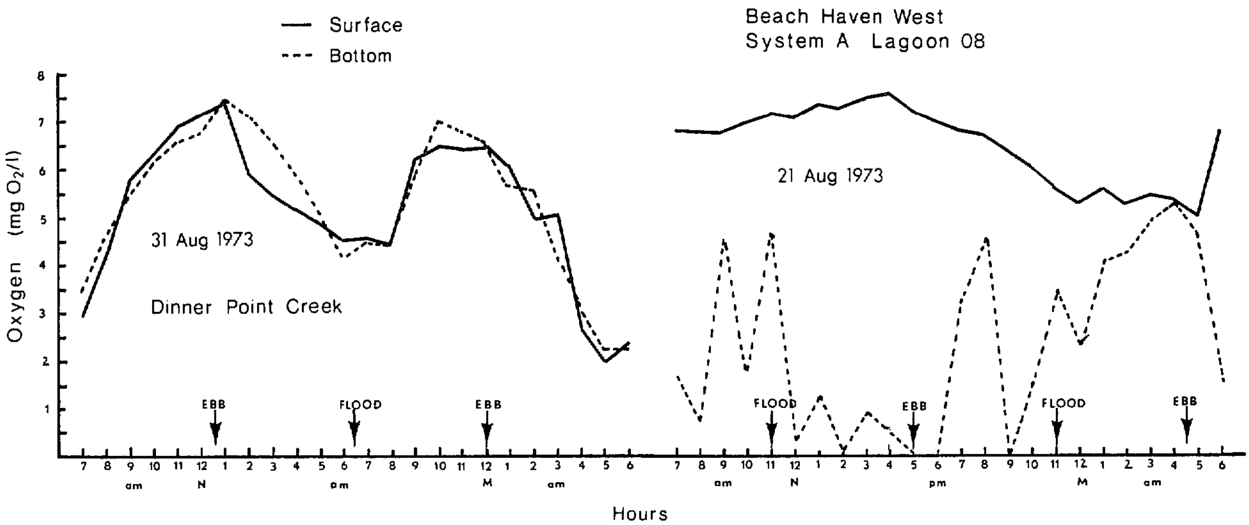

Fig. 26. Dissolved oxygen levels recorded during a 24 hour tidal survey, August 1973.

At the deeper or more remote lagoon stations, bottom dissolved oxygen levels were zero or very low during the summer. Based on the lagoon system surveys, such levels appeared to be widespread (Figure 27). Low levels were not as widespread during the cooler part of the year (Figure 28).

Lagoon A08 maintained prolonged anaerobic periods in the summer at the bottom and exhibited frequent oxygen level depressions during the rest of the year. At this station, these depressions often occurred during the winter (Figure 29).

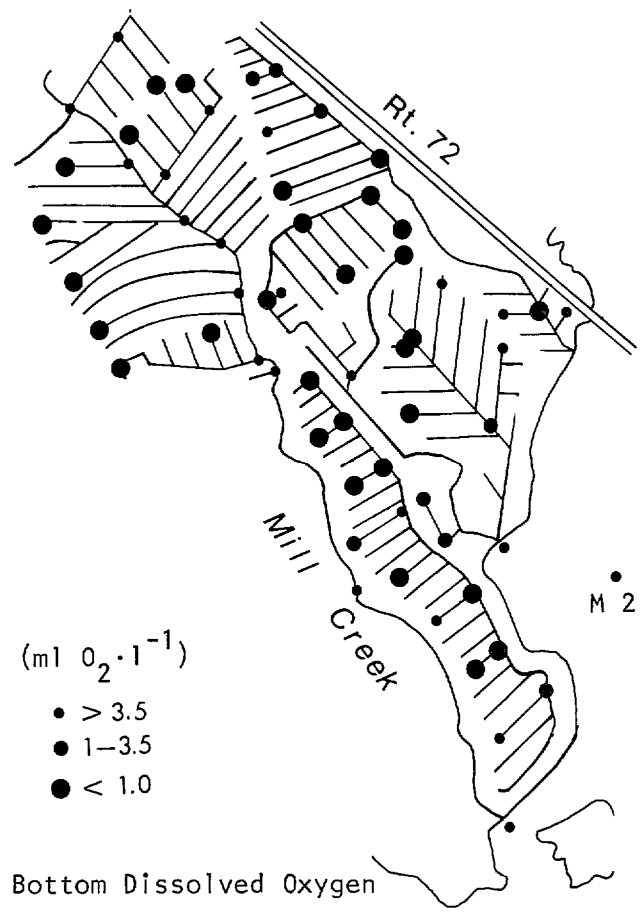

Fig. 27. Dissolved oxygen concentrations at the bottom of the lagoon systems on 9 July 1974.

Lagoon A02, however, was not like Lagoon A08. Periods of low oxygen conditions were limited in duration and occurrence compared to Lagoon A08 (Figure 30). Apparently, despite an increased depth at Lagoon A02, the circulation is sufficient to overcome the existing oxygen demand.

Lagoon B24 represents the most extreme gradient in the Village Harbour complex. Only during the late fall and winter did the bottom of Lagoon B24 become oxygenated (Figure 31).

Stratification

Stratification is a density phenomenon which divides a water body into distinct vertical zones between which mixing is restricted. Such an occurrence can exert great influence on the biota of a system because after a period of time anoxia and hydrogen sulfide production often result.

Several factors may combine to produce a stratified water body. Water temperature, salinity, and circulation factors are primary among them. Typically, in lagoon systems, circulation is limited because of the complicated channel

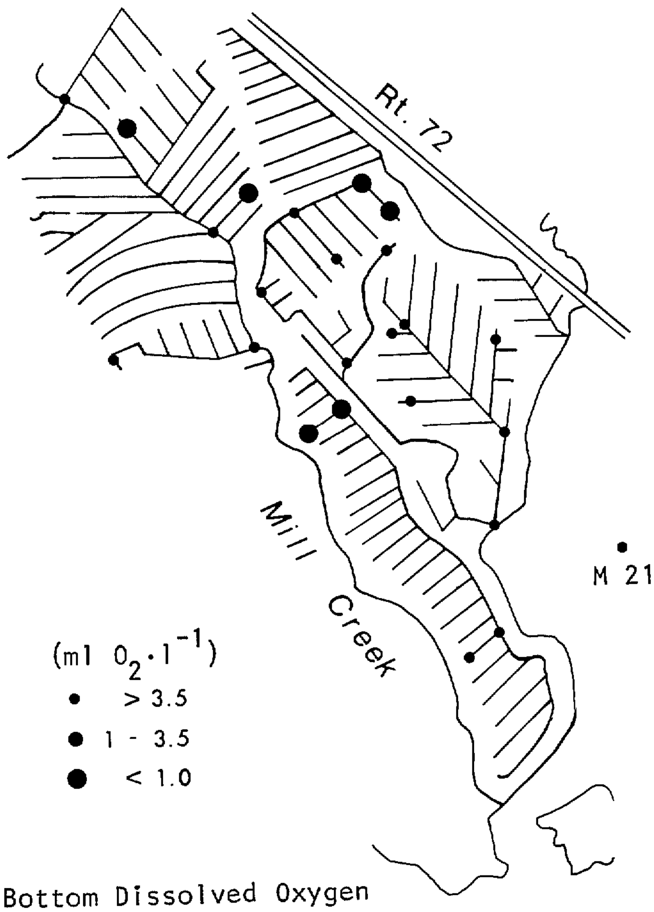

Fig. 28. Dissolved oxygen concentrations at the bottom of the lagoon systems on 8 February 1975.

configurations which enhance the probability of a stratified water column. Stratification and its effects have been recognized as a problem particularly in the waterfront communities of the Gulf of Mexico and the South Atlantic (Barada and Partington 1972; Lindall et al. 1975). They are not only restricted to coastal zone lagoon complexes in warmer climates. Daiber (1972) has also observed stratification and anoxia in Delaware systems.

In this study, the degree and seasonal pattern of stratification in the marsh systems, the lagoon development, and the back bay system were evaluated. The results indicate stratification is largely confined to the developed portions of the study area. Locations either relatively deep or removed from the bay are especially subject to this problem. In most cases, sharp temperature gradients were the cause of the observed stratification. Steep salinity gradients periodically caused or maintained stratification; however, they generally were only contributory.

Several structural features of the lagoon complex favor its formation. The back bay system averages 2 m (6.6 ft) in depth and the lagoons in excess of 3 m. Because they are deeper, the lagoons can trap and hold the water below 2 m behind the sill at the mouth of the lagoon network. In the Lagoon System A, over 20% of the volume is below 2 m. The bottoms of the lagoons are irregular and depths in excess

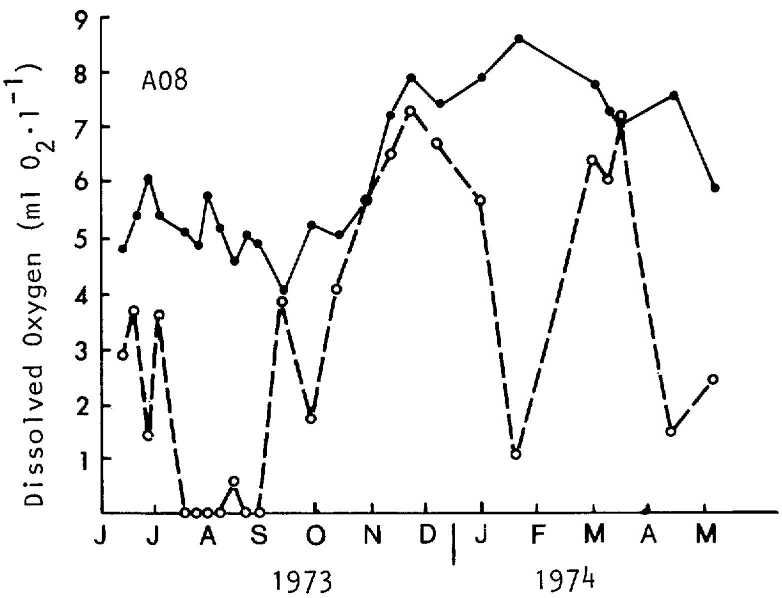

Fig. 29. Dissolved oxygen values at the surface and bottom of Lagoon A08.

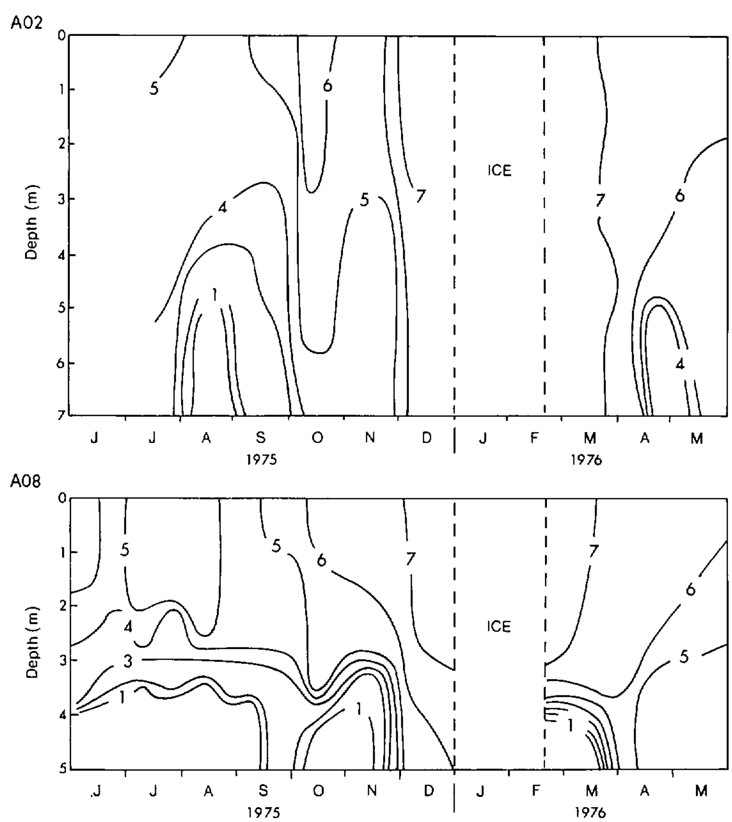

Fig. 30. Contoured dissolved oxygen concentrations for Lagoons A02 and A08 in (ml $O_2 \cdot l^{-1}$).

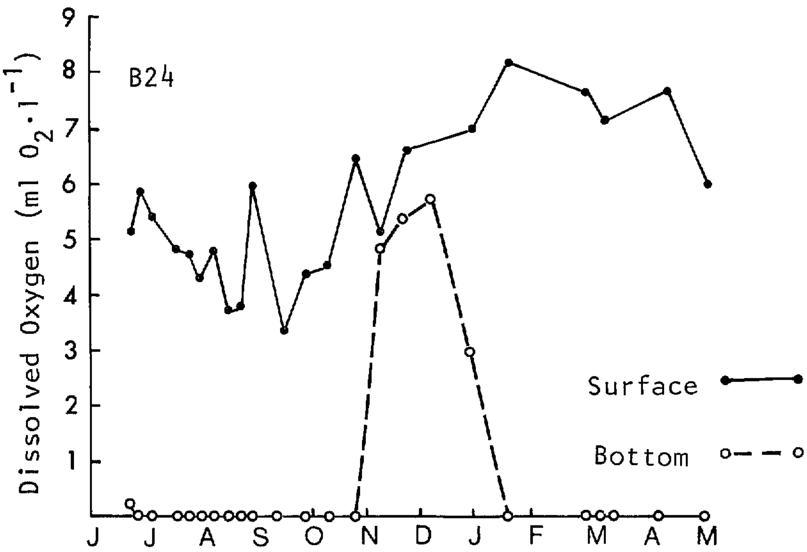

Fig. 31. Dissolved oxygen values at the surface and bottom of Lagoon B24.

of 8 m exist. In Figure 32 are longitudinal sections down the midlines of Lagoon System A which illustrate the variable nature of the bottom profile. Deep potholes are a regular occurrence, and with increasing depth, the trapping effect on the water is increased.

The great lengths of the lagoon networks also decrease the exchange of water between the bay and the more remote stations. The main channel of Lagoon System B is over 2,400 m (7,874 ft) long and has a convoluted configuration. The total length of lagoons in the system is 5,452 m (17,888 ft). Lagoon System A has a main channel length of 1,063 m (3,488 ft) and 4,370 m (14,338 ft) of lagoons. During a tidal cycle, exchange of water over these distances will be limited, if at all.

The dead end nature of the lagoons eliminates the possibility of flow through circulation. Consequently, the flooding tide traps the waters in these dead ends. Exchange requires several tidal cycles, and residence times of waters in these ends are correspondingly long.

The narrow lagoon width, the surrounding structures, and the complicated lagoon layout combine to reduce wind mixing.

The hydrographic features also help favor the formation of a stratified water body. The primary factor is the tidal regime. The tidal amplitude in the area is approximately 0.5 m (1.6 ft). Therefore, the tidal prism is small compared to the remaining lagoon system volume, and the potential for exchange is reduced in comparison to a system subject to a larger tide range. In a shallower area, like the Meyers Creek system, the tidal prism encompasses a much greater percentage of the total volume (Figure 33). The tidal prism in Lagoon System A is approximately 25% of the total volume, whereas in Meyers Creek system, it represents around 50%. Another point is the tidal prism of Meyers Pond approximates the Meyers Creek low water volume. At low tide, Meyers Pond water constitutes the low water volume of Meyers

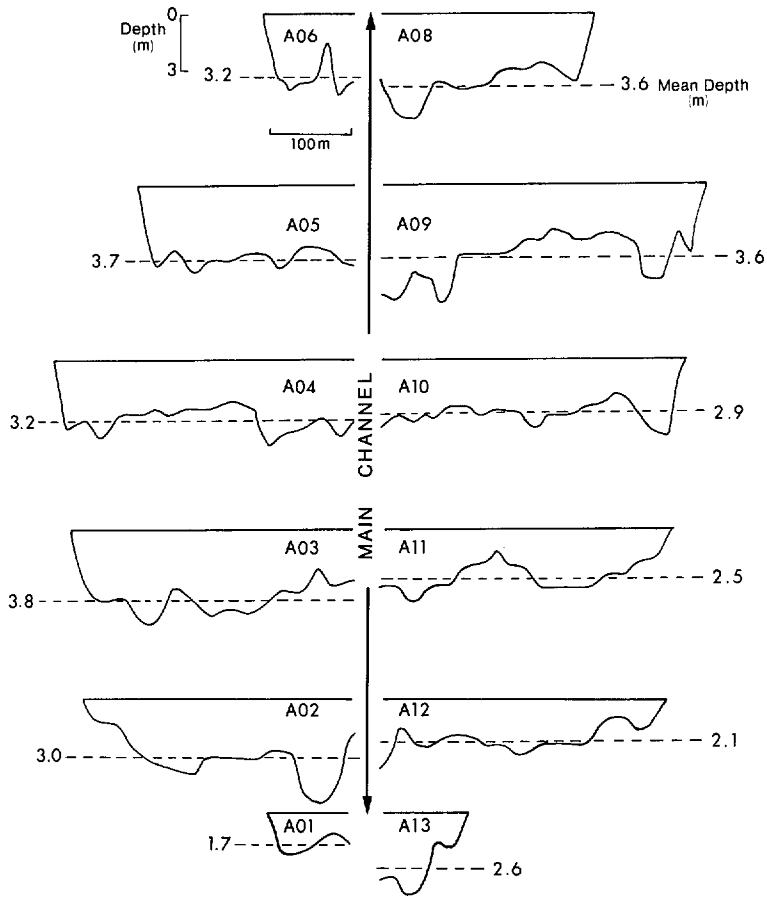

Fig. 32. Longitudinal sections of Lagoon System A.

Creek, and at high water, a substantial portion of the creek must be bay water. A smaller but appreciable fraction of Meyers Pond water at high tide is bay water since the mixing of creek and bay water would occur during the flooding tide. Similar exchange mechanisms operate in the other natural creeks and explain the lack of persistent stratification.

In the Village Harbour complex, the generalized seasonal pattern of stratification closely follows the temperature and salinity cycle. Stratification is best developed in the summer when temperature gradients are steepest and to a lesser extent in the winter. When the water is isothermal in the fall, stratification typically breaks down. There is also an isothermal period in the spring, but stratification can be maintained providing a halocline of sufficient strength is present. Often in the lagoons, a halocline is present and serves to reinforce the primary temperature effect.

The degree and persistence of stratification varies with distance from the bay and depth. At Lagoon B24, the oxygen data indicate stratification is present year-round except during the fall overturn, which begins in the late fall and extends into the winter (Table 14). At this time, temperature and salinity gradients are weakest. Stratification is reestablished during the winter. Lagoon

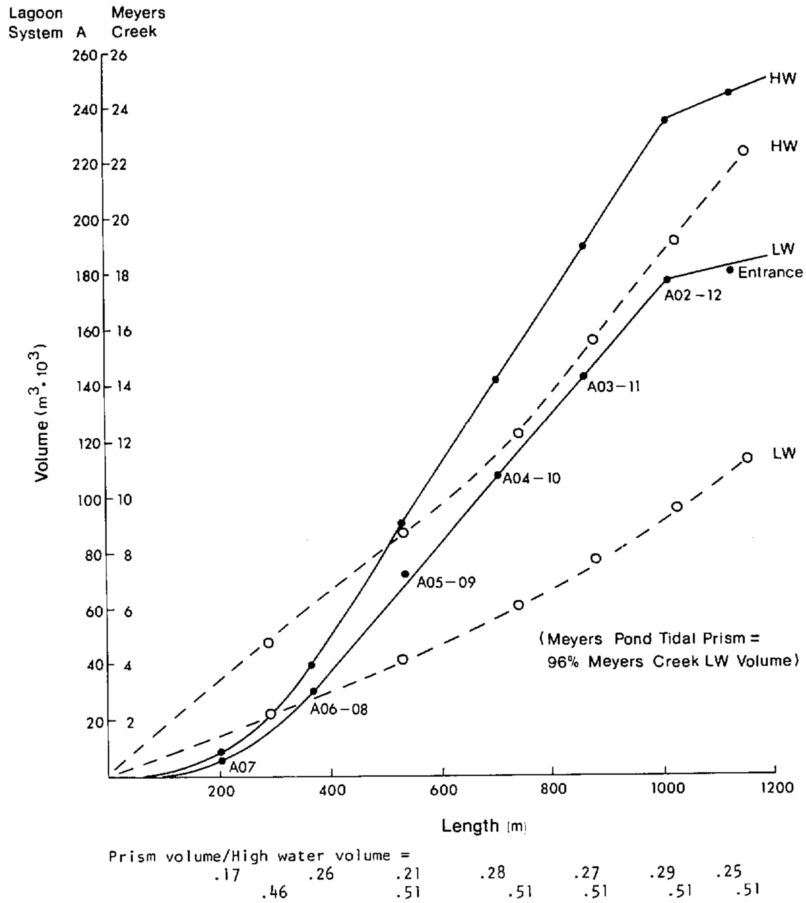

Fig. 33. Lagoon System A and Meyers Creek system. High and low water volumes and tidal prisms (Meyers system = o---o, Lagoon System A = ●——●).

B24 usually becomes isothermal sometime during March - April; however, the halocline is very pronounced at this time and anaerobic conditions are maintained on the bottom. Surface and bottom salinity differences can reach 4 - 5 $^{0}/oo$ around this period. The largest density differences between the surface and the bottom are established in the summer when the thermocline is strongest.

Lagoon A02 near the entrance to Lagoon System A, represents the opposite extreme of Lagoon B24. Apparently, proximity to the bay decreases the likelihood of stratification. Only once did the deep bottom waters become anaerobic, and depressed levels of dissolved oxygen are infrequent (Table 15). Gradients when present are usually transitory.

Lagoon A08 stratifies during the summer and to a much lesser extent the winter (Table 16). Because it is neither as deep nor as remote as Lagoon B24, the gradients formed are not as strong or as stable. Its intermediate nature between Lagoons A02 and B24 is indicated by the gradients listed in Table 16.

Table 14. Selected seasonal data for determining the degree of stratification at Lagoon B24.

Date	Surface temp. minus bottom temp. (°C)	Bottom S °/oo minus surface S °/oo (°/oo)	Bottom S^t minus surface S^t (°/oo)*	Bottom oxygen concentration ($ml\ O_2 \cdot l^{-1}$)#	Oxygen saturation (%)
7/23/73	13.5	6.48	0.008	0.0	0.0
11/20/73	-1.2	0.26	0.000	5.27	73.7
1/17/74†	-5.0	4.49	0.004	0.0	0.0
4/11/74	0.9	3.92	0.003	0.0	0.0
7/17/74	11.3	1.92	0.005	0.0	0.0
10/30/74	2.7	0.17	0.001	3.63	55.8
1/21/75	-5.3	5.16	0.003	0.0	0.0
4/22/75	1.6	3.93	0.003	0.0	0.0

*S^t is the specific gravity of seawater at temperature t (ambient).
#To convert $ml\ O_2 \cdot l^{-1}$ to ppm, multiply by 1.433.
†Data are from Lagoon B22.

Table 15. Selected seasonal data for determining the degree of stratification at Lagoon A02.

Date	Surface temp. minus bottom temp. (°C)	Bottom S °/oo minus surface S°/oo (°/oo)	Bottom S^t minus surface S^t (°/oo)*	Bottom oxygen concentration ($ml\ O_2 \cdot l^{-1}$)#	Oxygen saturation (%)
8/13/75	2.1	0.33	0.001	0.0	0.0
10/15/75	1.2	0.48	0.000	4.05	67.8
12/17/75	0.4	0.55	0.000	6.85	92.0
4/6/76	1.3	0.19	0.000	6.78	100.9
8/3/76	0.8	0.41	0.000	3.74	76.1
11/2/76	0.1	0.48	0.001	6.33	86.1
†					
5/12/76	1.0	0.02	0.000	5.61	89.8

*S^t is the specific gravity of seawater at temperature t (ambient).
#To convert $ml\ O_2 \cdot l^{-1}$ to ppm, multiply by 1.433.
†No data available due to ice cover.

Table 16. Selected seasonal data for determining the degree of stratification at Lagoon A08.

Date	Surface temp. minus bottom temp. (°C)	Bottom S °/oo minus surface S °/oo (°/oo)	Bottom S^t minus surface S^t (°/oo)*	Bottom oxygen concentration ($ml\ O_2 \cdot l^{-1}$)#	Oxygen saturation (%)
7/17/73	5.5	3.27	0.004	0.0	0.0
11/8/73	-1.0	0.46	0.000	6.52	94.3
1/17/74	-4.8	3.45	0.002	1.01	13.5
4/11/74	0.8	1.32	0.001	1.53	21.3
7/17/74	9.2	1.01	0.003	0.0	0.0
11/19/74	0.8	0.10	0.000	6.31	89.0
2/4/75	-3.8	3.38	0.002	0.0	0.0
4/1/75	0.9	0.39	0.001	6.08	82.1
8/13/75	2.3	-0.22	0.001	0.0	0.0
9/25/75	-0.2	0.74	0.000	2.19	40.1
2/26/76	0.4	0.86	0.000	0.57	7.7
4/6/76	2.1	-0.09	0.000	5.85	88.3

*S^t is the specific gravity of seawater at temperature t (ambient).
#To convert $ml\ O_2 \cdot l^{-1}$ to ppm, multiply by 1.433 .

The main axis of Lagoon System E stratifies; however, a strong halocline rather than a thermocline is the primary reason it does so. This is unique and reflects the importance of freshwater flow in Mill Creek. One noteworthy aspect of this freshwater flow is that it does not prevent stratification in the lagoons which branch off the main axis. In fact, the large downstream flow in combination with the depth and dead end nature of the lagoons limits the exchange between the main axis and these lagoons. Within the lagooned sections of this system, stratification is produced by both a thermocline and a halocline.

Stratification seems to occur in the water column at 2 - 4 m depth (7 - 13 ft). Areas in the lagoon, creek, and bay systems under 2 m in depth do not stratify. Stratification can be considered a "patchy" phenomenon occurring in the potholes and deeper channels of the lagoon systems. Its net effect is to seal off the waters located below the 2 m sill level and restrict their circulation with the overlying water layers, leading to anaerobic conditions on the bottom.

Physical and Chemical Characteristics of the Study Area: Nutrient Cycling

Nutrient cycling is related to energy flow because of its connection with material movement in the food web. This study focused on the movement of nitrogen because of its significance in limiting primary production in estuarine areas (Harrison 1974; Ryther and Dunstan 1971; Gallagher 1975; Durand 1979).

Differences in nitrogen cycling are important because they have direct effects on productivity and energy transfers. This also makes them potentially important in site comparisons.

The purpose of the nitrogen work is to: (1) determine the nitrogen forms present; (2) investigate the processes involved; and (3) evaluate the differences between systems.

METHODS -- The inorganic nitrogen compounds, ammonia-N (NH_3-N), nitrite-N (NO_2-N), and nitrate-N (NO_3-N) and the organic nitrogen compounds (org-N: total, soluble, and particulate forms) were sampled on the same schedule as temperature, salinity, and dissolved oxygen during study years I-III. The concentrations were determined by standard spectrophotometric analysis methods (Solorzano 1969; Bendschneider and Robinson 1952; Woods et al. 1967; Kjeldahl digestion after Strickland and Parsons 1968).

Nitrogen fixation rates were measured in study year III. A variety of sample types were examined using the acetylene reduction technique (Stewart et al. 1967). They included all the major vegetation substrates, the water column, and the benthos. Sampling was done in the Meyers Creek system and Lagoon System A on a quarterly basis with major types receiving more frequent testing.

Nitrogen in precipitation was monitored on a quarterly basis during study year III. Runoff from roof and road surfaces throughout Village Harbour were tested as well as direct rainfall.

The excretion study (*Modiolus demissus*, *Ilyanassa obsoleta*, and the zooplankton) and the study of benthic sediment ammonification were also sampled on at least a quarterly basis in study year III in Meyers Creek system and Lagoon System A. Concentration changes were measured in the sample water column after a 24 hour incubation period.

Additional information on methods and materials is available in Durand et al. (1974, 1975, 1976, 1977) for the marsh and lagoon systems and McClain et al. (1976) for the bay.

RESULTS AND DISCUSSION -- The inorganic nitrogen compounds in the surface waters of the study area are generally in low concentrations. Much higher concentrations occur at the bottoms of the deeper stations, such as Lagoon B24, where anaerobic or low oxygen conditions are often present. Overall, NH_3-N is the predominant inorganic nitrogen compound observed, followed by NO_3-N and then NO_2-N. NO_3-N and NO_2-N are confined to the aerobic portions of the water column.

Ammonia-N -- Surface NH_3-N levels at the natural creek mouths rarely exceeded 5.0 ug-at $NH_3\text{-N} \cdot l^{-1}$ (0.07 ppm) and were typically around 3.0 ug-at $NH_3\text{-N} \cdot l^{-1}$ (0.04 ppm) or less. The upper stations in these creeks exhibited higher concentrations, ranging as high as 23.9 $NH_3\text{-N} \cdot l^{-1}$ (0.33 ppm) but usually less than 10.0 ug-at $NH_3\text{-N} \cdot l^{-1}$ (0.14 ppm). The seasonal NH_3-N trends for the creeks were subject to variation from year to year. There was a relationship between increased upper end NH_3-N concentrations and reduced surface salinities.

The sewage outfall at Lagoon E68 and the large freshwater flow of upland origin are unique features of Mill Creek which greatly influenced the observed NH_3-N levels. Like the natural creeks, the surface NH_3-N values at the mouth station of Mill Creek were exceeded by the concentrations found at the upper stations. However, unlike the natural creeks, this gradient resulted partially from the upland freshwater input. Following the fall reduction of upland community primary production, increased levels of NH_3-N were transported downstream, producing a more extended interval of raised NH_3-N concentrations at Lagoon E87 compared to the upper ends of the other creeks. Vertical sampling at Lagoon E68 and at the mouth of Mill Creek also indicated the freshwater was moving downstream in a layer on top of the penetrating bay water. The bay related water was nitrogen poor compared to the upper layer. The failure of the bay water to mix and dilute the freshwater flow helped explain why the Mill Creek mouth was richer in NH_3-N than the other creek mouths. NH_3-N trends were further complicated by the sewage outfall at Lagoon E68. This outfall probably accounted for the irregular nature of the peaks and the high levels reached (over 50 ug-at $NH_3\text{-N}\cdot l^{-1}$ (0.70 ppm) at one time) at Lagoon E68.

At Lagoon E87, the highest NH_3-N concentrations were observed in the winter and reached values around 8.0 ug-at$\cdot l^{-1}$ (0.11 ppm). The mouth of the Lagoon System E approximated the pattern at Lagoon E87 but incorporated some of the peaks from Lagoon E68.

In the lagoons, surface NH_3-N concentrations were generally less than 2.0 ug-at $NH_3\text{-N}\cdot l^{-1}$ (0.03 ppm) and there was no evidence of a concentration gradient leading to the bay.

Because the lagoons are deeper and vertical mixing forces are reduced compared to those in the creeks, stratification occurs. NH_3-N accumulates at these deeper sites in proportion to the length and degree of stratification. The Lagoon A02 mouth station was infrequently stratified and showed only slightly raised NH_3-N levels. In contrast, Lagoon B24 had some concentrations in excess of 200 ug-at $NH_3\text{-N}\cdot l^{-1}$ (2.80 ppm) because of nearly continuous stratification. Lagoon A08 mouth was intermediate to these two sites with respect to stratification and NH_3-N concentrations. High concentrations of NH_3-N were confined to within 2.0 m of the bottom at Lagoon B24 and 1.0 m at the mouth of Lagoon A08.

At Lagoon B24, peak NH_3-N concentrations occurred at the bottom in the late summer - early fall. Concentrations dropped to levels below 20 ug-at $NH_3\text{-N}\cdot l^{-1}$ (0.28 ppm) at Lagoon B24 when stratification broke down in late fall. Following the fall overturn, concentrations again increased to the late summer levels. The main periods of stratification at Lagoon A08 were during the summer, when it was strongest, and during the winter. Peak bottom concentrations ranged as high as 265 ug-at $NH_3\text{-N}\cdot l^{-1}$ (3.71 ppm) in the summer and 66.3 ug-at $NH_3\text{-N}\cdot l^{-1}$ (0.93 ppm) in the winter. Concentrations were generally below 5 ug-at $NH_3\text{-N}\cdot l^{-1}$ (0.07 ppm) for the remainder of the year. The nearly year-round low surface concentrations in the lagoons resulted from several processes including photosynthetic demand and nitrification. At the Lagoon B24 station, the surface values did increase during the periods of destratification. Apparently, the bottom NH_3-N enriched the entire water column. The relation between lower surface salinities and increased surface NH_3-N concentration also suggests there was an input from runoff. The overall increase amounted to an additional 5 - 10 ug-at NH_3-N.l^{-1} (0.07 - 0.14 ppm) at the surface. At Lagoon A08 mouth, no similar increase was detected. For the most part, surface concentrations remained below 2.0 ug-at NH_3-N·l^{-1} (0.03 ppm).

The surface NH_3-N concentrations in the back bays were very similar to the surface waters of the lagoons. Study year II data were less than 2.0 ug-at NH_3-N·l^{-1} (0.03 ppm), except on rare occasions.

Nitrite-N -- NO_2-N occurred in low concentrations and had little effect on the level of available nutrients. Concentrations were usually below 0.5 ug-at NO_2-N·l^{-1} (0.01 ppm) and frequently were 0.0 ug-at NO_2-N·l^{-1}.

Nitrate-N -- NO_3-N is the second most abundant inorganic nitrogen compound. In general, most creeks and lagoons had surface concentrations of less than 2 ug-at NO_3-N·l^{-1} (0.03 ppm).

Most of the high NO_3-N concentrations were associated with Lagoon System E. Elevated values at Lagoon E87, up to 9.4 ug-at NO_3-N·l^{-1} (0.13 ppm), suggest a connection between NO_3-N and upland drainage. Again, the outfall probably accounted for the higher (as high as 57.6 ug-at NO_3-N·l^{-1} or 0.81 ppm) and more irregular values found at the Lagoon E68 station. If the extreme values are disregarded, similarities between the two upper Lagoon System E stations suggest the outfall represents an addition to the upland source of NO_3-N.

NO_3-N is also associated with periods of destratification at Lagoon B24. Elevated concentrations, which reached over 8 ug-at NO_3-N·l^{-1} (0.11 ppm), occurred concurrently with elevated NO_2-N levels.

Seasonal trends at all stations tend to vary from year to year, but there is a tendency for winter values to exceed summer values.

The bay NO_3-N data collected during the study employed a methodology different from that used by the Rutgers group in the lagoons and creeks. To simplify the analysis, another data set (Durand, pers. comm.)[4] collected concurrently and using compatible methods was utilized. This data set is from six stations between the Route 72/Manahawkin Bridge and Beach Haven Inlet (Marker 21, Marker 53, Long Point, Marker 72, Jeremy Point, and Buoy F at Holgate on the U.S.C.G. navigation charts).

During most of the year, NO_3-N concentrations in the bay were low. Fall - winter concentrations typically were between 1 and 4 ug-at NO_3-N·l^{-1} (0.01 and 0.06 ppm). Spring - summer values were usually less than 1 ug-at NO_3-N·l^{-1} (0.01 ppm). The station with the greatest NO_3-N levels was the inlet station, Buoy F at Holgate. Spring - summer values were again less than 1 ug-at NO_3-N·l^{-1} (0.01 ppm), but fall - winter concentrations were 2 - 7 ug-at NO_3-N·l^{-1} (0.03 - 0.10 ppm).

Inorganic Fractions -- The occurrence of peak inorganic nitrogen concentrations coupled with reduced surface salinities in the creek suggest the inorganic nitrogen concentrations are related to storm activity and/or upland drainage. Precipitation, surface runoff, and upland drainage could depress the surface salinities

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[4]This data is part of the CCES Offshore Powerplant Project headed by Dr. James Durand of Rutgers University. The Marker 21 data supplementing the offshore project material is from this study and was also collected by Durand's group.

and transport nutrients. Alternately, storm related wind and wave disturbance of the bottom could increase the amounts of inorganic nitrogen in the water column. In either case, the seasonal trend would be irregular from year to year because of the variability of storm occurrence. Any of these explainations could account for the elevated NH_3-N and NO_3-N concentrations seen at the upper ends of the creeks; probably a combination of them accounted for the observed levels.

These nutrient concentration gradients in the Dinner Point Creek, Meyers Creek, and Mill Creek systems suggest that these streams are acting as nitrogen sources for the bay. The lagoon systems show no evidence of a similar gradient or function.

In the deeper lagoons, NO_3-N and NH_3-N had different distribution patterns. The anaerobic conditions during periods of stratification favored the accumulation of NH_3-N. NO_3-N could be found in the lower layers when the water column was destratified; however, the main concentrations usually were in the upper part of the water column. Enrichment of the upper layers occurred following breakdown of stratification. At such times, accumulated NH_3-N circulated throughout the water column, and nitrification resulted in elevated NO_3-N and NO_2-N values.

The situation at the mouth of Lagoon A08 is different. Stratification was intermittent at the Lagoon A08 station and the water column vacillated between stratified and nonstratified conditions. Perhaps the similarity between the surface and bottom NO_3-N concentrations was a result of this. Also, unlike Lagoon B24, the surface NO_3-N and bottom NH_3-N concentrations did not maintain an inverse relationship. For the winter - spring periods, the relation could even possibly be interpreted as being direct.

Aside from diffusion and subsequent nitrification, a concurrent process in the lagoons was nutrient addition associated with storm activity. Surface salinity reductions in the lagoons could only result from freshwater input associated with rainfall. The periods of observed salinity reductions in the winter and fall coincided with elevated nutrient values. The implication was part or all of these increased concentrations were attributable to runoff/precipitation. Such values seemed possible based on the nitrogen runoff contributions determined in this study.

On an areal basis, the lagoon systems are much richer in nitrogen than the other systems because of the greater depths in the lagoons. The increased depths allows a greater volume of water per unit area. It also permits stratification which leads to elevated NH_3-N concentrations in the lower part of the water column. Considering the nitrogen poor condition, the elevated levels would seem a potentially beneficial attribute. However, the increased levels are confined to the bottom of the lagoons. The inorganic nitrogen is available neither to the bay, because of the lack of circulation, nor locally to the upper part of the water column because of the presence of a thermocline and/or halocline.

Organic Nitrogen -- Organic nitrogen is by far the most abundant form of nitrogen throughout the study area. During study year III, total org-N composed over 82% of the nitrogen present within the Meyers Creek system and Lagoon System A (Table 17). Seasonal variation occurred and was partially due to irregular particulate org-N concentrations. Soluble org-N exhibited high summer - fall and low winter - spring values (study year I).

Table 17. Nitrogen standing stocks in 10^6 ug-at for the Meyers Creek system and Lagoon System A during study year III.*

Station	Quarter	NH_3-N	NO_2-N	NO_3-N	Org-N (total)	Total N	Org-N / Total N
Meyers Creek	1	42.9	0.0	2.2	1,084.6	1,129.7	.96
	2	152.9	2.2	28.6	841.5	1,025.2	.82
	3	5.5	2.2	4.4	804.1	816.2	.99
	4	22.0	0.0	2.2	711.7	735.9	.97
Meyers Pond	1	31.1	0.0	2.7	918.5	952.3	.96
	2	120.6	1.8	22.5	982.8	1,127.7	.87
	3	21.6	2.7	14.4	720.9	759.6	.95
	4	22.5	0.0	1.8	629.1	653.4	.96
Lagoon A02	1	13.9	0.2	4.7	655.6	674.4	.97
	2	32.7	0.5	22.6	567.6	623.4	.91
	3	6.9	2.8	9.0	619.2	637.9	.87
	4	0.6	0.0	0.2	568.9	569.7	1.00
Lagoon A08	1	44.2	0.1	4.0	684.0	732.3	.93
	2	20.0	0.0	8.8	506.0	534.8	.95
	3	13.2	0.8	2.7	679.8	696.5	.98
	4	6.5	0.0	0.7	690.8	698.0	.99

*To convert ug-at N to ppm, multiply by 0.014.

During study year II, total org-N concentrations peaked during the summer with surface levels over 100 ug-at total org-N$\cdot l^{-1}$ (1.40 ppm) at some stations in the natural creeks and fully lagooned waterways. Values in the bay (based on data from the same six stations used in the NO_3-N analysis) were also elevated with a maximum of 90.1 ug-at total org-N$\cdot l^{-1}$ (1.26 ppm). Lower levels occurred in the fall and winter throughout the study area. More typical concentrations in the natural creeks and lagoons were 60 - 80 ug-at total org-N$\cdot l^{-1}$ (0.84 - 1.12 ppm) during the summer of study year II and 20 - 40 ug-at total org-N$\cdot l^{-1}$ (0.28 - 0.56 ppm) during the colder periods. In the bay, values ranged around 40 - 60 ug-at total org-N·l^{-1} (0.56 - 0.84 ppm) in the summer and 20 - 40 ug-at total org-N·l^{-1} (0.28 - 0.56 ppm) during the lower level periods.

The total org-N component was important not only because it was the largest nitrogen fraction but also because it represented a major nutrient reservoir. Eventually, decomposition processes would convert the org-N into NH_3-N. However, the release of this utilizable form would be over a long time increasing its effective availability. There was an apparent relationship between the seasonal organic-N patterns and some of the primary production factors measured. For example, the chlorophyll *a* variations in the lagoons seemed to be related to the total org-N changes. While not the only source of org-N, primary production by the phytoplankton would probably be the major source in the water column.

Nitrogen Fixation -- Marsh surface samples were divided into algal and non-algal (substrate) communities according to whether algae were or were not visible to the naked eye on the surface. Typically, higher rates of ethylene production (i.e. nitrogen fixation) were associated with the algal mats rather than the substrate. Rates were as high as 300 ug-at NH_3-N·$hour^{-1}$·m^{-2} in certain areas.

Algal mats were most often found in the SAS areas. Maximum algal cover occurred in the spring and fall quarters. Minimum cover occurred in the winter quarter. Although the winter minimum algal cover coincided with the seasonal low for nitrogen fixation rates, times of maximum algal cover did not coincide with times of maximum nitrogen fixation rates. Peak nitrogen fixation rates occurred in the latter part of the summer. The SP/DS areas generally lacked algal mats on the marsh surface. Apparently, the grass cover prevented the sunlight from penetrating eliminating the possibility of algal growth. Only in the limited areas where the macrophyte cover was degenerating were algae present. The *Spartina alterniflora* tall form/bank (SAT/B) area on Meyers Creek had little algae associated with it. Meyers Pond bank areas, however, had large algal bands which were active nitrogen fixers.

The nitrogen fixation rates for the corresponding substrate communities were low, usually below 5 ug-at NH_3-N·$hour^{-1}$.m^{-2}. Only twice did the rates exceed 50 ug-at NH_3-N·$hour^{-1}$.m^{-2} at any marsh site. These occurred during the fall quarter in the bank community at Meyers Pond and in the SAS community.

On an annual basis, nitrogen fixation by the benthic sediment community and the water column community were the lowest encountered in the marsh system. Essentially, no nitrogen fixation occurred in the water column.

The lagoon system differed from the marsh system because most marsh surface fixation was eliminated by housing and associated construction. The SAS algal mats were replaced by paved surfaces and house lots and the SAT/B zone communities by bulkheading. Algal communities were present on the intertidal portion of the bulkheading and we considered them to correspond to the SAT/B algal communities.

These bulkhead associations dominated the nitrogen fixation process in the lagoon system. The upper portion of this zone was primarily a blue-green algal crust and had a fixation rate as high as 575 ug-at NH_3-N·$hour^{-1}$·m^{-2}. As with the marsh surface algae minimum rates were detected in the winter quarter. The lower part of this zone, which was mostly green algae, had a peak rate of only 96 ug-at NH_3-N·$hour^{-1}$·m^{-2} and generally, did not exceed 30 ug-at NH_3-N·$hour^{-1}$.m^{-2}. Nitrogen fixation rates for the benthic sediments and water column communities were minimal.

The SAS zone contributed the greatest amounts of newly fixed nitrogen not only because it had the highest combined algal/substrate fixation rate, but also because it was the dominant cover type. This contribution was predominately from the algal community which fixed 2.5 times more nitrogen annually than the substrate community (7.1×10^7 and 2.8×10^7 ug-at NH_3-N·day^{-1}, respectively, for the Meyers Creek system). The relatively low rate of the SP/DS substrate community was also magnified by large distribution. This community was third highest in the contribution of fixed nitrogen with 5.0×10^6 ug-at NH_3-N·day^{-1}. The remaining communities, the SAT/B, benthic sediments, and water column, contributed a combined total input of 4.4×10^6 ug-at NH_3-N·day^{-1}. Again, distribution modified the significance of these processes. Only because the low benthic sediment and water column community rates were applied to large portions of the system were they significant. Because the SAT/B rates were representative of a relatively small region, the amount of nitrogen fixed was low.

The algal SAS community fixed 2.5 times more nitrogen annually than the substrate community in the Meyers Creek system. Similarly, in the SAT/B zone, the algal components fixed twice as much as the substrate community along Meyers Creek, despite very limited abundance, and nearly 7 times as much along the Meyers Pond perimeter where algal mats were prevalent.

The high rates of the bulkhead algal community were applied to relatively small areas. This minimized the importance of this type of nitrogen fixer and explained why only 5.5×10^5 ug-at NH_3-N·day^{-1} at Lagoon A02 and 2.5×10^5 ug-at NH_3-N·day^{-1} at Lagoon A08 were fixed. On the other hand, the importance of the low benthic sediment and water column rates was probably over magnified as it was in the creek system. Nonetheless, algal nitrogen fixation still dominated the nitrogen contributions to the system.

Nitrogen fixation is a significant process despite the relatively low rates observed. Its importance stems from its singular position as a mechanism for the introduction of previously unavailable nitrogen into the system. Other processes function only as recycling mechanisms of already fixed nitrogen. Only nitrogen fixation increases the absolute standing stocks of fixed nitrogen. The reduction of this capability in the lagoon systems is a major difference between the two systems and represents a drawback for the lagoon system. The importance of this difference is emphasized by the nitrogen poor condition of the surface waters in the study area and the limitation this places on photosynthetic rates. This reduced capability is primarily associated with the loss of the marsh surface in the developed areas. As measured, contributions via nitrogen fixation by the water column and its boundaries are small relative to the existing nitrogen stocks in both lagooned and natural systems.

Other Nitrogen Processes -- The nitrogen contributed by precipitation/runoff, excretion, and ammonification was measured in pilot experiments. The low sampling frequency permitted only generalizations to be made. The parameters measured were not necessarily representative of all the processes involved, e.g. *Modiolus, Ilyanassa,* and zooplankton were not representative of all biological excretion occurring.

The amounts of nitrogen introduced via precipitation and/or runoff are appreciable. The larger the surface of a particular system the larger the total nitrogen quantity introduced. Consequently, the marsh areas receive the most nitrogen via this pathway, averaging over 10 ug-at inorganic-N·day^{-1}·10^6 for both the Meyers

Pond and Meyers Creek areas. The nitrogen contributed to Lagoon A02 and A08 was under 1 ug-at $N \cdot day^{-1} \cdot 10^6$.

In this study, excretion was defined as the elimination of metabolic waste products. We measured the NH_3-N component of these wastes to evaluate the nitrogen recycling capabilities of the selected organisms. Only for a limited number of experiments were total org-N contributions and, therefore, fecal deposition measured.

Modiolus excretion rates are higher in the cooler months than in the warmer months. The rates ranged between 1.6 and 12.1 ug-at NH_3-$N \cdot organism^{-1} \cdot day^{-1}$ with a mean rate of 5.44 ug-at NH_3-$N \cdot organism^{-1} \cdot day^{-1}$ for study year III. It is estimated there are 1,653,453 *Modiolus* in the Meyers Creek system. Applying this population size to the rates obtained, approximately 9 ug-at NH_3-$N \cdot day^{-1} \cdot 10^6$ was the daily contribution made by *Modiolus*.

There was also a large amount of org-N introduced by excretion. At a mean rate of 9.4 ug-at total org-$N \cdot organism \cdot day^{-1}$, org-N accounted for more than 60% of the total nitrogen introduced by *Modiolus* to the creek system. This would extrapolate to a population contribution of 16 ug-at total org-$N \cdot day^{-1} \cdot 10^6$.

Ilyanassa obsoleta excretion rates ranged from 0.4 to 2.8 ug-at NH_3-$N \cdot organism^{-1} \cdot day^{-1}$. The trend at all experimental sites was for higher rates to occur around April and the lower rates around October. The respective mean rates during study year III for Meyers Creek, Meyers Pond, Lagoon A02, and Lagoon A08 were 1.12, 1.18, 1.22, and 1.35 ug-at NH_3-$N \cdot organism^{-1} \cdot day^{-1}$. Using the appropriate population estimates, these mean rates extrapolated to 61 (Meyers Creek), 12 (Meyers Pond), 4 (Lagoon A02), and 4 (Lagoon A08) ug-at NH_3-$N \cdot day^{-1} \cdot 10^5$.

About 70 - 75% of the total nitrogen excreted by *Ilyanassa* is org-N. Roughly 14, 32, 14, and 12 ug-at total org-$N \cdot day^{-1} \cdot 10^5$ were excreted to Meyers Creek, Meyers Pond, Lagoon A02, and Lagoon A08, respectively.

The local zooplankton populations had excretion rates between 0 and 140 ug-at NH_3-$N \cdot l^{-1} \cdot day^{-1} \cdot 10^{-3}$. The higher rates generally occurred in the spring and summer. For the Meyers Creek system, Lagoon A02, and Lagoon A08, the mean rates for study year III were 22, 39, and 26 ug-at NH_3-$N \cdot l^{-1} \cdot day^{-1} \cdot 10^{-3}$, respectively. These rates extrapolate to 4 (Meyers Pond), 5 (Meyers Creek), 6 (Lagoon A02), and 4 (Lagoon A08) ug-at NH_3-$N \cdot l^{-1} \cdot day^{-1} \cdot 10^{-3}$.

Differences between marsh and lagoon systems are largely a function of the population sizes present. The absence of *Modiolus* in the lagoon complex means a species with a large nitrogen recycling capability is unavailable. On the other hand, the increase in the amount of waterways in the lagoon complex versus the marsh allows the presence of a larger population of *Ilyanassa* or zooplankton which magnifies their contributions.

Ammonification was initially defined as the production of NH_3-N from the degradation of organic matter; however, the measured rates actually resulted from a variety of processes in addition to decomposition. Excretion by benthic populations, adsorption (to sediment fractions by mineralized nitrogen), nitrification, and denitrification would also be included in the rate. These ammonification rates then reflect the net degradation of organic matter to NH_3-N on a community basis and not by microorganismal populations alone.

The mean rates for study year III ranged between 1 to 4 ug-at NH_3-N·m^{-2}·day^{-1}·10^3. When extrapolated, these rates translate into nitrogen inputs of 23.9, 71.6, 33.6, and 6.1 ug-at NH_3-N·day^{-1}·10^6 for Meyers Creek, Meyers Pond, Lagoon A02, and Lagoon A08, respectively.

On a per square meter basis, ammonification is the dominant nitrogen pathway studied. However, contributions of nitrogen by ammonification are small relative to the existing nitrogen standing stocks in the water column.

Physical and Chemical Characteristics of the Study Area: Solar Radiation

The sun is the ultimate source of energy in any ecosystem. This energy is transmitted to the earth's atmosphere over a range of wavelengths from 100 nanometers (nm) to beyond 3,000 nm. The energy flux involves elements of the ultraviolet, visible, and infrared regions of the electromagnetic spectrum. The rate of input has been estimated to be approximately 2.0 cal·cm^{-2}·$minute^{-1}$ extraterrestially.

In traversing the atmosphere, both the character and intensity of the flux is altered. Atmospheric constituents such as ozone, oxygen, water vapor, carbon dioxide, and dust scatter or absorb portions of the spectrum. Those wavelengths less than 300 nm, the ultraviolet, are primarily absorbed by the ozone layer in the atmosphere. Infrared radiation, wavelengths longer than 760 nm, is irregularly reduced as selective absorption by water vapor, carbon dioxide, and ozone occurs. The visible light region between 380 and 760 nm also is attenuated, but in a more uniform manner. The resultant energy input is primarily in the visible and infrared regions as shown in Figure 34. The angle of incidence of the radiation (a function of latitude and time of year), reflection from surrounding surfaces, and reradiation from nearby sources can further alter the input as well.

Theoretical curves of the energy input at the earth's surface have been developed (Kimball 1928; List 1958). Only part of this input is utilized in photosynthesis. The photosynthetically active radiation (PAR) falls within the wavelengths range of 400 - 710 nm. Of particular significance is the radiation between the wavelengths of 610 - 700 nm and 400 - 510 nm because these are the main wavelengths absorbed by plants for photosynthetic purposes. Talling (1957) has estimated that this PAR comprises 47% of the total solar radiation input. Combining Talling's estimate with the total solar radiation curves derived from the Kimball tables and Smithsonian tables, we can calculate a theoretical energy input to the primary producers. It should be noted these curves are estimates of potential flux for our approximate study area under specific conditions. Cloud cover changes, varying levels of atmospheric components, and interaction with vegetation can cause deviations from the predicted values. On a theoretical basis, maximum energy input is reached in June and minimums in December with sinusoid transitions between the extremes.

The purpose of our PAR research is to determine the actual solar energy input to the primary producers and compare the results with theoretical estimates such as those cited above.

METHODS -- The instrument used to obtain incident PAR light data was a LiCor LI-500 integrator equipped with a calibrated LI-190S sensor. Located at the Rutgers University Little Egg Inlet Marine Field Station, a distance of ≃15 km (9 miles).

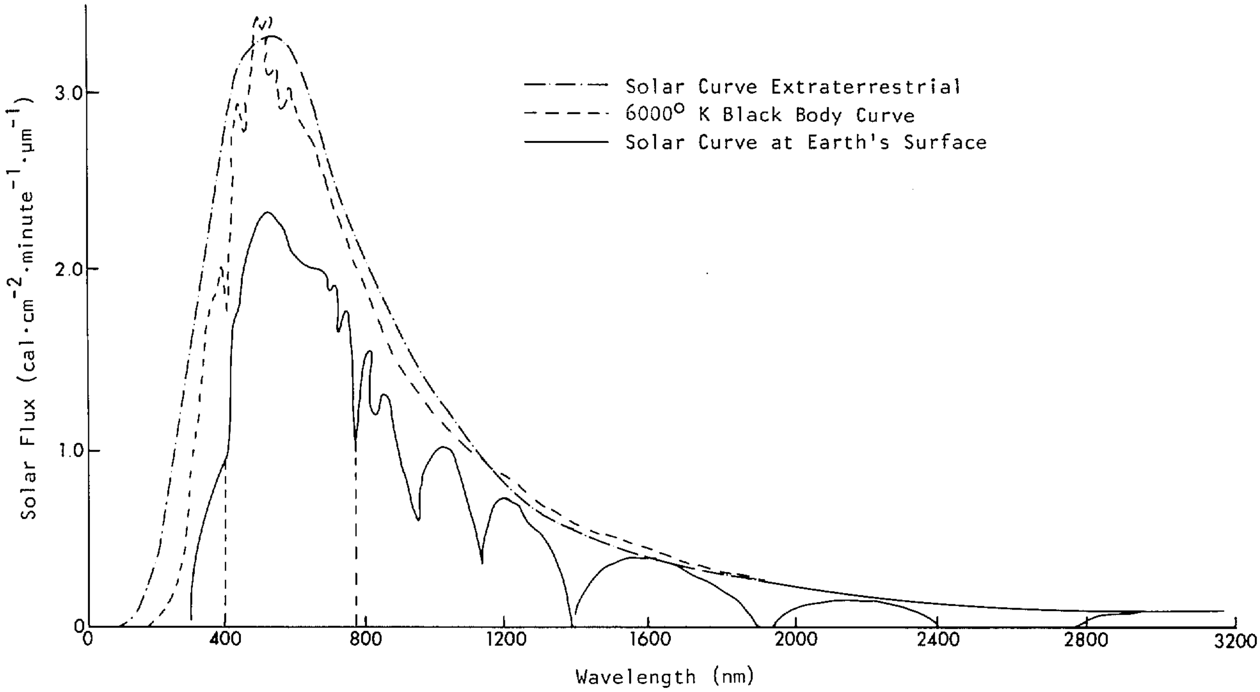

Fig. 34. Extraterrestial and terrestial light spectrums.

from the study site, this device was used to obtain multiple 24 hour estimates of light energy input per month during the period August 1975 - May 1977. The mean of these replicate observations was then extrapolated for the entire month. Annual totals were calculated by summing these derived values.

RESULTS AND DISCUSSION -- The measured PAR levels exhibit the same pattern as the corrected theoretical curves as seen in Figure 35. These levels also fall within the range defined by the two theoretical curves corrected to PAR values. The recorded values exceeded those of the Kimball curve, but were less than those predicted by the Smithsonian. The measured PAR values correlate well with the theoretical estimates. For the study year III data, high regression coefficients were obtained when the measured data was compared to the corrected Smithsonian curve (0.96) and Kimball curve (0.94). The recorded data is subject to short-term deviation from the predicted because of changing cloud conditions.

The cumulative monthly energy input was found to vary from a low around 1,900 $cal \cdot cm^{-2}$ in January 1977 to a high around 8,500 $cal \cdot cm^{-2}$ in July 1976 (Table 18). Utilizing the two years of data, the annual input for each of the periods June 1975 - May 1976 and June 1976 - May 1977 was approximately 63,400 $cal \cdot cm^{-2}$.

This level of energy represents the maximum energy available for utilization. The actual available energy at a particular place is subject to reduction by several factors in addition to those atmospheric effects already discussed. These include shading by vegetation and attenuation by interposed mediums, such as water.

The major vegetation types, SAS, SAT, and SP-DS, have different light regimes. SAS exhibits the highest marsh surface PAR levels. Below the SAS overstory, the conditions ranged from 34 to 15% of incident light ($\%I_o$) with minimum values during

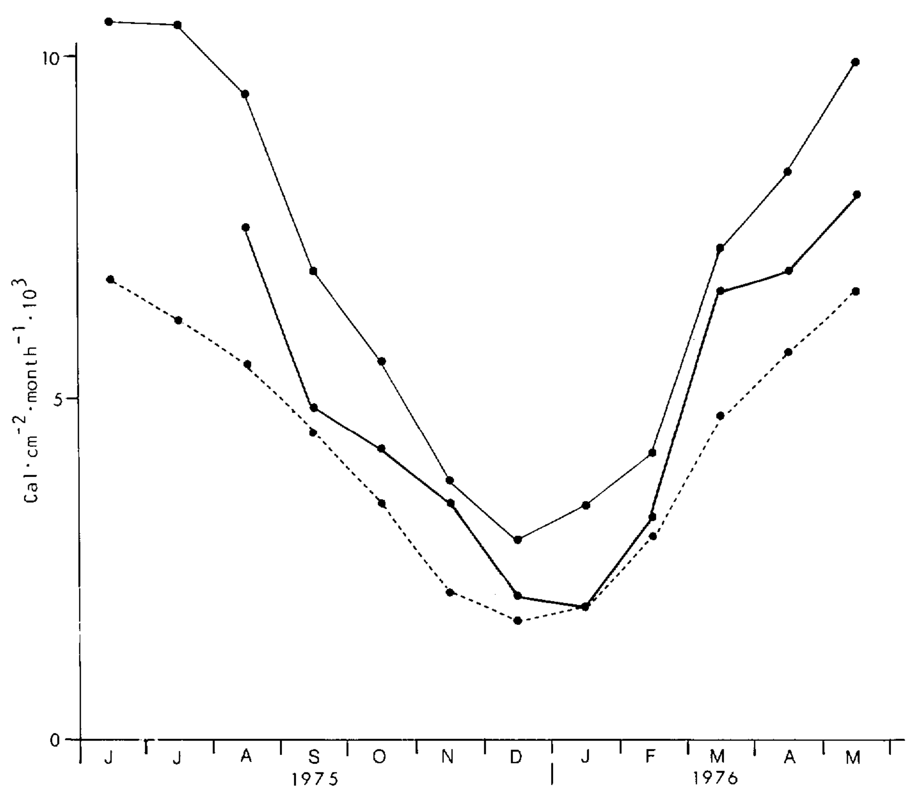

Fig. 35. Actual incident energy (●——●) compared with estimates based on Kimball (●---●) and Smithsonian (●——●) curves.

Table 18. Cumulative energy input on a monthly basis in (cal·cm^{-2}).

Date	n	Monthly total	Annual total
1975			
June		6,273.0*	
July		8,438.2*	
August	5	7,498.9	
September	9	4,842.0	
October	7	4,268.7	
November	2	3,426.0	
December	2	2,080.1	
1976			
January	5	1,912.7	
February	8	3,233.5	

Table 18. Continued.

Date	n	Monthly total	Annual total
March	1	6,562.7	
April	5	6,813.0	
May	3	7,960.8	63,309.6
1976			
June	8	6,273.0	
July	1	8,438.2	
August	7	7,954.6	
September	13	5,163.0	
October	4	5,006.5	
November	6	3,093.0	
December	5	1,987.1	
1977			
January		1,912.7#	
February	5	4,331.6	
March	13	5,294.8	
April	8	7,113.0	
May	10	6,882.0	63,449.5

*Assumed value based on second year data
#Assumed value based on first year data

the fall. The SAT overstory allowed a maximum %I_o of 20% and a minimum of 6% in the fall. The SP-DS overstory is the densest canopy of all and less than 1% of the incident light reaches the marsh surface at any time.

PAR reduction by the water column is indicated by Secchi disc data (study years II and III). Data representative of bay, marsh, and lagoon complex stations are shown in Figure 36. The shallower natural creeks were subject to greater wind stirring and wave action which reduced their transmission qualities. Maximum transparency in the lagoon complex occurred in the late fall and early winter. At Marker 21, transparency was usually higher during the summer and early fall. In general, transparency in the bay was relatively high, especially near the inlet.

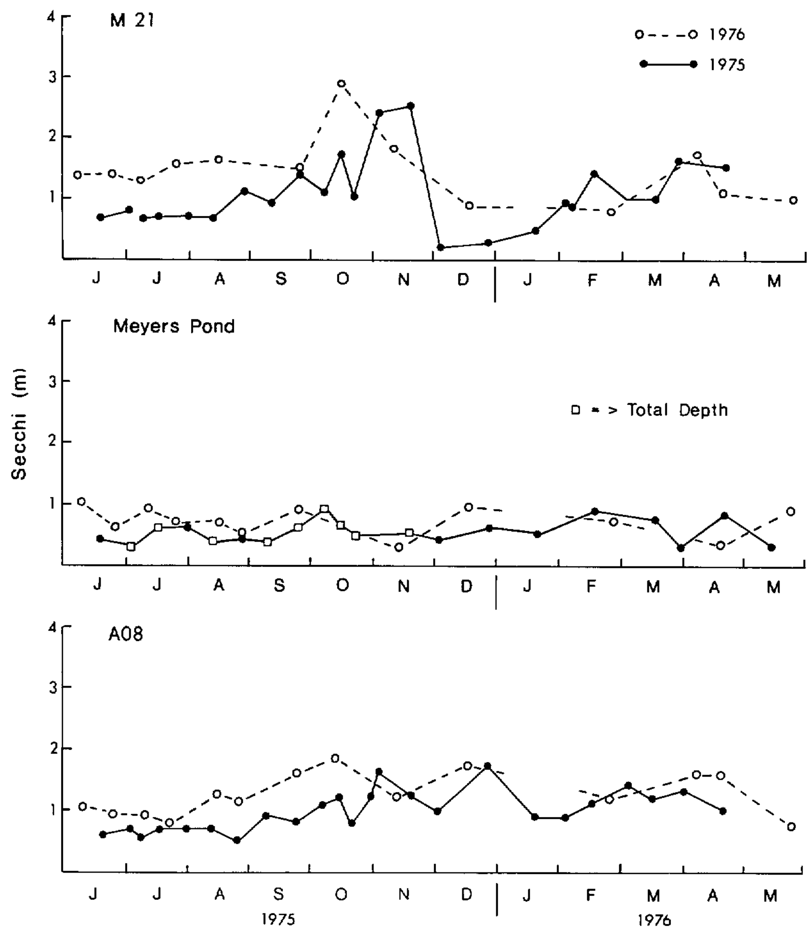

Fig. 36. Secchi data for study years II and III at Marker 21, Meyers Pond, and Lagoon A08.

FOOD WEB: INTRODUCTION

The basic unit in ecology is the ecosystem, defined as an abiotic environment and its associated biotic forms. A network of functional relationships exists not only between the organisms, but between the biotic components and the environment as well. Processes of energy flow and nutrient cycling, which provide the means by which the ecosystem functions, are central to these relationships.

From a trophic standpoint, the biotic community consists of two major categories, the autotrophs and the heterotrophs. The autotrophs or primary producers are generally chlorophyll-bearing plants which absorb solar energy and assimilate simple inorganic substances in order to synthesize organic compounds. Because they convert solar energy into chemical energy, they comprise the first trophic level within the ecosystem. Heterotrophs or consumers include those organisms which depend upon complex organic material for their energy sources. Herbivores or primary consumers are heterotrophs which obtain their energy directly from living plant material. They comprise the second trophic level. Heterotrophs which utilize other heterotrophs as energy sources are termed carnivores and may be either secondary or tertiary consumers depending on their relationship to the autotrophs in the energy transfer sequence. Heterotrophs would also include the decomposers which break down complex organic matter, satisfy their own energy requirements by absorbing some of the decomposition products, and characteristically release simple compounds suitable for uptake by autotrophs. The decomposers are typically an assemblage of microorganisms including bacteria, fungi, and protozoans. Because they derive their energy from sources on several different trophic levels simultaneously, the assignment of this group to a specific trophic level is difficult. Species are assigned to trophic levels based on the food resources which they utilize. However, many species are omnivorous, while others change their food preferences from season to season or during different life cycle stages.

The term food web refers to all the transfers of energy and nutrients between the various trophic levels within the ecosystem. The energy flow in the food web originates with the input of solar radiation. The total energy converted by an autotroph is termed gross primary production and represents only a small fraction of the incoming solar energy. A portion of the gross production is required for the maintenance of life processes and is converted to heat by the oxidative process of respiration. The residual is termed net primary production and is the food energy potentially available to the higher trophic levels. Alternately, this net production may be stored or exported.

Similarly, a portion of the total energy utilized by heterotrophs is diverted to the formation of body tissue and reproductive products and a portion to allow the organism to function. The energy respired to sustain the organism again results in heat energy lost to the environment.

The energy transfer within an ecosystem is irreversible. The energy amounts transferred between levels are rapidly reduced as a result of inefficient biological transfers and heat loss via respiration. Consequently, the available energy is decreased with each successive trophic level, which places a limit of four or five levels per ecosystem. These energy losses are somewhat offset by increased utilization efficiencies at the higher levels.

As part of the comparison of the natural marsh and the lagoon complex, the various types of populations studied were assigned to producer and consumer categories within their respective sites (Table 19). These populations will be considered in the following pages.

Table 19. Community structure with reference to trophic level.

Category	Population	Natural marsh	Lagoon complex
Aquatic primary producers	Phytoplankton	X*	X
	Benthic algae	X	X
	Submerged macrophytes	X	N.A.
Terrestrial primary producers	Emergent macrophytes	X	N.A.
	Marsh surface algae	X	N.A.
	Submerged salt pool macrophytes	X	N.A.
	Bulkhead algae	N.A.	X
Aquatic consumers	Benthic invertebrates	X	X
	Zooplankton	X	X
	Finfish	X	X
Terrestrial consumers	Marsh surface invertebrates	X	N.A.
	Rodents	X	N.A.
	Birds	X	X
	Man	X	X
Decomposers	Microorganisms	X	X

*X means present.
#N.A. means not present or not sampled.

FOOD WEB: AQUATIC PRIMARY PRODUCTION - PHYTOPLANKTON

The phytoplankton community is aquatic and composed of algal cells. In estuaries, the large algae or "net phytoplankton" are characteristically diatoms and dinoflagellates (Odum et al. 1974). However, it is the nanoplankton (generally small flagellates) which have the greatest primary production potential. These nanoplankton are present throughout the year and may bloom at any time. Based on Patten (1963), Marshall (1967), and Riley and Conover (1967), there is an annual pattern of community structure variations (Odum et al. 1974). Diatoms assume particular importance during the winter and are superseded or replaced to varying degrees during the summer by the dinoflagellates.

Between estuaries, the level of primary production varies because of the different population concentrations and environmental conditions encountered. Some of the observed rates are listed in Table 20. Species observed either in Little Egg Harbor or the general New Jersey area are listed in Table 1 of Appendix B.

Table 20. Production data for various locations in $g\ C\cdot m^{-2}\cdot year^{-1}$

Location	GP	NP	R	C^{14}*	Reference
St. Margaret's Bay Nova Scotia				190	Platt (1971)
Strait of Georgia				120	Parsons et al. (1970)
Bissel Cove, R.I.	174	80	94		Nixon et al. (1973)
Long Island Sound	380	170	210		Riley (1956)
Flax Pond, N.Y.				11.7	Moll (1977)
Continental shelf off Long Island				(<50m) 160 (>1,000m) 100	Ryther and Yentsch (1958)
Raritan Bay, N.J. Nacote Creek, N.J.	440	220	220		Bleecker (1971)
Chespeake Bay (upper)	73				Flemer (1970)
Patuxent River,				193-330	Stross and Stottlemyer (1965)
Beaufort Channel, N.C.	113	74	39		Williams and Murdoch (1966)
Estuaries, N.C.	100	48	52		Williams (1966)
Beaufort, N.C.				16-153 66.6 (mean)	Thayer (1971)
North Inlet, S.C.				273	Zingmark (1977)
Duplin River, Ga.	259	-11	270		Ragotzkie (1959)
Barataria Bay, La.	300	210	90		Day et al. (1973)

*Production as determined by the C^{14} technique.

The purpose of this study is to: (1) document the phytoplankton primary production and (2) compare the data from the different stations.

Methods

Standing crop estimates including oxidizable carbon and in particular chlorophyll *a* were determined according to the methods of Strickland and Parsons (1968). Phytoplankton primary production was measured using a light-dark bottle technique and the Winkler oxygen titration method with the azide modification to determine oxygen concentration changes. Incubation at ambient temperature were conducted for 24 hours. Nutrient enrichment experiments patterned after Ryther and Guillard (1960) were also performed. Natural diurnal quality and intensity light patterns were obtained by incubating in an outdoor tank supplied with running creek water. In addition, artificial light sources were used in some incubations. Graded light intensities in both instances were obtained with screens.

Samples were taken at the surface and occasionally at intervals in the water column. Though sampling stations varied over the course of the study, the major thrust was the comparison of the natural creeks like Meyers Creek and the lagooned waterways like Lagoon System A. All sampling locations are depicted in Figure 37. Sampling frequency was generally monthly with increased effort expended during the summer.

More detailed information or methods can be obtained from Durand et al. (1974, 1975, 1976, 1977).

Results and Discussion

PLANT PIGMENTS -- Relatively high concentrations of chlorophyll *a* characterize nearly all the stations in the study area during the summer. Particularly high concentrations were encountered in study year IV when summer levels exceeded 20 mg chl $a \cdot m^{-3}$ (20 ppb) for extended periods. A maximum of 130.5 mg chl $a \cdot m^{-3}$ (130.5 ppb) was observed at Lagoon B24 (surface) on 30 June 1976. Meyers Pond, Oyster Point Pond, and Lagoon E68 typically had high summer chlorophyll *a* concentrations; the Lagoon E87 station did not. A decline generally followed this summer phenomenon during October. Frequently, winter increases in pigment levels occurred for varying periods of time.

In Figure 38 are the chlorophyll *a* data for Lagoon A08, Marker 21, and Meyers Pond. These indicate the general seasonal patterns for the major waterway types. Note, however, the magnitude and duration of the maxima vary from year to year and location to location. For example, chlorophyll *a* levels during study years I and III were reduced for the summer periods at Marker 21, a bay station. This contrasted to study years II and IV as well as Lagoon A08 and Meyers Pond.

Within the water column, a marked vertical gradient of chlorophyll *a* and pheophytin (a plant pigment decomposition product) is observed in the more stratified lagoon environments. High concentrations were measured below the euphotic zone particularly at Lagoon B24 where chlorophyll *a* values at times exceeded 50 mg chl $a \cdot m^{-3}$ (50 ppb). Less stratified stations such as Lagoons A08 and A02 had vertical distributions which reflected their degree of stratification (Figure 39).

The pigment data are consistent with the patterns of high summer phytoplankton productivity observed in other studies. The concentrations recorded at the bottoms of the lagoons are possibly a result of settling out by the phytoplankton population and the restricted circulation caused by stratification.

PARTICULATE OXIDIZABLE CARBON -- Particulate oxidizable carbon (POC) is an indicator of the phytoplankton standing crop and in particular its energy content. As POC is measured in this study, it also includes undetermined detrital materials. The POC data for the study years I-IV at Lagoon A08, Lagoon B24, Marker 21, Meyers Pond, and Meyers Creek mouth are presented in Figure 40.

The natural creeks, including Oyster Point and Dinner Point creeks, were characterized by varied seasonal fluctuations. This was unlike the chlorophyll *a* data which had a more consistent seasonal pattern. These differences are a consequence

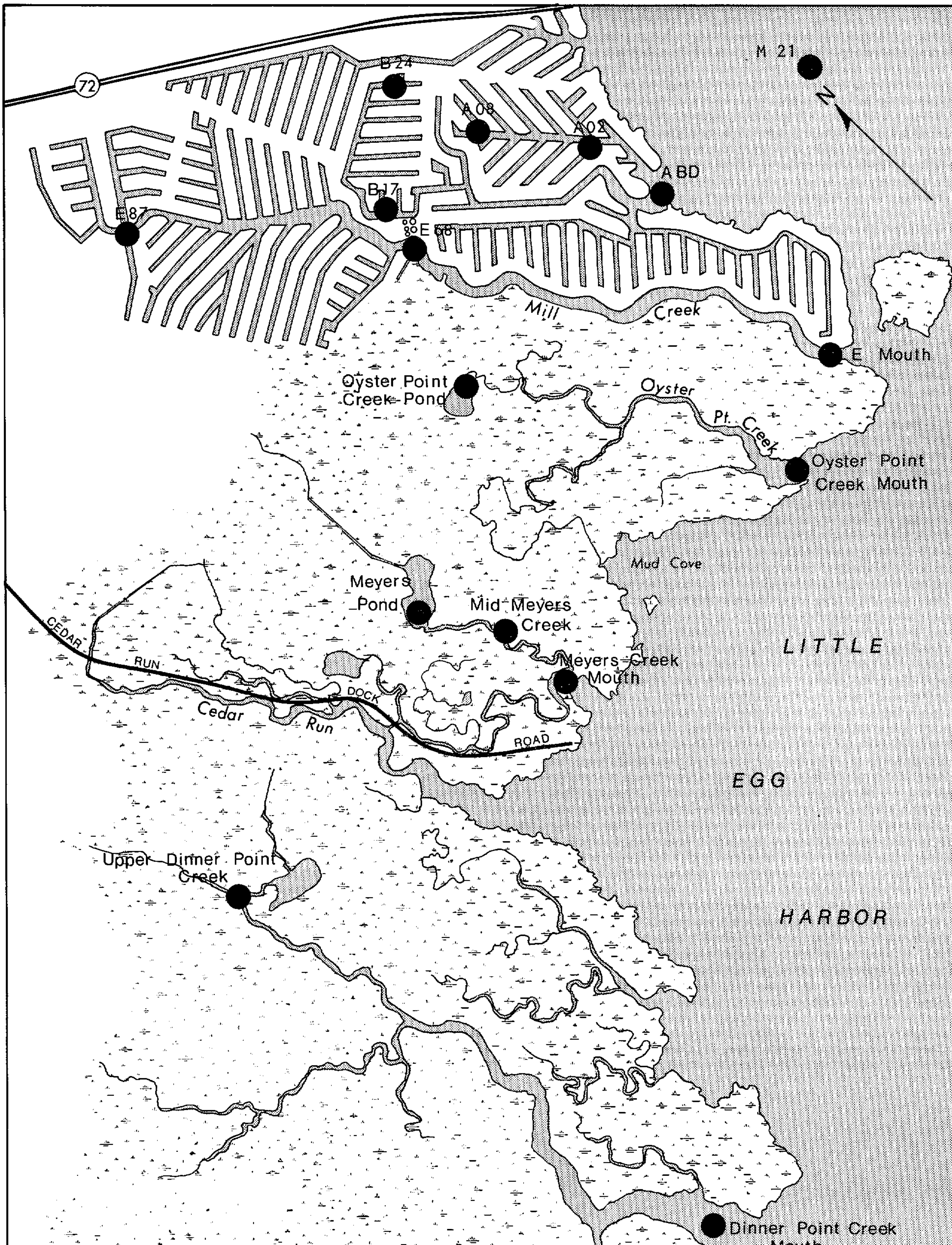

Fig. 37. Station locations.

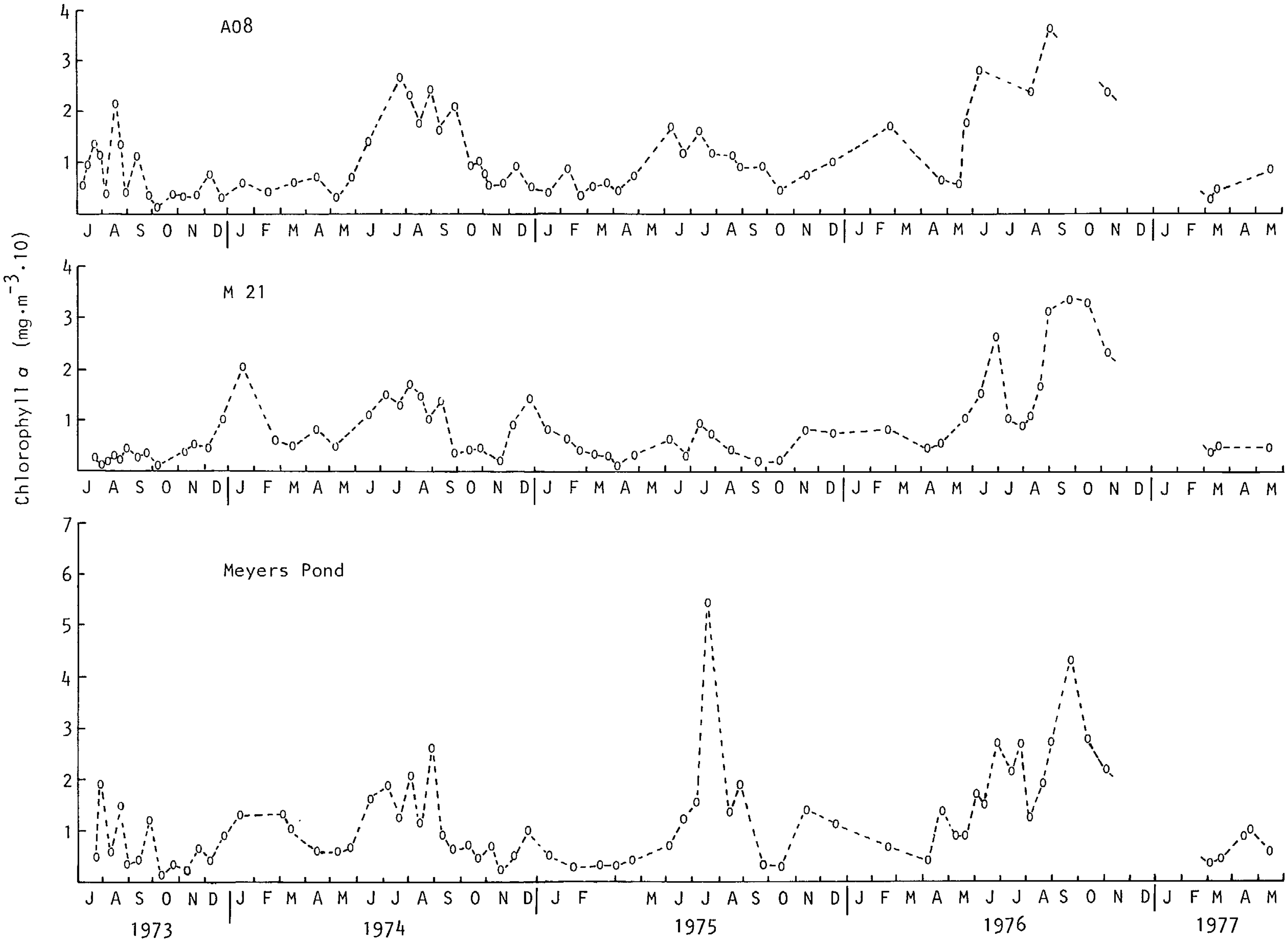

Fig. 38. Chlorophyll a data for Lagoon A08, Marker 21, and Meyers Pond in $mg \cdot m^{-3} \cdot 10$.

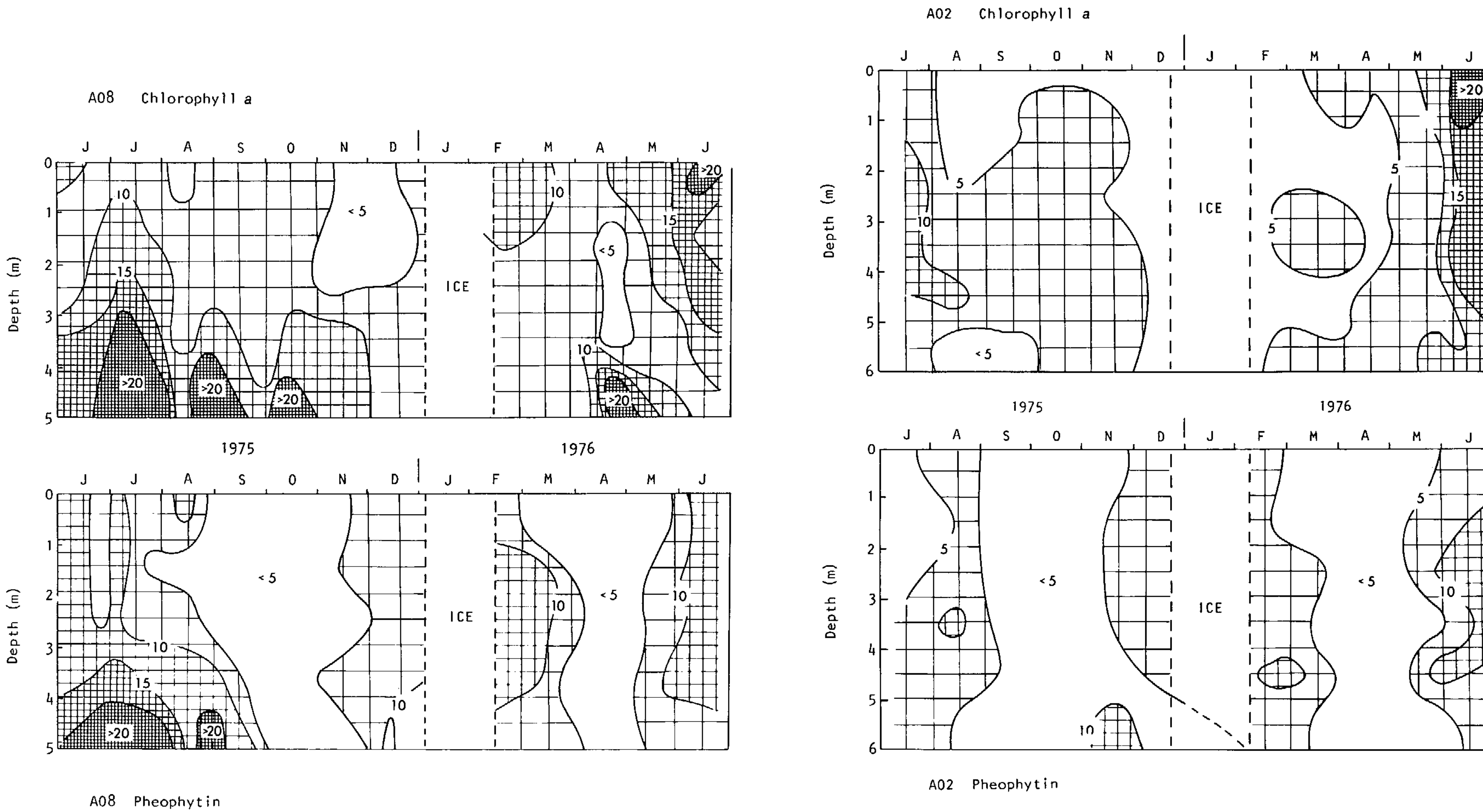

Fig. 39. Plant pigment levels ($mg \cdot m^{-3}$) at Lagoon A08 and A02 contoured.

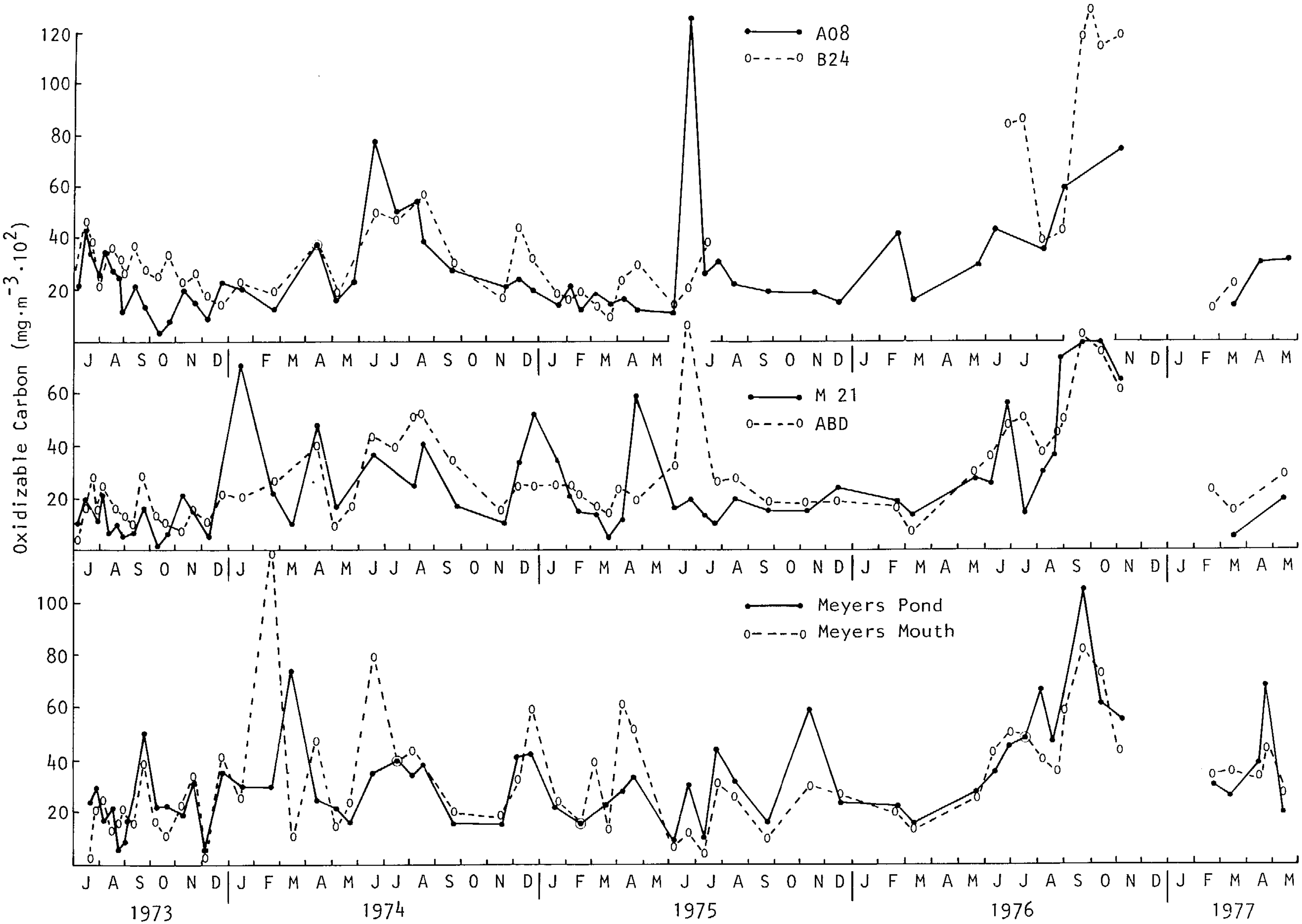

Fig. 40. Oxidizable carbon data for selected stations in mg·m$^{-3}\cdot 10^{2}$.

of the fact that the POC method measures materials other than the phytoplankton standing crop. The potential for elevated detritus levels due to wind stirring is increased in shallow water situations like the creek systems. The increase of suspended materials produces high POC levels not paralleled by high chlorophyll *a* concentrations and results in discrepancies between the seasonal patterns of the two. Despite this, the correlation coefficient between chlorophyll *a* and POC is relatively high for the Meyers Creek system (+0.83). Maximum levels in the creek systems were in excess of 10^4 mg POC$\cdot m^{-3}$ (10^4 ppb). More typical values were 1.5-3.5 x 10^3 mg POC$\cdot m^{-3}$ (1.5-3.5 x 10^3 ppb).

The POC seasonal pattern in the lagoon systems was subject to less variation than in the creek systems (Figure 40), and the pattern was similar to that of chlorophyll *a* with summer maxima and irregular peaks during the winter. Apparently, the reduced wind stirring and tidal circulation in the lagoon systems eliminate some of the creek POC increases. This results in an increased correlation coefficient between chlorophyll *a* and POC (+0.88). Again, maximum POC values exceeded 10^4 mg POC$\cdot m^{-3}$ (10^4 ppb).

The seasonal POC pattern of the bay (Marker 21) is similar to that of the creeks (Figure 40); however, maximum values were lower than the creeks and lagoons with no concentrations above 8.0 x 10^3 mg POC$\cdot m^{-3}$ (8.0 x 10^3 ppb). Along with the lagoon station ABD, Marker 21 represents an intermediate between the seasonal patterns of the creek and lagoon system. The proximity of these two stations is probably a major factor for the similarity.

In general, the POC data like the chlorophyll *a* data confirmed a large phytoplankton standing crop during the summer with elevated levels occurring occassionally during other seasons as well.

PRODUCTION -- The phytoplankton production per unit area is an integration of the productivity occurring throughout the water column. As such, it reflects the standing crop present at a particular depth, the light availability, and the overall size of the water column. The data are listed in Table 21. All measurements of ml $O_2\cdot m^{-2}\cdot day^{-1}$ have been converted to mg $C\cdot m^{-2}\cdot day^{-1}$ using a factor of 0.4464 which incorporates a PQ of 1.2.

The Meyers Creek system had maximum gross production (GP) rates per unit area during the June - September period. Rates achieved levels in excess of 1.4 x 10^3 mg $C\cdot m^{-2}\cdot day^{-1}$. Despite high respiration (R) rates during this time period (ranging over 600 mg $C\cdot m^{-2}\cdot day^{-1}$), net production (NP) rates were also maximized. The highest NP rates exceeded 1.1 x 10^3 mg $C\cdot m^{-2}\cdot day^{-1}$. Minimum levels were observed for GP, R, and NP during the winter with the result of negative NP in the extreme cases.

The lagoon systems had a much different seasonal NP pattern. Although GP and R were generally greatest during the June - September period, as in the Meyers Creek system, the unit area R values were much larger than the unit area GP values. Negative NP rates less than -670 mg $C\cdot m^{-2}\cdot day^{-1}$ were consequently observed, with minimum values less than -1.4 x 10^3 mg $C\cdot m^{-2}\cdot day^{-1}$. High NP was observed during September - April; however, the variation was considerable. Maximum NP was in excess of 1.3 x 10^3 mg $C\cdot m^{-2}\cdot day^{-1}$.

The relation between compensation depth and station depth caused the variation of NP patterns between the natural creek and the lagoon system stations. The natural creeks are shallower. For example, Meyers Pond has a mean depth of 0.42 m and

Table 21. Summary of production data in ml $O_2 \cdot m^{-2} \cdot day^{-1}$.

Date	Meyers Pond			Meyers Creek Mid			Marker 21			ABD		
	GP	R	NP	GP	R	NP	GP	R	NP	GP	R	NP
9/25/74	722	168	554				787	260	527	2,526	1,280	1,246
10/15	213	142	71				279	240	39	689	400	289
10/22	213	126	87				435	260	175	927	640	287
11/4	312	168	144				418	200	218	738	680	58
11/19	49	50	-1				90	120	-30	221	440	-219
12/3	25	17	8				98	80	18	394	280	114
12/27	336	126	210				492	280	212	820	560	260
1/21/75	16	76	-60				197	240	-43	197	400	-203
2/18	107	0	107				320	120	200	164	80	84
3/18	74	76	-2				221	140	81	402	240	162
4/1							287	360	-73	1,788	680	1,108
4/22	131	58	73				385	100	285	1,025	200	825
6/5	369	176	193				927	520	407	3,649	2,880	769
6/25	869	344	525				1,041	480	561	1,960	1,120	840
7/8	754	462	292				1,050	880	170	2,649	2,320	329
7/24	2,345	336	2,009	1,886	576	1,310	541	240	301	2,780	1,520	1,260
9/25	230	110	120	344	192	152	394	200	194	836	560	276
10/15	262	0	262	697	96	601	230	0	230	812	0	812
12/17	459	126	333	1,099	432	667	574	320	254	959	600	359
2/26/76	328	68	260	754	264	490	738	220	518	861	480	381
4/20	558	252	306	1,132	432	700	525	300	225	1,328	840	488
6/8	853	210	643	2,353	768	1,585	1,558	380	1,178	2,878	1,080	1,798
8/3	1,779	470	1,309	1,435	1,176	259	1,164	1,040	124	3,149	2,520	629
8/31	3,018	454	2,564	2,845	1,152	1,693	1,263	1,000	263	3,780	2,280	1,500
9/13	2,624	520	2,104	3,255	1,344	1,911	1,394	1,200	194	2,575	2,520	55
11/2	574	210	364	1,214	504	710	1,099	320	779	984	680	304
3/16/77	271	59	212	344	192	152	336	20	316	599	80	519

Table 21 . Continued.

	Lagoon A02			Lagoon A08			Lagoon B17			Lagoon B24		
	GP	R	NP	GP	R	NP	GP	R	NP	GP	R	NP
9/25/74				3,460	2,160	1,300				2,124	2,160	-36
10/15				1,615	1,872	-257				1,419	3,040	-1,621
10/22				1,509	1,224	285				4,330	2,960	1,370
11/4				1,115	2,016	-901				1,804	2,080	-276
11/19				640	1,224	-584				558	1,280	-722
12/3				574	288	286				1,337	800	537
12/27				820	864	-44				886	1,200	-314
1/21/75				279	720	-441				148	400	-252
2/18				418	144	274				262	160	102
3/18				853	720	133				1,279	960	319
4/1				2,025	1,800	225				1,886	1,360	526
4/22				1,591	432	1,159				1,000	480	520
6/5				2,731	2,880	-149				1,681	2,080	-399
6/25				2,862	2,592	270				2,280	3,200	-920
7/8				2,936	4,464	-1,528				2,886	6,080	-3,194
7/24	2,107	2,340	-233	3,460	5,040	-1,580						
9/25	2,739	1,200	1,539	4,477	1,440	3,037						
10/15	853	60	793	877	432	445						
12/17	1,542	1,020	522	2,025	792	1,233						
2/26/76	1,041	780	261	4,674	2,304	2,370						
4/20	1,681	1,140	541	1,968	1,152	816						
6/8	4,772	2,760	2,012	4,346	3,888	458						
8/3	3,821	4,140	-319	2,919	5,256	-2,337	4,395	3,360	1,035	4,936	6,240	-1,304
8/31	3,050	4,320	-1,270	2,132	5,472	-3,340	3,313	3,120	193	4,576	6,080	-1,504
9/13	3,895	4,200	-305	3,387	5,472	-2,085	4,149	3,360	789	4,567	6,080	-1,513
11/2	1,082	1,320	-238	1,320	2,016	-696	1,591	960	631	1,386	2,400	-1,014
3/16/77	812	300	512	853	360	493	1,214	336	878	1,164	560	604

Meyers Creek 1.2 m, whereas the lagoon stations are generally in excess of 3 m. Therefore, the euphotic zone extends throughout the water column of the creeks. Only once during September 1974 - April 1976 was the compensation depth less than 0.42 m at Meyers Pond. Consequently, the entire water column had a photosynthetic capability. At the deeper lagoon system stations, a significant proportion of the water column is below the euphotic zone. This places an increased respiratory burden on the active photosynthetic populations restricted to the top 2.5 m (8 ft) of the water column. Compensation (Dc) and mean depth data for selected stations in natural and developed systems are given in Table 22. The lagoon system stations have ratios of compensation depth to mean depth of less than 1.00 indicating only a portion of the water column will have a positive NP.

Table 22. Phytoplankton compensation depths for selected stations for the period July 1975 - March 1977.

Station	Mean depth (m)*	No. of observations	Dc (m) Mean	Dc (m) SD	$\left(\frac{Dc}{\text{Mean depth}}\right)$
Meyers Creek Mid	1.2	12	1.20	(0.49)	1.00
Meyers Pond	0.42	24	1.07	(0.49)	2.55
Marker 21	1.0	28	1.50	(0.94)	1.50
ABD	2.0	28	1.57	(0.77)	0.78
Lagoon A02 (Mouth & Upper)	3.0	18	1.74	(0.67)	0.58
Lagoon A08 (Mouth & Upper)	3.6	35	1.84	(0.87)	0.51
Lagoon B17	2.4	5	1.69	(0.78)	0.70
Lagoon B24	4.0	20	1.60	(0.82)	0.40

*To convert meters to feet, multiply by 3.281.

However, although the euphotic zone may be larger at the lagoon stations, the photosynthetic capabilities are often offset by the respiratory demand of the lower water column. During the summer, stratification reduces circulation which further separates the euphotic and aphotic portions of the water column. It also fosters a highly reduced environment conducive to high respiratory demand by the benthic community.

The relationship between GP and R for the phytoplankton populations of three stations is shown in Figure 41. Values of GP/R > 1 are characteristic of an autotrophic dominated metabolism and involve net storage or organic matter. Values of GP/R < 1 are characteristic of a heterotrophic dominated metabolism and involve a net loss of organic matter. Based on this data, Meyers Pond represents an autotrophic station with a high NP capacity. In contrast, Lagoon A08 has a variable nature undergoing heterotrophic periods as well as autotrophic.

Lagoon stations subject to better circulation, like the shallower ABD, did not exhibit as severe a negative NP as the deeper stations like Lagoons A08 and

B24. In fact, ABD was like the natural creek station, in exhibiting high NP during the warmer seasons. The range of NP values was between -100 and 790 mg $C \cdot m^{-2} \cdot day^{-1}$.

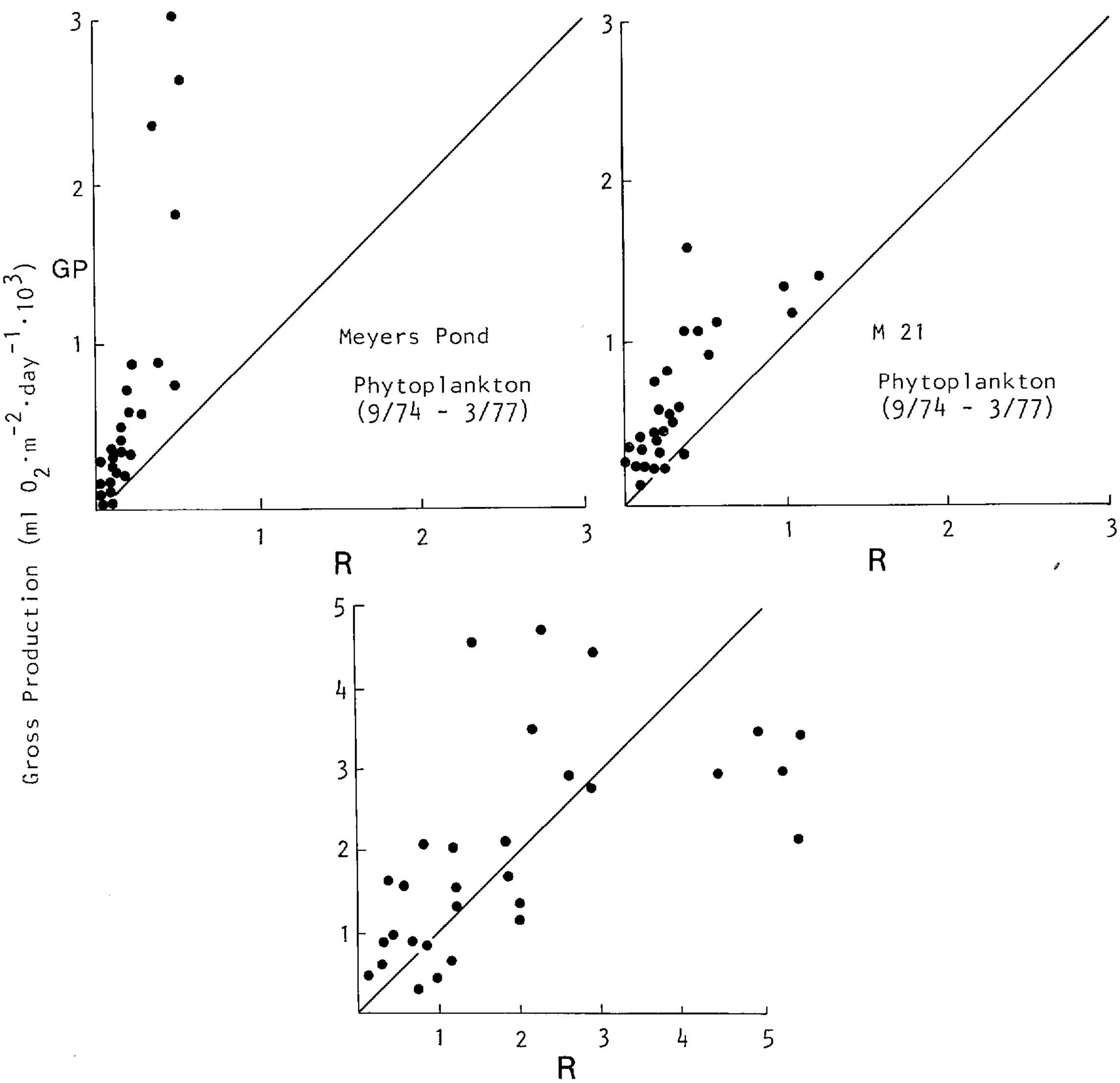

Fig. 41. The relationship between GP and R at Meyers Pond, Marker 21, and Lagoon A08.

The NP of the bay as indicated by Marker 21 follows a pattern similar to the natural creeks. However, the values attained were not as large as the Meyers Creek system maxima. The maximum NP at Marker 21 was less than 530 mg $C \cdot m^{-2} \cdot day^{-1}$. Negative NP rates were observed during the colder portion of the year, but none were in excess of -35 mg $C \cdot m^{-2} \cdot day^{-1}$.

A summation of the net production data in terms of carbon for selected stations is provided in Table 23.

Table 23. Phytoplankton net production data in mg $C \cdot m^{-2} \cdot day^{-1}$ for natural and developed salt marsh areas.

Location	Study year	Summer	Fall	Winter	Spring	Annual mean
Meyers	II					
Creek	III	585	168	258	312	
Mid	IV	526	585		68	
	Mean	556	377	258	190	345
Meyers	II		76	30	16	
Pond	III	337	85	132	137	
	IV	672	551		95	
	Mean	505	237	81	83	227
ABD	II		148	28	312	
	III	357	243	165	218	
	IV	584	80		232	
	Mean	471	157	97	254	245
Lagoon	II					
A02	III	-104	521	175	242	
	IV	63	-121		229	
	Mean	-21	200	175	236	148
Lagoon	II		-14	8	226	
A08	III	-333	777	804	364	
	IV	-777	-621		220	
	Mean	-555	47	406	270	42
Lagoon	II		-115	8	203	
B24	III	-672				
	IV	-627	-564		270	
	Mean	-650	-340	8	237	-186
Marker	II		83	43	44	
21	III	161	95	172	100	
	IV	233	217		141	
	Mean	197	132	108	95	133

Table 24 was constructed using the data from Table 21 and applying a conversion factor based on an oxy-calorific factor of 4.8 $cal \cdot ml\ O_2^{-1}$ (Crisp 1971). Also listed are the energy conversion efficiencies assuming a PAR level of 6.34×10^5 $kcal \cdot m^{-2} \cdot year^{-1}$.

Nutrient limitation and the relationship between light levels and photosynthetic rates were also studied because of their potential influence on the conversion of light energy into fixed carbon. The summer productive capacity in the creeks, lagooned waterways, and the bay was greatly affected by the addition of inorganic NO_3-N and NH_3-N. The data are detailed in Figure 42. Nitrogen enrichment increased net productivity several times at all stations during the summer. However, similar increases were not observed during the fall or winter at ambient

Table 24. Phytoplankton production and efficiencies for natural and developed portions of the study area.

Location	GP ($kcal \cdot m^{-2} \cdot year^{-1}$)	Efficiency of energy utilization* (%)	NP ($kcal \cdot m^{-2} \cdot year^{-1}$)	Efficiency of PAR conversion to NP# (%)
Meyers Creek Mid	2,231	0.35	1,354	0.2
Meyers Pond	1,212	0.19	891	0.1
ABD	2,574	0.41	962	0.2
Lagoon A02	3,143	0.50	581	0.1
Lagoon A08	3,798	0.60	165	0.0
Lagoon B24	3,488	0.55	-730	
Marker 21	1,146	0.18	522	0.1

*Defined as ($GP \cdot$ Incident PAR $level^{-1}$)
#Defined as ($NP \cdot$ Incident PAR $level^{-1}$)

or artificially enhanced light levels. Limitation by other nutrients, including phosphorus was uncommon.

Photosynthesis by surface populations of phytoplankton was inhibited at incident levels (100 $\%I_o$). Maximum photosynthetic rates were observed at the 50 $\%I_o$ level.

FOOD WEB: AQUATIC PRIMARY PRODUCTION - BENTHIC ALGAE

The benthic sediments in the Manahawkin study area, like those in most coastal marine habitats, are reducing environments. A thin surface oxidized layer overlies a "gray zone" in which oxygen and hydrogen sulfide are present in small amounts. Below is a well-developed anaerobic zone typically black due to the presence of high quantities of ferrous sulfides (Fenchel and Riedl 1970). The surface aerobic layer may be a few mm to several cm thick, or may be entirely absent in the case of an anaerobic water column.

Aerobic organisms dominate the oxidized layer, but both facultative and obligate anaerobes characterize the lower strata. These exhibit a variety of fermentative and anaerobic respiratory processes whose reduced end products (lactate, alcohols, fatty acids, CH_4, H_2, H_2S, and NH_3) accumulate and diffuse upward, transporting chemical energy derived from decomposition to the aerobic zone (Gargas 1970; Jorgensen 1977). Nutrient release may also be accomplished by bioturbation and by the stirring action of winds and currents (Berner 1977).

The net flux of major dissolved constituents between the sediment and the water column resulting from both aerobic and anaerobic metabolism is summarized in Figure 43 (Berner 1976). The sedimentary carbon pool inputs and outputs are detailed in Figure 44.

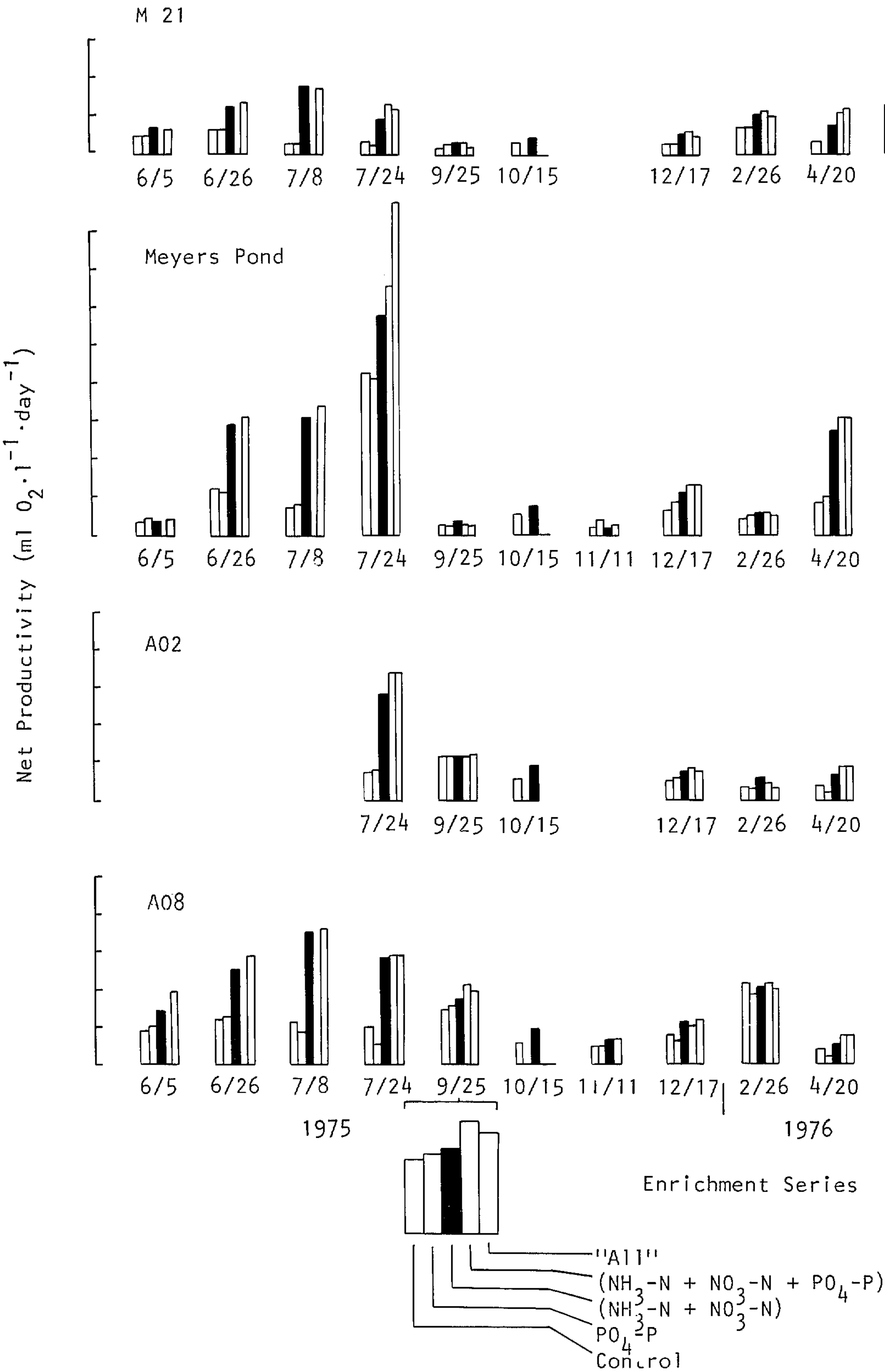

Fig. 42. Phytoplankton production and nutrient enrichment.

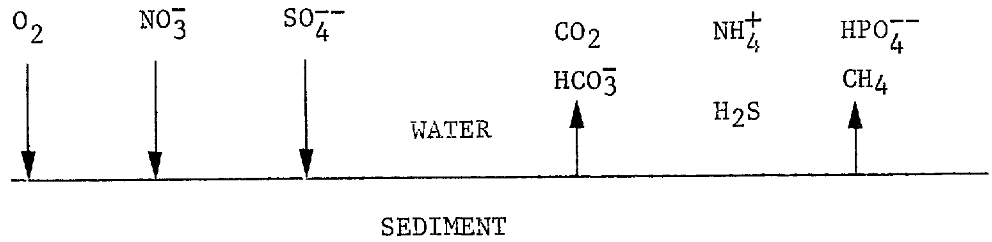

Fig. 43. Flux of dissolved compounds across the sediment water interface.

The purpose of the benthic primary production study is: (1) to estimate the productivity of the sediment microflora and (2) to determine differences between stations.

Methods

The study extended from January 1974 to April 1977. Sampling stations were located at Meyers Creek mouth, Meyers Creek mid, Meyers Pond, ABD, Lagoon A08, and Lagoon A12 (Figure 45). Cores of the sediment were incubated for 12 hours with gentle mixing under light and dark conditions at in situ temperatures. The changes in oxygen content of the overlying water were determined by the Winkler oxygen titration method (with the azide modification) and these values corrected for changes resulting from plankton metabolism.

The production measures expressed are "potential" rates, since incubations were conducted under standard lighting conditions with an artificial light source. These lighting conditions sometimes exceeded in situ levels particularly at the deeper lagoon stations where the light intensities approach or equal total darkness. An increase in dissolved oxygen in the "light" cores is therefore indicative of net community production; oxygen uptake in the "dark" cores is indicative of total community demand (algal, bacterial, faunal) in addition to that of inorganic chemical oxidation.

Additional information on methods can be found in Durand et al. (1974, 1975, 1976, 1977).

Results and Discussion

SUBTIDAL SEDIMENT COMMUNITY -- Negative NP was generally observed for the subtidal sediments in both the Meyers Creek system and Lagoon System A throughout the entire study period. Those positive rates which were recorded were usually minimal and occurred at the shallower stations during the colder months when respiratory demands had diminished (Table 25). In contrast, the algal community associated with the intertidal sediments bordering Meyers Creek was capable of high positive rates of NP, especially during the period June - September (Figure 46). Rates at this time exceeded 800 ml $O_2 \cdot m^{-2} \cdot day^{-1}$, but declined sharply after September.

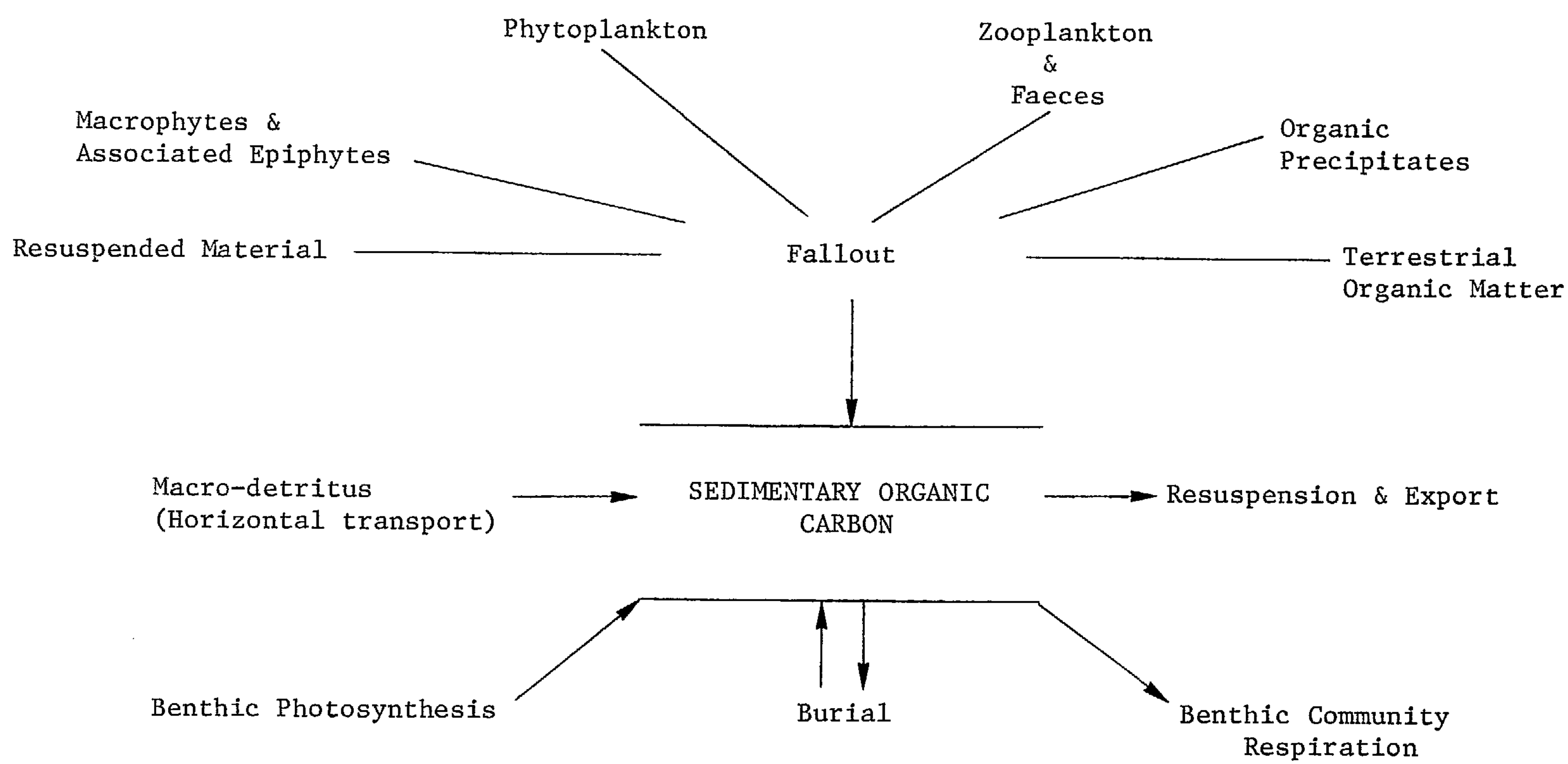

Fig. 44. Major inputs and outputs of carbon associated with the sedimentary organic carbon pool of estuaries. Adapted from Johnson (1974) and Hartwig (1976).

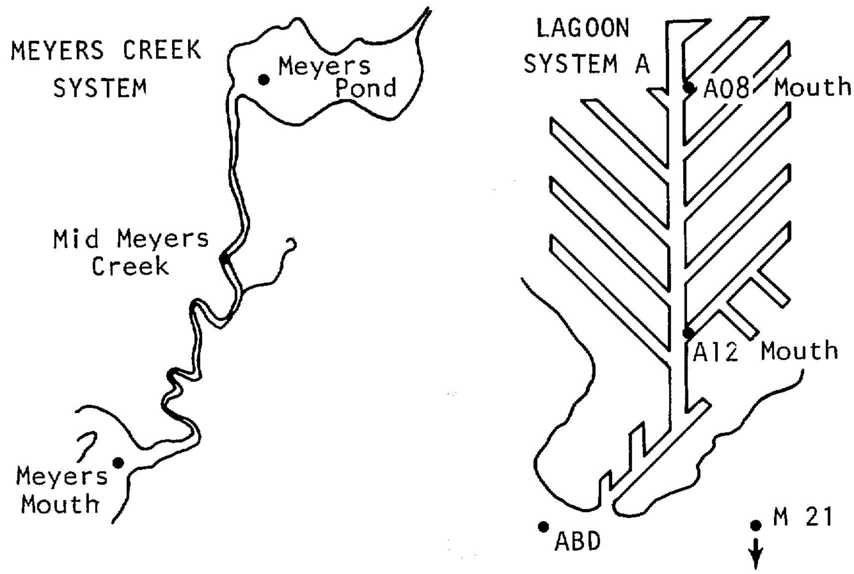

Fig. 45. Sampling locations for benthic algal production.

Benthic community respiration in the subtidal and intertidal habitats in both systems appeared to follow the seasonal trend in water temperature, with highest uptake rates taking place during the summer and minimal rates occurring in the colder months (Figure 46). Typical summer levels for those lagoon stations which were aerobic (ABD-A12) were approximately 700 ml $O_2 \cdot m^{-2} \cdot day^{-1}$. Summer uptake rates at Meyers Creek mouth were slightly lower (500-600 ml $O_2 \cdot m^{-2} \cdot day^{-1}$), except in 1975 when summer levels only reached about 200 ml $O_2 \cdot m^{-2} \cdot day^{-1}$. Oxygen uptake rates in Meyers Pond were generally higher than either the mid creek or creek mouth stations, exceeding 1,000 ml $O_2 \cdot m^{-2} \cdot day^{-1}$ in July 1976. High summer uptake rates were also observed for the mudflat habitat, over 700 ml $O_2 \cdot m^{-2} \cdot day^{-1}$ in 1974 and 1975. The 1976 values were significantly less.

The results for Lagoon A08 were complicated by the presence of anaerobic conditions at various times. No changes in oxygen concentration could be detected in anaerobic cores or cores that went anaerobic before termination of the experiment. The available oxygen demand data were consistently higher than those at the other lagoon stations.

Annual production estimates for these benthic communities were derived by planimetry of the seasonal curves and converted to a carbon base using a PQ of 1.2 and an RQ value of 1.0. These are listed in Table 26 and may be compared to those obtained by other investigators for a wide variety of habitats (Table 27).

MUDFLAT OR INTERTIDAL COMMUNITY -- The mudflat algal community along Meyers Creek was generally autotrophic. Total community respiration exceeded photosynthetic capacity only during the colder months. The annual NP of the mudflat microflora was 29-63 g $C \cdot m^{-2}$. The subtidal communities in both the natural and developed areas were much less productive. The stations located near the mouth of Lagoon System A (ABD-A12) were slightly less productive than Meyers Pond. Similar to the results previously described for the daily production estimates.

Table 25. Production of benthic communities from Meyers Creek system and Lagoon System A. All units, ml $O_2 \cdot m^{-2} \cdot day^{-1}$. The value within parentheses equals 1 SD.

Date	Meyers Creek mouth			Meyers Creek Mid			Meyers Pond		
	NP	R	GP	NP	R	GP	NP	R	GP
1/31/74	-58 (87)	70 (35)	12				41 (27)	211 (93)	252
2/14/74	53 (25)	88 (25)	141				70 (25)	211 (99)	281
3/28/74	-99 (20)	246 (35)	147				-105 (30)	421 (70)	316
7/11/74	-158 (25)	491 (50)	333				-289 (37)	667 (99)	378
7/24/74	-211 (50)	509 (74)	298	-281 (50)	632 (50)	351	-281 (25)	702 (50)	421
8/6/74	-216 (27)	561 (70)	345				-234 (27)	632 (70)	398
11/21/74	-73 (13)	251 (37)	178						
1/14/75	-18 (9)	152 (10)	134				26 (9)	175 (18)	201
2/13/75	0 (18)	234 (44)	234				79 (9)	181 (27)	260
3/26/75	140 (12)	79 (12)	219				48 (6)	175 (74)	223
4/30/75	170 (5)	193 (18)	363				79 (18)	655 (27)	734
7/17/75	-85 (13)	158 (18)	73				-159 (8)	404 (23)	245
10/2/75	-266 (22)	228 (30)	-38	-298 (26)	357 (103)	59	-523 (33)	874 (38)	351
12/11/75	-105 (9)	6 (10)	-99	-85 (18)	193 (30)	108	-64 (18)	170 (27)	106
3/12/76	-111 (13)	273 (23)	162	-164 (5)	439 (93)	275	-129 (13)	368 (18)	239
7/1/76	-330 (119)	632 (35)	302	-409 (81)	608 (54)	199	-561 (27)	1,010 (35)	449
8/24/76		515 (43)						640 (87)	
10/11/74	-90 (37)	202 (23)	112	-99 (18)	263 (32)	164	-96 (21)	303 (26)	207
4/13/77	-204 (19)	439 (29)	235	-239 (15)	488 (29)	249	-268 (23)	588 (24)	320
4/19/77		345 (57)						687 (110)	

Table 25. Continued.

Date	ABD NP	ABD R	ABD GP	Lagoon A12 NP	Lagoon A12 R	Lagoon A12 GP	Lagoon A08 NP	Lagoon A08 R	Lagoon A08 GP
3/28/74							-205 (20)	433 (54)	228
7/24/74	-219 (12)	561 (50)	342					-Anaerobic-	
8/6/74	-187 (10)	480 (54)	293						
11/21/74							-102 (13)	246 (35)	144
1/14/75	15 (5)	76 (27)	91				-140 (9)	287 (20)	147
2/13/75	12 (5)	105 (53)	117				-216 (22)	404 (53)	188
3/26/74	4 (6)	96 (12)	100				-272 (37)	588 (136)	316
4/30/75	26 (26)	298 (88)	324				-316 (9)	655 (44)	339
7/17/75	-228 (18)	690 (44)	462					-Anaerobic-	
10/2/75				-32 (31)	591 (37)	559	120 (62)	380 (170)	500
12/11/75				-231 (10)	199 (44)	-32		-Anaerobic-	
3/12/76				-88 (18)	409 (37)	321	-342 (23)	602 (37)	260
7/1/76				-330 (48)	673 (44)	343		-Anaerobic-	
10/11/76				-117 (13)	284 (19)	167		-Anaerobic-	
4/13/77				-155 (14)	459 (42)	304	-277 (16)	648 (33)	371

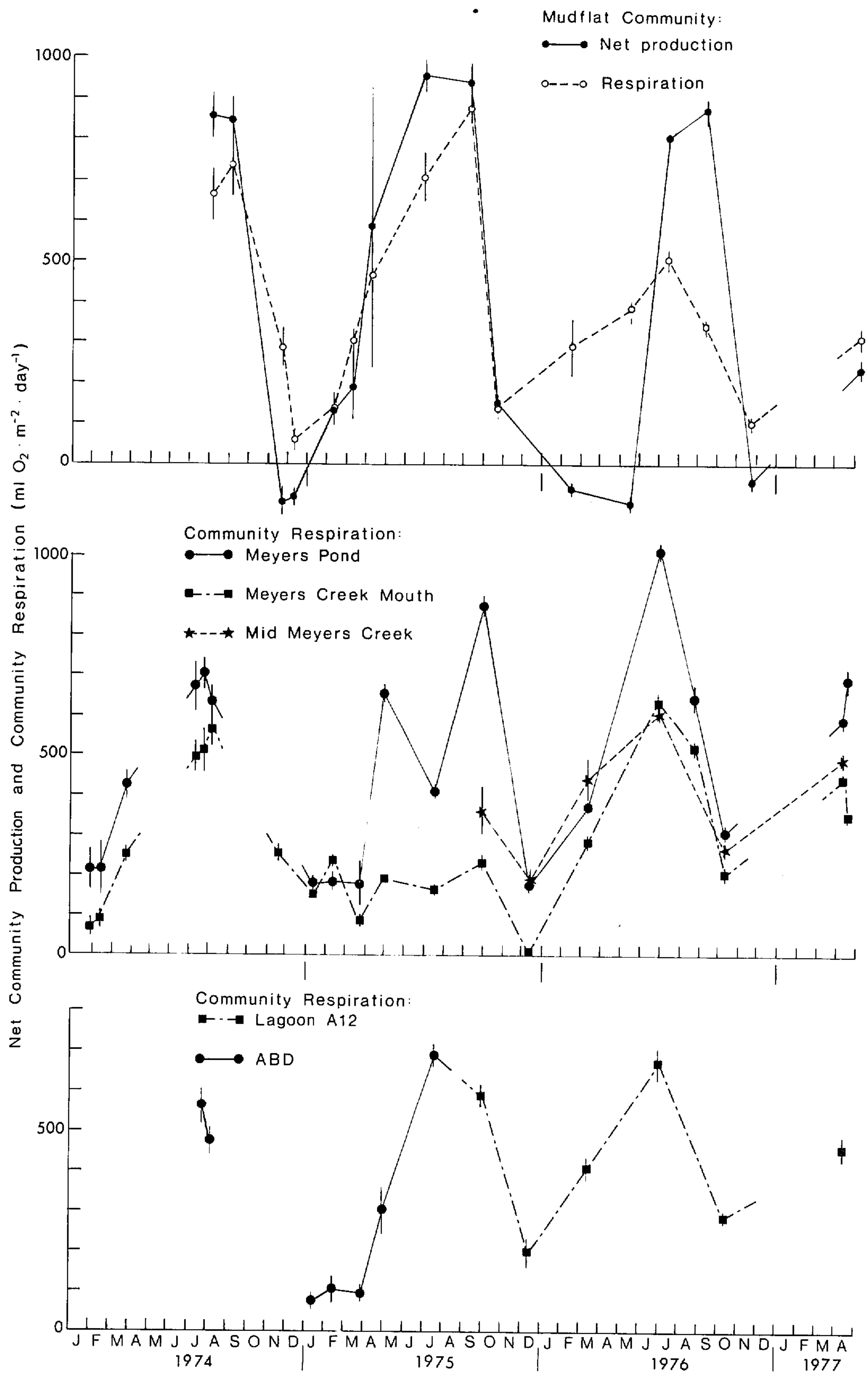

Fig. 46. Selected benthic net community productivity and community respiration data.

Table 26. Annual production of intertidal and subtidal microflora in g $C \cdot m^{-2} \cdot year^{-1}$.

Habitat	Location	Period	R	NP	GP
Intertidal	Meyers Creek mudflat	9/74 - 8/75	92	63	155
		9/75 - 8/76	71	29	100
Subtidal	Meyers Pond	1/74 - 12/74	82	-33	49
		1/75 - 12/75	83	-32	51
		1/76 - 12/76	96	-53	43
	Meyers Creek mid	10/75 - 9/76	75	-48	27
	Meyers Creek mouth	1/74 - 12/74	55	-26	29
		1/75 - 12/75	30	-12	18
		1/76 - 12/76	62	-36	26
	ABD-A12	1/75 - 12/75	68	-23	45
		1/76 - 12/76	77	-42	35

Annual respiratory requirements of the total benthic community within these sediments exceeded the input by photosynthetic carbon fixation. In Table 28 are approximations of the average light conditions at the sediment surface. Average Secchi values for the entire study period were used to estimate the percent of incident solar radiation ($\%I_o$) reaching the bottom at each of these stations. On the average, more incident light reached the sediments of Meyers Creek system and the bay (8-30 $\%I_o$) than in the lagoons. At those lagoon stations where the total depth exceeded 2.0 m (6.6 ft.), only 1% or less of the incident radiation was available for photosynthesis.

Since the subtidal communities were predominately heterotrophic, total depth and its effect upon light availability was probably not as significant a contributing factor as the predominance of nonphotosynthetic microbiota in the sediment.

Smith et al. (1972) found bacteria generally accounted for 30 - 50% of community respiration in both freshwater and marine sediments. These figures are similar to those obtained from preliminary studies at the Manahawkin study site involving the addition of antibiotic (streptomycin sulfate) to dark cores.

Both the presence of a significant heterotrophic component postulated earlier, and the seasonal cycle described for sediment oxygen uptake in the Manahawkin area

Table 27. Published benthic production data.

Location		GP	NP	R	C^{14}*	Reference
Marion Lake, B.C.		40	-17	57		Hargrave (1969)
New England estuaries					81	Marshall et al. (1971)
Nacote Creek, N.J. Mudflat#		16	6	10		Nadeau (1972)
North Inlet Estuary, S.C.					685	Zingmark (1977)
Duplin River Estuary, Ga.		200	100	100		Pomeroy (1959)
Barataria Bay, La.		362	244	118		Day et al. (1973)
Yaquina Bay, Re.	Sandy flats	275-325				Riznyk and Phinney (1972)
	Silty flats	0-125				
Puget Sound, Wash.	Sandy flats	143-226				Pamatmat (1968)
Ythan Estuary, Scot.	Mudflat				31	Leach (1970)
Loch Ewe	Sandy beach				4-9	Steele and Baird (1968)
Danish Wadden Sea					115-178	Grontved (1962)
Danish fjords					116	Grontved (1960)

*The carbon^{14} technique was used to measure these productivity estimates.
#April to November only.

are consistent with these findings. The actual amount of microfloral primary production which is respired by the total community remains unknown, since many alternative sources of organic matter, both autochthonous and allochthonous, are available.

Inorganic chemical oxidation by undisturbed sediment generally accounts for only a small fraction of the total oxygen uptake. Recorded values for Buzzards Bay, Mass. (Smith et al. 1973) and Sapelo Island, Ga. (Smith 1973) were 14% and 5-9%, respectively. These values, together with total sediment oxygen demand, may be expected to increase markedly upon disturbances of the surface oxidized layer and the exposure of anoxic subsurface sediment (Berg 1970; Carey 1967; Hargrave 1969; Frankenberg and Westerfield 1968).

If the conversion factor 4.8 kcal·ml O_2^{-1} (Crisp 1971) is applied to the mudflat data from study year III, we find the net primary production rate ranged from 461 to 1,181 cal·m^{-2}·12 hours^{-1}. For the limited study year III data (12/74, 2/75, 3/75, and 4/75), the lowest rate occurred in December 1974 and the highest in April 1975. Multiplying the 12 hour rate by 30 to obtain a monthly value, efficiency of PAR conversion into NP would be 0.04% and 0.07% for December 1974 and April 1975, respectively. Maximum rates around 3,840·m^{-2}·24 hours^{-1} were observed during July. Efficiency of conversion is 0.14% at these times.

Benthic metabolism had a significant effect upon the aquatic system in both natural and developed areas in terms of oxygen budget and the nutrient recycling resulting from organic matter oxidation. Low dissolved oxygen concentrations

Table 28. Approximation of average light conditions prevailing at the sediment-water interface for selected stations from the period June 1973 - May 1977.

Station	Mean depth (m)	No. of observations	Secchi(m) Mean (SD)	$\%I_0$ at mean depth (%)*
Meyers Creek mouth		75	0.7 (0.31)	
Meyers Creek mid	1.2	35	0.8 (0.40)	8
Meyers Pond	0.42	59	0.6 (0.26)	30
Meyers System		169	0.7 (0.32)	
Marker 21	1.0	69	1.2 (0.66)	24
ABD	2.0	74	1.0 (0.40)	3
Lagoon A02 mouth	3.0	24	1.1 (0.42)	1
Lagoon A02 upper	3.0	16	1.1 (0.41)	1
Lagoon A08 mouth	3.6	85	1.1 (0.42)	<1
Lagoon A08 upper	3.6	12	1.2 (0.39)	<1
Lagoon B17	2.4	17	0.8 (0.39)	<1
Lagoon B24	4.0	64	0.9 (0.37)	<1
Lagoon system		218	1.0 (0.41)	

*Percent of incident solar radiation capable of penetrating the entire water column. Calculated from the average Secchi value for each station where mean depths are available and the equation of Poole and Atkins (1929).

characteristic of Meyers Pond during the summer were attributable to the large respiratory demands of the benthos. However, aerobic conditions were maintained by the large input of oxygen-rich bay water during the flood tide.

At the bottom of the deeper lagoon stations, where aphotic conditions generally prevailed, high benthic respiration rates were a major factor in the frequent development of an anaerobic water column above the sediment. The anoxia was enhanced by the lack of a photosynthetic input of oxygen and the restricted circulation of bottom water in the lagoon complex.

Since the circulation processes are weak in these housing developments, large quantities of organic matter accumulate in the sediment as a result of the deposition of allochthonous matter (such as eelgrass fragments) and the retention of autochthonous organic material (Walton et al. 1976). As the concentration of dissolved oxygen in the isolated deep water declines due to the oxidation of this organic matter, the process of aerobic respiration would be replaced by nitrate reduction and finally, sulfate reduction (Anderson and Devol 1973). The accumulation of reduced compounds such as ammonia and hydrogen sulfide was noted for the Village Harbour lagoon bottoms. They are indicative of a relatively inefficient cycling of nutrients. This situation is quite different from the shallow tidal creeks and ponds where nutrients released by mineralization processes in the sediment are always returned to an aerobic and photic water column and thereby become immediately available to the phytoplankton community.

FOOD WEB: AQUATIC PRIMARY PRODUCTION - SUBMERGED VEGETATION

The marine angiosperms of major importance in northern temperate estuaries are eelgrass (*Zostera marina* L.) and widgeon grass (*Ruppia maritima* L.), neither of which are true grasses. *Zostera* is the most important species in north temperate areas, and ranges from Greenland to North Carolina (Moul 1973; Phillips 1974). Although it can survive a wide range of temperatures and salinities for brief periods, optimal growth conditions occurs at 10 - 20°C and 10 - 30 °/oo (Thayer et al. 1975a). The 1930's "wasting disease" epidemic along the North Atlantic coasts of the United States and Europe caused the destruction of 99-100% of the eelgrass standing crop in many areas and had a significant effect upon estuarine invertebrates, fish, and waterfowl (Moffitt and Cottam 1941; Phillips 1974).

Ruppia maritima is a cosmopolitan species and is found in brackish ponds and sublittoral beds of shallow estuaries from Newfoundland to Florida, the West Indies, and Mexico (Moul 1973). It also occurs in alkaline ponds, lakes, and streams of western North America (Dawson 1966; Muenscher 1944). Germination and seedling development are restricted to 15 - 20°C and vegetation growth and reproduction occur between 20 and 25°C (Setchell 1920, 1924). According to Phillips (1974), it is generally restricted to very shallow water and is probably of little relative significance as a temperate zone system.

The productivity of seagrass meadows is characteristically high, especially for eelgrass systems. Estimates of annual net production for *Zostera* have ranged from 10 to 1,200 g dry weight$\cdot$m^{-2}.year^{-1} (Phillips 1974), and can exceed the world averages for energy-subsidized grain agriculture (Odum 1971). Williams (1973) has estimated the eelgrass community near Beaufort, North Carolina accounted for approximately 64% (120 g C$\cdot$m$^{-2}\cdot$year^{-1}) of the combined annual production (187 g C$\cdot$m$^{-2}\cdot$year^{-1}) of the phytoplankton, *S. alterniflora*, and eelgrass, even though it only occupied 17% of the 53,200 ha (205 miles^2) estuary.

This large reservoir of stored energy may reach higher trophic levels either by way of a grazing food chain, or more importantly, as an indirect source through detrital pathways (Harrison and Mann 1975; Odum et al. 1973). Its importance to species of birds (Bellrose 1976; Correll and Correll 1972; Moffit and Cottam 1941; Sculthorpe 1967), fish (Darnell 1961; Milne and Milne 1951), and invertebrates (Dexter 1944; Marsh 1973; Odum et al. 1973) has been recognized but most observations have been qualitative.

Such dense vegetation provides a substantial surface area for colonizing epiphytes. Sullivan (1977) noted luxuriant growths of epiphytic diatoms (57 taxa) on the leaves and internodes of *Ruppia* collected from salt ponds in the Great Bay salt marsh near Tuckerton, New Jersey. The biomass of the attached algae may approach or even surpass that of the vascular plants (Nixon and Oviatt 1972; Thayer et al. 1975a), providing an important food source for grazing invertebrates (Kikuchi and Peres 1977).

The physical structure of the beds also creates a number of microhabitats which provide protection and nursery areas for many species of invertebrates and finfish. In the Newport River estuary (North Carolina), Thayer et al. (1975b) found the density and biomass of these groups within a *Zostera* bed to be much greater than in surrounding unvegetated areas. They were also significantly different in terms of species composition. The contribution (percent biomass) by the dominant invertebrate taxa and feeding types are listed below:

Epifauna:

Dominant taxa:	Gastropods (38%), decapods (30%), pelecypods (11%), amphipods (5%).
Feeding types:	Deposit feeders, suspension feeders, and carnivore-scavengers (30-36% each).

Infauna:

Dominant taxa:	Polychaetes (51%), pelecypods (34%), nemerteans (11%), decapods-echinoderms (4%).
Feeding types:	Deposit feeders (44%), suspension feeders (35%), carnivore-scavengers (21%).

The mean biomass (1.33 $g \cdot m^{-2}$) of the ichthyofauna for the eelgrass bed was similar to marsh-pond habitats. Dominant species included pinfish (*Lagodon rhomboides*), pigfish (*Orthopristes chrysopterus*), Atlantic silverside (*Menidia menidia*), and anchovies (*Anchoa mitchilli* and *Anchoa hepsetus*).

Due to the high plant and animal biomass and the variety of metabolic activities associated with the different trophic groups, seagrass ecosystems can have a profound impact on the estuarine biogeochemical cycles. Although comprehensive studies are lacking, the nitrogen, phosphorus, and sulfur cycles appear to be intricately linked with the activities of the seagrass biota (Phillips 1974).

Nutrient exchanges occurring between the sediment and water and the extensive root and leaf systems of *Zostera* have been studied by McRoy and Barsdate (1970) and McRoy and Goering (1974). Absorption of phosphorus and nitrogen is carried out both by the roots and leaves. Transfer of nutrients from the sediments to the leaves and finally to the water column is also possible, thereby establishing a "nutrient pump" mechanism. *Zostera* has also been directly linked with the production of ferrous sulfide in the mid as a result of its formation or organic reducing compounds (Wood 1954). An active sulfur cycle is also maintained by the large input of organic matter into the sediments and its subsequent decay (Thayer et al. 1975a).

Proteins, carbohydrates, fats, minerals, and B vitamins are also tied up by the living plant tissue (Burkholder and Doheny 1968). The breakdown of this huge organic reservoir will affect the nutrient dynamics within the *Zostera* bed and in the surrounding estuary. Pulich et al. (1976) hypothesized the cycling of detritus within a confined area near the source of production leads to optimal nutrient concentrations and rates of supply necessary to the long-term stability of the grass meadow.

The high photosynthetic and respiratory activity of the numerous plants and animals may also cause large and rapid fluctuations in dissolved oxygen concentrations. This is especially true if the volume of the aquatic environment is very limited, as in *Ruppia*-dominated marsh ponds (Christian, pers. comm.).[5]

These dense beds increase the stability of the sediment-water interface and provide relatively quiet, silt-free water. The well-developed anchoring systems of *Ruppia* and *Zostera* increase their sediment-binding capacity, and the dense leaf cover reduced current velocity, thereby increasing sedimentation rates (Phillips 1974). The decreased substrate erosion may be of great importance to the maintenance of the microflora-fauna community and the organic input provided by sedimentation may significantly enrich the mud for the numerous deposit feeders. Thayer et al. (1975b) found the eelgrass bed of Newport River estuary to be rising relative to sea level (12 - 22 $mm \cdot year^{-1}$ or 0.5 - 0.9 $in \cdot year^{-1}$) as a result of this "sediment trap" function.

A species list of benthic macrophytes observed in the study area and nearby Barnegat Bay is provided in Appendix B Table 2. According to Good et al. (1978), *Zostera* clearly dominates the submerged vegetation of Little Egg Harbor in terms of percent bottom cover. It occurred in approximately half of the 166 field stations which were situated throughout the bay during the period September 1976 - January 1978. *Ruppia* and mixed *Ruppia-Zostera* dominance accounted for only 11% and 7%, respectively, of the stations. About 30% of the stations were depauperate.

The dominant algal species in the bay are *Ulva lactuca* (sea lettuce), *Codium fragile* (spaghetti grass), *Gracilaria foliifera*, and *Agardhiella tenera* (Good et al. 1978; Smith 1974). No biomass data is available for Little Egg Harbor.

Standing crop estimates (in terms of wet weights) are available for Barnegat Bay to the northeast (Moeller 1964). *Zostera* was found to account for 1.77×10^7 kg (3.90×10^7 lbs), 67% of the total standing crop, 2.65×10^7 kg (5.84×10^7 lbs) and covered nearly 4,700 ha (18.1 $miles^2$) of the 21,200 ha (81.9 miles) bay. Other dominant species and their percent contribution to the total standing crop of submerged vegetation included: *Gracilaria* spp. (10%), *Ulva lactuca* (7%), *Agardhiella tenera* (5%), and "mixed reds"[6] (2%).

The distribution of this flora in Little Egg Harbor probably reflects a number of related environmental factors, turbidity, depth, current regime, and substrate. The following description of macrophyte distribution in terms of these factors relies heavily on the study by Good et al. (1978).

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[5] Dr. Robert Christian is an assistant professor at Drexel University.

[6] *Dasya pedicellata*, *Polysiphonia* sp., *Spyridia filamentosa*, *Champia parvula*, *Ceramium fastigiatum*, *Deramium* sp., and *Chondria baileyana*.

In general, the mean low water serves as a reliable boundary for the upper limit of seagrasses. The lower limit is much less rigid, depending upon the suitability of substrate and degree of turbidity (Thayer et al. 1975a). The average depth of *Ruppia*-dominated stations in Little Egg Harbor was 0.41 m (1.3 ft) compared to 0.93 m (3.1 ft) for eelgrass. Areas of mixed *Ruppia-Zostera* dominance were intermediate in depth, averaging 0.56 m (1.8 ft). Deeper regions of the bay (>1.5 m or 4.9 ft) were generally devoid of any vegetation.

Tidal current regimes are also important because of their role in sediment erosion, transport, and deposition. The scarcity of macrophytes near the southern end of Long Beach Island may reflect unfavorable areas of active sediment deposition. Conover (1968) also suggested there is a metabolic relationship between current velocity and plant growth capacity, involving relative transfer rates of gaseous and dissolved nutrients to the plant. Standing crops of several benthic species correlated with the current velocity regime, and *Ruppia* growth appeared to be optimal between 0.4 - 1.3 $km \cdot hour^{-1}$ (0.2 - 0.7 knots), compared to 0.9 - 1.9 $km \cdot hour^{-1}$ (0.5 - 1.0 knots) for *Zostera*.

The substrate of seagrass beds may range from pure firm sand to pure soft mud, but usually consists of a mud-sand mixture. The plants are rooted in a reducing environment which prevails underneath the oxidized surface layer (Phillips 1974; Thayer et al. 1975a). In Little Egg Harbor, *Zostera* was associated with a variety of mud-sand mixtures, while *Ruppia* generally occurred in the more sandy areas. This also appears to be the case for Barnegat Bay where *Ruppia* is most prevalent on the easterly sand flats of the bay (Loveland et al. 1974).

The amount of light received by the plant community will depend upon the depth of the overlying water column and the amount of particulate and dissolved material in the water column. This turbidity is in turn a function of substrate type and its susceptability to stirring by wind and tidal forces. Although the mean depth of Little Egg Harbor for the nonchannel areas is only 0.7 m (2.3 ft), light intensities may be limiting at times since Secchi disc values are generally less than 1 m (3.3 ft).

During severe winters, freezing and ice-scouring may severely affect the submerged vegetation. Large, shallow depressions devoid of macrophytes may be created. This phenomenon has been observed during the winter of 1976-77 in Little Egg Harbor (Good et al. 1978) and the winters of 1962-63 and 1963-64 in the Great Bay estuary (Moeller 1965).

Significant areas of *Zostera* and *Ruppia* (> 2 ha or 0.008 $miles^2$) were also observed at the mouths of several tidal creeks along the west side of the bay including Westecunk, Dinner Point, Meyers, and Oyster Point creeks. These drainage areas during the summer also have a distinct algal community comprised of *Fucus vessiculosus*, *Ulva lactuca*, *Enteromorpha* spp., *Gracilaria verrucosa*, *Spyridia filamentosa*, and *Polysiphonia harveyii* (Natural and Historic Research Associates 1973). These species become increasingly less common in the upper ends of the creeks, being replaced by diatoms and blue-green algae.

The presence of submerged macrophytes is prohibited in the lagoon systems as a result of anaerobic conditions, unfavorable light intensities due to excessive depth, and possibly the reduced current velocities. The mouths of the lagoons, however, may act as settling basins for uprooted eelgrass which contribute significant quantities of organic matter to the sediment (Walton et al. 1976).

The sublittoral vegetation of the bay and creeks exists in a state of dynamic flux and distinct seasonal patterns in species composition, growth rates, and standing crops are to be expected (Moeller 1964, 1965). Although eelgrass meadows are perennial, the individual leafy shoots (turions) are biennial and break off after a flowering stalk is produced in the second year (Setchell 1929). Conover (1958) observed the *Zostera* in Great Pond, Massachusetts to undergo this phase of leaf decline and decay during the periods June - early August, and then again in late September and October. Plant biomass was at a minimum during winter dormancy (January-February) and reached a maximum in July. He attributed this pattern to seasonal changes in insolation and water temperature.

Distinct seasonal patterns have been recorded for algal species and taxons within the Great Bay - Mullica River estuary (Moeller 1965). The number of attached algal species were observed to increase from eight in the spring to 31 in the summer, accompanied by a 9 times increase in the number of reproducing forms.

Some algal species are ephemeral in appearing very rapidly at a given location and existing for only a very brief period. This phenomenon has also recently been observed in Little Egg Harbor (Vaughan, pers. comm.).[7]

The Rhodophyta dominated the vegetation of Great Bay estuary during summer and fall, and were at a minimum during March, April, and May. The Phaeophyta, however, reached their maximum in the spring, and then declined throughout the summer. In contrast to these marked seasonal occurrences, the Chlorophyta were observed to reappear throughout the year in the same or at different locations in the estuary.

No comprehensive long-term studies of submerged vegetation and its variability over space and time are available for Little Egg Harbor. In Barnegat Bay, however, Loveland et al. (1974) noted except for *Codium fragile*, the dominant species have remained constant over the period 1965-1973 either in terms of frequency of occurrence or amount of biomass. *Codium* first appeared in Barnegat Bay in 1965 and by 1972 had established itself as the most common algal species. By the summer of 1973, it had significantly declined in abundance as a result of increased competition with endemic species.

FOOD WEB: TERRESTRIAL PRIMARY PRODUCTION - EMERGENT MACROPHYTES

The major terrestrial primary producers are the emergent macrophytes on the marsh surface. A list of all vascular plants observed on the Manahawkin marsh, together with upland and lagoon bank species, is provided in Appendix B, Table 3. The distribution of the major vegetation types obtained by aerial photography analysis and field surveys is presented in Figure 47 and Table 29.

The predominant species are typical of most Atlantic coast salt marshes and include several forms which have a cosmopolitan distribution (Chapman 1964; Cooper 1974). Four major families are present: Gramineae, Cyperaceae, Chenopodiaceae, and the Compositae. Their horizontal and vertical distribution are determined by several interrelated environmental factors including the salinity and the depth and frequency of tidal inundation (Good 1965; Hinde 1954; Miller and Egler 1950).

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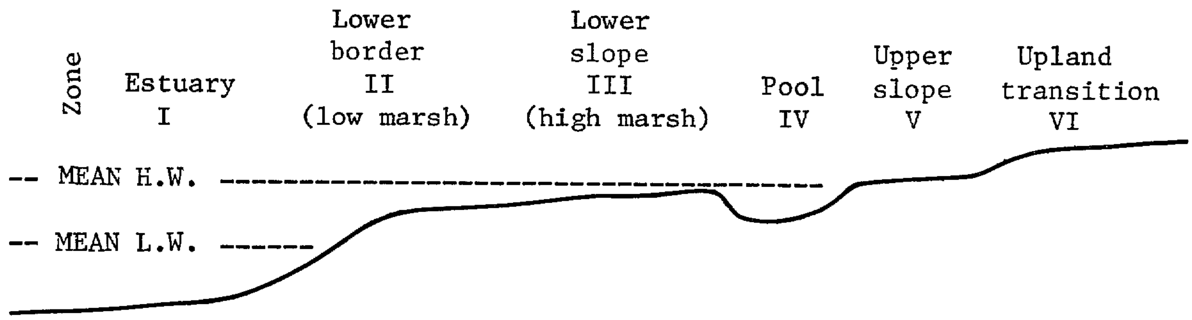
[7] David E. Vaughan is a Rutgers University graduate student who along with Dr. Ralph Good is studying submerged seagrasses.



Zone I. Estuary. Mostly covered with water, but may have fringing mud flats which are exposed at low tide.

Zostera marina *Ruppia maritima*

Zone II. Lower border. Marsh edge along tidal creeks, ditches, and bay shore. Flooded by normal tides twice daily. Few species.

Spartina alterniflora (tall form) dominant

Zone III. Lower slope. Flooded during higher tides. May be intervals with no flooding during some seasons.

Spartina alterniflora (short form)	*Suaeda* spp.
Spartina patens	*Salicornia* spp.
Distichlis spicata	*Solidago sempervirens*
Limonium carolinianum	*Iva frutescens*

Zone IV. Pool. Relatively permanent standing bodies of water only periodically linked with tidal circulation.

Ruppia maritima

Zone V. Upper slope. Subjected to flooding only during exceptional high tides and storm tides.

Juncus gerardi	*Solidago sempervirens*
Distichlis spicata	*Iva frutescens*
Limonium carolinianum	*Baccharis halimifolia*

Zone VI. Upland transition. Flooded during storm tides only. Mixture of tidal marsh species with upland vegetation.

Panicum virgatum	*Eleocharis* spp.
Phragmites australis	*Iva frutescens*
Spartina pectinata	*Baccharis halimifolia*
Scirpus spp.	*Hibiscus palustris*

Fig. 47. Distribution of major vascular plant species on the Manahawkin salt marsh (after Moul 1973).

Table 29. Areal coverage of the major vegetation types on the Manahawkin marsh study area, between Mill Creek and Cedar Run Dock Road.

Vegetation type	Area (ha or 2.471 acres)	Coverage (%)
Spartina alterniflora (short form) - SAS	327.6	59.9
Spartina patens - SP	140.5	25.7
Permanent salt marsh ponds*	36.7	6.7
Iva frutescens	11.8	2.2
Spartina alterniflora (tall form) - SAT	9.6	1.8
Distichlis spicata - DS	9.2	1.7
Phragmites australis	3.5	0.6
Mosquito ditches	3.0	0.5
Dredge spoil areas	2.8	0.5
Scirpus olneyi	1.2	0.2
Panicum virgatum	0.6	0.1
Total	546.5	99.9

*Some ponds support widgeon grass (*Ruppia maritima*).

These factors, together with the physiographic and topography of the marsh, affect the relative contributions to the vegetation cover by the different species.

The region is essentially a wetland "prairie" of low diversity and is dominated by short form *Spartina alterniflora* (SAS)[8] and *Spartina patens* (SP). SAS is characteristic of areas which periodically flood and rain poorly while SP, together with *Distichlis spicata* (DS) with which it is often associated, are typically found in the higher marsh, which has less regular flooding. *S. alterniflora* tall form (SAT) is characteristic of the low marsh zone, and accounts for only 1.8% of the areal coverage. It is restricted to areas of regular flooding (twice daily) along tidal creeks and ditches.

Human disturbances include a network of mosquito ditches and a low water impoundment bordering Mill Creek. Both provide sites of topographic relief and support distinct flora communities:

Common reed	*Phragmites australis*
Sea myrtle	*Baccharis halimifolia*
Marsh elder	*Iva frutescens*

[8]The range of growth forms exhibited by this species has been interpreted as a response to differing environmental conditions, thus representing different ecophenes and not genetically distinguishable ecotypes (Good 1965; Mooring et al. 1971).

Switch grass	*Panicum virgatum*
Swamp rose	*Hibiscus moscheutos*
Pokeweed	*Phytolacca americana*
Sea blite	*Suaeda linearis*
Evening primrose	*Oenothera biennis*
Common thistle	*Cirsium vulgare*
Seaside goldenrod	*Solidago sempervirens*

A number of far-reaching biological effects are attributed to mosquito ditching and involve changes in both the vegetation and the invertebrate fauna (Bourn and Cottam 1950; Daiber 1974), result in a lowered water table, encourage the growth of *S. patens*, and accelerate the decline in the number of ponds, which are characteristic features of a natural salt marsh (Miller and Egler 1950; Redfield 1972).

The marsh-upland ecotone is a zone subjected to storm tides only.and is comprised of a mixture of marsh and upland vegetation. Representative species include:

Common reed	*Phragmites australis*
Freshwater cordgrass	*Spartina pectinata*
Switch grass	*Panicum virgatum*
Spike rush	*Eleocharis*
Olney threesquare	*Scirpus olneyi*
Black grass	*Juncus gerardi*
Redberry greenbrier	*Smilax walteri*
Pin oak	*Quercus palustris*
Sweet gum	*Liquidambar styraciflua*
Dwarf sumac	*Rhus copallina*
Poison ivy	*Rhus radicans*
Red maple	*Acer rubrum*

The vegetation of the uplands proper is essentially a pine-oak-maple community with three basic habitats, each containing one or more floristic associations. They include deciduous and cedar swamps, pitch pine and white oak lowlands, and wooded upland with abandoned agricultural fields. This region has undergone considerable disturbance and has a high diversity resulting from a landscape with a varied topography, soil type, and water conditions (Natural and Historic Resource Associates 1973).

It is generally acknowledged the emergent macrophytes of the Atlantic coast estuaries are characterized by high rates of primary production (Keefe 1972; Mann 1972; Turner 1976; Reimold 1977). In fact, the production levels are among the highest known.

It is also recognized that this production is subject to limited herbivory in its initial state and that most of the organic material is available for use in the detrital pathways which are the basis of the estuarine food web.

The purpose of the emergent macrophyte study is: (1) to document the aboveground and belowground production and (2) to evaluate differences between vegetation types.

Methods

ABOVEGROUND PRODUCTION -- Aboveground production of SAS, SAT, SP, DS, and *Juncus gerardi* (JG) was investigated during study years I and II. The net aerial production of these grasses was measured by the harvest method (Odum 1971; Milner and Hughes 1968). Duplicate plots were hand clipped at approximately 1 month intervals between July/August and September/October in 1973 and between May/June and September/October in 1974. Following separation into live and litter portions, the sample material was dried at 80°C for 48 hours in a forced draft oven to obtain dry weight data.

During the second study year, the aboveground production of the woody shrubs, *Iva frutescens* and *Baccharis halimifolia* was also determined, using the direct method (Milner and Hughes 1968). The current season's growth was harvested after maturity, but prior to leaf or flower fall. Dry weight data were obtained using the same procedure described above.

Percent ash content of the live portion of the samples was also determined for all vegetation types except the woody shrubs. Caloric and chemical analyses were performed on selected SAS samples.

Sample stations were generally in uniform stands of the desired vegetation type. In Figure 48, stations 2, 4, 7, 9, 11, 14, 19, 20 and 21 are of the SAS type; stations 1, 3, 6, 8, 10, 13, and 16 are of the SP type; stations 5, 12, 15, and 22 are of the SAT type, and stations 17 and 18 are of the DS or DS-JG type.

BELOWGROUND PRODUCTION -- Belowground production was studied at 18 of the stations shown in Figure 48 (stations 11, 13, 16, and 17 were not sampled). Net primary production of the belowground component was estimated by differences in biomass over time (Dahlman and Kucera 1965). Sampling was conducted at monthly intervals between April 1974 and September 1975 and bimonthly between September 1975 and April 1976.

The samples consisted of 50 cm cores which were divided in half lengthwise and then into 5 cm segments for the upper 20 cm and into 10 cm segments between 20 and 50 cm core depth. One half of the core was dried untreated at 55°C for 3 days. The other half was similarly dried, after trapped sediment had been washed out.

Caloric and chemical analyses of samples from stations 19, 20, and 21 were determined.

For interpretative purposes, the stations in the SAS and SP areas were grouped into categories based on degree of disturbance. SAS stations 19, 20, and 21 and SP stations 1, 3, and 10 were designated as undisturbed. SAS stations 2, 4, 7, 9, and 14 and SP stations 6 and 8 represented conditions ranging from undisturbed to transitional. SAT station 5 was also in this latter category.

Additional information for both aboveground and belowground production methods is available in Good and Frasco (1977).

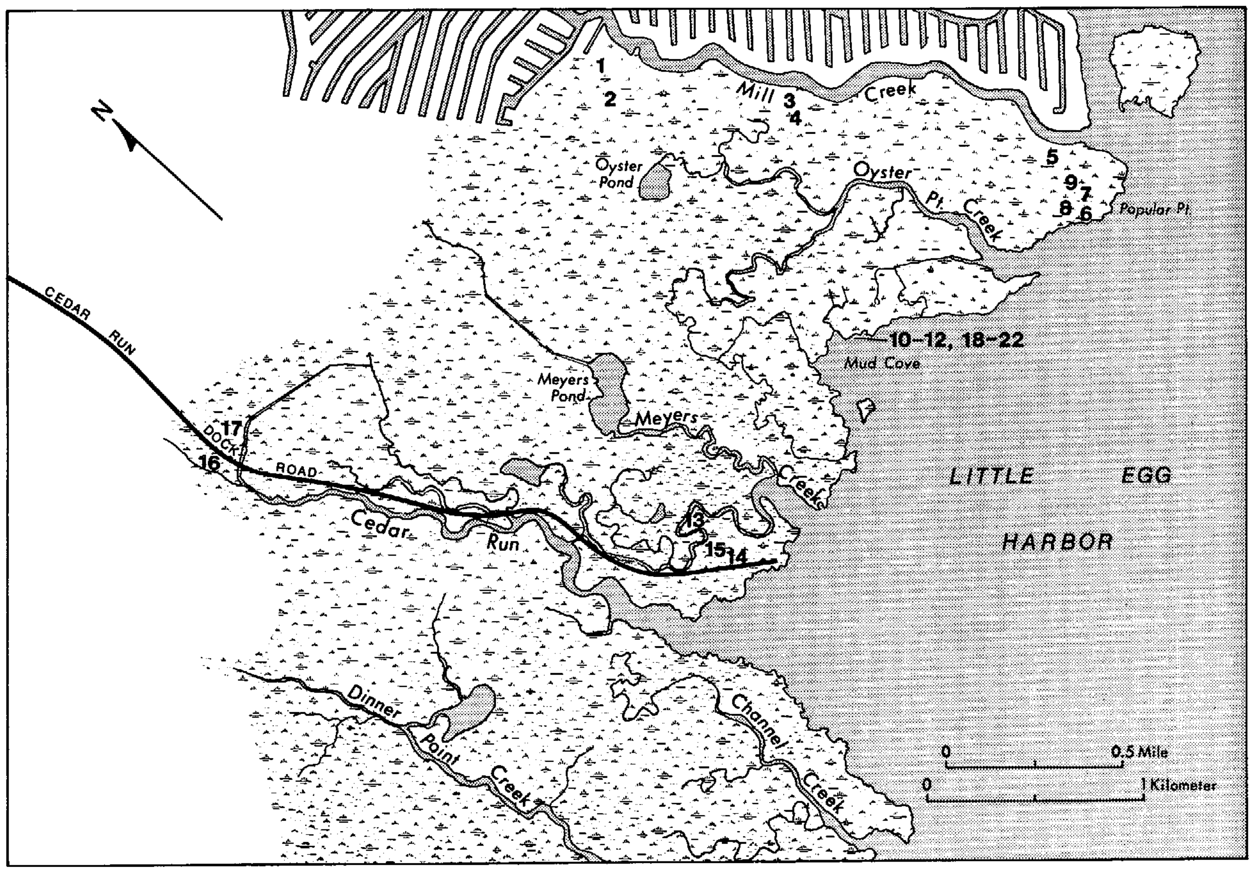


Fig. 48. Station locations for the aboveground and belowground production study.

Results and Discussion

ABOVEGROUND PRODUCTION -- Based on the survey by Ferrigno et al. (1974) and supported by surveys by Good and by Durand, the three major grass species found are SAS (60%), SP (26%), and SAT (2%). Of these, SAT exhibited the largest net production followed by SP and SAS (Table 30). The peak standing crop values, which were used as a measure of net primary production, however, were also subject to variation between growing seasons and between stations within a particular vegetation type.

Table 30. Comparison of the net primary production (NP in g dry wt$\cdot$m^{-2}) of the major vegetation types at the Manahawkin marshes.

Species	Station no.	1973 Peak		1974 Peak		Change
		NP	Date	NP	Date	(%)
S. alterniflora	2	669	9/7/73	374	7/3/74	-44%
short form	4	484	9/7/73	280	8/5/74	-42%
(SAS)	7	633	9/7/73	408	8/8/74	-36%
	9	442	9/5/73	290	8/8/74	-34%
	11	735	9/5/73	552	8/12/74	-25%
	14	483	9/5/73			
	19			574	7/15/74	
	20			512	7/31/74	
	21			460	7/1/74	
Average		574 ± 120*		444 ± 113*		-23%
S. patens	1	613	8/31/73	546	7/29/74	-11%
(SP)	3	684	9/12/73	644	7/29/74	- 6%
	6	519	9/4/73	478	8/28/74	- 8%
	8	746	9/4/73	434	7/29/74	-42%
	10	691	8/17/73	572	8/8/74	-17%
	13	694	8/24/73			
	16	380	8/27/73			
Average		618 ± 128*		535 ± 82*		-13%
S. alterniflora	5	1,098	8/24/73			
tall form	12	739	8/20/73	678	9/18/74	- 8%
(SAT)	15	639	8/6/73	669	9/26/74	+ 5%
	22			858	9/26/74	
Average		825 ± 241*		735 ± 107*		-11%
D. spicata (DS)	18	644	8/20/73	613	8/12/74	- 5%
D. spicata/ *J. gerardi* (DS-JG)	17	514	8/27/73			

*This is the mean plus or minus 1 SD.

Between station variation resulted in overlap in the ranges of net production values for SAS, SP, and SAT. This station variation is explained in part by changes in the density and culm weights between locations (Table 31). Within a species, culm weight and density varied by a factor of 2 or more. Between species, culm weight and density differed in extreme cases by more than a factor of 20.

Table 31. Density and culm weight of representative community types found in the study area.

Vegetation type	Sample date	Station no.	Average culm weight (g dry wt)	Density ($culms \cdot m^{-2}$)	Peak biomass (g dry $wt \cdot m^{-2}$)
SP	7/22/74	(1)	0.05	10,704	546
	7/22/74	(3)	0.06	10,480	644
	6/4/75	(6)	0.15	3,280	477
	7/22/74	(8)	0.04	11,696	434
SAS	7/22/74	(2)	0.21	1,776	374
	7/22/74	(4)	0.14	2,000	280
	7/22/74	(9)	0.30	960	290
SAT	7/22/74	(5)	0.45	816	364
	6/11/75	(12)	0.86	784	677
	6/11/75	(15)	1.35	496	669

The net primary productivity in study year I generally exceeded that of study year II. SAS showed the largest decrease in mean net primary production, a drop of 23%. The decrease in the other vegetation types ranged from 5 to 13%. Increased soil salinity due to decreased precipitation during the study year II growing season may have stressed the marsh vegetation and caused a reduction in growth. Alternatively, this decrease could be related to disturbance. A number of the stations in the "transitional" category (stations 2, 4, 5, 7, 8, and 9) showed sizeable decreases in net primary production, averaging changes of over -30%. This coincided with visible evidence of community degradation such as at SAS stations 7 and 9 where dikes prevented tidal circulation. Furthermore, station 5 had such poor growth of SAT that the aboveground biomass could not be sampled.

In general, the net production values found in the study area are comparable to other marshes in this region, especially those in New Jersey (Table 32). The SAT shows the greatest deviation from the net production levels of neighboring marshes. Possibly this is due to the limited stands present, the lower stem density, or a different tidal regime. Other factors such as nitrogen supply and soil salinity fluctuations could also account for differences in net production between the various marshes.

Table 32. Comparison of net production (g dry wt·m^{-2}) of aboveground parts for a number of salt marsh studies.

Vegetation type	Net production (g dry wt·m^{-2})	Date	Location	Authors(s)
Spartina alterniflora tall form	827	1969	Long Island, N.Y.	Udell et al.
	1,700	1972	Great Bay, N.J.	Good
	1,592	1974	Great Bay, N.J.	Squiers and Good
	850	1977	Great Egg Harbor, N.J.	Good
	825	1973	Manahawkin, N.J.	This study
	735	1974	Manahawkin, N.J.	This study
Spartina alterniflora short form	508	1969	Long Island, N.Y.	Udell et al.
	590	1972	Great Bay, N.J.	Good
	558	1973	Maryland and Virginia	Keefe and Boynton
	592	1974	Great Bay, N.J.	Squiers and Good
	548	1977	Great Egg Harbor, N.J.	Good
	574	1973	Manahawkin, N.J.	This study
	444	1974	Manahawkin, N.J.	This study
Spartina alterniflora all forms	300	1965	Cape May, N.J.	Good
	1,332	1969	Virginia	Wass and Wright
	427-558	1973	Maryland and Virginia	Keefe and Boynton
	362-573	1976	Virginia	Mendelssohn and Marcellus
Spartina patens	993	1918	Long Island, N.Y.	Harper
	805	1969	Virginia	Wass and Wright
	550	1972	Great Bay, N.J.	Good
	463	1972	Great Bay, N.J.	Nadeau
	618	1973	Manahawkin, N.J.	This study
	535	1974	Manahawkin, N.J.	This study
Distichlis spicata	360	1969	Virginia	Wass and Wright
	670	1972	Great Bay, N.J.	Good
	359	1972	Connecticut	Steever
	644	1973	Manahawkin, N.J.	This study
	613	1974	Manahawkin, N.J.	This study

Aboveground net production data for *Iva frutescens* and *Baccharis halimifolia* are listed in Table 33. These shrubs occupy the dikes and elevated spoil piles and account for over 2% of the marsh surface. Shrub production is similar in magnitude to SAT production.

Caloric content of the SAS aboveground biomass remained nearly constant the entire growing season with a mean value of 4.4 kcal·g ash-free dry wt^{-1}. These

Table 33. Standing crop of the current year's growth for the shrubs, *Iva frutescens*, *Baccharis halimifolia*, and minor associates.

Date	Marsh shrub	Dry wt ($g \cdot m^{-2}$)	Associates	Dry wt of the live material ($g \cdot m^{-2}$)	Total dry wt (live material) ($g \cdot m^{-2}$)
8/21/74	*Baccharis halimifolia*	858	*Spartina patens*	76	934
		775		190	1,002
			Pluchea purpurascens	37	
10/2/74	*Iva frutescens*	1,017	Mixed grasses	324	1,341
		763		192	955
		474		72	546
		951		319	1,270
Mean		806			1,008

results were similar to data obtained at Great Bay, New Jersey, which indicated the caloric content of SAS was 4.5 kcal·g ash-free dry wt^{-1} (Squiers and Good 1974). Frasco (1979) working in the same study area as this project determined caloric content estimates for SAS (4.5 kcal·g ash-free dry wt^{-1}), SP (4.4 kcal·g ash-free dry wt^{-1}), and SAT (4.5 kcal·g ash-free dry wt^{-1}). The estimates for all three species were nearly the same and confirmed the previous calorimetry work. The energy equivalents of the net primary production and the energy coefficients for the major species are listed in Table 34.

BELOWGROUND PRODUCTION -- Table 35 lists the belowground biomass data for the vegetation types studied. The data refer to the first 30 cm of the 50 cm core. This was done because most of the living component occurs in this layer.

Table 36 details for the major vegetation types the dates of greatest biomass differences, the peak biomass, the belowground net production, and the turnover rate. Belowground net production ranged from 2.25 kg dry wt·m^{-2} (SP disturbed) to 3.59 kg dry wt·m^{-2} (SAS disturbed). These values are comparable with belowground net production estimates from other studies (Valiela et al. 1976; Woodhouse et al. 1974), although some estimates reported are below the range observed at the study area (de la Cruz and Hackney 1977; Stroud 1976). Turnover rates ranged from 19.41% for SAS to 39.14% for SAT. The difference in turnover rates may well define those habitats thought to be responsible for the different growth responses of genetically indistinguishable *S. alterniflora* forms (Shea et al. 1975).

In Table 37, net annual aboveground and belowground production are listed for the various stations and vegetation types studied. Based on the root:shoot ratio, the annual net production of the belowground component is approximately 5 times that of the aboveground, except in the case of the SAS disturbed sites where it

Table 34. Net primary production data using the caloric content values of Frasco (1979).

Species	Date	Net production ($kcal \cdot m^{-2} \cdot year^{-1}$)	Efficiency of PAR conversion to NP per year (%)*	Efficiency of PAR conversion to NP per growing season (%)#
SAS	1973	2,131	0.34	0.43
	1974	1,648	0.26	0.33
SP	1973	2,474	0.39	0.50
	1974	2,142	0.34	0.44
SAT	1973	3,156	0.50	0.64
	1974	2,811	0.44	0.57
DS†	1973	2,675	0.42	0.54
	1974	2,546	0.40	0.52

*An energy input of 63.4 $kcal \cdot cm^{-2} \cdot year^{-1}$ was used in the calculations.
#The growing season was from March through September. An energy input of 49.2 $kcal \cdot cm^{-2}$ was used (data from March 1976 - September 1976).
†It was assumed the caloric content was 4.5 kcal·g ash-free dry wt^{-1}.

is more than 10 times. Confirmation of our data is provided by Valiela et al. (1976) who measured a root:shoot ratio of 8.3 for *S. alterniflora* and 4.0 for *S. patens*, and by Woodhouse et al. (1974) who observed a ratio for *S. alterniflora* in excess of 3.0.

Table 38 summarizes the caloric content and percent ash data for SAS at stations 19, 20, and 21. The caloric content of the belowground biomass exceeds that of the aboveground biomass (4.8 vs 4.4 kcal·g ash-free dry wt^{-1}). This is a finding supported by Stroud (1976) and de la Cruz and Hackney (1977).

For the entire 20 cm core, the caloric content varied from 4,621 to 4,919 cal·g ash-free dry wt^{-1} with a mean of 4,761 cal·g ash-free dry wt^{-1}. Minimum values were detected during the summer at the period of greatest aboveground growth. Based on the mean data for each depth layer, caloric content increased with depth. Smith et al. (in press) performed caloric analysis on SAS belowground material from the same area as this study. They found below the 20 cm level and down to 50 cm the caloric content remained relatively constant at 5.0 kcal·g ash-free dry wt^{-1}.

If a caloric content of 4.8 kcal·g ash-free dry wt^{-1} and the average ash content of 12% for this study is assumed for the belowground material of all vegetation types, the net production values for the belowground component in Table 39 result. Also in Table 39 are the aboveground net production data for the respective species and the overall efficiency of PAR conversion data.

Table 35. Belowground biomass (kg dry wt·m^{-2}) for the major vegetation types at Manahawkin during 1974-1975. The data is based on the initial 30 cm of core.

Date	SAS (19,20,21)*	SAS (2,4,7,9,14)#	SP (1,3,10)*	SP (6,8)#	SAT (5,12,15,22)	DS (18)
April 1974		10.53				
May 1974		9.59	8.19	6.06		
June 1974	10.39 11.03		8.76	6.79	8.50	7.35
July 1974	11.10	11.73	11.49	7.82	5.17	8.89
August 1974	11.09	13.18	9.87	8.24	9.74	10.08
September 1974	11.09	11.27			6.98	7.56
October 1974	11.73		10.12	7.13		
November 1974	11.07	10.97				8.19
December 1974	11.27		9.15	7.85	7.27	8.10
January 1975	9.97	12.04				
February 1975	10.22				7.22	7.29
March 1975	11.46		9.39	6.53		
April 1975	12.37	10.29			6.77	8.25
Mean	11.07	11.20	9.57	6.33	7.38	8.21

*Undisturbed sites
#Disturbed sites

Table 36. Maximum biomass, belowground production, and turnover rates for the major vegetation types at Manahawkin during 1974-1975.

Vegetation type	Period of greatest difference	Maximum biomass (kg dw·m^{-2})	Belowground production (kg dw·m^{-2})	Turnover rate (%)	Turnover rate (Years)
SAS undisturbed	Jan 28-April 30*	12.37	2.40	19.41	5.15
SAS disturbed	May 16-August 8*	13.18	3.59	27.21	3.67
SP undisturbed	May 8-July 29*	11.49	3.27	28.50	3.51
SP disturbed	May 8-August 26*	8.24	2.25	27.32	3.66
SAT	June 5*-July 15	8.50	3.33	39.14	2.55
DS	August 12*-Feb 3	10.08	2.78	27.63	3.62

*Date of greatest biomass

Table 37. Net annual production in 1974-1975 for the below and aboveground components of six communities and ratio of below to aboveground.

Vegetation type (station)	Net annual production (kg dry wt·m^{-2}) Aboveground	Belowground	Total	Root:shoot ratio
SAS (19,20,21)*	0.52	2.40	2.92	5.24:1
SAS (2,4,7,9,14)#	0.36	3.59	3.59	10.15:1
SP (1,3,10)*	0.59	3.27	3.86	5.58:1
SP (6,8)#	0.46	2.25	2.71	5.71:1
SAT (5,12,15,22)	0.64	3.33	3.97	4.53:1
DS (18)	0.62	2.78	3.40	4.50:1

*Undisturbed stations
#Disturbed stations

Table 38. Caloric values (cal v) in (cal·g ash-free dry weight^{-1}) and percent ash (% ash) for SAS belowground material by depth at stations 19, 20, and 21 during 1974-1975.

Date	0-5cm (cal v)	0-5cm (%ash)	5-10cm (cal v)	5-10cm (%ash)	10-15cm (cal v)	10-15cm (%ash)	15-20cm (cal v)	15-20cm (%ash)	0-20cm (cal v)
6/5/74	4,631	8.4	4,707	13.4	4,990	13.4	5,349	14.3	4,919
7/1/74	4,500	11.5	4,597	12.8	4,766	13.8	5,153	12.1	4,754
7/31/74	4,390	10.8	4,512	15.5	4,745	15.5	4,860	13.7	4,627
8/19/74	4,552	9.0	4,696	12.0	4,917	11.7	4,340	12.0	4,626
9/18/74	4,459	8.2	4,613	11.0	4,617	12.1	4,794	10.3	4,621
10/23/74	4,557	10.0	4,773	13.0	4,896	13.9	4,981	14.0	4,802
11/27/74	4,683	8.9	4,821	12.5	5,008	14.5	4,952	10.4	4,866
12/30/74	4,609	10.4	4,764	12.2	4,875	12.3	4,917	10.4	4,791
1/28/75	4,501	8.3	4,696	10.6	4,749	12.1	4,957	12.0	4,725
3/5/75	4,661	10.2	4,714	13.7	4,974	15.1	4,989	13.7	4,835
3/30/75	4,577	9.9	4,733	13.2	4,833	13.9	5,079	13.5	4,805
Mean	4,556		4,693		4,852		4,943		4,761

FOOD WEB: TERRESTRIAL PRIMARY PRODUCTION - MARSH SURFACE ALGAE

The microbial community associated with the surface centimeter of the sediment may contain a diverse assemblage of bacteria, fungi, protozoa, nematodes, and algae (Christian et al. 1975). The edaphic microflora is the microscopic algae associated with the soil beneath the grass canopy. Those forms actually attached to the grass culms are epiphytes. Studies of these organisms have been descriptive in nature dealing with taxonomic composition, seasonal abundance and environmental factors (Blum 1968; Webber 1967; Webber and Wilce 1972; Sullivan 1971, 1975, 1977).

Diatoms, especially pennate forms, are an important component of the edaphic microflora because of their great abundance and high diversity. Sullivan (1977) observed a total of 91 taxa (18 genera) inhabiting pure stands of SAS and SP on the Great Bay salt marsh near Tuckerton, New Jersey. Of this total, 8 taxa were endemic to the SAS stand, 42 to the SP stand, and 41 taxa were common to both areas. Approximately 67% of the 91 taxa were previously observed by Sullivan (1975) on Canary Creek marsh, Delaware. The vegetation zones studied, however, were not identical. On the Ipswich marsh, Massachusetts, Drum and Webber (1966) noted 151

Table 39. Caloric net production data from study year II for the major vegetation types.

Species	Belowground NP ($kcal \cdot m^{-2} \cdot year^{-1} \cdot 10^3$)	Aboveground NP ($kcal \cdot m^{-2} \cdot year^{-1} \cdot 10^3$)	Total NP ($kcal \cdot m^{-2} \cdot year^{-1} \cdot 10^3$)	Overall efficiency of PAR conversion to NP (%)*
SAS				
(19,20,21)#	10.14	1.93	12.07	1.90
(2,4,7,9,14)†	15.16	1.37	16.53	2.61
SP				
(1,3,10)#	13.81	2.36	16.17	2.55
(6,8)†	9.50	1.84	11.34	1.79
SAT				
(5,12,15,22)	14.07	2.45	16.52	2.61
DS				
(18)	11.74	2.58	14.32	2.26

*This assumes an energy input of 63.4×10^4 $kcal \cdot cm^{-2}$
#Undisturbed stations
†Disturbed stations

diatom taxa (44 genera) from a variety of marsh habitats. Fifty-six taxa of marine, brackish, and freshwater diatoms were associated with the marsh substrate.

The other major algal component which is widespread throughout the emergent marsh is the Cyanophyta. Webber (1967) described the systematics and vertical distribution patterns of 29 species of blue-green algae on the Ipswich marsh. While a few species were restricted to the sublittoral and supralittoral zones, most were present throughout the littoral region. Maximum development of the blue-green algae occurred during mid to late summer, but many species were observed all year round. Ten species were associated with *S. alterniflora* var. glabra, 13 species with *S. patens*, and 3 species with *Juncus gerardi*. *Calothrix confervicola* has been observed by Webber and Wilce (1972) and Blum (1968) to be a major epiphytic colonizer of the moist microhabitats provided by dead SP culms. Sullivan (1977) however, noted a complete absence of blue-green and green algae beneath the SP of the Great Bay marsh. He attributed this to an insufficient quantity of light penetrating the very dense canopy, thereby resulting in an exclusive diatom community tolerant of the low light intensities.

Although no edaphic algae taxonomy was carried out in the present study, a species list of representative forms is presented in Table 4 of Appendix B. Included are the edaphic diatoms observed by Sullivan (1977) beneath stands of *S. alterniflora* (short form) and *S. patens* on the Great Bay marsh (only 1.8 km or ∿3 miles away from the study area). Also included are the species of blue-green, green, and brown algae typical of the upper intertidal zone or frequently associated with the base of *Spartina* culms and mats of dead grass.

The vertical and horizontal distribution of the microflora and their seasonality is intricately linked with those of the grasses (Webber and Wilce 1972). The angiosperms not only reflect large-scale variations in environmental parameters within the marsh (solar input, tidal inundation, salinity regime), but also establish unique microhabitats of their own at the soil-air interface. The complex of environmental factors operating within a given grassy habitat, such as a pure stand of SP, may be expected to produce a "distinct and easily recognizable edaphic diatom community over an entire yearly cycle" (Sullivan 1975). This apparently holds true for the blue-green algae as well.

The presence of a grass canopy and its seasonal ontogeny have a significant impact on the microclimate of the marsh surface. Relative light penetration, air and soil temperatures, interstitial salinity, relative humidity, and susceptability to dessication are all affected (Blum 1968; Kraeuter and Wolf 1974 Gallagher and Daiber 1974a,b; Sullivan 1975, 1976, 1977; Sullivan and Daiber 1975; Van Raalte et al. 1976a).

Blum (1968) also suggested the peculiar vertical and horizontal structure of SP retains and conserves the autochthonous detritus produced within the stand. The nutritional significance of such a three-dimensional detrital mat in this high marsh community may also be important in terms of nutrient filtration and immobilization from the infrequent flooding tides.

The daily and seasonal input of solar radiation is of primary importance in regulating algal colonization and growth rates. A number of abiotic and biotic factors act in concert to affect the amount of light incident on the marsh surface (Blum 1968; Kraeuter and Wolf 1974; Pomeroy 1959; Gallagher 1971). The abiotic factors include: (1) incident solar radiation, I_0; (2) ice and tidal scouring of detritus; (3) presence of standing water; and (4) snow and ice cover. The biotic factors are: (1) aboveground standing crop and density of the emergent vegetation; (2) length of growing season of the grasses; (3) leaf decay processes in the canopy; (4) presence of dead grass rafts or 'wracks'; (5) rate at which end of the season material is removed from the marsh; and (6) self-shading by the algal community.

The presence of a grass canopy may also affect the rate at which temperature fluctuations occur on a diurnal and seasonal basis, although it may not always lessen the degree of such changes (Kraeuter and Wolf 1974). Important considerations involving such temperature effects include: (1) air temperature; (2) water temperature of flooding tides; (3) insolation; (4) evaporation of standing and interstitial water; and (5) shading and greenhouse effects by the canopy (Blum 1968; Gallagher 1971; Pomeroy 1959).

The purpose of the marsh surface algal community study is: (1) to document the production by this community and (2) to compare the data from the different stations.

Methods

The period of investigation extended from February 1974 to May 1977. The frequency of sampling, however, was variable due to the demands of other concurrent studies. Sampling stations were located within the three major vegetation types of the marsh: *Spartina alterniflora* (tall and short) (SA) and *S. patens*. All stations were located near the midpoint of Meyers Creek. Sediment cores were taken and filled with filtered creek water of known oxygen content. *Spartina* shoots, animal burrows, and macrofauna (snails, mussels, etc.) were excluded. The cores were incubated for 12 hours in laboratory incubators equipped with shaker mechanisms under light or dark conditions. Subsamples of the column were withdrawn and Winkler titrations performed. Daily rates of soil-water gas exchange were obtained from the changes in dissolved oxygen concentration over a known surface area and were converted to a ml $O_2 \cdot m^{-2} \cdot day^{-1}$ basis. A 12 hour daylight period was assumed. The rates measured were therefore "potential" estimates and indicative of total community response, incorporating algal, bacterial, and faunal activity, as well as sediment chemical demands.

Soil-air exchanges were not studied, but have been found by Teal and Kanwisher (1961) to be very similar to those under immersed conditions.

Measures of light penetration through the grass canopies were obtained with a Licor Quantum Meter (LI-170) and Sensor (LI-190S).

Additional information on methods is available in Durand et al. (1974, 1975, 1976, 1977).

Results and Discussion

The SP zone exhibited very little seasonal fluctuation and also spatial variation in its reduction of incident solar radiation by the canopy. Values of $\%I_o$ were consistently less than 3% - very similar to the findings of Blum (1968) for this species and also *Distichlis spicata* on the Barnstanble Marsh near Cape Cod. Such levels were therefore probably limiting to autotrophic algal growth. Conspicuous algal mats were absent beneath this dense cover of uniform shading.

Light conditions were much more favorable beneath the SA, often in the range of 30-60 $\%I_o$ during late winter and spring. As a result of *Spartina* growth and canopy closure, these values progressively diminished throughout the summer, reaching 6-16 $\%I_o$ in September. In addition to seasonal fluctuations, considerable spatial variation was often observed within both stands on a particular sampling date.

Daily production rates of the edaphic algal communities from February 1974 to May 1977 are summarized in Figure 49. The levels of net community productivity and their seasonal patterns were very similar for the two SA areas. The most active period of the year was April - September, when maximal rates of 200-300 ml $O_2 \cdot m^{-2} \cdot day^{-1}$ were typical. Minimal photosynthetic activity was observed during the winter, especially when freezing of the marsh surface occurred.

In contrast, daily net community production of the SP community was negligible during the summer and negative rates were very common throughout the rest of the year. This disparity in algal photosynthetic capacity between the SAT-SAS communities and the SP areas resulted from the unfavorable light conditions and absence of visible algal mats beneath the SP.

Respiration of the SA communities generally followed the seasonal trends described for net community production, with maximum uptake rates occurring in

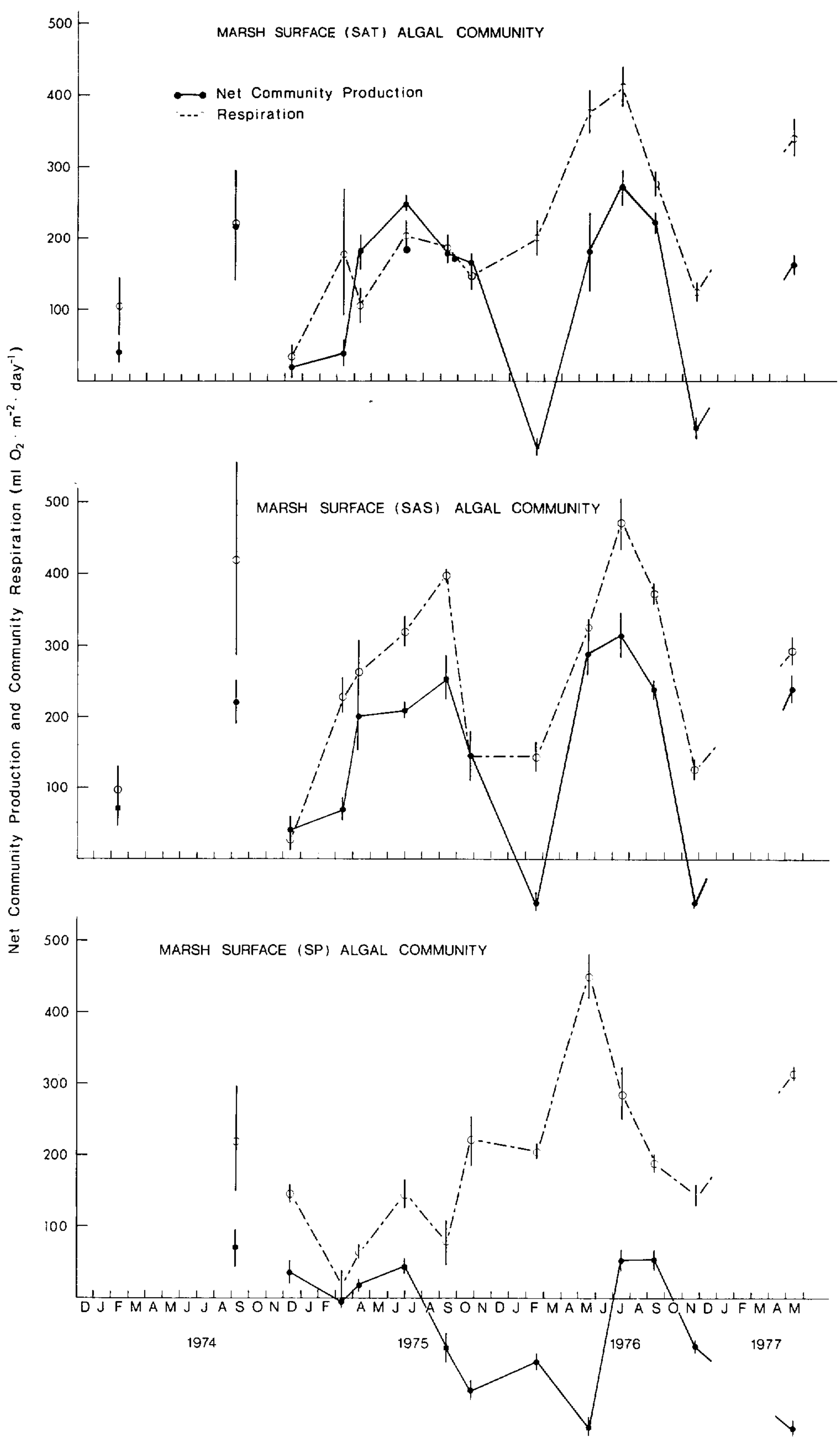


Fig. 49. Marsh surface algal community production data.

late spring and summer. For the SAS community, these summer rates were similar for 1975 and 1976 and were approximately 250-400 and 300-475 ml $O_2 \cdot m^{-2} \cdot day^{-1}$, respectively. Summer SAT respiration rates, however, were significantly different for these two years. Peak levels in 1976 (approximately 400 ml $O_2 \cdot m^{-2} \cdot day^{-1}$) were twice those of the preceding year. Even greater disparity was observed in the SP zone where unusually high respiratory levels also occurred in 1976, reaching a peak of 450 ml $O_2 \cdot m^{-2} \cdot day^{-1}$ (20 May 1976) compared to a 1975 summer peak of only 146 ml $O_2 \cdot m^{-2} \cdot day^{-1}$.

In contrast to the negligible photosynthetic rates at all Manahawkin stations during the winter, significant respiratory rates were often observed. Microbiota respiration accounted for a large proportion of the daily gross production of the edaphic algal community throughout the year. Respiration:gross production ratios (R:GP) for the three vegetation types are summarized in Table 40.

Table 40. Respiration:gross production ratios for SAT, SAS, and SP.

R:GP	SAT	SAS	SP
Mean ± 95% confidence limits	0.79 ± 0.31	0.75 ± 0.26	1.86 ± 1.19
Range	0.37 - 2.16	0.41 - 1.87	0.76 - 8.10

Gallagher and Daiber (1973) suggested bacterial respiration is probably responsible for the majority of such oxygen consumption by the soil community. Furthermore, the bacterial component of the Georgia salt marshes were estimated by Teal and Kanwisher (1961) to be second only to *Spartina* in total oxygen demand.

Annual production estimates on a square meter basis were obtained by planimetry of the seasonal oxygen production curves and converted to a carbon base (Table 41). The conversion equations of Strickland (1960) were employed. Caloric equivalents (Table 41) were derived from an oxy-calorific coefficient of 4.8 cal$\cdot$ml O_2^{-1} (Crisp 1971).

The following annual figures for gross primary production (g $C \cdot m^{-2}$) in 1975 and 1976 were obtained: SAT, 55-72; SAS, 72-79; and SP, 20-43. The caloric equivalents ($kcal \cdot m^{-2} \cdot year^{-1}$) are as follows: SAT, 536.4 - 673.6; SAS, 683.3 - 748.4; and SP, 166.6 - 365.2. Annual community respiration was approximately 52-72% of the annual SAT gross production and 64-65% in the SAS areas. The respiration of the SP community, in contrast, completely overrode the marginal photosynthetic capacity of the microflora, contributing 128-130% of the annual gross production.

A marked annual variation in the gross production figures was also observed in the SP area, where a 120% increase occurred in 1976. Corresponding increases of 26% and 10% were observed for the SAT and SAS communities, respectively. Much of this disparity was attributed to higher respiration rates the second year. The SAS community was remarkably consistent each year in terms of its annual productive capacity and also in regards to the relative contribution of photosynthesis and respiration to the annual gross production.

Table 41. Annual production of the edaphic microflora associated with SAT, SAS, and SP.

Cover type	Year	NP $(g\ C \cdot m^{-2} \cdot year^{-1})$	NP $(kcal \cdot m^{-2} \cdot year^{-1})$	R $(g\ C \cdot m^{-2} \cdot year^{-1})$	R $(kcal \cdot m^{-2} \cdot year^{-1})$	GP $(g\ C \cdot m^{-2} \cdot year^{-1})$	GP $(kcal \cdot m^{-2} \cdot year^{-1})$
SAT	1975	24	255.6	31	280.8	55	536.4
	1976	17	182.6	55	491.0	72	673.6
SAS	1975	23	248.5	49	434.8	72	683.3
	1976	24	259.8	55	488.6	79	748.4
SP	1975	-4	-46.8	24	213.4	20	166.6
	1976	-10	-108.8	53	474.0	43	365.2

The total area occupied by these vegetation types is approximately 87.4% of the marsh (between Cedar Run and Mill Creek). Of this total, the SAS contributes about 68.6%, the SP, 29.4%, and the SAT, 2%. Using these relative areal contributions and the mean annual gross production figures for each vegetation type, a weighted mean of 62 $g\ C \cdot m^{-2} \cdot year^{-1}$ or 581.4 $kcal \cdot m^{-2} \cdot year^{-1}$ was obtained for the edaphic algae of the Manahawkin marsh. The latter figure represents approximately 0.1% of the annual input of photosynthetically active radiation (PAR) on the marsh ($6.34 \times 10^5\ kcal \cdot m^{-2} \cdot year^{-1}$). This energy trapping efficiency is identical with the findings of Gallagher (1971) for the Canary Creek marsh. Due to light absorption by *Spartina* and standing water, the true efficiency will be greater, though probably less than 1% (Pomeroy 1959). A similar calculation on PAR conversion to NP yields a value of 0.02%.

Annual gross production of the three edaphic habitats in the Manahawkin marsh are compared with results from other Atlantic coast salt marshes (Table 42). The present findings are perhaps most similar to those from the Canary Creek marsh where a similar coring technique was employed. Differences between the various estimates are due in part to the variety of incubation techniques and metabolism measures used. Pomeroy's often cited value of 200 $g\ C \cdot m^{-2} \cdot year^{-1}$ would be expected to be higher than those for Manahawkin since highly productive bare strand habitats were included in the annual weighted mean. In addition, the relative areal coverage of SAT is much greater in the Georgia marshes. The SAT zone at Manahawkin only contributes 1.8% of the total marsh.

Estimates for the total annual production of the marsh surface algae presented in Table 43 were derived from the distribution and the mean annual gross production for each vegetation type.

Whereas the daily and annual GP rates on a square meter basis for the SAT and SAS communities were very similar, the extensive distribution of SAS clearly establishes this vegetation type as one of major importance in the contribution by

Table 42. Comparison of annual gross production estimates for the edaphic microflora of several Atlantic coast salt marshes.

Study area	Habitat	Method	Gross production ($g\ C \cdot m^{-2} \cdot year^{-1}$)	Author
Duplin River, Georgia	*	O_2#	200	Pomeroy (1959)
Nacote Creek, New Jersey	SAS	O_2#	15.67†	Nadeau (1972)
Canary Creek, Delaware	SAT	O_2**	79	Gallagher and Daiber (1974b)
	SAS		99	
	DS		61	
	Bare bank		38	
	Salt panne		91	
Great Sippewissett, Massachusetts	Low marsh S	C^{14}#	105.5	Van Raalte et al. (1976a)
Manahawkin, New Jersey	SAT	O_2**	55-72	This study
	SAS		72-79	
	SP		20-43	

*Weighted mean of bare strand, tall and medium *S. alterniflora* and levee top habitats was used.
#In situ incubation data used.
†Productivity during December-March was not measured.
**Laboratory incubation data used.

Table 43. Total annual gross production by the edaphic algal community in the dominant vegetation types in the area between Cedar Run Dock Road and Mill Creek.

Vegetation type	Areal coverage (ha)	Gross production ($g\ C \cdot marsh^{-1} \cdot year^{-1}$)	($kcal \cdot marsh^{-1} \cdot year^{-1}$)
S. alterniflora tall form	9.6	0.6×10^7	0.58×10^8
S. alterniflora short form	327.6	24.7×10^7	23.45×10^8
S. patens	140.5	4.4×10^7	3.75×10^8
Total	477.7	29.7×10^7	27.77×10^8

the microflora to marsh primary productivity. Although such rates in the SP areas were less than half those for *Spartina alterniflora*, they were compensated to some degree by the widespread distribution of SP.

Even though these algal communities may be expected to be present throughout the year (Sullivan 1971), significant levels of primary production appear to be restricted to the period, April-September, thereby coinciding with the active growing season of the grasses. This is contrary to the results of Gallagher and Daiber (1974b) who observed a large proportion of algal production at a time when the grasses were dormant. They suggested, however, that the trophic importance of the microflora may be enhanced because these represent an energy source immediately available to grazing and detrital pathways. This is in striking contrast to the rather delayed availability of the grasses to the marsh-estuary system. In addition, colonies of mucous-secreting diatoms and filamentous blue-greens are believed to be important agents in soil-binding and stabilization, processes which are necessary for angiosperm colonization and the establishment of the soil microflora (Carter 1932; Fauré-Fremiet 1951; Webber 1967).

The most important environmental factor regulating the colonization and growth of the algal flora is probably light intensity, which is a direct function of spermatophyte cover height and density. A reduction in marsh surface light intensity results from an increased standing crop, assuming there is no compensating rise in insolation. Estrada et al. (1974) demonstrated an exponential decrease in chlorophyll *a* concentration in the marsh sediment accompanying an increase in grass biomass. Conversely, Sullivan (1976) demonstrated significantly higher algal standing crops in experimentally clipped areas as compared to the natural marsh.

Edaphic algal growth, as determined from C^{14} uptake rates, increases linearly with light intensity and reaches maximal levels in those areas completely devoid of plant cover. In addition, the relative importance of the different algal phyla in the structure of the community appears to be dependent upon the light regime. Diatoms (Chrysophyta) typically become more important in terms of biomass with decreasing light intensity. Filamentous green and blue-green algae (Chlorophyta and Cyanophyta) tend to dominate areas with full ambient sunlight (Sullivan 1976; Sullivan and Daiber 1975).

These investigators also demonstrated significant responses in algal standing crops (chlorophyll *a*) to fertilization experiments on the marsh involving additions of inorganic nitrogen (ammonium phosphate) and phosphorus (water-soluble superphosphate). Phosphorus was concluded to be most limiting to the algae during the period mid-March to mid-May, while nitrogen was most limiting from mid-June to mid-August. Differential responses in diatom species abundance were also noted, and Sullivan (1976) suggests that certain species may be used as 'indicator species' in monitoring marsh eutrophication.

FOOD WEB: TERRESTIAL PRIMARY PRODUCTION - SUBMERGED SALT POOL MACROPHYTES

Localized shallow depressions are a characteristic feature of salt marshes. Consisting of distinctive biotic communities which can tolerate rapid and wide-ranging environmental fluctuations (Chapman 1960; 1964, Nicol 1935; Ranwell 1972; Redfield 1972; Teal and Teal 1969), they have been classified on the basis of their morphogenesis (Miller and Egler 1950; Yapp et al. 1917), salinity levels (Nicol 1935), and bottom substrate (Chapman 1938).

Salt ponds have vertical or undercut walls, and standing water which prohibits *Spartina* invasion (Redfield 1972) but may permit dense growths of *Ruppia*. They are only periodically flushed by the tides. Such ponds in Connecticut marshes are generally less than 30 cm deep, with *Ruppia* covering 1-30% of the surface area (Miller and Egler 1950). The formation of ponds and their distribution throughout the Great Marshes of Barnstable, Massachusetts is discussed by Redfield (1972).

Due to the luxuriant growths of *Ruppia* and a host of attached and free-living algal forms which are often present, such aquatic subsystems can contribute significantly to the total productivity of a salt marsh. In the Manahawkin study area, they compose approximately 6.7% of the marsh surface (Ferrigno et al. 1974).

The basic objectives of the study were: (1) to describe those factors which most differentiate *Ruppia* ponds from those which do not support *Ruppia* and (2) to estimate the productivity of *Ruppia* using peak standing crop measurements.

Methods

A total of 31 permanent salt ponds (with and without *Ruppia*) were examined during the period March 1975 - September 1976 for measures of seasonal changes in *Ruppia* biomass and certain environmental factors (Slate 1978). The latter included pond morphometry (surface area and water depth) and physico-chemical factors (water temperature, dissolved oxygen, salinity, and pH). The location of the ponds were on a transect approximately parallel to the Oyster Point Creek system (Figure 50). In order to determine the frequently of ponds supporting *Ruppia* growth, a grid system of 12 transects in the area between Mill Creek and Cedar Run was surveyed.

Ruppia productivity was estimated using the harvest method and assuming maximal seasonal biomass to be a reasonable approximation of annual net production (Milner and Hughes 1968; Westlake 1969). In 1975, two 0.143 m^2 plots (1.5 ft^2) were harvested biweekly to detect the occurrence of peak biomass at which time two replicate 0.5 m^2 plots (5.4 ft^2) were sampled from 38 *Ruppia*-supporting ponds. In 1976, triplicate 0.5 m^2 plots were collected biweekly. During harvesting, total plant material (including roots, rhizomes, and attached algae) was removed, washed free of sediment, and wet weights and dry weights (85°C (185°F) for 48 hours) obtained.

Additional information on methods is available in Slate (1976, 1978).

Results and Discussion

FACTORS AFFECTING *RUPPIA* PRESENCE -- As a result of tidal inundation, rainfall, and evaporation, the water level within each pond varied throughout the study period. Mean depths ranged from 12.0 - 37.3 cm (4.7 - 14.7 in), averaging 26.5 and 22.3 cm (10.4 and 8.8 in) in 1975 and 1976, respectively. *Ruppia* was consistently associated with the deeper ponds. The surface area of the ponds exhibited great variation, 11.0 - 3,999.5 m^2 (118 - 43,000 ft^2). The larger ponds were most subject to *Ruppia* colonization.

Based upon an inventory of 123 ponds scatterd throughout the Manahawkin marsh, approximately one-third were shown to support *Ruppia*, the only submerged vascular plant inhabiting the ponds. Frequently associated with *Ruppia* were the green algae, *Enteromorpha calthrata* and *Cladophora* sp. These were present in at least trace amounts in all *Ruppia* and non-*Ruppia* ponds. Other algal species included *Lyngbya* sp., *Ectocarpus* sp., *Vaucheria* sp., *Elothrix* sp., *Oscillartoria* sp., and *Gracilaria foliifera*.

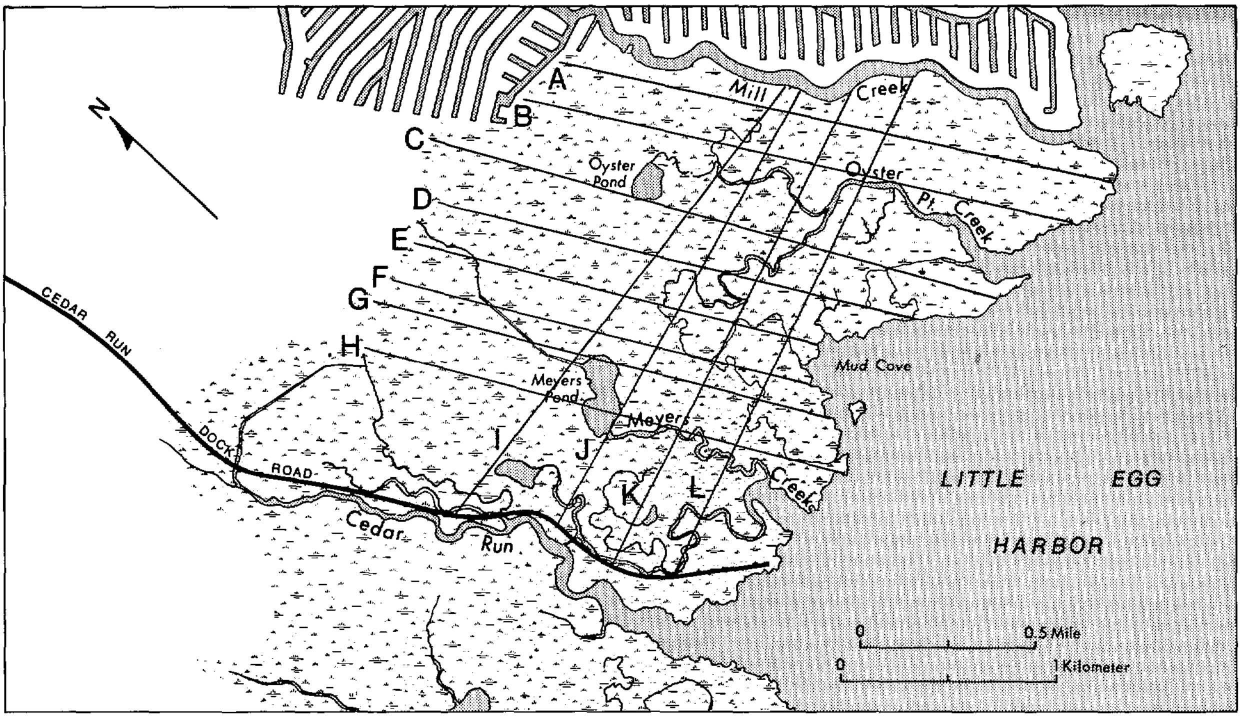


Fig. 50. *Ruppia* study sampling transects.

The environmental data were analyzed by a stepwise discriminant procedure (BMD07M of the Biomedical Computer Program Library) in order to determine which factors could most effectively be used to predict the presence or absence of *Ruppia*. Three indices, depth, salinity, and surface area (in decreasing order of importance), predicted accurately 21 of 24 attempts and 26 of 31 attempts in 1975 and 1976, respectively. The presence of *Ruppia* appears to be favored by relatively large, deep salt ponds with low salinity levels. Although mean water temperatures were not significant different for the two pond types, the smaller and shallower non-*Ruppia* ponds were characterized by greater temperature extremes. Midday concentrations of dissolved oxygen and pH were also significantly higher in the vegetated ponds, possibly reflecting the greater photosynthetic activity by *Ruppia* and its epiphytes.

The *Ruppia* growing season began near the first week of May in 1975 and peaked near the end of July. During 1976, growth was initiated approximately one month earlier and peaked at the end of June. The unseasonably warm spring of 1976 was probably responsible for this pronounced difference.

Temporary drought in 8 of 17 ponds under investigation accompanied the low summer precipitation levels in 1976. The majority of these were bordered by SP and less frequently by mixed SP-SAS stands. Salinity levels in July 1976 exceeded 100°/oo and midday temperatures of 38°C (100°F) were noted in late June. Ponds which maintained standing water were surrounded primarily by SAS and therefore probably received more frequent tidal inundation. The effect of pond drought on the submerged vegetation was temporary, for an immediate growth response was observed following the 9.8 cm (3.9 in) rainfall and exceptional high tides which accompanied Hurricane Belle on 9 August 1976. These observations stress the importance of tidal and rainfall replenishment of *Ruppia* ponds and certain management ramifications are discussed by Slate (1978).

PRODUCTION -- Each year the peak biomass varied for different *Ruppia*-supporting ponds. Peak biomass for 1975 ranged from 0.04-84.66 g dry weight·m^{-2}, with a grand mean of 16.64 g dry weight·m^{-2}. In 1976, it ranged from 0.40-127.16 g dry weight·m^{-2}, with a grand mean of 32.40 g dry weight·m^{-2}. The disparity between the two years appeared to be attributable, at least in part, to two very highly productive ponds in 1976 which had previously demonstrated little growth.

This marked annual variation in certain ponds may be related in some way to the occurrence of algal blooms, since an inverse functional relationship was observed between algal biomass and total mean biomass (*Ruppia* plus algae) when the latter was equal to or exceeded 20 g dry weight·m^{-2}. Causative mechanisms may involve shading effects (Backman and Barilloti 1976; Koch et al. 1974; Southwich, and Pine 1973) or nutrient competition (Gargas 1970; Koch et al. 1974). According to Southwich and Pine (1975), such pronounced annual variation is common in submerged grass ecosystems including instances of complete disappearance.

These estimates of maximal seasonal biomass are assumed equivalent to annual net production, and are comparable to the values for a variety of aquatic habitats in Table 44. These data are necessarily underestimates, since plant death and grazing are unaccounted for. The importance of such losses is unknown, however, Wetzel (1964) obtained similar values for annual net production from maximum biomass estimates and by graphical integration of C^{14} uptake rates throughout the growing season (Table 44). Even those ponds in the Manahawkin area which had minimal *Ruppia* growth were classified as *Ruppia*-supporting ponds and included in the annual estimates. The maximum biomass levels observed in this study (85-127 g dry weight·m^{-2}) approach those from other areas, except for the extremely high values reported for Bissel Cove, Rhode Island. They also compare favorably with the results for four man-made ponds constructed in 1968 near Tuckahoe, New Jersey (Slate, unpublished data).

If a caloric value on a dry weight basis of 3.24 kcal·g^{-1} is assumed for this species (Nixon and Oviatt 1973), then the average annual net production of *Ruppia* in the Manahawkin marsh is approximately 79 kcal·m^{-2}·$year^{-1}$. This represents a conversion of PAR energy to NP at an efficiency of 0.01%. The most productive ponds appear to be capable of fixing over 400 kcal·m^{-2}·$year^{-1}$ (efficiency = 0.06%). These figures do appear to be low for marine submerged macrophytes in general (Westlake 1963). However, such habitats may be one of the most highly dynamic communities of the marsh-estuarine complex in terms of energy throughput and carbon cycling on a unit area basis. Eleven diurnal oxygen curve and light-dark bottle studies were carried out from March 1977 through September 1978 and represent the first such attempts at evaluating the community metabolism in permanent salt ponds (Christian, unpublished data).[9] Production rates were high, especially in the warmer months, and averaged 2 g C·m^{-2}·day^{-1}. *Ruppia* and its aufwuchs dominated the total community metabolism during its entire growing season of May to September, while the benthic community was dominant the rest of the year. Phytoplankton contribution to the total system productivity was relatively low at all times,

[9] Dr. Robert Christian is an assistant professor at Drexel University.

Table 44. Annual net production of a variety of aquatic habitats.

Annual net production (g dry wt$\cdot m^{-2} \cdot year^{-1}$)	Date	Location	Author(s)
17	1975	Salt ponds Manahawkin, New Jersey	This study
32	1976	Salt ponds Manahawkin, New Jersey	This study
99	1976	Artificial ponds Tuckahoe, New Jersey	Slate (unpublished)
140	1958	Naeraa Strand Denmark	Grontved
250	1973	Chincoteague Bay	Anderson
800	1973	Patuxent River	Anderson
180-1460	1973	Tidal embayment Bissel Cove, RI	Nixon and Oviatt
64	1964	Borax Lake, California	Wetzel

accounting for 4-31% of total community production and 5-14% of community respiration. Estimates of annual gross production and community respiration were 100 g-atom $O_2 \cdot m^{-2} \cdot year^{-1}$ and 120 g-atom $O_2 \cdot m^{-2} \cdot year^{-1}$, respectively. Using the conversion equations of Stickland (1960), carbon base equivalents were as follows: 1,440 g $C \cdot m^{-2} \cdot year^{-1}$, annual gross production; 1,240 g $C \cdot m^{-2} \cdot year^{-1}$, annual community respiration.

FOOD WEB: TERRESTIAL PRIMARY PRODUCTION - BULKHEAD ALGAE

Pilings and bulkheads represent one of many new coastal ecosystem types associated with human disturbance. Such artificial surfaces, even though chemically treated, may develop characteristic and very productive fouling communities of bacteria, plants, and animals (Crisp 1964; Lindgren 1974). Vertical and horizontal patterns in the community structure are influenced by a number of environmental factors including latitude, light intensity, oxygen tension, water temperature, salinity, and prevailing currents. Temporal patterns, such as those involved in reproductive cycles, migration periods, and biotic succession, exist (Cooke 1956; Crisp 1964; Lindgren 1974). Due to the economic importance of the boring invertebrates, many ecological studies of wood infestation have stressed the heterotrophic components of such communities.

Due to the extensive length of the bulkhead-water interface within the Village Harbour complex, it was necessary to investigate attached algal biomass and metabolism. The purpose of the bulkhead algae study is to document the bulkhead algal production so comparisons of the bulkhead community to other primary producers can be made later.

Methods

Measurements were begun in July 1975 and were continued until April 1977 on an approximately bimonthly schedule. Sampling stations were situated along the main channel of Lagoon System A (upper, mid, and lower sections). Circular mats of known surface area were removed from the bulkhead community (almost exclusively algal in composition) and placed in light-dark BOD bottles, which were subsequently filled with Millipore-filtered (0.8μ) lagoon water. These were incubated in the laboratory under artificial illumination at in situ temperatures. Rates of photosynthesis and respiration were determined from changes in dissolved oxgyen concentration and extrapolated to a square meter basis. Such estimates are necessarily of a "potential" nature due to the use of artificial illumination and the simulation of only submerged conditions during incubation.

Measures of algal biomass were obtained by drying the circular mats at 100°C (212°F) to constant weight (dry weight), followed by ignition at 500°C (932°F) for 1 hour (organic and inorganic fractions). These estimates were also extrapolated to a square meter basis.

Additional information on methods is in Durand et al. (1976, 1977).

Results and Discussion

BIOMASS -- The results for bulkhead algal biomass are summarized in Figure 51. Maximum biomass exceeded 700 g dry wt$\cdot$m^{-2} during the summer of 1976 and was comparable to the peak aboveground standing crop observed for SAT (735-825 g dry wt$\cdot$m^{-2}) in the Manahawkin marsh. Minimal levels (<100 g dry wt$\cdot$m^{-2}) were observed in May and November 1976, a 10-fold annual range in standing crop. Though relatively high levels were recorded each summer, substantial values were also evident during the spring and fall.

The organic matter reached a peak of 510 g$\cdot$m^{-2} in July 1976 and averaged about 51% of the dry weight during the entire study. Higher proportions (70%) were recorded for the summer-fall period of 1976. This figure was affected to a varying degree by the presence of sand grains which had washed out from behind the bulkheads and settled onto the mats.

A number of biological and physical factors influence seasonal fluctuations. Increases in standing crop (total dry weight) result from algal NP and the growth of associated heterotrophs (bacteria, fungi, and protozoa). The input of suspended detritus is also significant, since eelgrass fragments became incorporated into the mats. Losses could arise from grazing or from sloughing due to the decay of underlying layers (Kevern et al. 1966). Such fragments, rich in organic matter, may be an important input to the lagoon aquatic system, especially during the period of fall dieback (Nixon et al. 1973). The presence of an extensive ice cover within the lagoon complex during the winters of study years III and IV also had an adverse effect upon these mats and their subsequent spring rejuvenation. The crushing and abrasive forces acting on these marine structures at such times can be considerable (Corps of Engineers 1975).

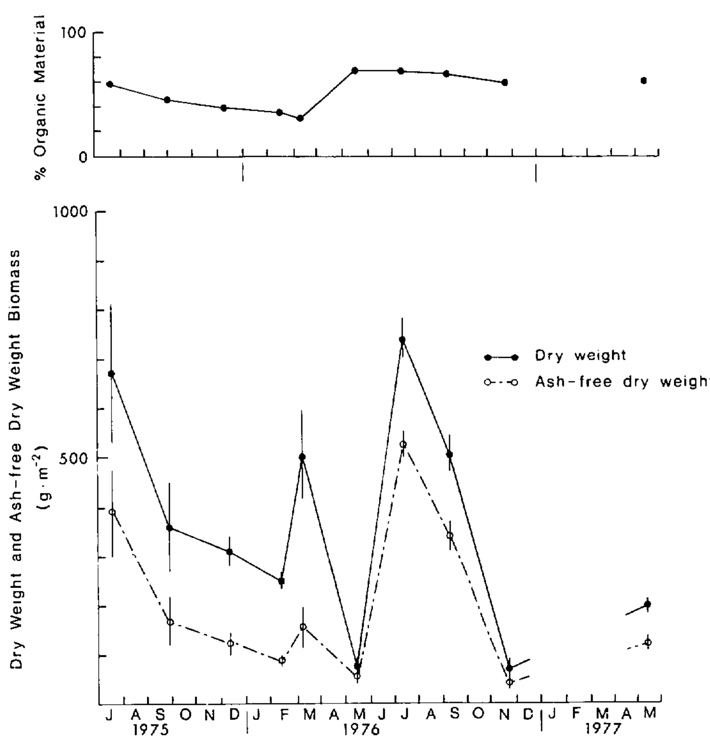


Fig. 51. Bulkhead algal community biomass data for Lagoon System A mid main channel.

PRODUCTION -- The results for bulkhead algal production are presented in Figure 52. The respiration values include both autotrophic and heterotrophic demands. By far the major proportion of oxygen exchange is a result of algal metabolism.

Although significant differences were occasionally observed for the three stations, production levels and seasonal patterns were very similar along the main channel of Lagoon System A. Maximum net productivity (>1,200 ml $O_2 \cdot m^{-2} \cdot day^{-1}$) was observed in May 1977. Relatively high rates appear to be characteristic of the summer and fall, usually exceeding 600 ml $O_2 \cdot m^{-2} \cdot day^{-1}$.

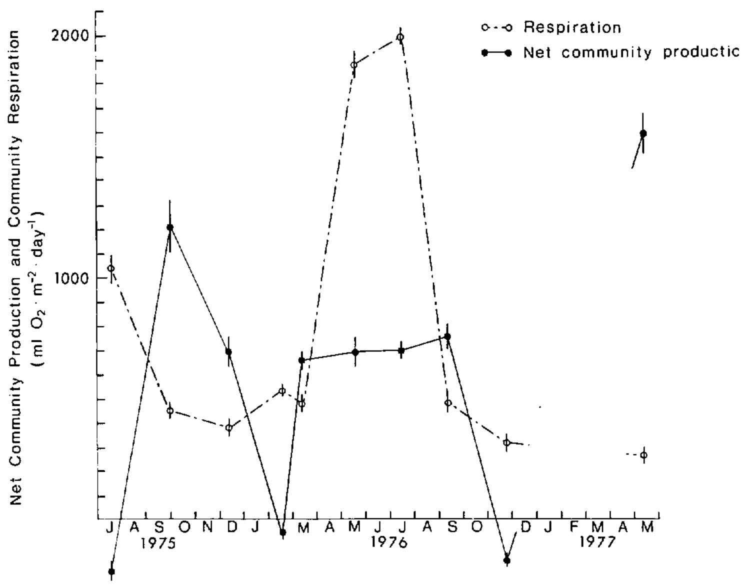


Fig. 52. Bulkhead algal community production data for Lagoon System A mid main channel.

The results for 17 July 1975 despite a relatively high standing crop were unusually low. This is perhaps indicative of the heavy rains which fell during 11-15 July, exceeding 11 cm (4.33 inches) (NOAA Environmental Data Service, Tuckerton Station). Likewise, the data for 1 July 1976 may also reflect abnormal environmental conditions, resulting from an extensive period of negligible rainfall and very high salinities (>29°/oo).

Minimal levels of net production were observed in February and November 1976. Water temperatures at these times were 6 and <0°C (42.8 and <32.0°F), respectively.

Respiration rates were highest in May and July 1976, exceeding 2,500 ml $O_2 \cdot m^{-2} \cdot day^{-1}$. Water temperatures were approximately 15 and 26°C (59.0 and 78.8°F), respectively. During the rest of the year, respiration was relatively low, ranging from 300 to 500 ml $O_2 \cdot m^{-2} \cdot day^{-1}$.

Although respiratory activity generally accounted for a significant proportion of the daily gross production, algal photosynthesis typically exceeded demands, indicative of an autotrophic community. Respiratory uptake exceeded photosynthesis (R/GP >1) only in February and November of 1976 and July 1975.

An estimate of bulkhead annual production on a square meter basis was obtained by planimetry of the daily oxygen production curves. These values were converted to a carbon base using a PQ of 1.2, an RQ of 1.0, and the conversion equations of Strickland (1960). Caloric equivalents were derived with an oxy-calorific coefficient of 4.8 cal·ml O_2^{-1} (Crisp 1971). The data obtained from the three stations were pooled in arriving at the figures presented in Table 45. These values were then multiplied by the total area of the bulkhead algal community for a rough approximation of the absolute annual production for the entire Lagoon System A. An average algal band width of 0.28 m (11.0 in) (Sugihara, pers. comm.) and a perimeter of 8,287 m (9,066 yd) were employed.

Table 45. Annual bulkhead algae production for Lagoon System A.

Units	NP	R	GP
g C·m^{-2}·$year^{-1}$	98	140	238
10^4 g C·Lagoon System A^{-1}·$year^{-1}$	22.74	32.48	55.22
10^3 kcal·m^{-2}·$year^{-1}$	1.05	1.51	2.56
10^6 kcal·Lagoon System A^{-1}·$year^{-1}$	2.44	3.50	5.94

Annual NP of the bulkhead algal community was approximately 1.05 x 10^3 kcal·m^{-2}·$year^{-1}$. This figure accounts for about 40% of the annual gross production, and represents an efficiency of PAR conversion of 0.17%. The actual efficiency is probably higher because the effects of shading and attenuation by a variable water column reduce the actual solar energy available, below the value used as the incident level in the calculations. The comparable calculation for energy trapping efficiency yields a value of 0.40%.

The study results indicate the bulkhead community is dominated by autotrophs with high areal photosynthetic rates; however, the impact of these organisms is minimized by a limited distribution within the lagoon system.

FOOD WEB: PRIMARY PRODUCTION SUMMARY

The salt marsh site in the study area is characterized by high levels of NP. As measured at the Meyers Creek system stations, the phytoplankton are the dominant aquatic primary producers, with NP rates on the order of 1,000 kcal·m^{-2}·$year^{-1}$. The mudflat algal community is also autotrophic and demonstrates high NP rates particularly during the summer; however, its limited distribution in the intertidal zone minimizes its overall contributions. The other aquatic primary producer studied, the benthic algal community, typically had negative NP values except during the colder portions of the year. Assuming an oxy-calorific coefficient of 4.8 cal·ml O_2^{-1}, the benthic algae at Meyers Pond during study year II exhibited a summer NP rate of -470 kcal·m^{-2}·$year^{-1}$ and a winter and spring NP rate around 100 kcal·m^{-2}·$year^{-1}$. Of the terrestial primary producers, the emergent macrophytes are the dominant type. When aboveground and belowground NP are considered together, the emergent macrophytes contribute the largest amount of NP of any primary producer studied at the salt marsh site. Generally, belowground NP exceeded aboveground NP by a factor of 5. When the aboveground and belowground components were summed, the NP for SAS, SP, SAT, and DS ranged from 11.3 x 10^3 to 16.5 x 10^3 kcal·m^{-2}·year^{-1} (study year II). These high rates are further magnified by the extensive distribution of the grasses in the salt marsh relative to other producers. The net aboveground production rate of *Iva* and *Baccharis* was comparable to that of the grasses, but these plants only occupied about 2% of the marsh. Consequently, their NP was relatively small. The marsh surface algal community in the SAS and SAT areas had a NP rate approximately 200-250 kcal·m^{-2}·year^{-1}. The negative NP rates of the SP areas (-50 to -100 kcal·m^{-2}·year^{-1}) reflected the reduced algal community resulting from a low light regime. The large areal coverage of SP on the salt marsh (26%) combined with the negative NP rates of the SP algal community offset somewhat the positive NP contribution of the SAS algal community. *Ruppia* production in the salt pools was also studied. In terms of NP rates, the values observed averaged less than 100 kcal·m^{-2}·year^{-1}. These rates, together with a limited coverage, minimized the contribution made by *Ruppia*.

In comparison, the net production associated with the lagoon system was smaller than that of the salt marsh system. The most important difference between the two sites was the absence of a biologically productive marsh surface. In the lagoon complex, the SAS, SAT, SP, and DS communities were largely replaced by housing or paved surfaces. This meant aboveground grass and shrub production, belowground grass production, marsh surface algal production, and salt pool production were all eliminated from the lagoon system. The only terrestial primary producer comparable to any of the supplanted communities is the bulkhead algal community. This community occupies a location similar to the SAT algal community, and exhibits NP rates about 10^3 kcal·m^{-2}·year^{-1}. Confined to a small area on the intertidal portions of bulkheads, pilings, and other structures, its absolute amount of NP is correspondingly limited. Because there is a higher proportion of waterway to drainage area in the lagoon complex, the relative contribution by the aquatic producers would be increased even if terrestial primary producers were present. This expanded habitat favors the phytoplankton which are the dominant aquatic primary producer in terms of rate as well as distribution. The lagoons are also deeper than the marsh creeks and the larger euphotic zone is reflected in the increased efficiency of energy utilization. It is also reflected in the NP rates which ranged from 581 to -730 kcal·m^{-2}·year^{-1}. The large amount of water column below the compensation depth coupled with the effects of stratification lead to NP rates lower than those observed in the natural creeks due to increased oxygen demand. The high respiration rate of the benthic community also contributes to this problem. Only on one occasion did the benthic algal community in the upper parts of Lagoon System A exhibit a positive NP. Periods of anoxia or low oxygen tension were frequent which prevented production measurements. Such conditions suggested high respiration rates which would lead to negative NP values. Lagoon A08 was typical of the lagoon stations. During study year II, Lagoon A08 was anoxic during the summer and had NP rates of -179 to -554 kcal·m^{-2}·year^{-1} for the rest of the year. The small amounts of mudflat in the lagoon system limited their effect on the NP compared to the other producers.

The only production measures performed in the bay dealt with the phytoplankton. A mean NP rate of 522 kcal·m^{-2}·year^{-1} was obtained. An unknown, but probably significant, production level is associated with submerged macrophytes, especially *Zostera*. Moeller (1964) estimated a large submerged macrophyte standing crop, 67% *Zostera*, was present in Barnegat Bay, just north of the study area.

FOOD WEB: DECOMPOSITION

The section on primary producers emphasized NP because NP represents the amount of biomass or energy potentially available to other trophic levels. Phytoplankton and algal mats are subject to immediate consumption or degradation. This is not true of the higher vascular plants such as *Spartina*. *Spartina* must undergo a certain degree of decomposition prior to utilization. Because of its overriding importance as a primary producer, the form in which *Spartina* enters the food web is critical to an estuarine ecosystem.

Work by Smalley (1959) and Teal (1962) indicate little of the *Spartina* is grazed directly while alive. Consequently, most of the organic material is left after the plant dies at the end of the growing season. This plant material is subject to decomposition, a process involving: (1) rapid loss of soluble organic compounds; (2) colonization by bacteria and fungi which initially use the soluble organics as a food source and then later the more resistant materials; and (3) mechanical fragmentation by wind, waves, or chewing organisms (Odum et al. 1973). It is hypothesized chewing organisms strip off the microorganisms during the ingestion process and utilize them as a food source while simultaneously mechanically reducing the size of the ingested particle. Following egestion of the particles, recolonization occurs and the ingestion/digestion process can be repeated (Fenchel 1977). The net result is the production of detritus of varying particle sizes available for use in the detrital food pathways.

The purpose of the decomposition study is: (1) to examine how the NP of the emergent macrophytes, particularly the *Spartina* becomes a food source and (2) to measure the amounts available.

Methods

ABOVEGROUND DECOMPOSITION -- There were three phases of the aboveground decomposition work. These were: (1) phenological studies; (2) decomposition studies using end of the season material; and (3) decomposition studies using live material.

The phenological study traced the fate of individual stems during and after the growing season at five *Spartina alterniflora* stations (Stations 1 - 5 on Figure 53 and Table 46). This was mainly an effort to measure the biomass component lost during the season which would be unaccounted for by the harvest method of determining NP. This was done during study years III and IV.

The decomposition experiments with end of the season material was the focal point of the decomposition investigation. Air dried aboveground material collected on 28 October 1975 was placed in 5 mm (0.2 in) nylon mesh bags. All bags were set out on 2 November 1975 at their respective stations and replicates retrieved at 4 week intervals between 2 December 1975 and 10 October 1976. This was done at stations 1-8 (Figure 53 and Table 46). Upon collection, the bags were washed free of mud, air dried, and subjected to weighing, ashing, and chemical analyses.

The decomposition work with the live material was conducted at stations 1-5 (Figure 53 and Table 46) during the summer and fall of 1976. Material was harvested on 4 June 1976, air dried, bagged in 5 mm (0.2 in) nylon netting, and set out on 16 June 1976. Replicates were retrieved at monthly intervals, washed, and weighed. Two additional experiments were run. The first extended from 17 August 1976 to

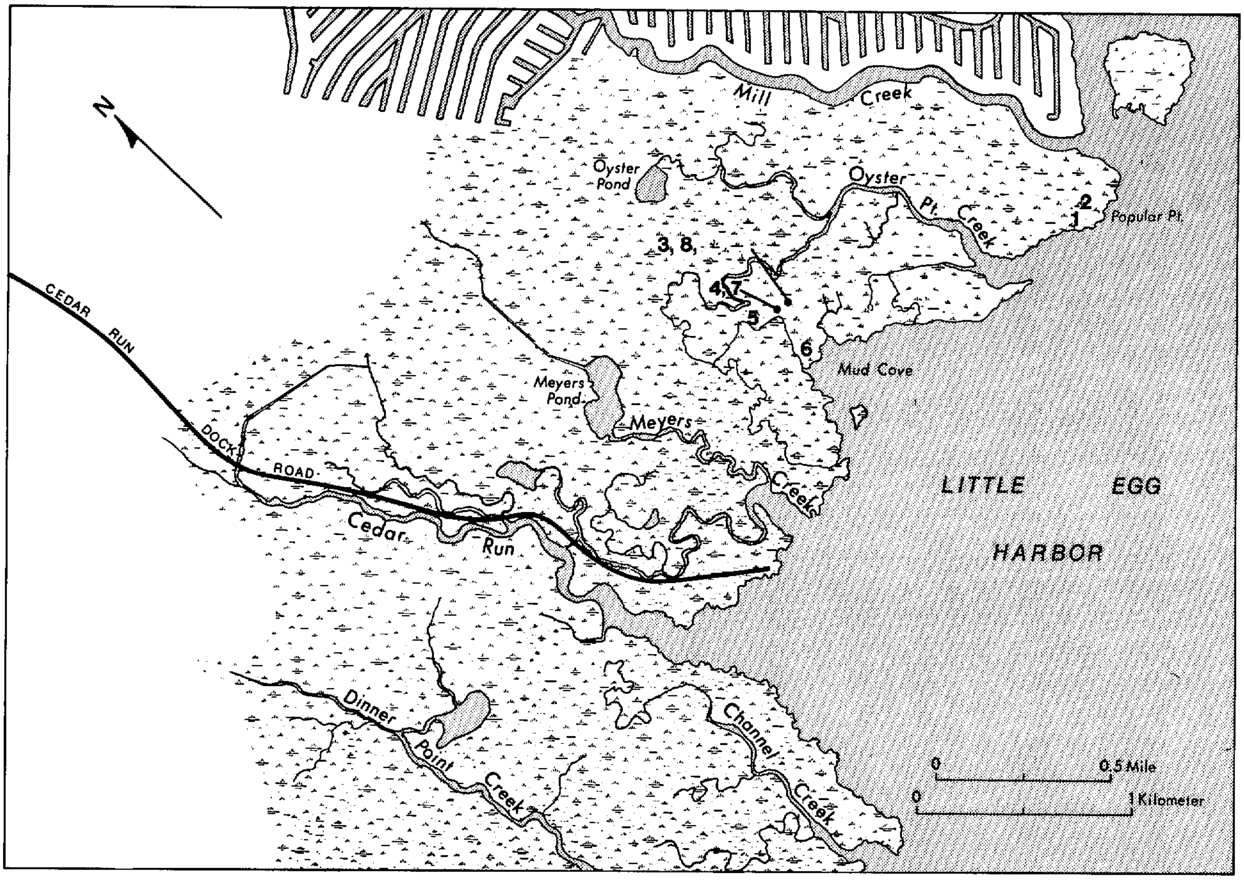


Fig. 53. Station locations for the decomposition studies.

Table 46. Stations, locations, and vegetation used for the decomposition of end of season material study.

Location and vegetation used	Station no.
Popular Point	
Spartina alterniflora short form (SAS)	1
Spartina alterniflora medium form (SAM)	2
Mud Cove	
SAS	3
SAM	4
SAT	5
SP	6
SAS (placed belowground)	7
SAT (placed in ditch)	8

10 October 1976 and used material harvested on 20 July 1976. The second used 17 August 1976 material and lasted from 14 September 1976 to 10 October 1976. This work was an extension of the other decomposition work to determine the effect the initial state of the litter would have on the decomposition process.

BELOWGROUND DECOMPOSITION -- An effort was made to measure in situ decomposition of belowground material at stations 3 and 6 (Figure 53 and Table 46). On 9 June 1976, 12 cores (30 cm or 1 ft) were taken at each station, divided into half, and the halves weighed. One half of each core was placed in 5 mm (0.2 in) nylon mesh and returned to its core hole. The other half, upon return to the laboratory, was washed free of mud, air dried, and weighed in order to allow calculation of an initial root dry weight of the core half left in the marsh. At 4 week intervals between 23 June 1976 and 21 November 1976, two replicate cores were recovered from each station and similarly processed. The difference between the calculated initial dry weight of the core and the actual dry weight of the core on its return from the marsh was determined. If there was a loss, it was considered due to decomposition.

Additional information on the methods for all decomposition work is available in Good and Frasco (1977).

Results and Discussion

ABOVEGROUND DECOMPOSITION -- In the phenological study, leaves at all stations were found to follow a similar pattern of growth and death. Leaves attain a certain maximum size which is smaller for leaves formed early in the growing season compared to those formed later. Chlorosis and necrosis of the older leaves progresses from the blade tip to the stem. With complete necrosis, the leaves lose rigidity, fall to the marsh, and begin to decompose. Eventually, the leaves separate from their sheaths. This process occurs throughout the growing season and into the fall. Rotting and wind damage then affect the leaves, especially the larger lower ones, and later the culms. By mid winter many of the culms have rotted. Much of the plant material is washed away as whole plants (60-80% of the original material present) in the areas where tidal flooding is moderate to heavy. At less flooded areas like the SAS stations, the plant material tends to remain on the marsh surface. Table 47 summarizes the leaf loss data and also compares it with other similar studies. The leaf loss is substantial and NP values should be revised accordingly to reflect such growing season losses.

Decomposition studies of the aboveground end of the season material indicated a linear decomposition rate for many of the stations (Table 48). This differs from the decomposition curves of other workers which usually have three more or less distinct sections with differing slopes (Odum et al. 1973; Gosselink and Kirby 1974). The plant material used was harvested on 28 October 1975. Apparently, leaching or translocation of the soluble organics from the aboveground component had already occurred. Consequently, an initial rapid weight loss of plant material was not observed or was limited in the experiment. That it did occur was supported by data from stations 3, 5, and 6 (Table 49). Several of the study stations had decreases in weight loss increments towards the end of the study. If the study had been extended, it is likely lower decomposition rates associated with the breakdown of more refractory material would have been observed.

Decomposition was responsible for the conversion of high proportions of whole plant material into detritus or soluble products. The percent weight loss data are indicative of this conversion and are summarized in Table 50.

Table 47. Comparison of percent leaf loss of *Spartina alterniflora* during the growing season for several salt marsh studies.

Marsh location	Leaf loss (%)	Author
New Jersey		This study
Station 1	27.3	
Station 2	31.5	
Canada		
Tall	23.3	Hatcher and Mann 1975
Medium	27.1	
Short	35.1	
North Carolina		
Marsh average	19.3	Williams and Murdoch 1972
Georgia		
Streamside	22.4	Odum and Fanning 1973
Medium and low marsh	8.9	
Average all studies	21.6	

Table 48. Linear regression line equations and correlation coefficients (r) for percent weight loss of decomposition samples for the study period 2 November 1975 - 10 October 1976 at Popular Point and Mud Cove.

Station	Linear regression line equation	Correlation coefficient (r)
1 SAS	$y = 8.86 + 4.56x$	.967
2 SAM	$y = 0.71 + 6.90x$	.971
3 SAS	$y = 11.62 + 4.54x$	.918
4 SAM	$y = 4.46 + 7.41x$	.979
5 SAT	$y = 0.94 + 6.08x$	.983
6 SP	$y = 12.66 + 1.53x$	.584
7 SAS	$y = 2.97 + 2.55x$	.821
8 SAT	$y = -3.00 + 6.52x$	.953

Table 49. Percent weight loss increments of decomposition samples at all Popular Point and Mud Cove stations for the period 2 December 1975 - 10 October 1976.

Stations	12/2	12/31	1/26	2/23	3/26	4/26	5/20	6/23	7/20	8/17	9/14	10/10
1 SAS	14.4	1.2	15.0	-3.4*	8.1	-1.0	8.7	5.0	3.3	7.7	-3.1	0.4
2 SAM	11.6	7.1	10.5	-11.0	6.5	12.2	20.0	-6.7	13.5	15.4	-1.9	3.8
3 SAS	23.6	3.9	4.6	4.4	-2.6	-6.6	14.8	-2.3	5.9	6.9	18.5	-2.1
4 SAM	7.8	20.8	0.8	10.4	2.0	1.5	10.5	1.3	19.6	15.0	-7.1	9.3
5 SAT	14.7	2.5	3.4	1.3	2.0	6.9	9.0	7.9	11.0	6.8	3.9	6.9
6 SP	21.3	3.4	-11.0	-2.1	11.7	2.7	10.2	-9.6	-13.9	10.4	13.6	-8.7
7 SAS	11.3	3.3		-10.4	4.7	9.4	2.9	8.2	-3.4			
8 SAT	6.0	6.9	2.9	9.1	-1.1	-2.5	25.5	-0.3		35.4		

* A negative value indicates the percent weight loss was lower than the percent weight loss on the previous sampling date at that station.

Table 50. Percent weight loss (± 1 SD) for aboveground end of the season material at stations 1 - 8 from 2 December 1975 to 10 October 1976.

Station	Vegetation	Percent weight loss (%)
1	SAS	56.3 ± 9.7
2	SAM	81.0 ± 0.2
3	SAS	70.0 ± 0.7
4	SAM	91.9 ± 1.4
5	SAT	76.3
6	SP	28.0
7	SAS	26.0*
8	SAT	71.9#

* Data as of 20 July 1976.
\# Data as of 17 August 1976.

The data indicate the decomposition rates are affected by environmental conditions such as moisture, exposure to air, and the nature of the plant material. Apparently, the combination of conditions was the most favorable at the SAM stations followed by SAT, SAS, and SP. Anaerobic conditions seem to slow the decomposition process and indicate aerobic decomposers are either more efficient or more plentiful than anaerobic decomposers. Stations with longer air exposure times are also subject to lower decomposition rates. These findings were confirmed by Frasco (1979). On the Manahawkin marshes, Frasco found in situ decomposition patterns for SAS, SP, and SAT followed a three stage pattern with the SAT decomposing faster than the SAS and the SP (which decomposed slowest). Under identical conditions, the SAT material decomposed faster than the SP material, indicating the nature of the two materials affected the rate of decomposition. The decomposition of either SAT or SP material in both the SAT and SP locations showed the SAT location favored faster decomposition and confirmed the influence of moisture regime on decomposition rates.

Experiments with the live material showed decomposition occurred in the typical three stage pattern. The rate of decomposition was also much faster for the live material. In all cases, the initial losses with live material exceeded those of the end of the season material (Table 51).

BELOWGROUND DECOMPOSITION -- The belowground material decomposition data are summarized in Table 52. The data indicate root growth occurred followed by some decomposition. The decrease from the peak values in September 1976 indicates some belowground decomposition occurred.

Table 51. Percent weight loss (± 1 SD) of live harvested decomposition bags at Popular Point and Mud Cove. Except where noted, bags were set in the field on 16 June 1976.

Station	Date of collection 6/23/76	7/20/76	8/17/76	9/14/76	10/10/76
1 SAS	35.3	39.2 ± 3.2	59.6 ± 2.2	61.9	
				13.7 ± 2.1*	32.7 ± 1.9*
					24.1 ± 1.7#
2 SAM	34.7	71.5 ± 1.3	84.2 ± 0.7	84.8	
				57.9 ± 1.1*	66.7 ± 0.2*
					34.9#
3 SAS	42.3 ± 8.1	57.1 ± 6.5	69.4		
				18.0 ± 1.7*	56.6 ± 6.0*
					36.1 ± 2.6#
4 SAM	32.5	50.8 ± 0.4	66.1 ± 2.6	80.7	
				35.4 ± 2.8*	60.5 ± 3.0*
					43.8 ± 5.5#
5 SAT		79.3 ± 0.3	84.8 ± 1.0		
				58.7 ± 0.2*	68.0 ± 0.4*
					50.0 ± 0.7#

* Bags set in field 8/17/76
# Bags set in field 9/14/76

Despite the large NP associated with the belowground component, only a small percentage of the production will probably enter the detrital food chain. Most will be incorporated into the sediment and peat structure of the marsh.

FOOD WEB: PRIMARY NET PRODUCTION AND THE FOOD CHAIN

The vascular plant material transformed by decomposition and the more readily consumable phytoplankton and algae provide nutrients and energy to the upper trophic levels. The amount of NP available is the factor which determines the size of the food web.

It is generally acknowledged that in a shallow estuary like the system studied the detrital food chain is the dominant pathway as opposed to a grazing food chain. In any case, the upper trophic levels are dependent on the NP of the primary producers.

FOOD WEB: BENTHIC INVERTEBRATE COMMUNITY

When the detritus, algae, and associated microbial forms are suspended in the water column, they serve as food sources for the planktonic fauna (Heinle et al. 1977). An important component of this planktonic fauna is the zooplankton. In

Table 52. Estimated initial dry root weight, actual dry root weight, and actual-initial dry root weight difference for belowground samples collected from 23 June 1976 to 21 November 1976 at Mud Cove.

Vegetation type	Collection date	Estimated initial dry root wt (g)	Actual dry root wt (g)	Difference in dry root weight (actual-initial) (g)
SAS	23 June 76	31.3	53.3	+22.0#
SAS (a)	20 July 76	31.7	*	
(b)		32.0	*	
SP (a)		26.8	*	
(b)		23.4	*	
SAS (a)	17 August 76	34.9	32.9	- 2.0†
(b)		36.8	39.7	+ 2.9
SP (a)		23.3	26.8	+ 3.5
(b)		28.3	32.0	+ 3.7
SAS (a)	14 September 76	31.7	52.2	+20.5
(b)		29.9	37.0	+ 7.1
SP (a)		23.6	29.8	+ 6.2
(b)		24.5	35.0	+10.5
SAS (a)	10 October 76	31.0	39.0	+ 8.0
(b)		34.4	34.1	- 0.3
SP (a)		24.2	22.8	- 1.4
(b)		29.1	23.6	- 5.5
SAS	21 November 76	32.2	33.1	+ 0.9

*Sample incorrectly processed, data obtained not valid
#Positive value indicates increase in root biomass
†Negative value indicates decomposition of root material

shallow areas, copepods typically dominate the zooplankton community with occasional dominance by other taxa (Odum et al. 1973). It is this zooplankton community which is acknowledged as the intermediary between the phytoplankton and the carnivores in the classical aquatic food chain (Williams et al. 1968). However, other studies indicate benthic invertebrates are important phytoplankton consumers even in deeper areas (Riley 1956; Harvey 1950). Williams et al. (1968) further suggest it is the benthic animals which are the important herbivore link in the food chain.

Much of the suspended material is eventually deposited in the sediments. It is then available for further microbial decomposition or utilization by benthic organisms. Major food sources of the benthic invertebrates are the bacterial and diatom populations associated with these materials (Adams and Angelovic 1970; Hargrave 1970; Giere 1975). The benthic invertebrates in turn serve as the major food source for many species of epibenthic invertebrates and estuarine fish (Odum et al. 1973).

The purpose of the benthic invertebrate study is to determine the structure, distribution, production, and food web relationships existing in the creeks and lagooned waterways in the study area.

Methods

Sampling was conducted on a quarterly basis from July 1973 to March 1977 at the stations indicated in Figure 54. Natural creeks (Meyers and Dinner Point creeks), partially disturbed waterways (Mill Creek and Cedar Run), fully lagooned waterways (Lagoon System A and B), and the bay (reference station) were studied during the investigation. All samples were taken with a ponar grab which sampled 0.05 m^2, sieved through screens with mesh openings of 1.0 cm^2 and 1.0 mm^2, preserved, sorted, and identified. Except during study year I, five grab hauls comprised a sampling. It was determined 90% or more of the total species found by more intensive sampling (8 or 10 grab hauls) were collected by the fifth haul.

During the period July 1973 - February 1975, the main effort was to inventory the species found in the different types of waterways. During the period July 1975 - March 1977, only the Meyers Creek system and Lagoon System B were sampled. Emphasis was placed on the study of the dominant species. Unlike the previous samples, the grab hauls in the second phase were kept separate to allow more detailed statistical analysis. Dry weight biomass and ash-free dry weight biomass were determined for all samples. Size frequency and limited gut contents analyses were also performed, as well as respiration experiments.

Analysis of variance was carried out on logarithmically transformed data. In addition, diversity, dominance, species composition, and similarity indices were used to evaluate the data along with other numerical methods. Calculations for determining production from respiration and biomass values were also done.

Additional information on methods is available in Haskin and Ray (1977).

Results and Discussion

During the July 1973 - February 1975 sampling, 185 species (Table 5 of Appendix B) and 231,135 organisms were collected. Over 93% of all the organisms belong to 22 species (Table 53). *Ampelisca abdita* was the most abundant species and comprised 56% of the collected organisms. Among the different waterway types, *Ampelisca* accounted for 48 - 62% of the total sample. *Streblospio benedicti* was the second most abundant and accounted for 10% of the specimens. This polychaete was particularly important in the lagooned waterways where it comprised 25% of the collected organisms. Third most abundant was *Hypaniola grayi* which made up 8% of the total collection. Its distribution was limited primarily to the natural creeks and partially disturbed waterways where it accounted for about 10% of the total sample.

Grouping the data for all study years, the 10 most common species collected are (in order): *Ampelisca abdita, Streblospio benedicti, Hypaniola grayi, Leptocheirus plumulosus, Nereis succinea, Heteromastus filiformis,* Oligochaeta, *Nereis* spp., *Cyathura polita,* and *Scoloplos robustus.* The most numerous of the three major taxonomic groups is the Crustacea followed by the Polychaeta and then the Mollusca.

The total species lists for the different types of waterways are nearly the same; however, the degree of persistence and the loss or gain of species differ.

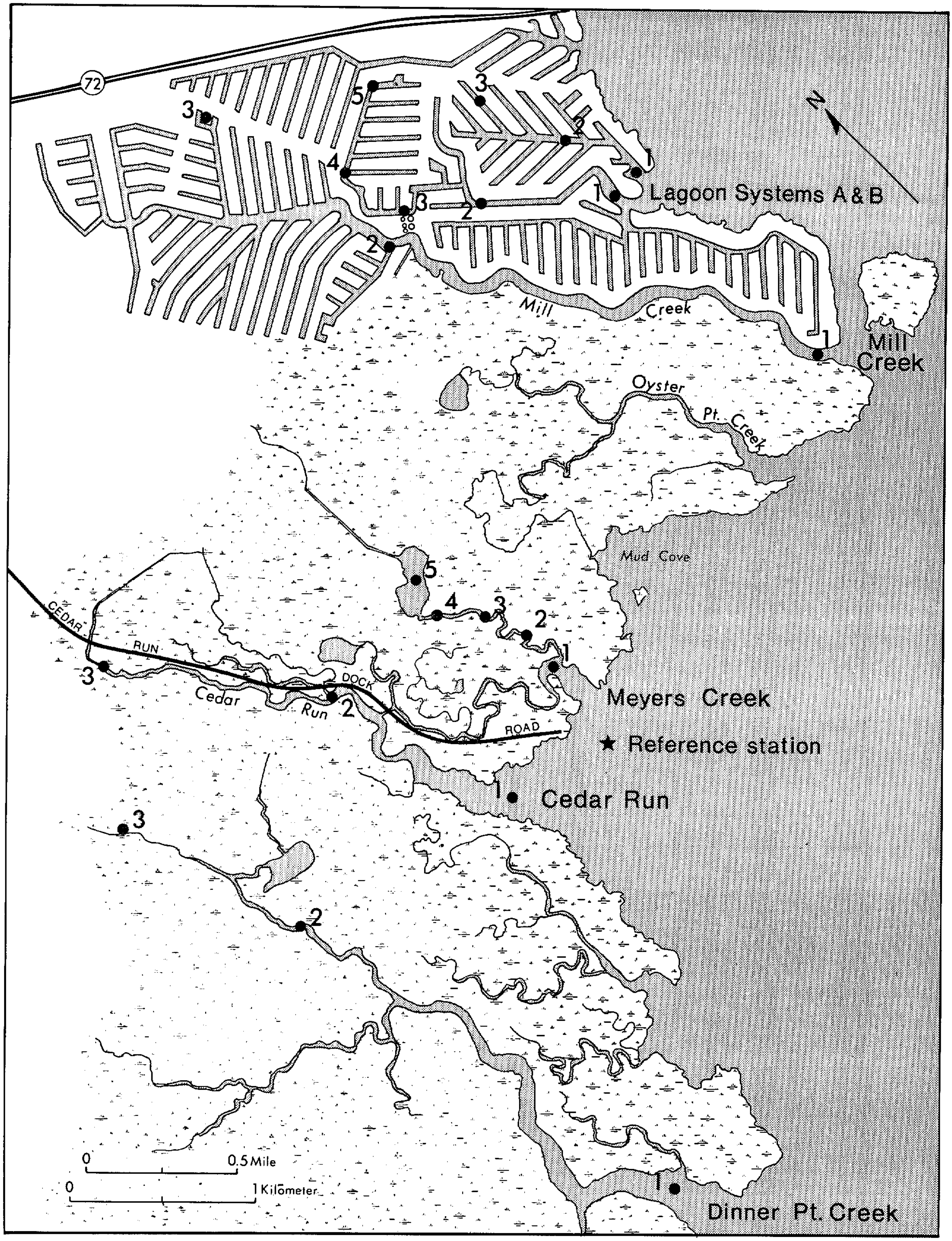


Fig. 54. Sampling locations.

Table 53. Percentage numerical composition of most abundant species for 1973-1975.

Species	Natural creeks	Partially disturbed	Lagoons	Reference station	Total
Polychaetes:					
Eteone heteropoda	0.93	0.37	0.27	0.07	0.66
Glycera spp.	0.10	0.07	0.09	1.32	0.13
Glycinde solitaria	0.51	0.71	1.46	1.26	0.72
Heteromastus filiformis	1.92	0.95	0.63	1.69	1.47
Hypaniola grayi	8.99	10.90	0.10	0.08	7.99
Lumbrineris tenuis	0.60	0.16	0.36	1.23	0.47
Maldanopsis elongata		0.06	0.05	1.18	0.07
Melinna cristata	0.06	0.08	0.03	0.26	0.07
Nereis succinea	3.21	2.58	1.68	0.02	2.71
Polydora ligni	0.31	1.08	1.67	0.07	0.70
Scoloplos robustus	1.02	0.93	2.46	2.09	1.23
Streblospio benedicti	9.07	7.81	25.09	0.19	10.57
Terebellidae	0.02	0.02	0.04		0.02
Crustaceans:					
Ampelisca abdita	59.77	52.76	48.29	62.45	56.37
Gammarus palustris	0.72	0.20		0.06	0.68
Leptocheirus plumulosus	0.82	5.29	0.22	0.02	2.63
Lysianopsis alba		0.02	0.03		0.01
Melita nitida	0.03	0.06		1.04	0.07
Cyathura polita	1.31	2.41	0.48	1.38	1.50
Edotea triloba	0.59	0.66	0.05	0.07	0.57
Leptochelia savigni		0.04			0.01
Ostracod	0.01	0.02	0.01		0.01
Neomysis americana	0.14	0.30	0.98	7.25	0.56
Molluscs:					
Gemma gemma	0.82	0.44	1.08	0.68	0.75
Mulinia lateralis	0.04	0.02	0.14	3.85	0.19
Ilyanassa obsoleta	0.95	1.03	1.46		1.01
Retusa canaliculata	0.27	0.40	0.67	5.67	0.73
Miscellaneous Oligochaeta:	1.50	1.41	1.61	0.06	1.44
Molgula manhattensis	0.02	0.09	0.09		0.05
Number of species	120	121	95	82	190
Percent of population contributed by the 22 most abundant species	93.06	89.10	87.74	91.92	93.86

The percentage of species present for at least four of the quarterly samplings during 1973 - 1975 was highest in the natural creeks (26%) followed by the partially disturbed waterways (17%) and the lagooned waterways (11%). The percentage of species present during all samplings of the 1975 - 1977 period was 20% for the Meyers Creek system and 11% for Lagoon System B. Besides having species that were less persistent, the lagooned and partially disturbed systems lost or replaced species at a faster rate than the natural creeks. This indicates the more variable nature of the resident populations.

Statistical analysis of the data indicates there are significant differences in the distribution of the number of individuals between the types of waterways. Figure 55 details the total species data and the data for the three major taxonomic groupings. During the period summer 1974 - winter 1975, all four of these categories and 10 individual species had statistically different distributions between waterway types. Nearly all of these were most abundant in the natural creeks, less so in the partially disturbed creeks, and scarcest in the lagooned waterways. The natural creeks had 9 times more organisms present than the lagoon systems. Natural creek densities varied from 400 to 6,500 animals$\cdot m^{-2}$ whereas the lagooned waterways varied from 80 to 340 animals$\cdot m^{-2}$.

Statistical analysis also indicates significant differences between the waterway types for biomass. Of those statistically different, only *Melinna cristata* had more biomass associated with the lagoons than the natural creek. Figure 56 displays the data for total species, total polychaete species, and total crustacean species. On the average, there was 25 times more biomass associated with the creeks than the lagoons. Biomass ranged from 0.2 to 3.2 g ash-free dry wt$\cdot m^{-2}$ in the natural creeks and 0.02 - 0.20 g ash-free dry wt$\cdot m^{-2}$ in the lagooned waterways.

According to Haskin and Ray (1977), decreases in number of species, number of individuals, and biomass within the waterways frequently occurred as distance from the bay increased. They hypothesize the observed distributions are partially explained by a parent community in the bay which supplies the species that establish themselves in the waterways. Most of the benthic invertebrates have planktonic larvae, increased distance from the parent stock would be expected to reduce the density and biomass of the species present as well as diversity. Such expected distributions would be modified by salinity, dissolved oxygen levels, and sediment characteristics. Interspecific competition and depth were also cited as important influences at some of the natural creek sites.

Seasonal variations in species present, numbers of individuals, and biomass are largely a function of reproductive success. Also important are the predator species which utilize the benthic invertebrates as a food source.

Most of the dominant benthic invertebrates are classified as nonspecific deposit feeders or omnivores (Table 54). The larger forms such as the crabs and shrimps belong to this latter category. Examination of the gut contents of 10 of the more important benthic invertebrate species confirmed their dependence on the NP of the primary producers and the associated microbial forms. Detritus, diatoms, and plant and algal fragments were the major organic components of the gut contents. Examination of the larger forms such as *Palaemonetes vulgaris*, *Crangon septemspinosa*, *Neopanope texanna*, *Panopeus herbstii*, and *Callinectes sapidus* were also done. The major component identifiable in all of them was plant material. In addition, the Caridean shrimp contained gammarid remains and an unidentified polychaete.

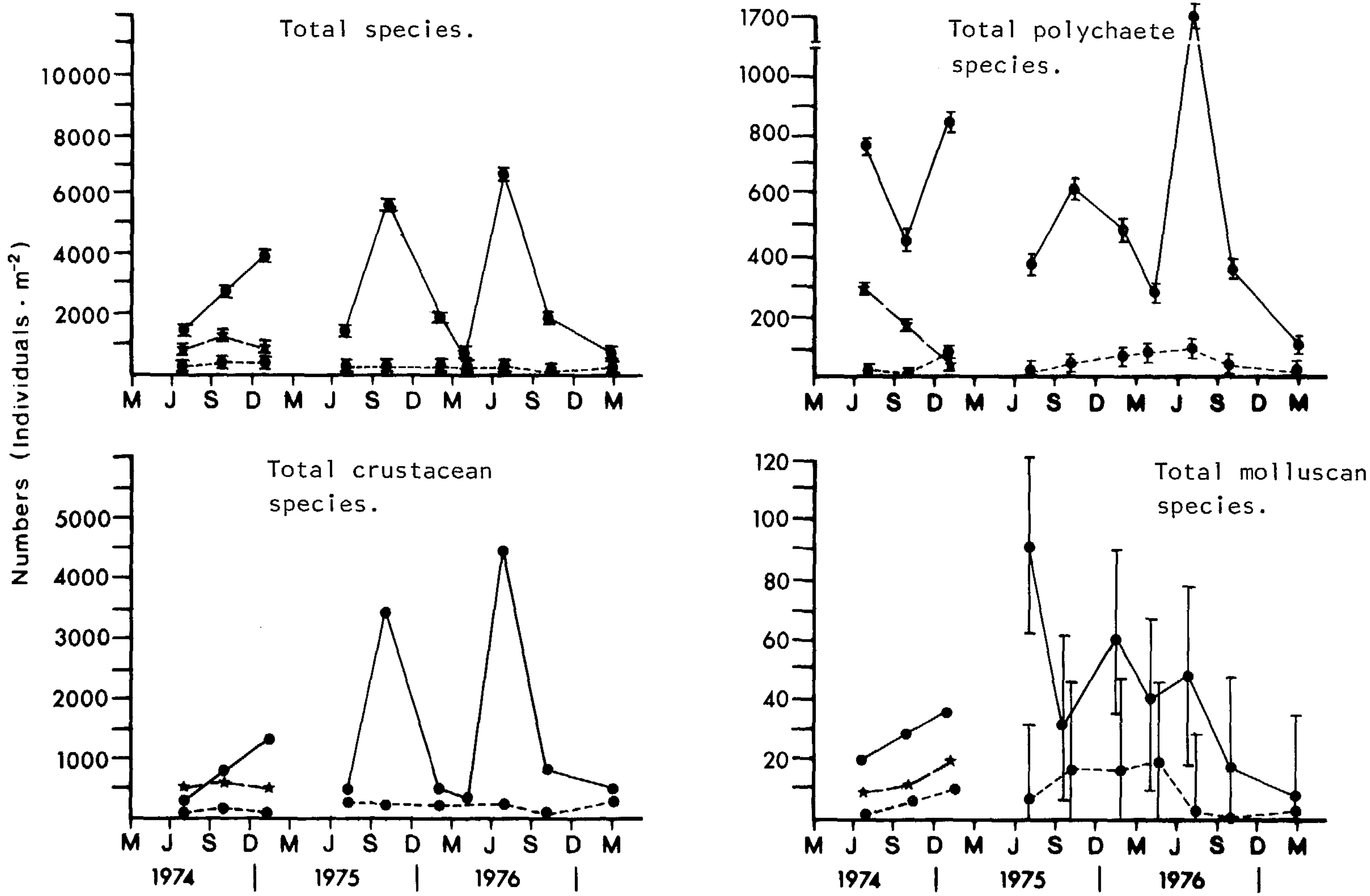


Fig. 55. Waterway totals of individuals·m^{-2} for the overall categories with 95% confidence interval indicated. Data are for natural creeks (●—●), partially disturbed waterways (★—★), and lagooned waterways (●---●).

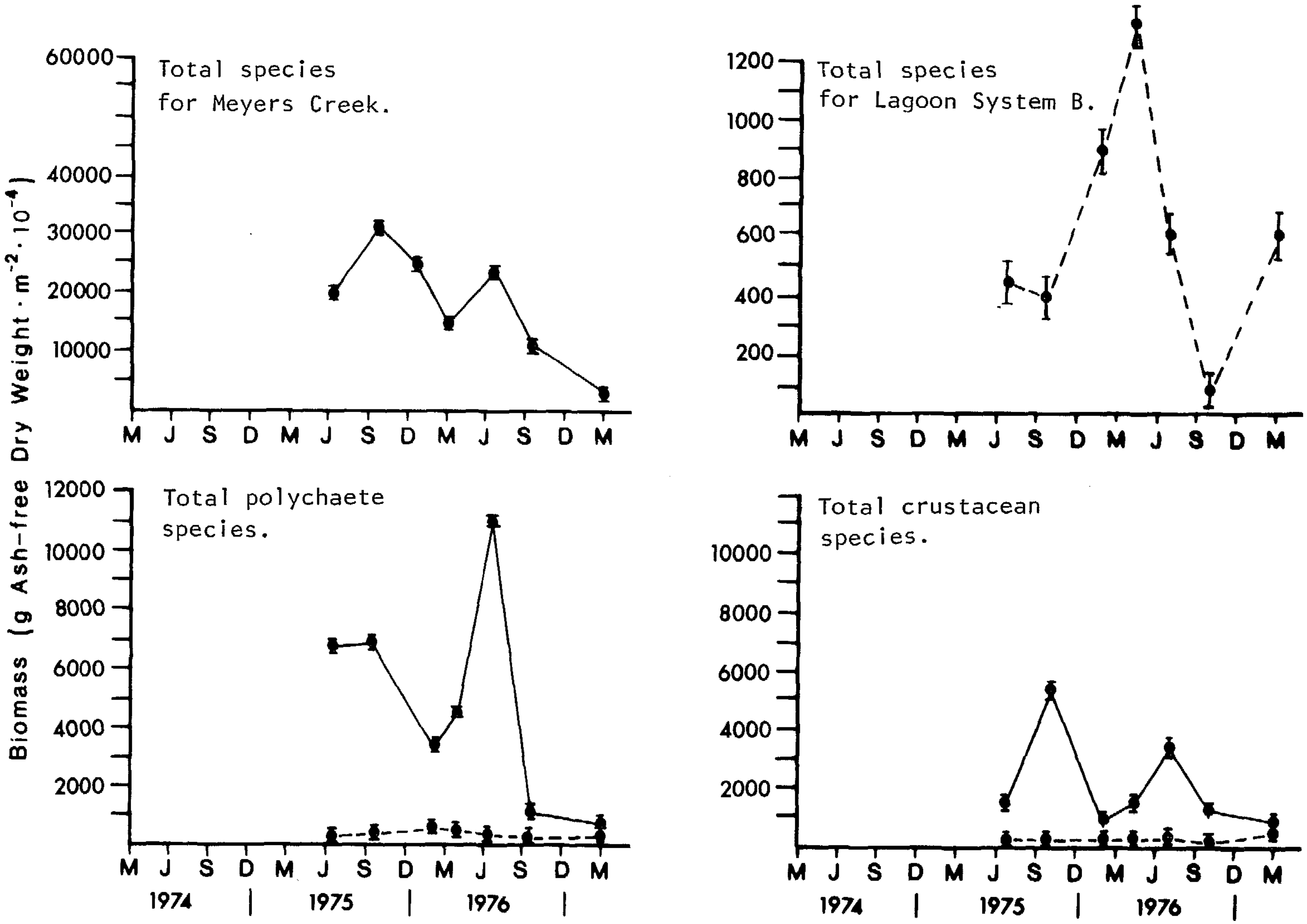


Fig. 56. Waterway biomass totals for the overall categories with 95% confidence interval indicated. Data are for natural creeks (•——•) and lagooned waterways (•- - - -•).

This is not to imply that these larger species are primarily detritivores or herbivores. While it is known *Palaemonetes* consumes detritus (Welsh 1975), Caridean shrimp and crabs are certainly omnivores (Tagatz 1968; Odum and Heald 1972; Nixon and Oviatt 1973). The lack of identifiable remains other than plant material is a result of ingestion/digestion.

Table 54. Feeding habits of the dominant marsh invertebrates.

Species	Feeding habit	Reference
Polychaeta		
Eteone heteropoda	NSDF*	Sanders (1962)
Glycera americana	Scavenger, DF#	Sanders (1962)
Glycera dibranchiata	Scavenger, DF	Pettibone (1963)
Heteromastus filiformis	NSDF	Sanders (1962)
Lumbrineris tenuis	NSDF	Sanders (1960)
Melinna cristata	SDF†	Sanders (1960)
Nereis succinea	Omnivore	Sanders (1962)
Polydora ligni	SDF	Sanders (1962)
Scolplos robustus	NSDF	Sanders (1962)
Streblospio benedicti	SDF	Sanders (1962)
Crustacea		
Ampelisca abdita	SDF	Mills (1967)
Leptocheirus plumulosus	SDF	
Cyathura polita	Omnivore	Burbanck (1962)
Edotea triloba	Omnivore	Sanders (1960)
Leptochelia savignyi	NSDF	Odum and Heald (1972)
Palaemonetes spp.	Omnivore	Nixon and Oviatt (1973) and Odum and Heald (1972)
Callinectes sapidus	Omnivore	Odum and Heald (1972)
Xanthid crabs	Omnivore	Odum and Heald (1972)
Mollusca		
Gemma gemma	SF**	Sellmer (1967)
Mulinia lateralis	SF	Sanders (1960)
Ilyanassa obsoleta	Omnivore	Scheltema (1964)

*NSDF = Nonspecific deposit feeder
DF = Detritus feeder
† SDF = Selective deposit feeder
** SF = Surface feeder

Based on the conversion of experimentally determined respiration and biomass values, production equalled 2.9 and 0.3 kcal·m^{-2}·$year^{-1}$ for the natural creek and the lagoon systems, respectively. The production estimates by taxonomic group are listed in Table 55. It is important to note the production rates of the natural creek populations are several times those of the lagoon systems.

FOOD WEB: MARSH SURFACE INVERTEBRATE COMMUNITY

Marsh surface invertebrate studies have primarily dealt with taxonomic composition and distribution. The populations studied include salt marsh insects (Davis and Gray 1966; Cameron 1972), spiders (Barnes 1953), fiddler crabs (Teal 1958), and the ribbed mussel (Kuenzler 1961a).

The relatively few species able to adapt to the rigors of the salt marsh are often quite abundant because the reduced competition levels allow them to occupy broad niches (Teal 1962). Adult organisms may either persist throughout the year or occur in seasonal cycles, utilizing their respective resources as they become available. Although a major portion of the energy circuit is based upon a detrital food base, herbivores, carnivores, parasites, and deposit-aufwuch feeding omnivores are all represented.

The primary objective of the marsh surface invertebrate study is to obtain summer population data for several important invertebrate species inhabiting the different vegetation types.

Methods

The study was carried out during August 1974. Sample plots, approximately 4.05 m^2 (mil-acre) in size, were randomly located along nine transect lines (Figure 57). The vegetation types samples and the number of sampling plots employed were SAT (15), SAS (35), SP (24), and DS (10).

A list of representative invertebrates of the emergent marsh is provided in Table 6 of Appendix B and includes those taxa on which population studies were carried out. A summary of the mean density and standard deviation of the original counts for each of the 11 invertebrate forms is present in Table 56. Also included are estimates of the total number of individuals on each of the 10 cover types along with estimates of the total number of individuals for each taxa. Of the organisms studied, the most prevalent forms in terms of density and wide spread distribution were: *Melampus bidentatus, Philoscia vittata,* leaf-hoppers, *Orchestia grillus,* and the spiders (in decreasing order of importance). These accounted for approximately 99% of the total number of invertebrates on the study area.

Melampus bidentatus was the most abundant invertebrate on the emergent marsh and accounted for 65% of the total. Most frequently associated with the accumulated detritus at the base of SAS, SP, and DS, the diet of this nocturnal deposit feeder consists of diatoms, filamentous green and blue-green algae, epidermal cell fragments of *Spartina*, and animal remains (Hauseman 1932, 1936).

Table 55. Production estimates from respiration data for 1975 - 1977.

Taxonomic group	Meyers Creek Production (kcal·m^{-2}·year^{-1})	% of waterway production	% of taxonomic group production
Total polychaetes	1.267	46.16	
Nondominant species	0.986	35.92	77.82
Dominant species	0.281	12.24	22.18
Nereis succinea	0.129	4.70	10.18
Total crustaceans	1.478	53.84	
Nondominant species	0.599	21.82	40.53
Dominant species	0.879	32.02	59.47
Ampelisca abdita	0.869	31.66	58.80
Cyathura polita	0.007	0.26	0.47
Total molluscs	0.154	5.61	
Nondominant species	0.051	1.86	33.12
Dominant species	0.103	3.75	66.88
Ilyanassa obsoleta	0.101	3.68	65.58
Total for waterway	2.899		

Table 55. Continued.

Taxonomic group	Lagoon System B Production (kcal·m^{-2}·year^{-1})	% of waterway production	% of taxonomic group production
Total polychaetes	0.110	33.03	
Nondominant species	0.041	12.31	37.27
Dominant species	0.069	20.72	62.73
Nereis succinea	0.039	11.71	35.45
Total crustaceans	0.219	65.77	
Nondominant species	0.060	18.02	27.40
Dominant species	0.159	47.75	72.60
Ampelisca abdita	0.155	46.55	70.78
Cyathura polita	0.002	0.60	0.91
Total molluscs	0.004	1.20	
Nondominant species	0.003	0.90	75.00
Dominant species	0.001	0.30	25.00
Ilyanassa obsoleta			
Total for waterway	0.333		

The present findings show *Melampus* is widely distributed, but reaches the highest mean densities in the SAS. Values there exceeded 10^3 individuals per square meter (ind·m^{-2}), over 2 times those in SP and 5 times the DS levels. Although numerous in the study area, the relative importance of its biomass is reduced due to its rather small size, individuals being generally less than 10 mm in length (Fitzpatrick 1975).

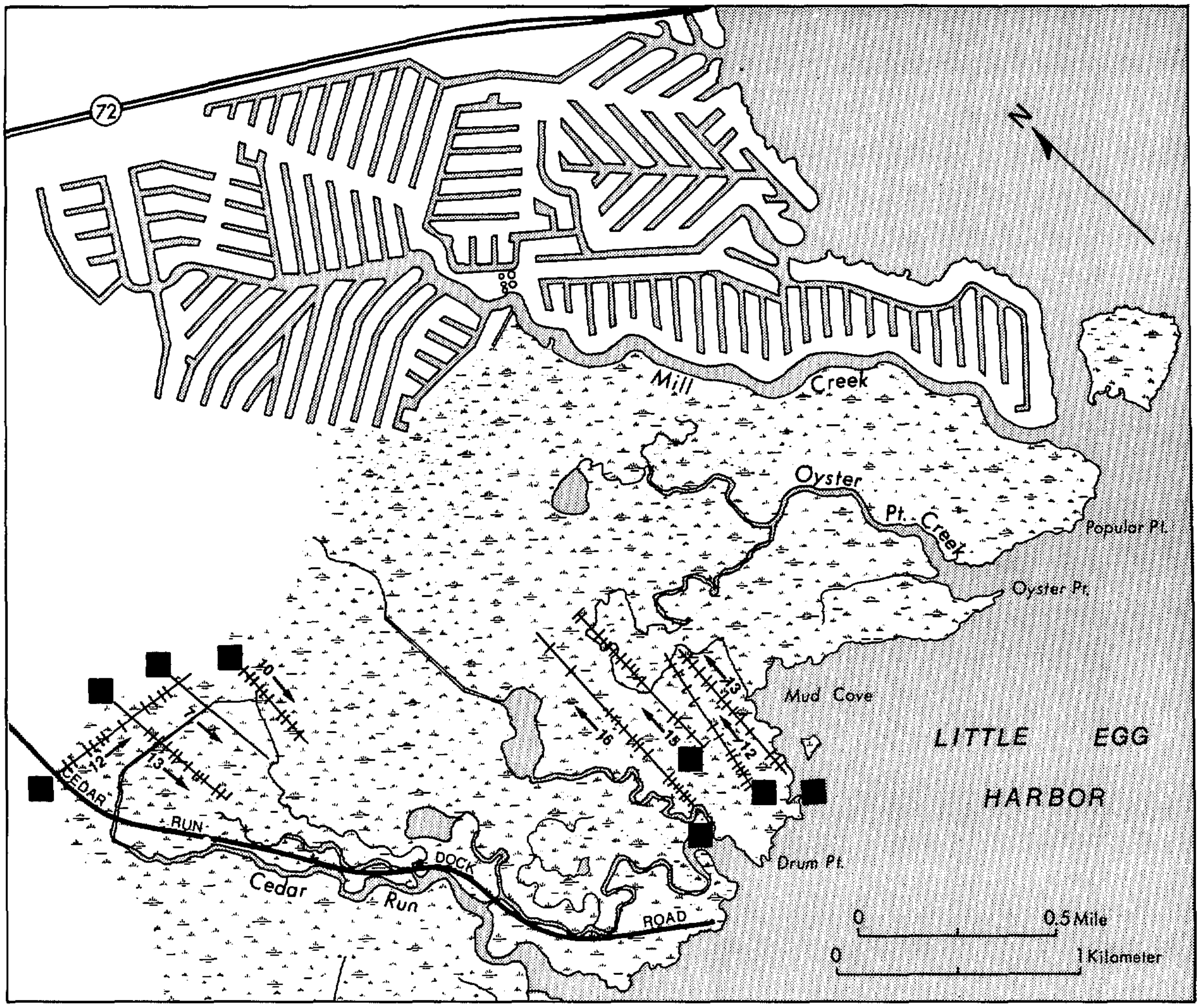


Fig. 57. Marsh surface invertebrate sampling plots.

The Manahawkin densities are high compared to other recent findings. The investigation of Ferrigno et al. (1969) on several salt marshes of southern New Jersey also described optimum production of *Melampus* in the SAS zone, although at a lower level (468.23 ind$\cdot$m^{-2}). Results for other vegetation types were as follows: SAT (20.53 ind$\cdot$m^{-2}), SP (2.36 ind$\cdot$m^{-2}), and *P. australis* (zero).

Isopods and orchestrid amphipods are both commonly associated with the base of *Spartina* culms and mats of decaying grass (Reimold and Queen 1974; Teal and Teal 1969), and are probably important agents in the fragmentation process of the detrital pathway (Day et al. 1973; Fenchel 1970). A significant grazing effect on edaphic algal mats of the Great Sippiwissett marsh, Massachusetts, was also demonstrated for the gammaridean amphipod, *Talorchestia longicornis* (Brenner et al. 1976).

The isopod, *Philoscia vittata*, and the amphipod, *Orchestia grillus*, together accounted for almost 20% of the total Manahawkin marsh population. Peak densities of both species occurred in stands of SP and along mosquito ditches (MDSP): *Orchestia* (SP = 207.6 ind$\cdot$m^{-2}, MDSP = 87.5 ind$\cdot$m^{-2}), *Philoscia* (SP = 319.2 ind$\cdot$m^{-2}, MSDP = 418.5 ind$\cdot$m^{-2}). Reduced populations were typical of the low marsh.

Table 56. Mean density per square meter of invertebrates in different vegetation types in August 1974. Parentheses enclose values equal to 1 SD.

Vegetation type	*Modiolus demissus*	*Melampus bidentatus*	*Uca pugnax*
SAT	84.6 (59.1)	183.4 (239.1)	192.2 (76.2)
SAS	4.0 (8.9)	1,036.6 (771.1)	7.2 (17.0)
SP	0.3 (1.8)	467.9 (286.0)	0.6 (2.4)
DS		179.5 (151.7)	1.7 (5.3)
I. frutescens		211.7 (150.6)	21.2 (42.5)
P. virgatum			
P. australis		139.0 (130.0)	
S. olneyi			
Ditches	21.0 (25.5)	376.5 (303.9)	39.5 (34.3)
Fill			
Estimated total number of organisms for entire marsh ($x10^3$)	22,478 (5,196)	4,128,435 (434,932)	47,013 (9,965)

Table 56. Continued.

Vegetation type	Ants	True bugs	Crickets
SAT			
SAS		0.4 (2.3)	
SP			2.8 (7.7)
DS		3.4 (10.7)	
I. frutescens	5.5 (11.0)	12.7 (25.5)	
P. virgatum		21.0	
P. australis			
S. olneyi			
Ditches		3.5 (7.0)	16.5 (33.0)
Fill	29.5 (16.2)		
Estimated total number of organisms for entire marsh ($x10^3$)	1,462 (723)	3,362 (2,024)	4,422 (2,291)

Table 56. Continued.

Vegetation type	Grasshoppers	Leaf-hoppers	*Philoscia vittata*
SAT		29.2 (35.0)	3.8 (8.6)
SAS	0.5 (2.3)	94.8 (75.0)	68.4 (125.0)
SP	3.4 (11.5)	151.8 (130.6)	319.2 (207.0)
DS		134.0 (126.9)	64.8 (78.2)
I. frutescens		17.7 (35.5)	126.7 (100.3)
P. virgatum		53.0	
P. australis		6.0 (10.3)	
S. olneyi		32.5 (45.9)	
Ditches		174.0 (37.5)	418.5 (345.7)
Fill			93.0 (67.8)
Estimated total number of organisms for entire marsh ($x10^3$)	6,674 (3,572)	547,557 (56,134)	709,325 (91,596)

Table 56. Continued.

Vegetation type	*Orchestia grillus*	Spiders	Total number
SAT	34.8 (54.9)	21.7 (32.9)	52,739 (6,641)
SAS	53.9 (80.3)	47.5 (40.4)	4,302,793 (437,481)
SP	207.6 (217.8)	121.1 (78.0)	1,791,858 (126,836)
DS	22.0 (42.1)	99.0 (96.3)	46,332 (6,901)
I. frutescens		297.0 (309.4)	81,854 (21,495)
P. virgatum		90.0	995 (752)
P. australis		46.0 (32.5)	6,723 (2,734)
S. olneyi		131.5 (17.6)	1,991 (423)
Ditches	87.5 (108.0)	141.5 (85.9)	38,799 (7,362)
Fill		19.5 (27.5)	3,908 (1,461)
Estimated total number of organisms for entire marsh ($x10^3$)	476,477 (76,759)	380,787 (36,718)	6,327,992 (456,175)

The leaf-hoppers were abundant in high marsh areas, reaching peak densities in the vegetational complex associated with mosquito ditches (174.0 $ind \cdot m^{-2}$) and in stands of SP (151.8 $ind \cdot m^{-2}$) and DS (134.0 $ind \cdot m^{-2}$). These grazing homopterans, which feed on plant sap with piercing and sucking mouthparts, ranked third in total abundance, and contributed approximately 9% of the invertebrate fauna.

The spiders were also well represented in the study area and were observed in each of the 10 cover types investigated. They were especially abundant within stands of *I. frutescens* (297.0 $ind \cdot m^{-2}$) and other regions of high marsh including SP, *S. olneyi*, and mosquito ditches. They were less frequent and in smaller numbers within SAT and SAS. These terrestrial invaders of the marsh have been shown to be the major arthropod predators on the Sapelo marshes and utilize organisms in both the grazing and detrital trophic pathways as energy sources (Marples 1966).

The fiddler crab, *Uca pugnax*, is characteristically found in vegetated areas of Atlantic coast salt marshes where a muddy substratum is present (Teal 1958). Its feeding behavior consists of picking up mud from the substratum, sorting the material with the feather-like hairs present on the second maxillipeds, and depositing rejected matter (consisting mainly of the larger particles) back onto the marsh surface. The organic matter consumed may consist of detritus, bacteria, microflora, nematodes, or animal remains (Coward et al. 1970; Teal 1962; Teal and Teal 1969). Dense populations of *Uca* may have a considerable effect on the marsh surface community as a result of their continual reworking and processing of the substrate and by the deposition of fecal pellets which may contain about one third more calories than the original mud.

The greatest abundance of *Uca pugnax* in the Manahawkin marsh was noted in the SAT (192.2 $ind \cdot m^{-2}$). Numbers declined with higher elevation (SAS = 7.2, SP = 0.6, and DS = 1.7 $ind \cdot m^{-2}$). Ferrigno et al. (1969) also found maximum utilization of the SAT in several southern New Jersey marshes. This species together with other detritus-eating decapods possesses a very unrestricted diet and assimilates an average of 206 $kcal \cdot m^{-2} \cdot year^{-1}$ (Teal 1962).

The ribbed mussel, *Modiolus demissus*, is most prevalent in the upper intertidal zone distributed among the *Spartina alterniflora* roots. It is a filter feeding lamellibranch and likely subsists on suspended detritus, phytoplankton, and zooplankton.

The highest population levels at the Manahawkin marsh were associated with SAT (84.6 $ind \cdot m^{-2}$) and the vegetation bordering mosquito ditches (21.0 $ind \cdot m^{-2}$). The density quickly declined with higher marsh elevation. These values are much higher than those reported for several southern New Jersey marshes (Ferrigno et al. 1969): SAT = 4.68, SAS = 0.21, and SP = 0.07 $ind \cdot m^{-2}$.

Kuenzler's (1961 a, b) work remains the most comprehensive study of the structure and function of *Modiolus* populations. Total annual energy flow was estimated at 56 $kcal \cdot m^{-2} \cdot year^{-1}$, similar in magnitude to estimates for nematode, insect, crab, bird, and mammal populations. However, this species is probably more important as a biogeochemical agent in the marsh-estuarine complex than as an energy consumer. This results from its ability to remove large quantities of particulate phosphorus from the water overlying the marsh (5.4 mg $P \cdot m^{-2} \cdot day^{-1}$) and to regenerate and deposit phosphate in the form of feces and pseudofeces which are then available to the deposit-feeders (Kuenzler 1961b).

The remaining invertebrates studied, including ants, true bugs, crickets, and grasshoppers, were either scarce or entirely absent from the marsh cover types during August.

The relative importance of the 10 vegetation cover types in terms of their ability to support invertebrate populations depends directly on the population densities cited above and also reflects the areal coverage of each type within the Manahawkin marsh. Whereas SAS, SP, and the mosquito ditch areas had the largest populations on a unit area basis, 96% of the total marsh surface population was present in the SAS and SP zones as a result of their extensive cover. Invertebrates were scarce in *Phragmites australis, Scirpus olneyi, Panicum virgatum,* and in the incompletely lagooned area at Popular Point. The importance of these regions was further minimized by their minimal areal contribution.

The derived population estimates are only partially indicative of the summer aspect of the marsh fauna. Marked seasonal fluctuations are expected in species composition and succesion. Most species of the Orthoptera, Coleoptera, Hemiptera, and Diptera, for example, would probably not occur during the winter aspect (Davis and Gray 1966).

The food habits of some of the major marsh surface invertebrates, including those involved in this study, are listed in Table 57 (after Davis and Gray 1966). Carnivores which are supported by the herbivorous fauna include predatory insects, spiders, marsh wrens, and sparrows. The mud-dwelling deposit and suspension feeders are preyed upon by crabs, raccoons, wading and shore birds, and birds of the marsh proper (Teal 1962). *Melampus*, for example, is fed upon by wintering black ducks, song and swamp sparrows, red-winged blackbirds, willets, killifish, and the larvae of the green-head fly (Hauseman 1932; Ferrigno et al. 1969; Fitzpatrick 1975). According to Ferrigno et al. (1969), *Uca* accounts for approximately 90% of the clapper rail's diet in New Jersey.

The direct and indirect effects of the invertebrates on the marsh vegetation, and vice versa, have been summarized by Kraeuter and Wolf (1974). As a result of the high insect diversity demonstrated by Davis and Gray (1966) and the observations by Marples (1966) concerning other direct herbivores in addition to *Orchelimum* and *Prokelisia*, they suggest an annual consumption by insects of about 10% of the *Spartina* net production. This is only slightly higher than those reported for the combined utilization of *Orchelimum* and *Prokelisia* by Teal (1962) (4.6%) and Smalley (1959) (7%).

FOOD WEB: FISH COMMUNITY

The fish community in the study area includes a wide range of species which differ in behavior, habitat, and trophic level. Some species utilize the estuary as a nursery ground. Many are present because of the food resources available. Studies on similar systems have indicated the food webs present are often complex. Members of the fish community occupy roles as herbivores, carnivores, or omnivores, and can have very diverse diets.

The purpose of the fish community study is: (1) to identify the fish community present and (2) to describe the food resources being used.

Table 57. Food habits of the major marsh surface invertebrates.*

Feeding habits	Food	Invertebrates
Herbivorous	Plant tissues	Grasshoppers, ants, crickets
	Plant sap	Leaf-hoppers, Hemiptera
	Plant secretions	Diptera
Carnivorous	Animal tissues	Spiders, dragonflies, malachiid-clerid-coccinellid beetles
	Animal body fluids	Spiders, midges, culicid-asilid-sciomyzid flies
Omnivorous (Detritus)	Aufwuch and/or deposit feeders	*Melampus bidentatus*, *Uca pugnax*, Amphipods-isopods, *Littorina irrorata*, ephydrid-dolichopodid flies
	Suspension feeders	*Modiolus demissus*
Parasitic	Plant tissues and sap	Dipterous larvae
	Animal tissues and body fluids	Larvae of parasitic Hymenoptera

* Source: Davis and Gray 1966;
Day et al. 1973;
Marples 1966;
Teal 1962;
Teal and Teal 1969.

Methods

Sampling was conducted monthly during study years I and II except when prohibited by ice or equipment failure. The stations sampled are indicated in Figures 58 and 59. Gill nets (G), seines (S), and trawls (T) were used to collect the fish samples. There were 8 gill net, 18 seine, and 21 trawl stations. Each catch was counted by species, and all fish were weighed and then measured. When the catch size made this impractical, subsamples were processed instead. The purpose was to determine the fish species present.

The feeding habits of the fish community were investigated by stomach contents examination. Samples were selected from the catches made with the gill net, seine, or trawl. In addition, a hook and line sampling augmented the normal collection methods.

All types of waterways were sampled; however, the major emphasis was on the back bay system.

Additional information on methods is available in McClain et al. (1976) and Festa (1978).

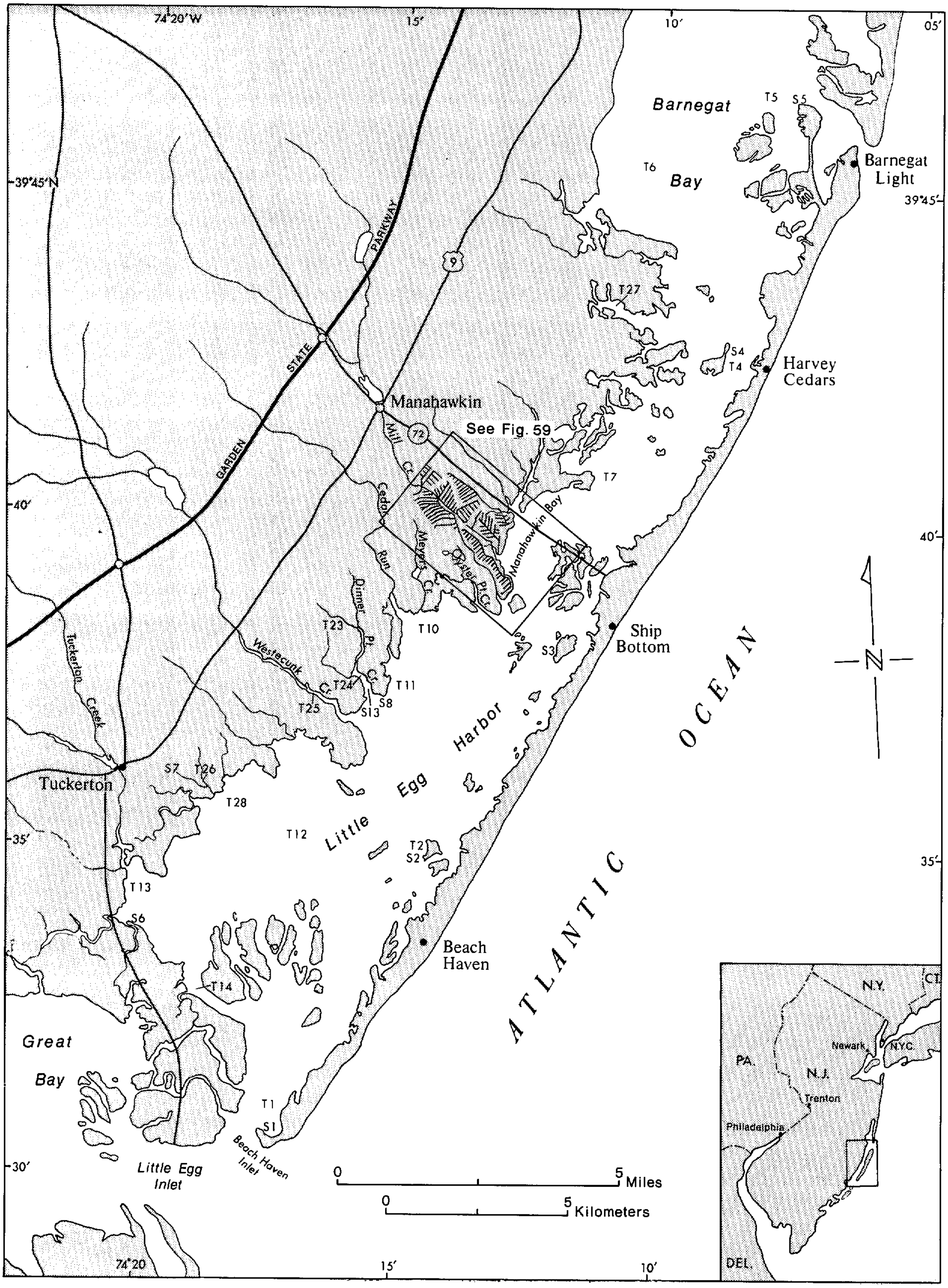


Fig. 58. Location of fish sampling stations in the creeks and bay.

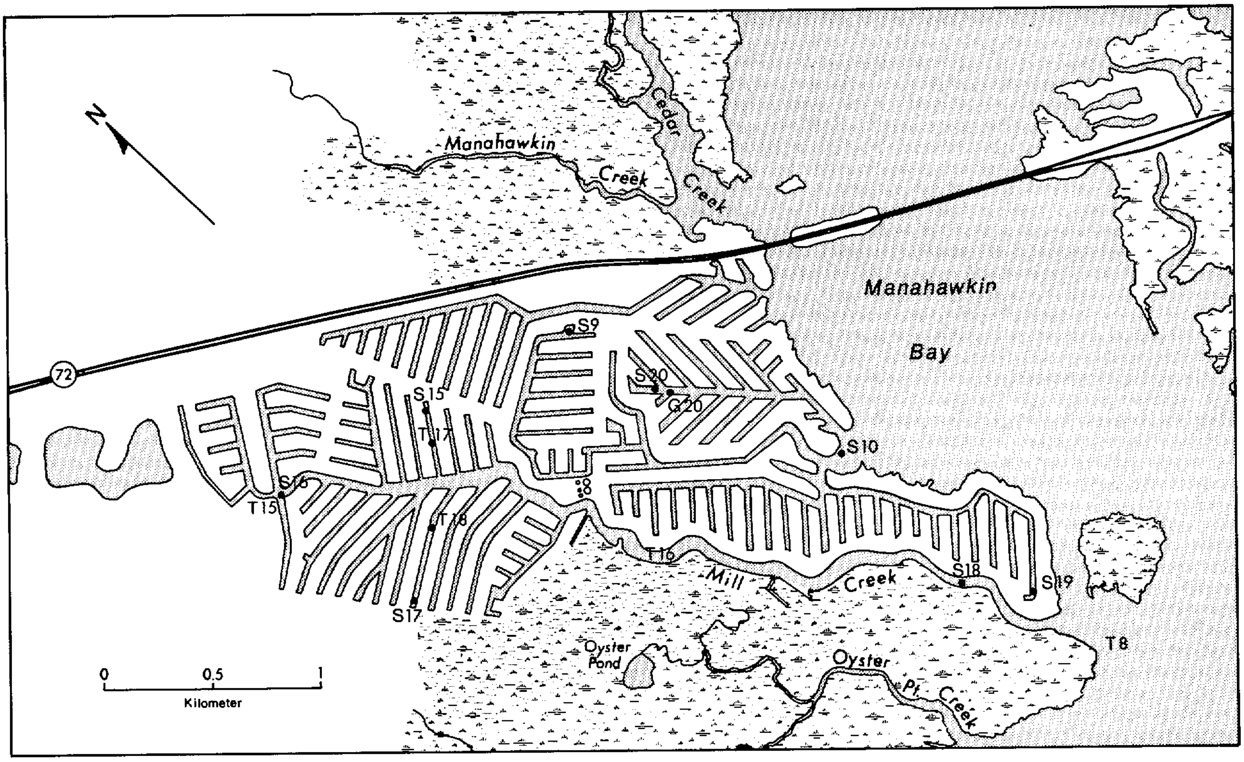


Fig. 59. Location of fish sampling stations in Village Harbour.

Results and Discussion

COMMUNITY DESCRIPTION -- There were 66 species of finfish collected during the study. A listing of the species is available in Table 7 of Appendix B. Over 35,000 specimens were taken and the large majority of these were forage species. The Atlantic silverside, bay anchovy, fourspine stickleback, mummichog, and tidewater silverside accounted for over 29,100 specimens alone. Table 58 breaks down the catch by species and collection method and provides ranking information.

The bay anchovy comprised 27% of the total catch and was captured by seine and trawl in roughly equal amounts. Over 9,700 fish were collected, which was the most for any species. They were most abundant during the summer and were widely distributed.

The Atlantic silverside was the second most abundant fish collected with 26% of the total catch. Nearly all were captured in the seine (98%) and summer was again the peak population period based on the catch data (57%). Widely distributed, it was taken throughout the year.

The third ranking fish was the fourspine stickleback. Accounting for 14% of the total catch, this species was taken mostly by seine (77%). Like the others, it was widely distributed. Very abundant during the summer (48% of the species catch), it was present year-round.

These three species together make up 67% of the total catch. The mummichog and tidewater silverside account for another 7 and 6%, respectively. No other species represented more than 5% of the total catch.

Table 58. Number of each species by gear type, overall rank, and percent of total catch.

Species	Number				Rank	Percent
	Seine	Trawl	Gill net	Total		of catch
Alewife	4	6	27	37	30	*
American eel	29	22		51	27	*
American sand lance	77	3		80	24	*
American shad		2		2	56	*
Atlantic croaker		3		3	54	*
Atlantic menhaden	172	316	310	798	7	2
Atlantic needlefish	103			103	23	*
Atlantic silverside	9,135	188	7	9,330	2	26
Banded killifish	544	1		545	8	2
Bay anchovy	5,004	4,730		9,734	1	27
Black sea bass		22	1	23	32	*
Blueback herring	120	85	5	210	15	*
Bluefish	58	17	78	153	17	*
Blue runner		1		1	62	*
Bluespotted cornetfish		1		1	62	*
Brown bullhead		9		9	40	*
Bluefish	1	1		2	56	*
Crevalle jack	65	5		70	26	*
Cunner		4		4	50	*
Fourspine stickleback	4,044	1,180		5,224	3	14
Golden shiner		3	1	4	50	*
Gray snapper	7	2		9	40	*
Hogchoker	19	87		106	22	*
Inshore lizardfish	2			2	56	*
Lined seahorse		10		10	38	*
Lookdown		4		4	50	*
Mojarra sp.	7			7	43	*
Mummichog	2,264	331	4	2,599	4	7
Naked goby	148	72		220	14	*
Northern kingfish	3	2	1	6	44	*
Northern pipefish	166	137		303	11	1
Northern puffer	2	4		6	44	*
Northern sea robin	4	5	1	10	38	*
Northern sennet	73			73	25	*
Oyster toadfish	61	198	5	264	13	1
Permit	2		1	3	54	*
Pinfish	14	3		17	36	*
Planehead filefish	16	4		20	33	*
Pollock		2		2	56	*
Pumpkinseed		2		2	56	*

Table 58. Continued.

Species	Number: Seine	Trawl	Gill net	Total	Rank	Percent of catch
Rainwater killifish	136			136	20	*
Red hake		4		4	50	*
Redfin pickerel		1		1	62	*
Scup		5		5	49	*
Sheepshead minnow	154	1		155	16	*
Silver perch	324	164	4	492	9	1
Smallmouth flounder	1	5		6	44	*
Smooth dogfish			18	18	35	*
Spot	530	1,074	66	1,670	6	5
Spotted hake	1	29		30	31	*
Striped anchovy	2	4		6	44	*
Striped bass			1	1	62	*
Striped burrfish	7	4	1	12	37	*
Striped killifish	153			153	17	*
Striped mullet	6			6	44	*
Striped sea robin	1	1		2	56	*
Summer flounder	5	35	5	45	29	*
Tautog	17	27	2	46	28	*
Threespine stickleback	17	2		19	34	*
Tidewater silverside	1,953	262		2,215	5	6
Weakfish	3	133	3	139	19	*
White mullet	130			130	21	*
White perch	27	193	73	293	12	1
Windowpane		8		8	42	*
Winter flounder	49	293		342	10	1
Herring sp.	1					*
Notropus sp.	1					*
Total	25,662	9,707	614	35,983		
Total %	71	27	2	100		

* Less than 1%

The recreationally important fish include the bluefish, winter flounder, weakfish, white perch, tautog, and summer flounder. These fish each accounted for 1% or less of the total catch.

Seasonal occurrence data for the collected species is available in Table 59.

DIET COMPONENTS OF THE FISH COMMUNITY -- The food web observed is very complex. There were 142 taxa identified in the stomachs of 55 species of fish. Food resources were often shared by a number of these species, and food habits varied

Table 59. Seasonal occurrence of finfish in the Manahawkin Bay - Little Egg Harbor system.

Species	Season			
	Winter	Spring	Summer	Fall
Alewife	x	x	x	
American eel	x	x	x	x
American sand lance	x	x		x
American shad		x		x
Atlantic croaker			x	
Atlantic menhaden	x	x	x	x
Atlantic needlefish		x	x	x
Atlantic silverside	x	x	x	x
Banded killifish	x	x	x	x
Bay anchovy				
Black sea bass		x	x	x
Blueback herring	x	x	x	x
Bluefish		x	x	x
Blue runner				x
Bluespotted cornetfish			x	
Brown bullhead		x	x	
Butterfish			x	
Crevalle jack			x	
Cunner			x	
Fourspine stickleback	x	x	x	x
Golden shiner		x	x	
Gray snapper		x	x	x
Hogchoker		x	x	x
Inshore lizardfish			x	
Lined seahorse		x	x	
Lookdown			x	x
Mojarra sp.			x	
Mummichog	x	x	x	x
Naked goby		x	x	x
Northern kingfish			x	x
Northern pipefish	x	x	x	x
Northern puffer			x	
Northern sea robin		x	x	x
Northern sennet			x	x
Oyster toadfish		x	x	x
Permit			x	
Pinfish			x	
Planehead filefish			x	x
Pollock		x		
Pumpkinseed		x		

Table 59. Continued.

Species	Season Winter	Spring	Summer	Fall
Rainwater killifish	x	x	x	x
Red hake		x		
Redfin pickerel			x	
Scup			x	x
Sheepshead minnow	x	x	x	x
Silver perch			x	x
Smallmouth flounder				x
Smooth dogfish			x	
Spot		x	x	x
Spotted hake	x	x	x	
Striped anchovy			x	x
Striped bass	x			
Striped burrfish			x	
Striped killifish	x	x	x	x
Striped mullet	x	x		x
Striped sea robin		x	x	
Summer flounder		x	x	x
Tautog		x	x	x
Threespine stickleback	x	x		
Tidewater silverside	x	x	x	x
Weakfish			x	x
White mullet		x	x	x
White perch	x	x	x	x
Windowpane		x	x	x
Winter flounder	x	x	x	x

between size groups of the same species. The diet of a particular species is frequently diverse. Such complexity allows the available resources to support a broad spectrum of species and their different life stages.

Although the major pathway for plant material is through the invertebrates, certain species utilize algae and vascular plant detritus as a food resource. The major portion of the Atlantic menhaden diet was algal material. Other species such as striped mullet, white mullet, planehead filefish, and banded killifish apparently grazed large amounts of algae off the substrate. The proportion of algae found in the stomachs of these fish ranged from 15.7 to at least 39.7%. Vascular plant detritus was found in 35 fish species. While some fish ingested the detritus coincidental to ingesting another type of food material, in others it was probably used as an energy source. These species would include the oyster toadfish, banded killifish, smooth dogfish, white mullet, and sheepshead minnow. In the oyster toadfish, plant detritus constituted 11% of the volume of the stomachs examined and occurred in 63.7% of the white mullet specimens.

Based on the findings of Haskin and Ray (1977), the 10 most numerous macrobenthic forms are *Ampelisca abdita, Streblospio benedicti, Hypaniola grayi, Leptocheirus plumulosus, Nereis succinea, Heteromastus filiformis,* Oligochaeta, *Nereis* spp., *Cyathura polita,* and *Scoloplos robustus.* The use of these species in fish diets varies considerably.

Ampelisca is a very important fish food directly consumed by at least seven commerically or recreationally valuable fish species. It is of particular importance to young winter flounder (14.4% of the stomach volume examined) and to a lesser extent young weakfish (4.8% of the stomach value). *Ampelisca* also is consumed by the forage fish, especially Atlantic silversides, which in turn are utilized by the piscivorous fish. Figure 60 details the consumption of *Ampelisca.*

Leptocheirus was utilized year-round and was associated with the lower salinity regime in Mill Creek. It formed a major component of the 7 - 12 cm (2.8 - 4.7 in) white perch (35.4% of the stomach contents), although its use declined in the older fish of this species. The banded killifish (16.1% of the stomach volume) and blueback herring (19.7% of the stomach volume) were also important consumers.

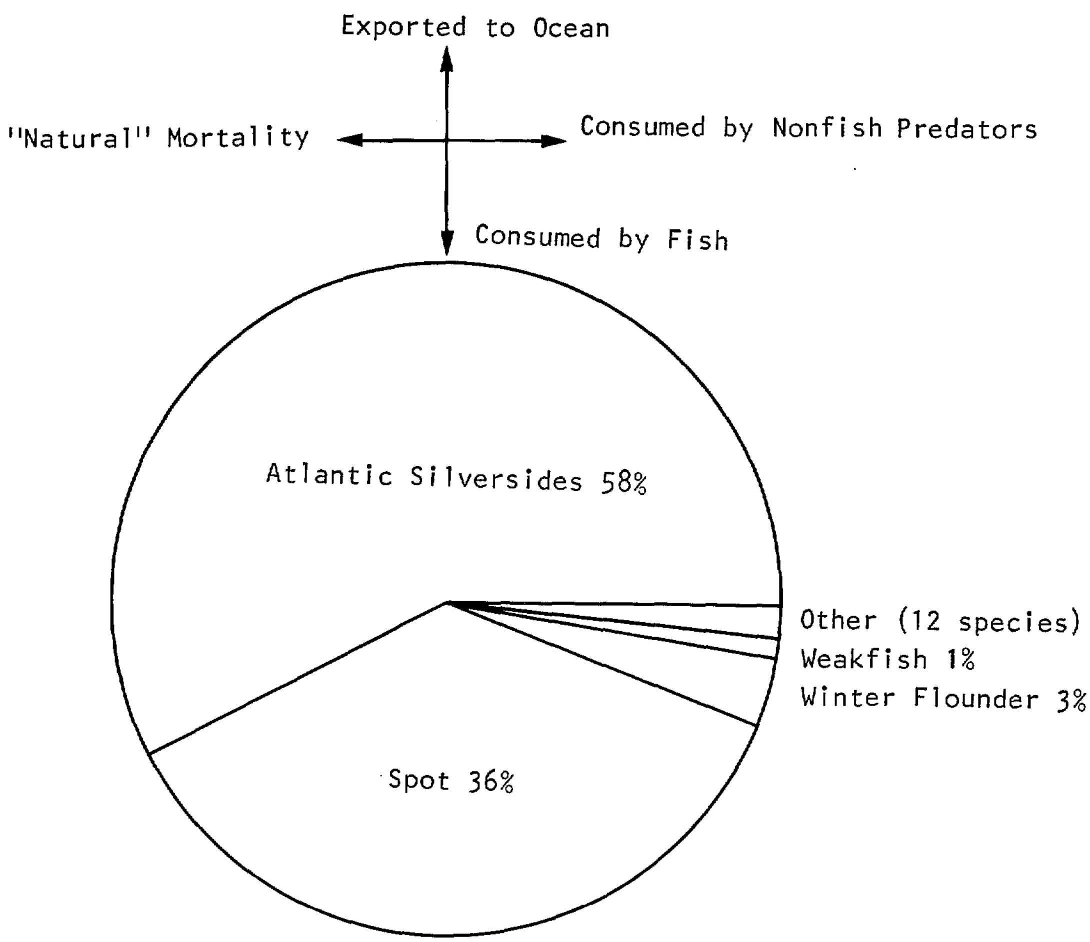


Fig. 60. Fate of *Ampelisca abdita* in the study area.

Nereis is also an important component in the fish food web and is one of the main polychaete taxa consumed. Forming a significant portion of the diets of 6 - 10 cm (2.4 - 3.9 in) bluefish (17.4% of the volume examined), 11 - 13 cm (4.3 - 5.1 in) oyster toadfish (20.1% of the stomach volume), and 12 - 21 cm (4.7 - 8.3 in) winter flounder (12.4% of the volume), it is also utilized by the Atlantic silversides and bay anchovy, which are the leading predators on *Nereis*. A total of 15 species consumed *Nereis*.

The Capitellidae which include *Heteromastus* were not as widely consumed; however, they were approximately 12% of the diet of young winter flounder. This would be for size groups 3 - 11 cm (1.2 - 4.3 in) and 12 - 21 cm (4.7 - 8.3 in).

The other macrobenthic invertebrates were not used to the same extent as these. *Hypaniola* was eaten by pumpkinseed, spot, striped killifish, white perch, and winter flounder in limited quantities. *Cyathura* was eaten by eight species of fish and was most important in the diet of the banded killifish (10.5% of the stomach contents). *Streblospio* and *Scoloplos* were limited diet items in the winter flounder. The Oligochaeta did not comprise a significant portion of the fish diets, except possibly for spot.

Based on the data for these 10 macrobenthic species alone, a considerable portion of the invertebrate standing crop passes into the food pathways of the fish community. However, there are other species which serve as important food resources.

Probably the most important group are the mysid shrimp, and in particular *Neomysis americana*. A diet component of 24 fish species, they account for over 20% of the stomach content volume in alewife, bay anchovy, crevalle jack, threespine stickleback, fourspine stickleback, pipefish, silver perch, 4 - 7 cm (1.6 - 2.8 in) striped sea robin, 14 - 37 cm (5.5 - 14.6 in) white perch, and 5 - 17 cm (2.0 - 6.7 in) weakfish. They comprise over 10% of the volume in seven other species and are considered a prime food for the young of summer flounder, alewife, weakfish, and winter flounder. The resident sport fish, the white perch, is dependent on the mysids for over 34% of its diet volume. Forage species which support the piscivorous fish populations also consume the mysids in sizeable amounts. The utilization of the *Neomysis* is outlined in Figure 61.

Crangon septemspinosa is the most widely utilized individual species. This Caridean shrimp is a diet component of 26 fish species. It is the dominant food resource for northern sea robin, northern kingfish, silver perch, spotted hake, 6 - 24 cm (2.4 - 9.4 in) summer flounder, large white perch, and windowpane flounder. Atlantic silverside, sea bass, crevalle jack, seahorse, mummichog, red hake, and weakfish also consume *Crangon* (Figure 62).

The prefered diet of the zooplankton feeding fish is calanoid copepods. Found in 24 species of fish, these copepods are a major portion of the diets of sand lance, larger alewife, bay anchovy, and blueback herring.

The piscivorous fish largely fed on anchovies, silversides (2 species), killifish (*Fundulus* spp.), and fourspine stickleback, the species most abundant in the study area. Some of food webs involving the more recreationally or commercially important species are shown in Figures 63, 64, and 65.

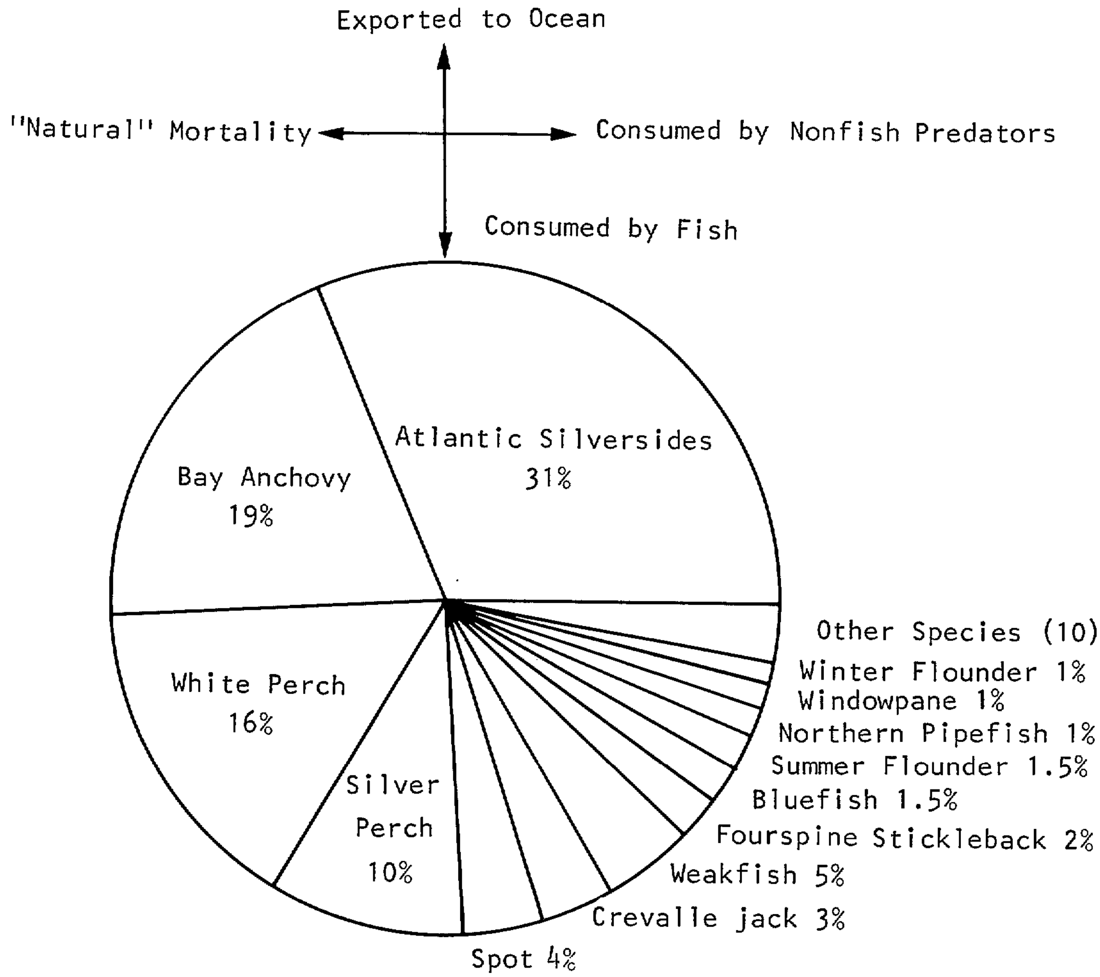


Fig. 61. Fate of *Neomysis americana* in the study area.

Not all the sport fish species are piscivorous. The tautog feeds to a large extent on isopods when small (63.3% of the diet volume) and Brachyuran crabs (87% of stomach volume) in its adult forms. Crabs are also a significant portion of the black sea bass diet (55.2%). Polychaetes and gammerids comprise a large part of the diet of spot. Polychaetes (35.3%), clam siphons (14.1%), and Caridean shrimp (19.5%) form the basis of the winter flounder diet. As mentioned before, the white perch feed to a large extent on *Crangon* (30.2%) and *Neomysis* (34.3%).

The connections then between the fish and the lower trophic levels are many and diverse (Figure 66) (Table 60). The complexity and the amounts of biomass transfered emphasize the importance of the communities, such as the macrobenthic and epibenthic invertebrates, which channel energy and nutrients from the primary producer level to the upper consumer levels.

FOOD WEB: MAMMALIAN COMMUNITY

Mammal studies were not undertaken with the purpose of determining their trophic relationships. However, a short discussion based primarily on the

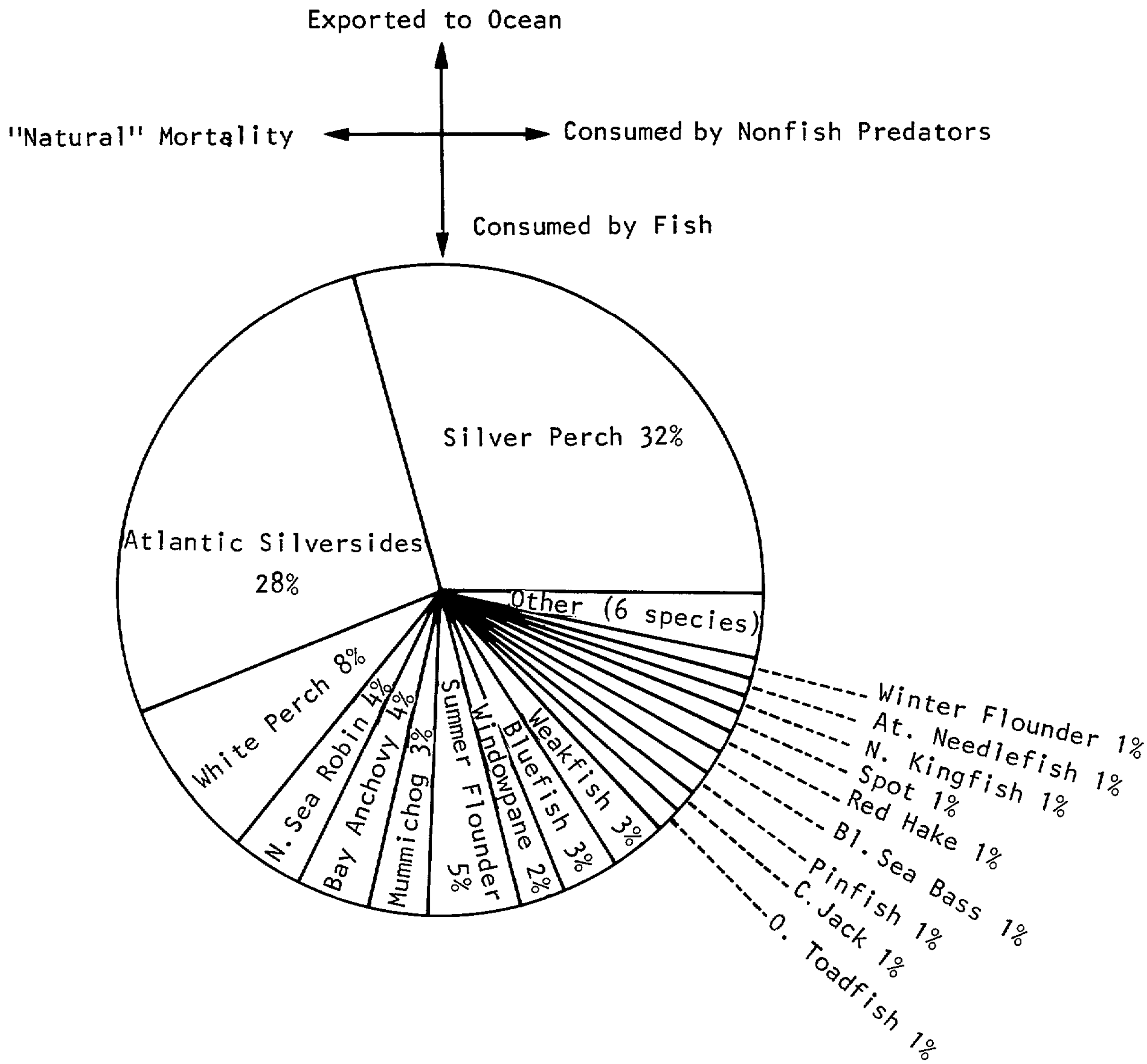


Fig. 62. Fate of *Crangon septemspinosa* in the study area.

literature is included to provide the reader with a sense of the mammal's and in particular the rodent's role in the food web. Table 8 of Appendix B lists typical mammalian species for the study area.

The five rodent species which were trapped during this study (Bosenberg 1977) are widely distributed throughout North America, but differences in their relative abundance and distribution occur within limited geographical areas, such as in a salt marsh. Variations in topographical relief and those resulting from human alteration of the marsh are accompanied by zones of emergent vegetation which are preferentially utilized by these populations.

Muskrats, for example, appeared to favor *Scirpus*-dominated stands near the upland border. Meadow vole densities were highest within *Distichlis* and in the vegetational complexes associated with lagoon embankments and mosquito ditch spoil

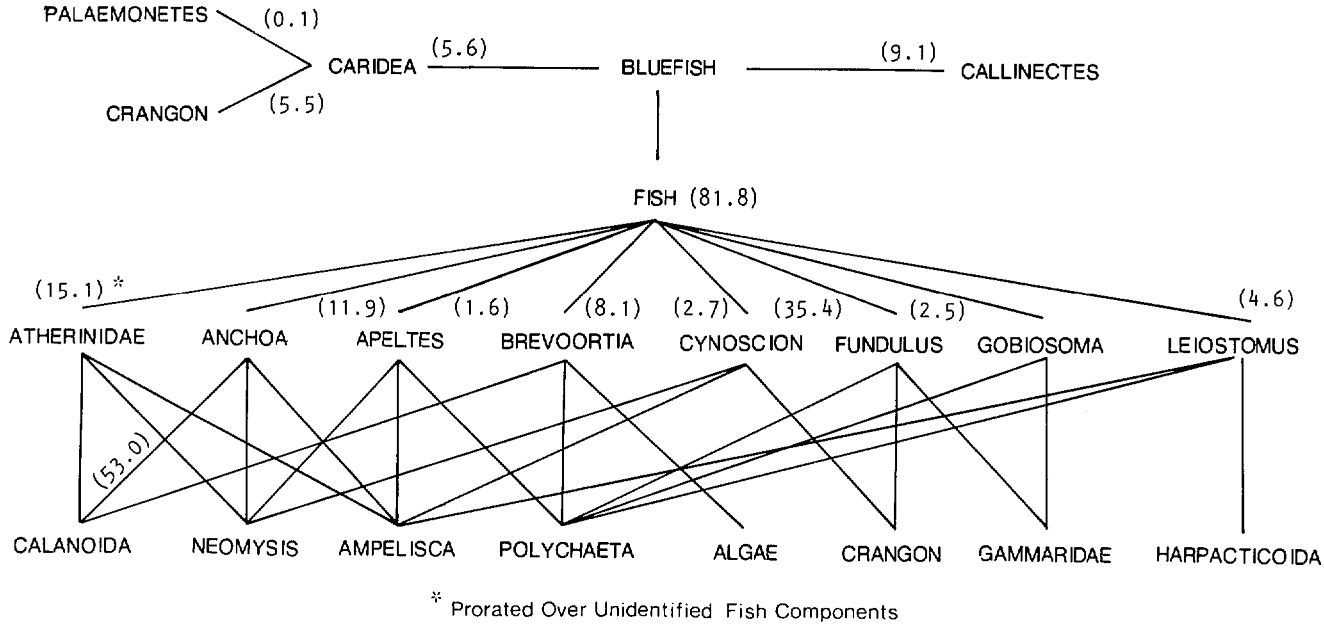


Fig. 63. A portion of the food web involving 11-20 cm bluefish (% stomach contents in parentheses).

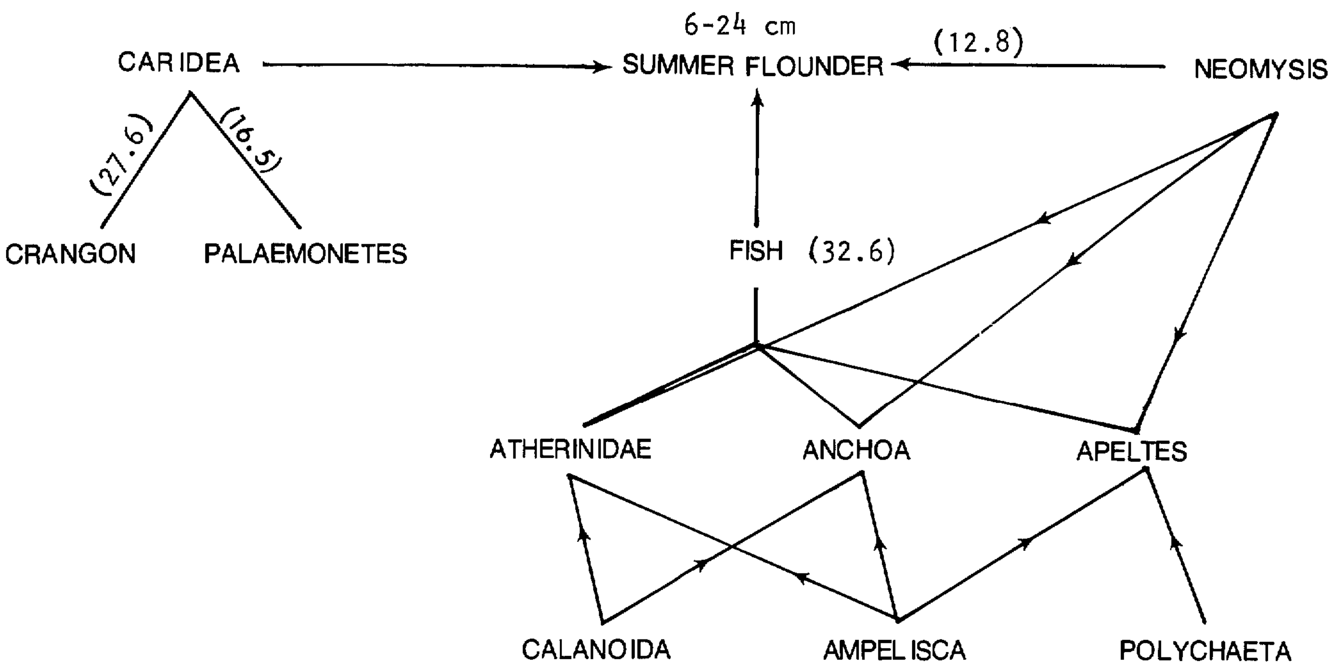


Fig. 64. A portion of the food web involving 6-24 cm summer flounder (% stomach contents in parentheses).

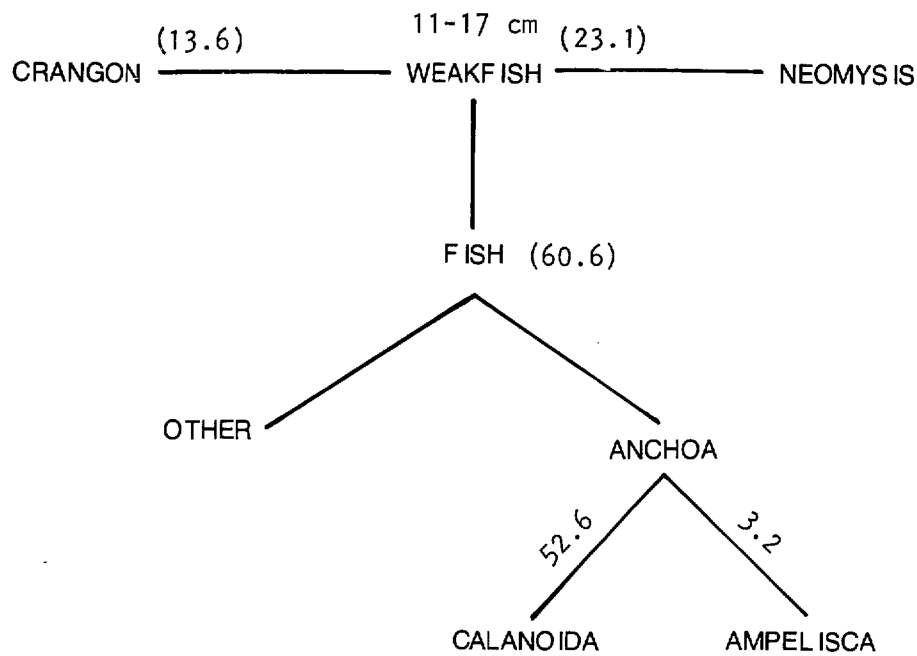


Fig. 65. A portion of the food web involving 11-17 cm weakfish (% stomach contents in parentheses).

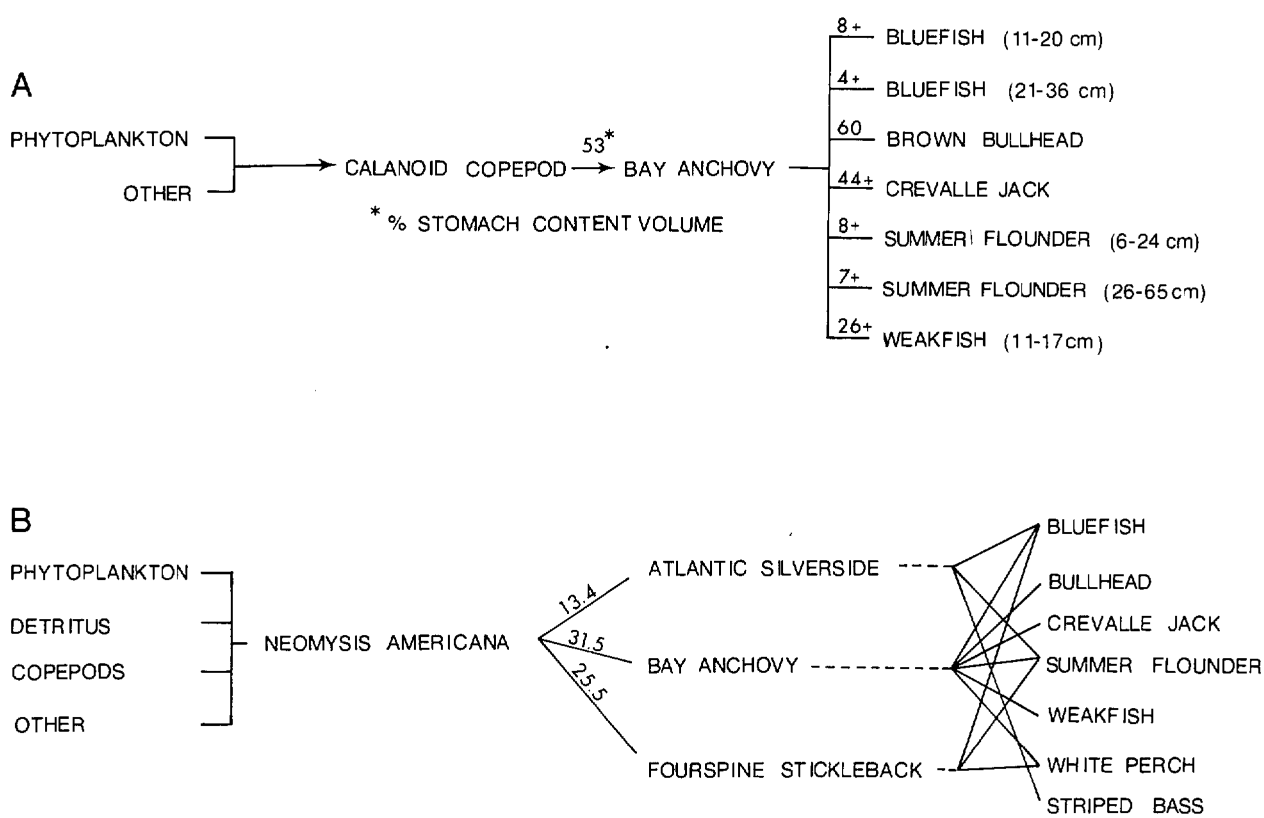


Fig. 66. Some simplified trophic relationships observed in the study area.

Table 60. Fish forage taxa of greater importance in the Little Egg Harbor estuary.

Forage taxon	High importance in the diet of:
Plant material: Algae and plant detritus	menhaden , mullet, filefish, sheepshead minnow, mummichog
Gastropoda	permit, northern puffer
Mercenaria mercenaria (siphons)	winter flounder
Phyllodocidae	naked goby
Nereis spp.	oyster toadfish, pumpkinseed, bluefish, winter flounder
Capitellidae	naked goby, winter flounder
Terebellidae	winter flounder
Insecta	Atlantic needlefish
Calanoida	alewife, American sand lance, bay anchovy, blueback herring, stickleback
Harpacticoida	spot
Cyathura polita	banded killifish
Idotea spp.	oyster toadfish, striped killifish, tautog, gray snapper
Ampelisca abdita	Atlantic silversides, cunner, winter flounder
Cymadusa compta	seahorse, pipefish
Corophiidae	filefish, white perch
Gammarus mucronatus	rainwater killifish
Elasmopus leavis	cunner, naked goby
Leptocheirus plumulosus	banded killifish, blueback herring, white perch
Neomysis americana	alewife, Atlantic silversides, bay anchovy, crevalle jack, stickleback, pipefish, silver perch, sea robin, summer flounder, white perch, weakfish
Palaemonetes vulgaris	alewife, bluefish, pinfish, silver perch, spotted hake, winter flounder
Crangon septemspinosa	kingfish, sea robin, pinfish, red hake, silver perch, spotted hake, summer flounder, white perch, weakfish, windowpane
Callinectes sapidus	American eel, smooth dogfish, striped burrfish
Neopanope texanna	tautog

Table 60. Continued.

Forage taxon	High importance in the diet of:
Rhithropanopeus harrisii	oyster toadfish
Fish eggs	Atlantic silversides, striped killifish, white perch
Silversides	Atlantic needlefish, bluefish, northern sennet
Anchovies	crevalle jack, weakfish
Stickleback	Atlantic needlefish
American sand lance	striped bass
Atlantic menhaden	bluefish, red hake
Spot	oyster toadfish
Killifish	bluefish, white perch

piles. On a larger scale, *Microtus* densities were higher in the incompletely lagooned section of the Manahawkin marsh than either the mosquito-ditched or natural areas.

Environmental factors which may be operating include the ability of the habitat to provide adequate refuge from tidal inundation and predation, nesting sites and material, utilizable water, and favored food items. Since the plant communities, with their distinctive structure and composition, are in large part a reflection of elevational differences, patterns of rodent distribution of the Manahawkin marshes are essentially topographically controlled (Shure 1970).

Consumption of the emergent vegetation is probably only significant for the muskrat and the meadow vole, both of which are primarily herbivores (Day et al. 1973; Walker 1975; Burt and Grossenheider 1976). Muskrats chiefly feed upon the roots and stems of freshwater and brackish water plants, such as *Typha* and *Scirpus*. Clams, frogs, mussels, fish, and crayfish are also eaten occasionally. The meadow vole feeds upon grasses, sedges, seeds, grains, roots, bark, and some insects. The meadow jumping mouse relies more heavily upon insects, especially the Coleoptera and lepidopterous larvae. Seeds, fruits, and some fungi are also consumed (Walker 1975).

Both the house mouse and Norway rat are omnivores whose diet consists of a wide range of edible items including human refuse, household articles, seeds, fleshy roots, leaves, stems, insects, and carrion when available (Walker 1975). According to Figley and Vandruff (1974), Norway rats, together with raccoons and fish crows, preyed heavily on the mallard nests located in their travel lanes along the impoundment dikes and spoil banks adjacent to Mill Creek.

The exposure of such small mammals as the voles, mice, and rats to avian predation may be considerable during exceptionally high tides, when vegetation cover is reduced and individuals become concentrated in the most elevated portions of their home ranges. Birds which have been observed to feed upon these rodents in the salt marshes near Tuckerton, New Jersey include the short-eared owl, marsh hawk, great blue heron, great black-backed gull, and the herring gull (Pokras and Pokras 1973). These investigators also found *Microtus* comprised a major portion of the diet of a barn owl in Absecon, based upon analysis of regurgitated pellets. Rats, birds, and other mammals were also consumed.

Based upon this feeding behavior and the relatively great abundance of *Microtus* in the Manahawkin marsh and other New Jersey salt marshes, this species is probably a major link between the emergent vegetation and the highest trophic levels of the salt marsh community.

FOOD WEB: AVIAN COMMUNITY

Although the role of the estuarine bird populations in the food web was beyond the scope of the project. Table 61 is enclosed to provide a limited view of the many pathways the birds are a part of. The birds utilize a variety of food types which are found on all the different trophic levels. They certainly are important as one of the higher carnivores in the food web. Table 9 of Appendix B lists species associated with the study area.

Table 61. Partial list of food items for some major components of the estuarine avifauna.* Percentages indicate the % by volume of gut contents or castings.

Species	Percent volume of gut contents or castings (%)	Food items
Fishing birds:		
Gulls (Herring, Laughing, Great black-backed)		Young birds, eggs, fish, crabs, molluscs, refuse, and carrion.
Terns (Common, Least, Forster's)		Small fish, eels, and insects.
Black skimmer		Small fish, shrimp, and other small crustaceans.
Double-crested cormorant		Mostly fish, some eels; also amphibians, crustaceans, aquatic insects, and plants.
Waterfowl:		
Canada goose		Shoots of grasses and sedges, berries, cultivated grains, aquatic plants, and seeds. Species include: *Ruppia maritima* (widgeon grass), *Eleocharis* (spike rush), *Najas* (naiads), *Salicornia* (glassworts), *Scirpus* (bulrushes), *Distichlis* (spike grass). Also insects, crustaceans, and molluscs.
Brant		Before 1932: *Zostera marina* (eelgrass) - 85%, *Ruppia* - 12%, algae - 1%, other plants - 2%, animals - trace. After 1932: *Zostera* - 9%, Algae (especially *Ulva lactuca*) - 64%, *Ruppia* - >12%, animals - trace.
Diving ducks:		
Greater scaup	46.5%P : 53.5%A#	Pondweeds, muskgrass, sedges, wild rice, wild celery, and water milfoils. Animals include various molluscs, crustaceans, and insects.
Lesser scaup	60%P : 40%A	Seeds and other parts of pondweeds, grasses, and sedges. Molluscs and aquatic insects.

Table 61. Continued.

Species	Percent volume of gut contents or castings (%)	Food items
Oldsquaw	12%P : 88%A	Mostly crustaceans, and also molluscs, insects, and fish. Seeds of grasses and pondweeds.
Bufflehead	10-30%P : 70-90%A	Mainly insects in freshwater habitat and molluscs and crustaceans in marine habitat (Oct.-early April).
Surface-feeding ducks:		
Mallard	90%P : 10%A	Stems and seeds of aquatic plants, mast, and cultivated grains. Species include: *Scirpus, Zizania aquatica* (wild rice), *Panicum* (switch grass), *Potamogeton pectinatus* (Sago pond weed), *Ruppia maritima, Najas flexilis, Zostera marina.* Also aquatic insects, molluscs, frogs, tadpoles, small fish, and fish eggs.
Black duck		Varies widely for different habitats, with plant foods predominating in fresh- and brackish-water environments, and animal foods in marine habitats. Brackish items: Primarily seeds, stems, and root-stalks of *Ruppia, Potamogeton*, also seeds of *Scirpus, Spartina,* and *Zostera.* Marine items: Mostly *Mytilus edulis* (blue mussel), and a wide range of molluscs, crustaceans, insects, and small fish.
Shorebirds:		
American oystercatcher		Oysters, shrimp, fiddler crabs.
Ruddy turnstone		Small crustaceans, molluscs, insects and their larvae.
Willet		Grasses, tender roots, and seeds. Aquatic insects, marine worms, small crabs, molluscs, and fish.

Table 61. Continued.

Species	Percent volume of gut contents or castings (%)	Food items
Wading birds:		
Herons (Great blue, Little blue, Green, and Black-crowned night heron) and egrets (American, snowy)		Chiefly nongame fish; also game fish, insects, frogs, snakes, turtles, crustaceans, mice, and rats.
Glossy ibis		Little specific information. Some crayfish, insects, and snakes.
Marsh proper:		
Clapper rail		Plants; small crabs, snails, fish fry, and aquatic insects.
Sparrows	20%P : 80%A	Insects (Hemiptera, especially leaf-hoppers, Diptera, Orthoptera, Lepidoptera, Coleoptera, Hymenoptera); amphipods; arachnids; small snails; seeds of marsh grasses.
Red-winged blackbird	73%P : 27%A	Mostly weed seeds; beetles, caterpillars, grass-hoppers, spiders.
Long-billed marsh wren		Summer - Arachnids, Hymenoptera, Coleopters, Diptera. Winter - Homoptera, Hymenoptera (ants), Coleoptera, Hemiptera.
Birds of prey:		
Hawks (Marsh, Red-tailed, Broad-winged, and Sparrow hawks) and owls (Barn, and Short-eared)		Insects, frogs, snakes, lizards, poultry and game birds, mice, rats, young rabbits, skunks, squirrels, shrews, and moles.
Osprey		Shallow-water fish.

*Source: Bent (1961, 1962, 1963a, 1963b, 1965, 1968); Palmer 1976; Kale 1964.

#P = plant; A = animal.

NONTROPHIC FUNCTIONS OF THE STUDY AREA: USE

Recreational use is an extremely important function of the study area. Although this use partially involves harvesting of the upper trophic level populations, it is not strictly a food web relationship. There are other aspects involved which are not related to the procurement of food but are more aesthetic in nature such as the pleasure derived from boating, sailing, or bird watching.

The recreational function of the area is central to the local economy. Work from this study indicates approximately 8.3×10^6 man-days of recreation were provided by the New Jersey coastal environment via ocean fishing (1.7×10^6 man-days), estuary fishing (2.0×10^6 man-days), crabbing (2.5×10^6 man-days), surf fishing (1.1×10^6 man-days), and clamming (1.0×10^6 man-days) (Applegate and Sterner 1975). Between 15 and 19% of New Jersey's population is estimated to be involved in a recreational activity of some type at the New Jersey shore (Applegate et al. 1974; Applegate and Sterner 1975). This level of participation brings a sizeable cash flow into the area, and much of the local business is geared towards the accomodation of the resulting needs.

The purpose of the use study is to: (1) examine the level of recreation activity occuring in the study area and (2) estimate its economic impact.

Methods

The investigation consisted of three distinct efforts. The first was a telephone survey of the general New Jersey population. The results from this work were applicable to the entire coastal zone and set the stage for the more site specific work. The main line of investigation employed aerial, bag and creel, and expenditure surveys within the study area proper. Over 135 aerial flights (Figure 67) were made to estimate the general area use. These data were then applied to bag and creel surveys (over 4,500 interviews) to determine the harvest of the area's resources. Expenditures were similarly determined using data based on an additional 4,000 interviews. This effort was supported by a supplementary study which analyzed waterfowl harvest in the marshes between Cedar Run and Mill Creek.

The telephone study was done between June 1973 and May 1975. The other studies were done during July 1973 - February 1974 and/or June 1974 - May 1975.

Additional information on methods is available in Applegate et al. (1974), Applegate and Sterner (1975), Sterner and Applegate (1976), McClain et al. (1976), and Shoemaker and Ferrigno (1974).

Results and Discussion

The data from these studies indicate a high level of utilization of the area's resources, and the aerial survey results indicate an increasing trend in its use between study years I and II. For comparable months, the activity levels between the first and second study periods increased by 16.3%. The estimated monthly use for study years I and II are detailed in Table 62.

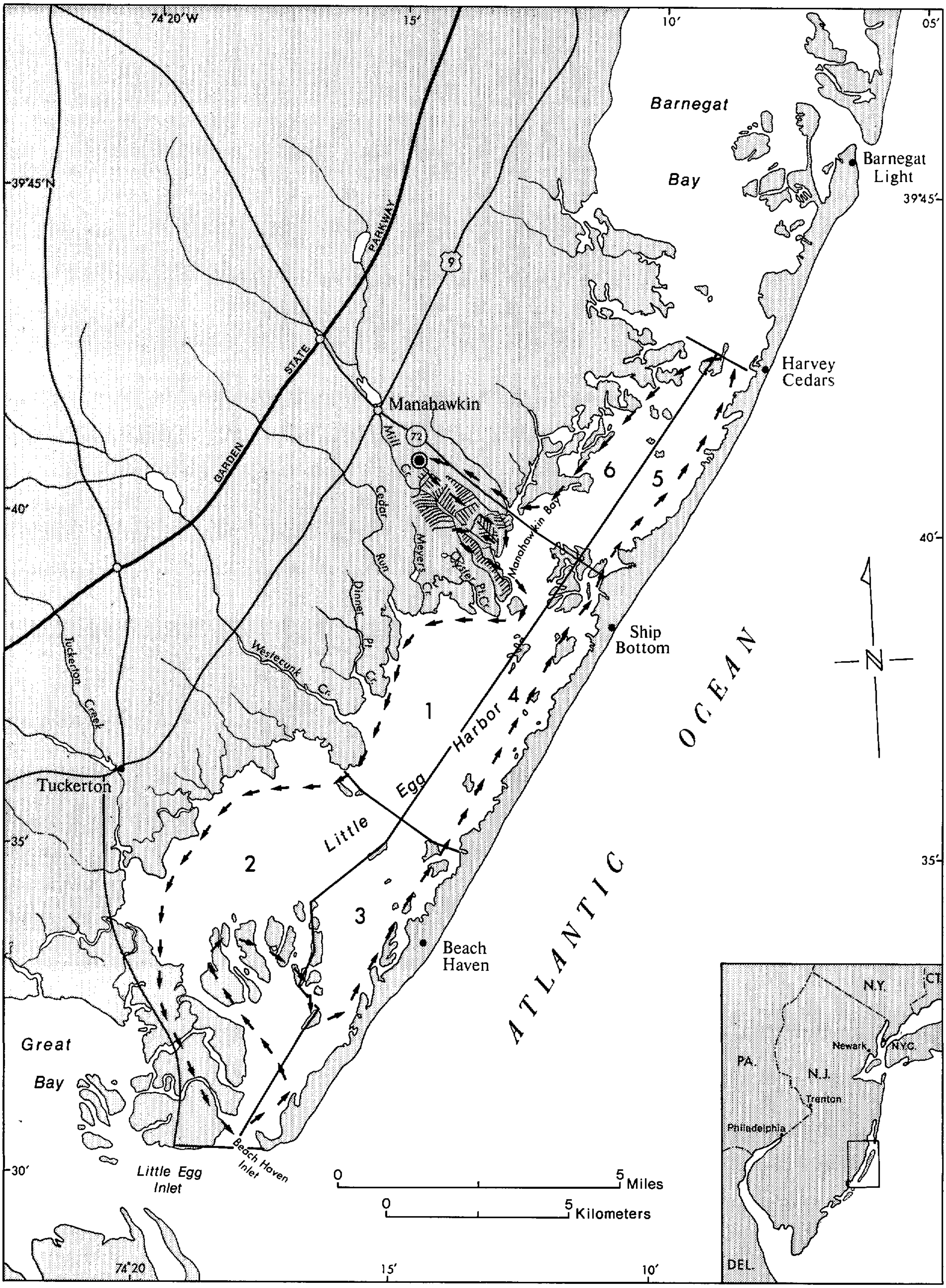


Fig. 67. Aerial flight path and section designations for the use study.

Table 62. Activity level by month.

Month	June 1973 - May 1974 Man-days	% of total	June 1974 - May 1975 Man-days	% of total
June			29,030	12.6
July	57,678	36.4	65,100	28.3
August	61,726	39.0	73,559	31.9
September	22,029	13.9	23,324	10.1
October	7,948	5.0	11,061	4.8
November	3,274	2.1		
December	2,306	1.5		
January	2,000	1.3	2,532	1.1
February	1,308	0.8	1,960	0.9
March			5,564	2.4
April			7,739	3.4
May			10,457	4.5

The categories of activity include bank fishing, boat fishing, shellfishing, hunting, boating, sailing, water skiing, bathing, and a miscellaneous grouping called other. A summary of the activity level by category is provided in Table 63.

Those pursuits related to the harvest of the area's resources (extractive) demonstrate the highest participation levels. These include boat fishing, bank fishing, shellfishing, and hunting. These activities account for 59.2% of the total estimated man-days of activity in study year I and 70.3% in study year II. The bulk of this use is attributable to boat fishermen and occurs to a large extent during the summer. The data for study year II shows 46.6% of the total activity is boat fishing related and 76.4% of this percentage took place during the summer. Bank fishing which represents only 6.9% of the total area use shows a similar seasonal pattern with 65.5% of the bank fishing done in the summer. The other extractive types of activity are either confined to the cooler parts of the year (i.e. hunting) or are proportionately more important during this time of year relative to the other activities taking place (i.e. shellfishing). In study year II, shellfishing accounts for 11.7%, 15.3%, 92.2%, and 40.2% of the activity occurring during the summer, fall, winter, and spring, respectively.

Table 63. Activity level by category in man-days.

Activity category	June 1973 - May 1974		June 1974 - May 1975	
	Man-days of activity	% of total	Man-days of activity	% of total
Boat fishing	66,861	42.2	107,239	46.6
Bank fishing	7,771	4.9	15,920	6.9
Shellfishing	18,603	11.8	38,574	16.7
Hunting	538	0.3	117	0.1
Extractive activities	93,773	59.2	161,850	70.3
Boating	35,621	22.5	50,682	22.0
Sailing	17,250	10.9	8,467	3.7
Water skiing	1,071	0.7	381	0.2
Bathing	8,795	5.6	7,691	3.3
Other	1,759	1.1	1,255	0.5
Nonextractive activities	64,496	40.8	68,476	29.7
Total	158,269	100.0	230,326	100.0

In terms of the overall area use, hunting is not a major activity (less than 1.0% for study year I and II). However, Shoemaker and Ferrigno (1974) reported during the first study year the marshes between Cedar Run and Mill Creek provided considerable recreational value to the hunters. Approximately 874 man-days were spent harvesting 2,407 waterfowl during this period and hunter use amounted to 1.6 hunters per hectare (0.6 hunters per acre) with a harvest rate of 4.4 waterfowl per hectare (1.8 waterfowl per acre).

Of the nonextractive or appreciative activity types, boating is the favored category ranking second in overall importance. For the second study year, 22.0% of all activity is accounted for by this recreation form. This figure, however, might be somewhat inflated as boats in transit to participate in other activites may be incorrectly included in this category. Among the appreciative activities, sailing and bathing were secondary to boating in importance with water skiing and the remaining activities accounting for an even smaller number of man-days.

All the nonextractive activities demonstrate a marked seasonal pattern with 72.8% of this activity type occurring during the summer season.

In terms of where all these activities occurred, there was a definite increase in use levels as the Little Egg Inlet was approached. Based on the sectors designated in Figure 67, there was no major difference in back bay use in an east-west direction; however, a definite north-south gradient was indicated.

The western portions of the back bay near the inlet (sector 2) and north of Route 72 (sector 6) are the prime bank fishing areas (51%). The east and west portions of the inlet area (sectors 3 and 2) account for 61.9% of all the boat fishing. Sector 2 is also the major clamming area. Sailing and water skiing activities are generally restricted to the deeper water in the eastern part of the entire back bay. Much of the bathing activity (54.4%) is done in the eastern portion of the Upper and Lower Manahawkin Bay (sectors 5 and 4). The western inlet sector is also a major swimming area with 22.7% of the bathing demand accommodated here. Hunting is mostly done in sectors 2 and 6.

The harvest of fish and shellfish from the study area is appreciable (Table 64). Based on individuals collected during study year II (10 months of data), clamming is the major harvesting activity with an estimated shellfish catch of 18,677,104. Boat fishing yields the next largest estimated catch with 412,287 fish and bank fishing follows with 46,594 fish. Although not indicated in the second study year data, scalloping is important on an irregular basis. During the first study year, an estimated 4,286,570 scallops were dredged from the bay system.

The clam landings were greatest during the August-September period; however, unlike the fish landings, relatively large landings were made throughout the entire year. During the winter of the second study year, fish catches were extremely low whereas the available data indicates a decreased but still sizeable clam harvest rate of 1.2×10^6 clams per month.

In terms of composition of the fish catch (Table 65), the species most frequently caught were *Callinectes sapidus* (blue claw crab), *Pomatomus saltatrix* (bluefish), *Psuedopleuronectes americanus* (winter flounder), and *Paralichthys dentatus* (fluke). Based on the individuals caught during study year II, *Callinectes* was the primary harvest organism.

The total estimated expenditures associated with the activities of bank fishing, boat fishing, shellfishing, bathing, and sailing were over 2.2×10^6 dollars for the study year II survey period (Table 66). This did not include any other expenses associated with any of the other activities which occurred in the area. Certainly, the expenditures for fuel and equipment would be sizable for the boating category which overall was the second most popular activity. Consequently, this dollar figure represents a minimum estimate.

Of the detailed costs, travel and equipment expenses account for over 70% of the estimated expenditures made to participate in an area activity. Travel costs are particularly important for most categories. Only for the boat fishermen did another category (equipment) exceed travel.

Table 64. Catch data summary.

Month	Bank fishing catch	Boat fishing catch	Clamming catch	Scalloping catch
June 1973				
July	10,815	148,032	3,157,287	
August	5,619	121,097	2,083,499	
September	3,355	80,918	806,406	
October	2,681	70,415	548,957	
November	406	2,693	483,250	371,756
December	61	535	736,858	1,811,578
January 1974	25	95	649,323	2,474,992
February	0	7	1,241,996	
March				
April				
May				
Study year I	22,962	423,792	9,707,576	4,658,326
June 1974	4,629	71,756	302,949	
July	10,245	123,855	1,952,862	
August	19,711	117,057	3,326,492	
September	9,110	66,051	3,122,094	
October	1,131	13,079	1,720,837	
November				
December				
January 1975	83		1,249,891	
February	12		1,247,888	
March	956	4,536	1,866,822	
April	466	7,570	2,208,657	
May	251	8,383	1,678,612	
Study year II	46,594	412,287	18,677,104	

On the activity basis, boat fishing represents the greatest source of cash flow. Of the total expended by all the listed activities, over 70% is attributable to the boat fishing category ($\$1.6 \times 10^6$).

NONTROPHIC FUNCTIONS WITHIN THE STUDY AREA: HABITAT

Another vital function of the study area is the providing of habitat for adult and juvenile forms. In addition to food resources, the marsh provides a protected habitat. The shallow creeks and bays and the often dense macrophytic cover offer some security from many of the larger predators. This study dealt briefly with habitat with respect to the fish, birds, and mammals (rodents). Detailed information on methods is available for the fish in McClain et al. (1976), for the mammals in Bosenberg (1977), and for the birds in Penkala and Sweger (1976), Widjeskog and Ferrigno (1975), Trout (1975), and Shoemaker and Ferrigno (1974).

Table 65. Total estimated catch composition for the period June 1974 - May 1975.

Species caught	Bank fishing Total	Bank fishing Percent	Boat fishing Total	Boat fishing Percent
Blackfish	147	0.32	939	0.23
Blowfish	17	0.04	55	0.01
Blue claw crabs	41,747	89.60	242,651	58.85
Bluefish	1,815	3.90	31,112	7.55
Eels	381	0.82	1,926	0.47
Flounder	1,385	2.97	15,222	3.69
Fluke	85	0.18	79,450	19.27
Kingfish	0	0.0	55	0.01
Porgy	195	0.42	475	0.12
Sea bass	203	0.44	21,590	5.24
Spot	244	0.52	219	0.05
Striped bass	0	0.0	55	0.01
Weakfish	24	0.05	11,390	2.76
White perch	53	0.11	0	0.0
Other species	298	0.64	7,148	1.73
Total	46,594	100.01	412,287	99.99

Fish Populations

Wang and Kernehan (1979) reported of the 195 species of fish collected from mid New Jersey to Chesapeake Bay, 40 species spawn in the estuaries between Manasquan and Cape May and 136 species use them as nursery grounds. These include all of the important forage species and the main sport fish sought by inshore fishermen.

The data we have available deal with length frequency changes over the course of the study. Tables 67, 68, and 69 are data for silver perch, winter flounder, and bluefish. Steady increases in the mean population size are observed as time progresses. Aside from showing utilization of the area, the data indicate growth is occurring in these popular sport fish. This growth occurs in sizes 5 cm (2 in) or under through the adult stages and confirms the nursery function of the study area waterways.

Mammalian Populations

The food and habitat requirements of a small number of mammal species, especially rodents, are accommodated by the dense grassy cover of the tidal marsh. These species are often present year-round, but are usually infrequently observed

Table 66. Estimated total expenditures for the various user categories during study year II.

Type of expenditure	Bank fishermen	Boat fishermen	Shell-fishermen	Bathers	Sailors	Total
Bait	$ 9,419	$ 70,532				$ 79,951
Gas and oil for the boat		57,812	$ 40,617			98,429
Equipment rental	259	219,712			$ 7,667	$227,638
Food	9,791	31,370	9,931	$12,863	19,236	83,191
Lodging	7,669	87,727		22,857	26,289	144,542
Fees	357	2,347	13,365	325	3,546	19,940
Equipment	6,278	712,989	60,856		48,124	828,247
Mileage (at $.12 per mile)	82,692	448,192	85,156	25,956	82,100	724,096
Total	$116,465	$1,630,681	$209,925	$62,001	$186,962	$2,206,034
Per trip expense	$7.33	$15.21	$6.23	$8.15	$23.24	

Table 67. Length frequency of 88 silver perch taken in the Manahawkin Bay - Little Egg Harbor system in 1974.

Length (cm)	August	September	Cumulative total
3	2		2
4	10		12
5	10	15	37
6	1	25	63
7	3	11	77
8		2	79
9		1	80
10		1	81
11		2	83
12		5	88
Total	26	62	88

Table 68. Length frequency of 169 winter flounder taken in the Manahawkin Bay - Little Egg Harbor system from June 1974 through May 1975.

Length (cm)	Jun	Jul	Aug	Oct	Mar	Apr	May	Cumulative total
1								
2							2	2
3								
4								
5	1							3
6	3	3						9
7	10	15	4					38
8	2	21	9					70
9	1	5	5	1				82
10		1	1	3				87
11				1	2			90
12				3				93
13				1	2	1		97
14							1	98
15					2	3		103
16	1				1	3	2	110
17		1	1		1	1	5	119
18		2				1	1	123
19	1					1	1	126
20	1	2	2			2		133
21		2			2		1	138
22		1			2			141
23			1			1		143
24					2			145
25						1		146
26			1		1	1		149
27					4	2		155
28					1			156
29					3			159
30					1	2		162
31					1	1		164
32						2		166
33					2			168
34								
35								
36								
37						1		169
38								
39								
40								
Total	20	53	24	9	27	23	13	169

Table 69. Length frequency of 128 bluefish taken in the Manahawkin Bay - Little Egg Harbor system in 1974.

Length (cm)	June	July	August	September	October	Cumulative total
1						
2						
3						
4						
5						
6	3					3
7	1	1				5
8	2					7
9	4	1				12
10	1	2				15
11	1	5				21
12		4	1			26
13		2	3			31
14			9			40
15		2	8			50
16			13	1		64
17			12	1		77
18		1	3	2		83
19			3	9		95
20			3	4		102
21			6	4		112
22			2	3		117
23			3	1		121
24			2	1		124
25						
26			1	1		126
27						
28						
29				1		127
30						
31					1	128
Total	12	18	69	28	1	128

as a result of their nocturnal habits, small size, and secretive behavior. This terrestrial component of the marsh fauna may occur throughout the entire marsh or be confined to the less saline regions of the upland-marsh ecotone. Although their trophic importance has yet to be adequately assessed, herbivorous, carnivorous, and omnivorous species are all represented. Fur-bearing mammals such as the muskrat, raccoon, fox, mink, skunk, opossum, and weasel are harvested by approximately 3,000 licensed trappers in New Jersey with a total annual commercial value of about 3.5 million dollars (Kantor 1977). The meadow vole (*Microtus pennsylvanicus*) is probably the most abundant small mammal in the New Jersey salt marshes (Shure 1970; Pokras and Pokras 1973).

In the present study, investigation of mammals inhabiting the salt marsh was limited to rodent species. The purpose of this research is to assess the population densities of the rodent species utilizing the major vegetation types of the tidal marsh. Specifically, they included the meadow vole (*Microtus pennsylvanicus*) and the muskrat (*Ondatra zibethica*).

METHODS -- Trapping of these species was carried out periodically from April 1975 to June 1977, using both live and killing traps. Total trapping effort amounted to 18,610 trap nights.

Microtus studies -- Studies of *Microtus* were conducted in 1975, 1976, and 1977. This was the only mouse species captured in sufficient numbers to make population estimates. The study area was partitioned into three major alteration types or sections (ST) (Figure 68): (1) ST 1: Lagoon embankment area; (2) ST 2: Mosquito ditch area; and (3) ST 3: Relatively undisturbed salt marsh. Cover types (CT) within these sections where trapping was conducted included stands of SAS and SAT, SP, DS, and the vegetational complexes associated with the mosquito ditch spoil piles (MDSP). Population estimates were derived from the Schnabel with Overton correction for known losses procedure (Chapman and Overton 1966; Overton 1965).

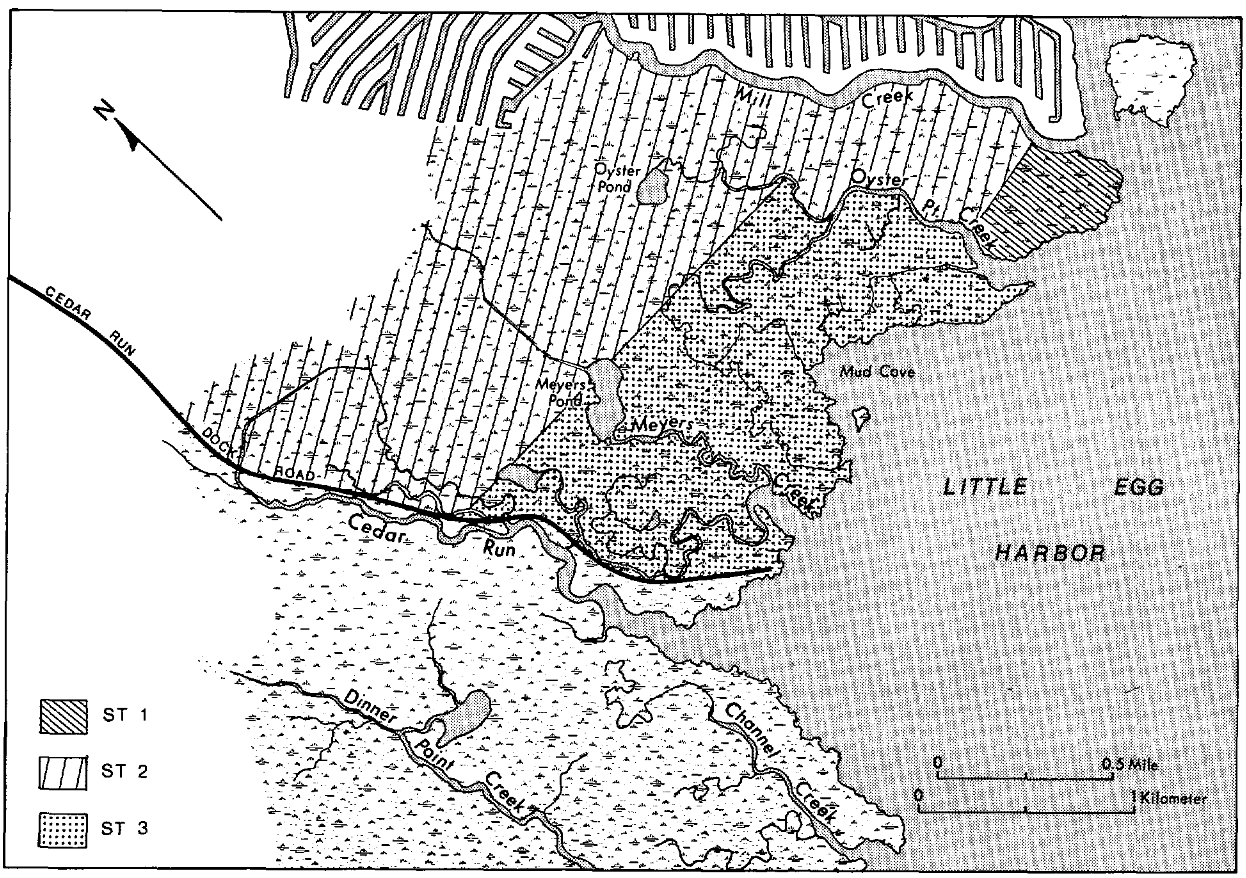


Fig. 68. Marsh alteration type (ST) for the *Microtus* study.

Muskrat study -- A population study of muskrats was conducted from 27 November - 5 December 1976. The study areas selected (Figure 69) were based upon previous surveys of muskrat huts and sign (feeding stations, surface feeding activity, burrow entrances, and fecal pellets). Population estimates from this removal technique were derived from a regression of captures per 100 trap nights on cumulative captures (Hayne 1949) and the inverse prediction method described by Zar (1974). Due to the extensive freeze-up which occurred after the third day of trapping, another population study was conducted at Location B from 9-17 March 1977.

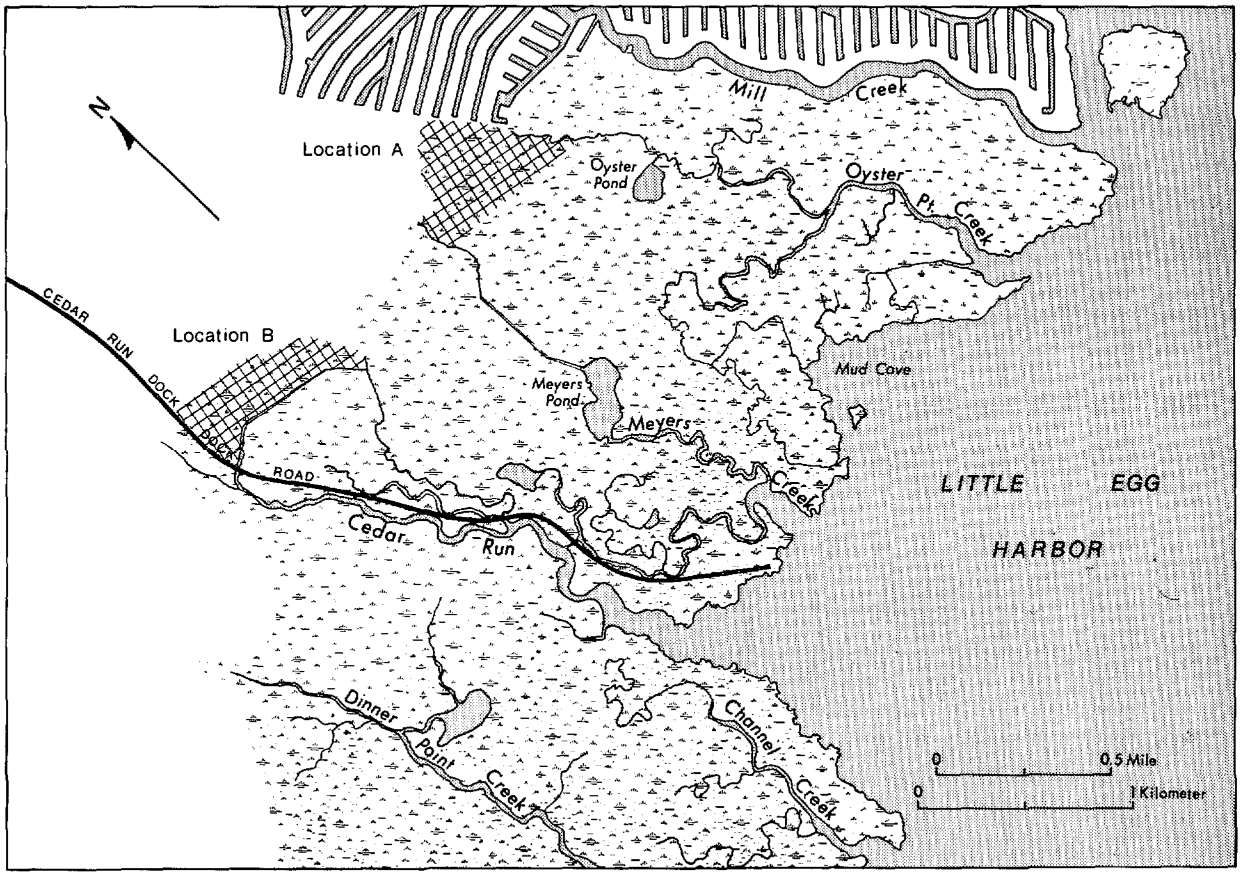


Fig. 69. Sampling locations for the muskrat study.

RESULTS AND DISCUSSION -- During the rodent investigations conducted April 1975 - June 1977 on the Manahawkin marsh, a total of five species were captured by live and killing traps: meadow vole (*Microtus pennsylvanicus*), muskrat (*Ondatra zibethica*), house mouse (*Mus musculus*), meadow jumping mouse (*Zapus hudsonius*), and the Norway rat (*Rattus norvegicus*). Only the first two species were captured in sufficient numbers to permit estimates of population densities.

Microtus study -- The data for the *Microtus* study is summarized in Tables 70, 71, and 72.

Table 70. Summary of rodent captures from the 1975 and 1976 *Microtus* studies conducted on the Manahawkin marsh.

Study period	Trap nights	Total captures	Capture success	Individual rodents
4/20-11/11/75	6,133	804	13%	319 = 316 *Microtus*, 2 *Mus*, 1 *Zapus*
4/24-9/10/76	8,880	1,902	21%	608 = 595 *Microtus*, 12 *Mus*, 1 *Rattus*

Table 71. Summary of *Microtus* live capture data from the 1977 study performed in ST 2.

Study period	Trap nights	Total captures*	Capture success	Individual *Microtus*
6/2-6/6/77				
Replicate #1	870	49	6%	30
Replicate #2	715	60	8%	47

*Includes initial captures and re-captures of marked individuals.

Table 72. *Microtus* population estimates obtained by live and snap trap methods for replicate areas of the Manahawkin marsh (ST 2) in 1977. Parentheses indicate 95% confidence intervals.

Study period	Method	Study area	Total population	Population density ($Microtus \cdot 0.2\ ha^{-1}$)*
6/2-6/6/77	Mark-release	Rep #1	38 (27-52)	5 (4-7)
		Rep #2	59 (40-90)	9 (6-13)
6/7-6/11/77	Removal	Rep #2	14 (6-34)	2 (1-5)

*Note 2.471 acres equal 1 hectare.

Microtus population density was a function of both time and ST during both 1975 and 1976 study periods. Maximum density occurred in early July, following a three to four-fold increase from April. Populations subsequently declined and by early October reached levels similar to those in late April. High tides and winds during 1975 apparently had a negligible impact on the *Microtus* populations.

Density within the incompletely lagooned section of the marsh (ST 1) was greater than in either the mosquito-ditched (ST 2) or natural marsh (ST 3) areas. The latter two ST's were very similar, especially in the first year.

A number of causative factors affecting the observed spatial and temporal distribution of *Microtus* may be operating on the Manahawkin marsh. The highest population densities noted for the incompletely lagooned section of the marsh, as opposed to the mosquito-ditched or natural marsh locations, may be expected as a result of its provision of many areas of topographic relief which are favored by this species (Fisler 1961; Harris 1953; Shure 1970, 1971). Such areas, and the emergent vegetation associated with them, have been shown to provide an important escape mechanism for *Microtus* from unusually high tides (Fisler 1961; Johnston 1957). Another major difference between the three marsh sections may be the availability of suitable nesting sites. *Microtus* nests were observed in all cover types except SAS. In ST 3, all nests were located in *S. patens*, approximately 2.54 cm (1 in) above the marsh surface. In ST 2, nests of similar construction were found in SP, DS, and MSDP cover types. In addition, nesting also occurred along the lagoon embankments comprised of layered marsh sod, where presumably *Microtus* would be less subjected to inundation and predation.

Muskrat study -- The results of the muskrat (*Ondatra zibethica*) studies conducted during the fall of 1976 and the spring of 1977 have been summarized in Table 73.

Statistical treatment of the spring captures in Location B suggested a disproportionate number of captures were associated with *Scirpus*-dominated areas or along waterways directly opposite such areas. Estimated densities for Location B were 3.2 muskrats$\cdot$ha^{-1} (1.3 muskrats$\cdot$acre^{-1}) or 4.7 muskrats$\cdot$ha^{-1} (1.9 muskrats$\cdot$acre^{-1}) of *Scirpus* cover.

Table 73. Muskrat capture data and population estimates from Locations A and B of the Manahawkin marsh.

Study period	Trap nights	Number of animals captured	Capture success	Ratio of males to females	Estimated population size (95% C.L.)
11/27-12/5/76					
Location A	126	6	5%	3/3	
Location B	414	27	7%	16/11*	N = 32 (21-52)
3/9-3/17/77					
Location B	522	23	4%	12/11#	N = 26 (16-36)

*Not significantly different from a 50/50 sex ratio ($P < 0.5$)
#Not significantly different from a 50/50 sex ratio ($P < 0.9$)

The muskrat population of the entire Manahawkin marsh probably exceeded 114 animals. This figure is based upon the assumption of 5 individuals associated with each of the 21.5 huts (average) observed on the study area and also accounting for the 6 individuals captured in Location A. The population density estimates from trapping agree with the findings of Widjeskog and Ferrigno (1973) for other N.J. marsh habitats, although they are lower than the densities reported for Swans Bay and Tuckahoe Wildlife Management Area (Widjeskog and Ferrigno 1974).

Bird Populations

Because the Manahawkin marsh and Little Egg Harbor are in the Atlantic flyway, they accommodate, with marked seasonal pulses, a large and diverse assemblage of birds. The diversity is augmented because this area also represents the southern range limit of many northern species and the northern limit of many southern species (Natural and Historic Resource Associates 1973).

Three separate ornithological studies in the Manahawkin area were conducted during the period 1973-1976. The main objectives of these projects were: (1) to estimate the diversity and density of the avifauna on the marsh during the spring and fall migration period; (2) to assess the degree of waterfowl utilization of the marsh and adjacent bay during the fall and winter; and (3) to determine the species and density of birds nesting within the major vegetation types of the marsh.

METHODS -- Diversity and density study -- The line transect-mean flushing distance method of censusing was employed in the bird diversity-density study. Four different transects were censused in 1975 on 20 April, 30 April, 21 May, 9 June, and 8 August. The number of different bird species observed was used as a simple index of species diversity. Bird density (number of birds per ha) was obtained by dividing the total number of individuals of a given species observed during each trip by the area censused.

Waterfowl utilization study -- Waterfowl utilization of the marsh and adjacent bay was estimated from monthly aerial counts conducted from September 1973 to January 1974. The immediate study area consisted of the marsh between Cedar Run Dock Road and Mill Creek.

Nesting study -- The species and density of birds nesting on the Manahawkin marsh were obtained from ground searches of 0.20 ha (0.5 acre) randomly selected plots made during August 1974. Sample plots were proportioned among nine vegetation types.

RESULTS AND DISCUSSION -- Diversity and density study -- A total of 87 species were observed in the four vegetation types investigated during the period April-August 1975. The number of total individuals and species by visit and by cover type are summarized in Table 74.

The average numbers of species per station were *S. alterniflora* (17.0), upland ecotone (12.0), creek and bay-marsh interface (11.8), *Iva-S. patens* (9.0). The average numbers of individuals per visit were *S. alterniflora* (68.3), *I. frutescens-S. patens* (43.3), creek and bay marsh-interface (36.3), and upland ecotone (29.3). The greatest number of birds present on the marsh generally occurred during late May and early June.

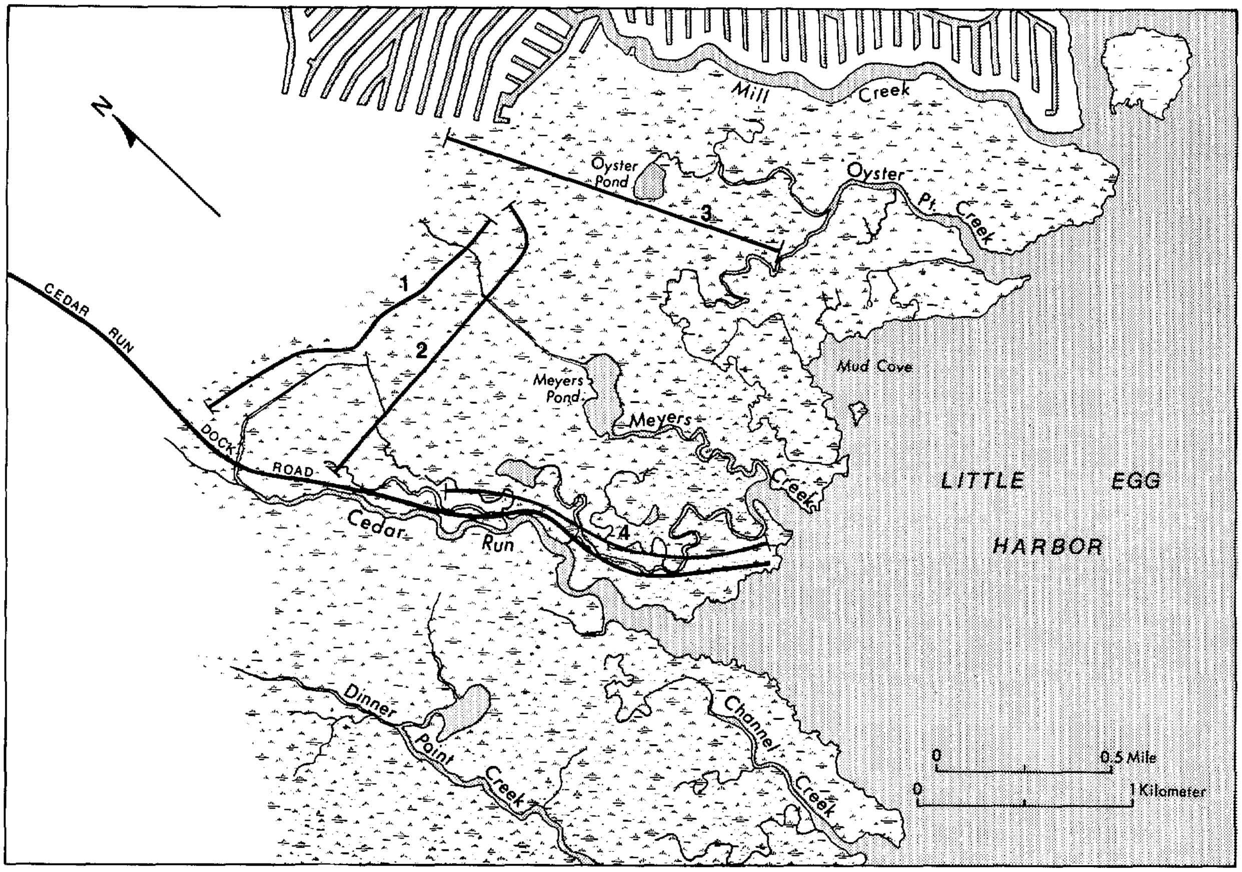


Fig. 70. Transects for the avian density and diversity study. Transects 1-4 are in the upland marsh edge, *Iva*/SP area, *S. alterniflora* area, and creek and bay-marsh interface, respectively.

Sharp-tailed sparrows exhibited the highest densities of any species and and were prevalent throughout the marsh except in the upland ecotone. They were followed by the red-winged blackbird and the barn swallow which had similar distributions. The laughing gull was the most abundant of the larger species and was chiefly observed along the *S. alterniflora* transect and within the creek and bay-marsh interface. Those birds sighted most frequently are regarded as typical summer residents and include the red-winged blackbird, sharp-tailed sparrow, clapper rail, barn swallow, common crow, fish crow, willet, laughing gull, herring gull, common egret, snowy egret, long-billed marsh wren, glossy ibis, and the great blue heron.

Some of the most important species within each of the four transect sites are listed in Table 75.

Waterfowl utilization study -- The results of the five waterfowl aerial surveys for the immediate study area during the fall and winter of 1973-1974 are presented in Table 76. The species are listed in order of total abundance. A total of 9,270 birds were tallied for the immediate study area (740 ha) (1,829 acres) which included 546 ha (1,349 acres) (74%) of marsh and 194 ha (479 acres) (26%) of creeks and bayshore situated between Cedar Run Dock Road and Mill Creek. A marked seasonal progression was evident in this prime wintering area with numbers

Table 74. Bird counts and number of species observed on the Manahawkin marsh during the period, April - August 1975. Number of individuals per number of species is indicated.

Major vegetational association	Date						Average per site
	20 April	30 April	21 May	3 June	9 June	8 August	
Upland marsh edge	30* / 14#	20 / 11	38 / 13	†	†	†	29.3 / 12.0
I. frutescens-S. patens area	25 / 8	65 / 9	66 / 11	61 / 10	11 / 7	32 / 9	43.3 / 9.0
S. alterniflora area	69 / 16	59 / 19	96 / 17	73 / 18	46 / 15	67 / 16	68.3 / 17.0
Creek and Bay-Marsh Interface	33 / 16	48 / 17	63 / 13	34 / 9	27 / 8	13 / 8	36.3 / 11.8
Average per visit	39.2 / 13.0	48.0 / 14.0	65.7 / 13.5	56.0 / 12.3	28.0 / 8.3	37.3 / 11.3	

* Bird counts.
\# Number of Species observed.
† Observations were discontinued.

Table 75. Species of the four transects.

Transect	Species
Upland-Marsh ecotone	American goldfinch Rufous-sided towhee Yellowthroat Carolina chickadee Yellow-shafted flicker
I. frutescens-S. patens	Sharp-tailed sparrow Red-winged blackbird Barn swallow
S. alterniflora	Sharp-tailed sparrow Red-winged blackbird Barn swallow Mallard Black duck Willet Laughing gull Least tern
Creek and Bay-Marsh Interface	Sharp-tailed sparrow Red-winged blackbird Barn swallow Clapper rail Starling Laughing gull Mallard

increasing from 800 on 17 September 1973 to a peak of 3,200 by mid-December. Nineteen different species were represented.

The five most abundant species were the black duck (35.3%), greater and lesser scaup (20.5%), mallard (13.7%), and bufflehead (12.3%). The blue and green-winged teal, American widgeon, and Canada goose, accounted for 12.9% of the total. The remaining 10 species contributed only 5.2%.

In Table 77, the waterfowl utilization of the surrounding marsh-estuary complex which extended from Marshelder Island to Route 72 is summarized; 22 species were tallied during these flights.

The total waterfowl observed during the September-January period exceeded 50,000 birds, beginning with 1,600 in September and expanding to about 20,000 in December and January. The four most abundant species comprised 62% of the total included the brant, greater and lesser scaup, and the black duck. Next in importance were the bufflehead and mallard. The remaining 16 species together contributed only about 13%.

Table 76. Waterfowl utilization of the Manahawkin marsh and its shoreline during the fall and winter of 1973-1974, based on monthly aerial surveys.

Species	9/17/73 No.	9/17/73 %	10/22/73 No.	10/22/73 %	11/20/73 No.	11/20/73 %	12/18/73 No.	12/18/73 %	1/7/74 No.	1/7/74 %	Total No.	Total %
Black duck	90	11.2	630	62.3	800	51.0	970	30.3	780	29.0	3,270	35.3
Scaup*	0	0.0	0	0.0	0	0.0	1,000	31.3	900	33.5	1,900	20.5
Mallard	410	51.3	20	2.0	230	14.7	270	8.4	340	12.6	1,270	13.7
Bufflehead	0	0.0	0	0.0	10	0.6	820	25.6	310	11.5	1,140	12.3
Blue-winged teal	300	37.5	20	2.0	0	0.0	0	0.0	0	0.0	320	3.5
Green-winged teal	0	0.0	100	9.9	200	12.7	0	0.0	0	0.0	300	3.2
American widgeon	0	0.0	0	0.0	300	19.1	0	0.0	0	0.0	300	3.2
Canada goose	0	0.0	200	19.8	0	0.0	40	1.3	40	1.5	280	3.0
Brant	0	0.0	0	0.0	0	0.0	60	1.9	100	3.7	160	1.7
Mergansers#	0	0.0	0	0.0	0	0.0	30	0.9	70	2.6	100	1.1
Canvasback	0	0.0	0	0.0	0	0.0	0	0.0	60	2.2	60	0.7
Pintail	0	0.0	30	3.0	20	1.3	0	0.0	0	0.0	50	0.5
Goldeneye	0	0.0	0	0.0	0	0.0	0	0.0	40	1.5	40	0.4
Old squaw	0	0.0	0	0.0	0	0.0	10	0.3	20	0.8	30	0.3
Whistling swan	0	0.0	0	0.0	0	0.0	0	0.0	30	1.1	30	0.3
Gadwall	0	0.0	10	1.0	0	0.0	0	0.0	0	0.0	10	0.1
Shoveller	0	0.0	0	0.0	10	0.6	0	0.0	0	0.0	10	0.1
Total	800	100.0	1,010	100.0	1,570	100.0	3,200	100.0	2,690	100.0	9,270	99.9

*Greater and lesser scaup.

#Red-breasted and hooded mergansers.

Table 77. Waterfowl utilization of Little Egg Harbor and the adjacent marshes from Marshelder Channel to Route 72 during the fall and winter of 1973-1974, based on monthly aerial surveys.

Species	9/17/73		10/22/73		11/20/73		12/18/73		1/7/74		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Brant	0	0.0	300	13.9	3,600	48.5	3,000	15.0	4,000	21.2	10,900	21.8
Scaup*	0	0.0	0	0.0	500	6.7	6,000	29.9	4,000	21.2	10,500	21.0
Black duck	500	31.3	900	41.9	1,400	18.8	4,800	24.0	2,000	10.6	9,600	19.2
Bufflehead	0	0.0	0	0.0	500	6.7	4,000	20.0	3,000	15.9	7,500	15.0
Mallard	800	50.0	390	18.1	900	12.1	1,200	6.0	1,800	9.6	5,090	10.2
Goldeneye	0	0.0	0	0.0	0	0.0	200	1.0	2,000	10.6	2,200	4.4
Mergansers#	0	0.0	0	0.0	0	0.0	400	2.0	700	3.7	1,100	2.2
Old squaw	0	0.0	0	0.0	0	0.0	400	2.0	600	3.2	1,000	2.0
Canvasback	0	0.0	0	0.0	0	0.0	0	0.0	500	2.7	500	1.0
Canada goose	0	0.0	200	9.5	0	0.0	40	0.2	200	1.1	440	0.9
Blue-winged teal	300	18.7	20	0.9	0	0.0	0	0.0	0	0.0	320	0.6
Green-winged teal	0	0.0	100	4.6	200	2.7	0	0.0	0	0.0	300	0.6
American widgeon	0	0.0	0	0.0	300	4.0	0	0.0	0	0.0	300	0.6
Scoters†	0	0.0	200	9.3	0	0.0	0	0.0	0	0.0	200	0.4
Pintail	0	0.0	30	1.4	20	0.3	0	0.0	0	0.0	50	0.09
Whistling swan	0	0.0	0	0.0	0	0.0	0	0.0	30	0.2	30	0.08
Gadwall	0	0.0	10	0.4	0	0.0	0	0.0	0	0.0	10	0.02
Shoveller	0	0.0	0	0.0	10	0.1	0	0.0	0	0.0	10	0.02
Total	1,600	100.0	2,150	100.0	7,430	99.9	20,040	100.1	18,830	100.0	50,050	100.09

*Greater and lesser scaup.

#Red-breasted and hooded mergansers.

†White-winged, surf, and common scooters.

The relative abundance of certain waterfowl species was quite different for these two study areas and may be attributed to the predominance of either a marsh or open water habitat. For example, the black duck, Canada goose, blue and green-winged teal, and American widgeon were relatively more abundant within the vicinity of the Manahawkin marsh. In contrast, the brant, goldeneye, old squaw, and scooters were more important in the primarily open water habitat of the Little Egg Harbor complex.

Utilization of the Manahawkin marsh increased from 1.46 birds$\cdot$ha^{-1} in September to 5.86 birds$\cdot$ha^{-1} in December. During the same period, use of the Little Egg Harbor marshes increased from 0.42 to 5.26 birds$\cdot$ha^{-1}. Such a high degree of waterfowl use is a source of considerable recreation value for local hunters.

The adaptability of the mallard to urban areas has enabled it to become an extensive breeder along the New Jersey shore where it had previously been of only minor importance.

Coastal lagoon communities, according to Figley (1974) represent almost a total loss of habitat for all waterfowl species, except the mallard. The relative abundance of species utilizing these suburban areas therefore would not be expected to reflect conditions prevailing in the surrounding natural habitat.

Of approximately 900 ducks present in the Village Harbour development in January 1973 (Figley 1974), 850 or about 94% were mallards.

Although natural food supplies are scarce in the lagoons, large year-round populations of mallards were maintained by the abundant supply of food provided by the residents. A major proportion of the population also utilized the adjacent marsh for night roosting and possibly feeding.

Nesting study -- The results of the August 1974 nesting survey are presented in Table 78. A total of 149 nests were observed during the ground searches conducted in the nine vegetation types of the marsh. Seven species of birds utilized the marsh for nesting purposes: clapper rail (*Rallus longirostris*), sharp-tailed sparrow (*Ammospiza caudacuta*), seaside sparrow (*A. maritima*), long-billed marsh wren (*Telmatodytes palustris*), willet (*Catoptrophorus semipalmatus*), red-winged blackbird (*Agelaius phoeniceus*), and the black duck (*Anas rubripes*). All sparrow nests were grouped into one category since they were very difficult to distinguish.

The estimated total number of nests in the area between Cedar Run Dock Road and Mill Creek was 2,739.5 (1 SD = 361.0).

The most important nesting species on the marsh were the sparrows, which accounted for 64% of the total. They were found nesting in 7 of 9 vegetation types, but were especially abundant in *S. olneyi*, *S. patens*, and *I. frutescens-P. virgatum* (in decreasing order of importance). The clapper rail and the willet were next in importance and contributed 16.4% and 11.3%, respectively, of the total. Clapper rails exhibited a marked preference for the SAT bordering tidal creeks and whose width varied from 1.5 to 3.0 m. The density of nesting here was the highest recorded for the study area, 13.29 nests$\cdot$ha^{-1}, and probably reflects the limited and unique distribution pattern of SAT. Although the density of willet nests was relatively low in the three cover types utilized (SP, DS, and SAS), their

Table 78. Bird nesting in the major vegetational types of the Manahawkin marsh study area during August 1974. Mean number of nests per ha. Parentheses indicate 1 SD.

Vegetation type	Plots sampled	Clapper Rail	Sparrows	Long-billed marsh wren	Willet	Red-winged blackbird	Black duck	Estimated total nests
SAT	16	13.29 (11.52)	1.24 (2.87)					139.1 (23.1)
SAS	36	0.84 (1.88)	2.62 (4.35)	0.15 (0.84)	0.15 (0.84)			1,213.9 (262.5)
SP	24	0.20 (0.99)	5.78 (7.81)		1.88 (3.26)			1,099.6 (239.3)
DS	10	2.47 (3.51)	1.48 (3.31)		0.49 (1.58)			40.8 (12.9)
I. frutescens	5		4.94 (3.51)	9.88 (9.88)		4.94 (4.94)		233.6 (58.5)
P. virgatum	1		4.94 (*)					2.0 (1.1)#
P. australis	3							
S. olneyi	4		6.18 (4.74)			1.24 (2.47)	1.24 (2.47)	10.5 (2.0)
Fill	1							
Estimated total number of nests on study area		448.7 (107.5)	1,757.9 (321.8)	161.7 (66.8)	309.8 (100.5)	59.9 (24.9)	1.5 (0.8)	2,739.5 (361.0)

*No standard deviation - only one observation.

#Based on the pooled standard deviations associated with the other vegetation types for this species.

importance was magnified by the extensive areal coverage of the grasses concerned. The long-billed marsh wren (SAS and *Iva*), red-winged blackbird (*Iva* and *Scirpus*), and black duck (*Scirpus*) appeared to be the most selective in terms of nesting sites. Together these three species only accounted for about 8% of the total nests.

The extensive areas of SAS and SP were the most important cover types with regards to number of nesting sites (2,313.5 or about 84% of the total). Five of the seven bird species used these two areas. Only the sparrows were observed to nest within *P. virgatum*, and none of the seven species utilized the *P. australis* or fill areas for nesting purposes.

The mallard duck (*Anas platyrhynchos*) was shown to be the predominant nesting and brood rearing species in the disturbed areas (spoil banks and earthen piles) immediately adjacent to Mill Creek and also within the Village Harbour lagoon development (Figley and Vandruff 1974). Nesting began in late March and peaked in early May.

Urbanized areas, such as the Village Harbour lagoon development, represent a loss of valuable marsh and mudflat habitats with subsequent effects upon local breeding populations. Such residential areas, by providing unnatural food resources and shelter, may serve as important mallard reservoirs (Figley 1974), but also lead to declines in such important harvest species as the black duck as a result of increased competition. The ability of the Manahawkin area and other coastal marshes to support, year after year, a rich and abundant avifauna, however, must lie in the continued preservation of a natural complex of interdependent habitats consisting of salt marsh, tidal creeks, salt ponds, and bays. The creation of artificial islands through dredging activity, however, may benefit many species which formerly utilized barrier islands for nesting purposes but have been forced to seek more remote locations (Buckley and McCaffrey 1978).

A SUMMARY

Clearly the physical-chemical environment of the lagooned waterways differ from that of the natural marsh creeks. The restricted circulation, both vertical and horizontal, in the developed portions of the study area represents a major difference between the natural marsh and the lagoon systems. Unfortunately, the poorer circulation has detrimental consequences. In particular, anoxia or low oxygen concentrations result or are enhanced. Such conditions are suboptimal for most of the biota normally found in such environmental systems. Prolonged or extensive anoxia is undesirable and should be avoided.

The food web in the study area is extremely complex. A simplified version of this network illustrates some of the major relationships observed (Figure 71). It is important to realize the upper portions of the food web are dependent on the energy and nutrients provided by the primary producers and channelled to the higher organisms by the invertebrate and forage fish populations. It is evident that on all the lower trophic levels examined, the natural marsh is more productive than the lagoon development. An extremely important difference between the systems is the loss of a biologically active marsh surface in the lagoon complex. This represents a tremendous decrease in net primary production. The production associated with the marsh surface invertebrate community is also lost. In addition, the biomass of the benthic macrofauna in the natural creeks far exceeds the values found in the lagooned waterways. If the flow through the food web is reduced because of decreased intermediate trophic level populations such as the invertebrates, the production of the upper levels will also decline. This will be manifested in decreased populations of desirable species such as the sport and commercial fin and shellfish and the aquatic birds which feed upon these intermediate populations.

The use study emphasizes the importance of the recreational and commercial activities to the economy of the area. Both of these activity types are supported by the productivity of the area. Actions which decrease the size of the harvestable populations have a corresponding effect on these activities. Reduction in the amount and/or quality of the salt marsh systems is such an action. The initial effect is to reduce the area available for performing the activity. More importantly, habitat studies verify the nursery function of the natural marsh. Development eliminates much of the primary production potential which support the juvenile and lower trophic levels. Habitat destruction subjects these same organisms to either reduced areas for breeding and growth or increased risk of predation and exposure to more hostile conditions. Ultimately, the loss of wetlands will cause a decline in the size and diversity of the upper trophic level populations which are harvested by man. The effect of any reduction in these populations is further accentuated by the ever-increasing demand for utilization of the resources of the area. The economic consequences could be serious and widespread if proper management of these coastal systems does not occur.

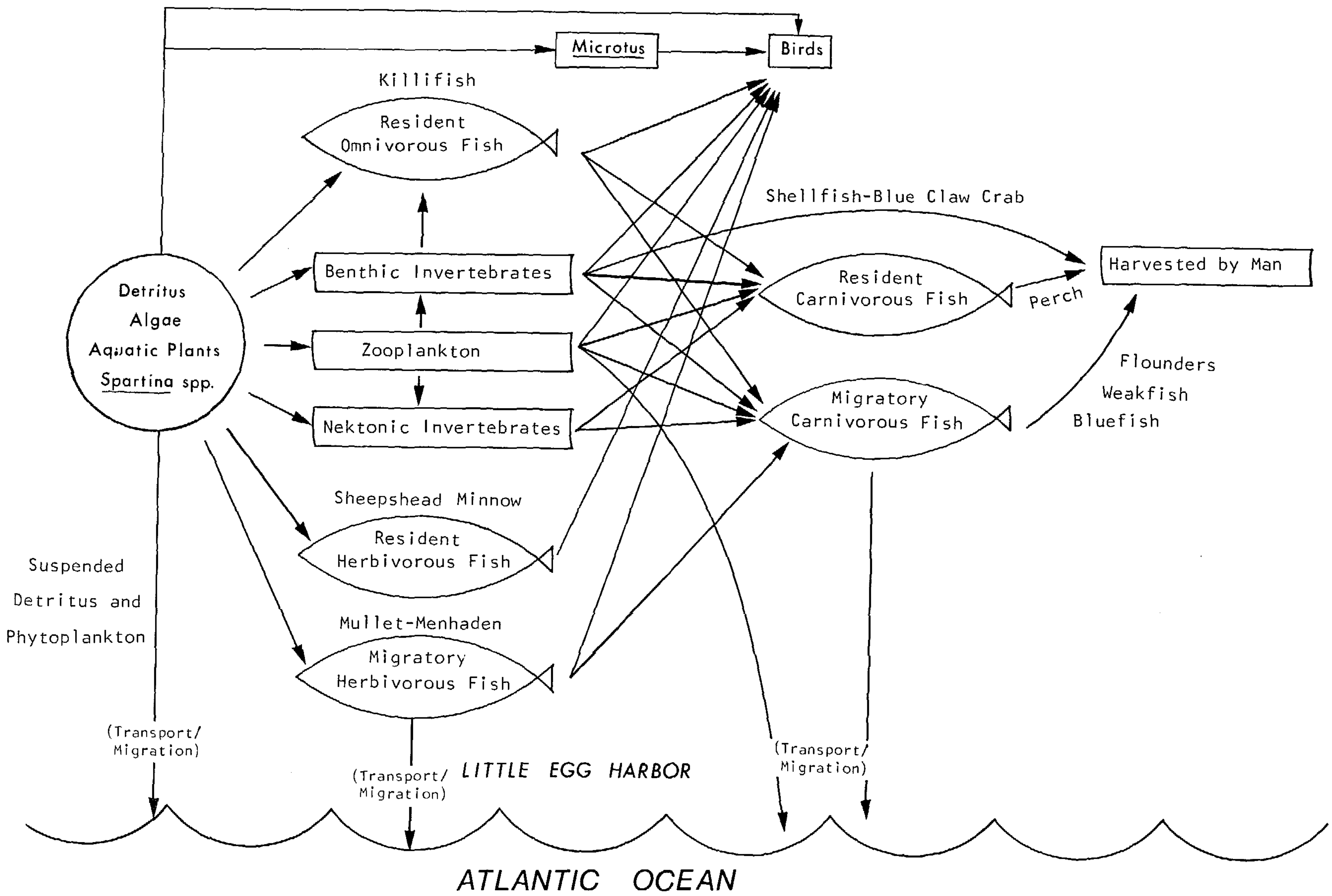


Fig. 71. A simplified food web for the study area.

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APPENDIX A
CONVERSION FACTORS

1 ha = 2.471 acres

1 ha = 10^4 m^2

1 ha = 0.003861 $miles^2$

1 cm = 0.3937 in

1 km = 0.6214 mile

1 m = 3.281 ft = 1.094 yd

1 ml $O_2 \cdot l^{-1}$ = 1.433 ppm O_2

1 ug-at $N \cdot l^{-1}$ = 0.014 ppm N

$$^oC = \frac{(5)\ (^oF-32)}{(9)}$$

$$^oF = \frac{(9)\ (^oC)}{(5)} + 32$$

$^o/oo$ = ppt = parts per thousand

$mg \cdot m^{-3}$ = ppb = parts per billion

1 kg = 2.203 lbs.

1 m^3 = 35.32 ft^3

1 = 1.057 qt = 0.264 gal

APPENDIX B
Species List

Table 1. Phytoplankton species observed in Little Egg Harbor, Barnegat Bay, and Tuckerton Bay.*

DIVISION CHRYSOPHYTA

CLASS BACILLARIOPHYCEAE (Diatoms)

Actinoptychus senarius (Ehrenberg) Ehrenberg
Amphora spp.
Asterionella japonica Cleve & Moller ex Gran
Biddulphia alternans (Bailey) Van Heurck
Chaetoceros spp.
C. breve Schutt
C. ceratosporum Ostenfeld
C. curvisetum Cleve
C. danicum Cleve
C. didymum Ehrenberg
C. filiforme Meunier
C. gracile Schutt
Cocconeis spp.
Corethrop criophilum Castracane
Coscinodiscus spp.
Cyclotella spp.
Dimeregramma minor v. *nana* (Gregory) Van Heurck (?)
Ditylum brightwellii (T. West) Grunow ex Van Heurck
Eucampia zodiacus Ehrenberg
Eunotogramma spp.
Fragilaria spp.
Leptocylindrus danicus Cleve
L. minimus Gran
Licmophora sp.
Nitzschia spp.
N. closterium (Ehrenberg) Wm. Smith
N. pungens v. atlantica Cleve (?)
N. reversa W. Smith
N. seriata Cleve (?)
Paralia sulcata (Ehrenberg) Cleve
Pleurosigma spp.
Rhizosolenia spp.
R. alata Brightwell
R. delicatula Cleve
R. fragilissima Bergon
R. hebetata f. *semispina* (Hensen) Gran (?)
R. shrubsolei Cleve
Skeletonema costatum (Greville) Cleve
Stephanopyxis sp.
Streptotheca tamesis Shrubsole
Thalassiosira condensata Cleve
T. decipiens (Grunow ex Van Heurck) Jorgensen
T. gravida Cleve
T. nordenskioldii Cleve

Table 1. Continued.

T. rotula Meunier
Thalassiothrix spp.
T. nitzschioides Grunow, Van Heurck

CLASS SILICOFLAGELLATOPHYCIDAE

Distephanus speculum (Ehrenberg) Haeckel

DIVISION CHLOROPHYTA

Family Chlamydomonadidae
Non-motile forms

DIVISION CYANOPHYTA

2-3 um diameter forms

DIVISION PYRROPHYTA#

Exuviaella apora Schiller
Exuviaella lima (Ehrenb.) Butschli
Prorocentrum micans Ehrenberg
Prorocentrum triangulatum Martin
Amphidinium fusiforme Martin
Gymnodinium splendens Lebour
Gymnodinium subrufescens n. sp.
Polykrikos kofoidi Chatton
Dinophysis acuminata Clap. and Lach.
Glenodinium danicum Paulsen
Gonyaulax scrippsae Kofoid
Gonyaulax spinifera (Clap. and Lachm.) Diesing ex Kofoid
Peridiniopsis rotunda Lebour
Peridinium claudicans Paulsen
Peridinium trochoideum (Stein) Lemm.
Peridinium leonis Pavillard
Peridinium excavatum n. sp.
Peridinium brevipes Paulsen

*Source:

Chrysophyta, Chlorophyta, and Cyanophyta

J.H. Currie, "Protoplankton and periphyton." *In* Ecological Studies in the Bays and Other Waterways Near Little Egg Inlet and in the Ocean in the Vicinity of the Proposed Site for the Atlantic Generating Station, New Jersey, Vol. III. 1974.

Pyrrophyta

G.W. Martin, "Dinoflagellates from Marine and Brackish Waters of New Jersey." University of Iowa Studies in Natural History, Vol. XII, Number 9.

#List only includes the most abundant species.

Table 2. Species of benthic macrophytes observed (X) in Little Egg Harbor, Barnegat Bay, and several tidal creeks in the Manahawkin marsh.*

Taxonomic group	Barnegat Bay	Little Egg Harbor	Tidal creeks#
VASCULAR PLANTS			
Family Zosteraceae			
Ruppia maritima	X	X	X
Zostera marina	X	X	X
PHAEOPHYTA (Brown Algae)			
Family Ectocarpacceae			
Ectocarpus sp.	X		
Ectocarpus confervoides		X	
Family Sphacelariaceae			
Spacelaria cirrosa	X		
Family Corynophloeaceae			
Leathesia difformis		X	
Family Punctariaceae			
Desmotrichum undulatum	X		
Family Fucaceae			
Fucus sp.			X
Fucus vesiculosus	X	X	
CHLOROPHYTA (Green Algae)			
Family Ulotrichaceae			
Ulothrix implexa	X		
Family Chaetophoraceae			
Entocladia viridis	X		
Family Monostromaceae			
Monostroma sp.		X	

Table 2. Continued.

Taxonomic group	Barnegat Bay	Little Egg Harbor	Tidal creeks#
Family Ulvaceae			
Ulva lactuca	X	X	X
Entercomorpha sp.		X	X
Enteromorpha intestinalis	X	X	
Enteromorpha linza	X		
Enteromorpha plumosa	X		
Enteromorpha prolifera	X		X
Family Cladophoraceae			
Chaetomorpha aerea	X		
Chaetomorpha linum	X		
Cladophora sp.	X		X
Cladophora glaucescens		X	
Cladophora gracilis	X		
Rhizoclonium sp.			X
Rizoclonium riparium	X		
Family Codiaceae			
Codium fragile	X	X	
RHODOPHYTA (Red Algae)			
Family Bangiaceae			
Bangia fuscopurpurea	X		
Porphyra so.	X		
Family Acrochaetiaceae			
Acrochaetium sp.	X		
Family Solieriaceae			
Agardhiella tenera	X	X	
Family Phodolpyllidaceae			
Cystoclonium purpureum		X	
Family Gracilariaceae			
Gracilaria foliifera	X	X	X
Gracilaria verrucosa	X		X

Table 3. List of vascular plant species observed on lagoon banks, and on the salt marsh and adjacent uplands.*

SCIENTIFIC AND COMMON NAMES#	LOCATION†		
DIVISION PTERIDOPHYTA			
Family Lycopodiaceae			
Lycopodium inundatum L. (Bog club moss)			U
Lycopodium lucidulum Michx. (Shining club moss)			U
Family Osmundaceae			
Osmunda cinnamomea L. (Cinnamon fern)			U
Family Polypodiaceae			
Dryopteris noveboracensis (L.) Gray (New York fern)			U
Pteridium aquilinum (L.) Kuhn (Bracken fern)			U
Woodwardia virginica (L.) Sm. (Virginian chain fern)			U
DIVISION SPERMATOPHYTA			
SUBDIVISION GYMNOSPERMAE			
Family Pinaceae			
Chamaecyparis thyoides (L.) BSP (Atlantic white cedar)			U
Juniperus virginiana L. (Red cedar)			U
Pinus rigida Mill. (Pitch pine)			U
Pinus strobus L. (Eastern white pine)			U
SUBDIVISION ANGIOSPERMAE			
Family Typhaceae			
Typha angustifolia L. (Common cattail)	M		
Family Zosteraceae			
Ruppia maritima L. (Widgeon grass)	M		
Family Gramineae			
Andropogon scoparius Michx. (Broom beardgrass)			U
Distichlis spicata (L.) Greene (Spike grass)	M	L	
Echinochloa walteri (Pursh) Nash (Walter millet)	M	L	
Panicum virgatum L. (Switch grass)	M	L	U
Phragmites communis Trin. (Common reed)	M	L	U
Spartina alterniflora Loisel (Salt marsh cordgrass)	M	L	
Spartina patens (Ait.) Muhl. (Salt marsh hay)	M	L	

Table 3. Continued.

SCIENTIFIC AND COMMON NAMES#	LOCATION†		
Spartina cynosuroides (L.) Roth (Tall cordgrass)	M	L	
Spartina pectinata Link (Fresh water cordgrass)	M	L	
Family Cyperaceae			
Carex spp. (Sedge)			U
Cladium jamaicense Crantz (Saw grass)	M	L	
Cladium mariscoides (Muhl.) Torr. (Twig rush)	M	L	
Cyperus grayii Torr. (Sedge)			U
Cyperus sp. (Sedge)	M	L	
Eleocharis sp. (Spike rush)	M		
Scirpus americanus Pers. (Common threesquare)	M		
Scirpus olneyi Gray (Olney threesquare)	M	L	
Scirpus robustus Pursh (Salt marsh bulrush)	M		
Family Xyridaceae			
Xyris caroliniana Walt. (Yellow-eyed grass)			U
Family Juncaceae			
Juncus effusus L. (Soft rush)			U
Juncus gerardi Loisel. (Black grass)	M		
Juncus tenuis Willd. (Rush)			U
Family Liliaceae			
Smilax glauca Walt. (Sawbrier)			U
Smilax walteri Pursh (Redberry greenbrier)		L	U
Family Orchidaceae			
Cypripedium acaule Ait. (Stemless lady's slipper)			U
Habenaria blephariglottis (Willd.) Hook. (White-fringed orchis)			U
Habenaria spp. (Fringed orchis)			U
Isotria verticillata (Willd.) Raf. (Whorled pogonia)			U
Pogonia ophioglossoides (L.) Ker (Pogonia)			U
Family Myricaceae			
Comptonia peregrina (L.) Coult. (Sweet fern)			U
Myrica pensylvanica Loisel. (Bayberry)			U
Family Corylaceae			
Alnus rugosa (Du Roi) Spreng. (Speckled alder)			U
Betula papyrifera Marsh. (American white birch)		L	
Betula populifolia Marsh. (Gray birch)			U

Table 3. Continued.

SCIENTIFIC AND COMMON NAMES#	LOCATION†		
Family Fagaceae			
Quercus alba L. (White oak)			U
Quercus coccinea Muenchh. (Scarlet oak)		L	
Quercus ilicifolia Wang. (Scrub oak)			U
Quercus marilandica Muenchh. (Blackjack oak)			U
Quercus palustris Muenchh. (Pin oak)			U
Quercus phellos L. (Willow oak)			U
Quercus prinus L. (Chestnut oak)			U
Quercus rubra L. (Red oak)			U
Quercus stellata Wang. (Post oak)			U
Quercus velutina Lam. (Black oak)			U
Family Polygonaceae			
Polygonum sp. (Smartweek)	M		
Rumex verticillatus L. (Swamp dock)		L	
Family Chenopodiaceae			
Atriplex patula var. *hastata* (L.) Gray (Orach)	M		
Chenopodium rubrum L. (Coast blite)	M		
Salicornia bigelovii Torr. (Bigelow glasswort)	M		
Salicornia europaea L. (Slender glasswort)	M		
Salicornia virginica L. (Woody glasswort)	M		
Suaeda linearis (Ell.) Moq. (Atlantic sea blite)	M		
Suaeda maritima (L.) Dumort. (Atlantic sea blite)	M		
Family Amaranthaceae			
Acnida cannabina L. (Water hemp)	M		
Family Phytolaccaceae			
Phytolacca americana L. (Pokeweed)	M		
Family Magnoliaceae			
Magnolia virginiana L. (Sweet bay)			U
Family Lauraceae			
Sassafras albidum (Natl.) Ness (Sassafras)		L	U
Family Cruciferae			
Cakile edentula (Bigel.) Hook. (Sea rocket)	M		

Table 3. Continued.

SCIENTIFIC AND COMMON NAMES#	LOCATION†		
Family Sarraceniaceae			
Sarracenia purpurea L. (Pitcher plant)			U
Family Droseraceae			
Drosera intermedia Hayne (Sundew)			U
Drosera linearis Goldie (Sundew)			U
Drosera rotundifolia L. (Round-leaved sundew)			U
Family Hamamelidaceae			
Liquidambar styraciflua L. (Sweet gum)			U
Family Rosaceae			
Amelanchier obovalis (Michx.) Ashe (Coastal juneberry)		L	
Rosa palustris Marsh. (Marsh rose)	M	L	
Rubus hispidus L. (Dewberry)			U
Family Leguminosae			
Lathyrus latifolius L. (Everlasting pea)		L	
Robinia pseudo-acacia L. (Black locust)		L	
Family Polygalaceae			
Polygala cruciata L. (Marsh milkwort)	M		
Polygala lutea L. (Yellow milkwort)			U
Family Anacardiaceae			
Rhus copallina L. (Dwarf sumac)		L	U
Rhus radicans L. (Poison ivy)	M	L	U
Rubus sp. (Blackberry)		L	
Family Aquifoliaceae			
Ilex glabra (L.) (Inlberry)			U
Ilex opaca Ait. (American holly)		L	U
Family Aceraceae			
Acer rubrum L. (Red maple)		L	U
Family Vitaceae			
Vitis spp. (Grape)		L	

Table 3. Continued.

SCIENTIFIC AND COMMON NAMES#	LOCATION†		
Family Malvaceae			
Hibiscus moscheutos L. (Swamp rose)	M		
Hibiscus palustris L. (Marsh mallow)	M	L	
Family Nyssaceae			
Nyssa sylvatica Marsh. (Black gum)		L	U
Family Melastomataceae			
Rhexia mariana L. (Maryland meadow beauty)			U
Family Onagraceae			
Oenothera biennis L. (Evening primrose)	M		
Onagraceae sp. (Evening primrose)		L	
Family Umbelliferae			
Daucus carota L. (Queen Anne's lace)		L	
Eryngium aquaticum L. (Eryngo)			U
Family Clethraceae			
Clethra alnifolia L. (Coast pepperbush)		L	U
Family Pyrolaceae			
Chimaphila sp. (Pipsissewa)			
Family Ericaceae			
Epigaea repens L. (Trailing arbutus)			U
Gaylussacia baccata (Wang.) K. Koch (Black huckleberry)			U
Gaultheria procumbens L. (Wintergreen)			U
Gaylussacia frondosa (L.) T.&G. (Dangleberry)			U
Kalmia latifolia L. (Mountain laurel)			U
Lyonia mariana (L.) D. Don (Stagger bush)			U
Rhododendron viscosum (L.) Torr. (Clammy azalea)			U
Vaccinium arboreum Marsh. (Sparkleberry)			U
Vaccinium corymbosum L. (Highbush blueberry)		L	U
Vaccinium macrocarpon Ait.(Cranberry)			U
Vaccinium vacillans Torr. (Lowbush blueberry)			U
Family Plumbaginaceae			
Limonium carolinianum (Walt.) Britt. (Sea lavender)	M	L	

Table 3. Continued.

SCIENTIFIC AND COMMON NAMES#	LOCATION†		
Family Gentianaceae			
Sabatia dodecandra (L.) BSP. (Big sea pink)	M		
Sabatia stellaris Pursh (Little sea pink)	M		
Family Asclepiadaceae			
Asclepias lanceolata Walt. (Coast milkweed)	M		
Family Polemoniaceae			
Cuscuta epithymum Murr. (Clover dodder)		L	
Family Scrophulariaceae			
Gerardia purpurea L. (Purple gerardia)			U
Melampyrum lineare Desr. (Cow wheat)			U
Verbascum thapsus L. (Common mullein)		L	
Family Rubiaceae			
Mitchella repens L. (Partridge berry)			U
Family Caprifoliaceae			
Viburnum lentago L. (Sweet viburnum)			U
Viburnum recognitum Fern. (arrowood)		L	
Family Adoxaceae			
Sambuscus canadensis L. (Common elderberry)		L	
Family Compositae			
Aster nemoralis Ait. (Bog aster)			U
Aster subulatus Michx. (Annual salt marsh aster)	M		
Aster tenuifolius L. (Perennial salt marsh aster)	M		
Baccharis halimifolia L. (Sea myrtle)	M	L	
Bidens cernua L. (Beggartick)	M	L	
Cirsium vulgare (Salvi) Tenore (Common thistle)	M		
Eupatorium capillifolium (Lam.) Small (Dog fennel)	M	L	
Hieracium sp. (Hawkweed)		L	

Table 3. Continued.

SCIENTIFIC AND COMMON NAMES#	LOCATION†		
Iva frutescens L. (Marsh elder)	M	L	
Lobelia nuttallii R.&S. (Lobelia)			U
Pluchea camphorata (L.) DC. (Salt marsh fleabane)	M	L	
Pluchea purpurascens (Sw.) DC. (Salt marsh fleabane)	M		
Solidago sempervirens L. (Seaside goldenrod)	M	L	

*This study, Figley (1974), and Natural and Historic Resource Associates (1973) were used as sources for this table.

#Nomenclature following Fernald (1950).

†Location Key:

M = Salt Marsh and/or dredge spoil banks
L = Lagoon banks
U = Upland and upland-marsh ecotone

Table 4. Species of marsh surface algae, including macrophytes and edaphic microflora, observed and those likely to occur on the Manahawkin salt marsh.*

DIVISION CHRYSOPHYTA

CLASS BACILLARIOPHYCEAE (Diatoms)

Achnanthes biasolettiana (Kutz.) Grun.
A. hauckiana Grun.#†
A. lanceolata var. dubia Grun.#
A. submarina Hust.
Amphiprora alata (Ehr.) Kutz.
A. pulchra Bailey
Amphora angusta var. oblongella Grun.
A. coffeaeformis (Ag.) Kutz.
A. cymbelloides Grun.
A. exigua Greg.
A. laevis var. perminuta Grun.
A. securicula Per.
A. spartinetensis Sulliv. & Reim.
A. tenerrima Aleem & Hust.
A. tenussims Hust.
Bacillaria paradoxa Gmelin
Cocconeis placentula var. euglypta (Ehr.) Cl.
C. scutellum var. parva Grun.
C. stauroneiformis (V.H.) Okuno
Cyclotella caspia Grun.
C. meneghiniana Kutz.
C. striata var. americana A. Cl.
Cymbella pusilla Grun.

Table 4. Continued.

Denticula subtilis Grun.#†
Diploneis constricta (Grun.) Cl.
D. elliptica (Kutz.) Cl.
D. interrupta (Kutz.) Cl.
D. pseudovalis Hust.
Fragilaria leptostauron var. dubia (Grun.) Hust.†
Mastogloia lanceolata Thw.
M. pumila (Grun.) Cl.
M. pusilla Grun.
Melosira numuloides Ag.†
M. sulcata (Ehr.) Kutz.
Navicula abunda Hust.
N. aeqourea Hust.
N. ammophila Grun.
N. cruciculoides Brock.
N. digito-radiata (Greg.) Ralfs
N. diserta Hust.
N. flanatica Grun.
N. gregaria Donk.
N. halophila (Grun.) Cl.
N. hudsonis Grun.
N. hyalinula DeToni
N. incerta Grun.
N. lanceolata (Ag.) Kutz.
N. menisculus Schum.
N. meniscus Schum.
N. misella Hust.
N. mutica var. cohnii (Hilse) Grun.
N. nolens Simon.
N. palpebralis Breb.
N. pavillardi Hust.
N. peregrina (Ehr.) Kutz.
N. phyllepta Kutz.
N. pseudocrassirostris Hust.
N. regularis Hust.
N. salinarum Grun.
N. salinarum forma minima Kolbe#
N. salinicola Hust.
N. subirritans Giffen
N. taraxa Hohn & Hellerm.
N. tripunctata (Mull.) Berry#†
N. tripunctata var. schizonemoides (V.H.) Patr.
Nitzschia aequorea Hust.
N. angularis W. Sm.
N. bilobata var. ambigua Mang.
N. communis var. hyalina Lund
N. debilis (Arnott) Grun.
N. delauneyi Mang.
N. dissipata (Kutz.) Grun.
N. frustulum var. perminuta Grun.

Table 4. Continued.

N. hungarica Grun.
N. microcephala Grun.
N. obtusa var. nana Grun.
N. paleacea Grun.
N. procera Hust.
N. romanoides Mang.
N. sigma (Kutz.) W. Sm.
N. silicula Hust.
N. subcapitellata Hust.
N. vitrea var. salinarum Grun.
N. sp. No. 1
Pleurosigma salinarum Grun.
Rhopalodia gibberula var. protacta Hust.
R. gibberula var. succincta Breb.
Stauroneis amphioxys Greg.
S. amphioxys var. obtusa Hendey
Synedra affinis var. gracilis Grun.

CLASS XANTHOPHYCEAE

Vaucheria spp.

DIVISION CYANOPHYTA

Oscillatoria spp.
Nostoc spp.
Callothrix spp.
Rivularia spp.
Lyngbya spp.
Anabaena spp.

DIVISION CHLOROPHYTA

Spirogyra
Ulothrix flacca Thur.
Cladophora spp.
Rhizoclonium spp.

DIVISION PHAEOPHYTA

Fucus vesiculosus L.
Ascophyllum nodosum (L.) LeJolis f. scorpioides (Hornemann) Reinke

*Source:

Diatoms: Sullivan (1977)
Other: Blum (1968); Natural and Historic Resource Associates (1973); Ursin (1972).

#Dominant taxa associated with *S. alterniflora* (short form) based on average relative abundance in 12 collections.

†Dominant taxa associated with *S. patens*.

Table 5. Macrobenthic invertabrates of the study area.

Polychaetes:

Ampharetidae
Autolytus prolifera
Autolytus sp. 1
Autolytus sp. 2
Axiothella catenata
Capitella capitata

Capitellidae
Cirratulidae
Dodecaceria sp.
Drilonereis longa
Eupomatus dianthus
Eteone flava
Eteone heteropoda
Eteone sp.
Exogene dispar
Exogene sp.
Fabricia sabella
Glycera americana
Glycera capitata
Glycera dibranchiata
Glycinda solitaria
Gyptis vittata
Heteromastus filiformis
Hypaniola grayi
Lumbrineris tenuis
Maldanopsis elongata
Melinna cristata
Microphthalmus aberrans
Nereis diversicolor
Nereis sp.
Nereis succinea
Nereis virens
Notomastus latericeus
Pectinaria gouldii
Pereplanosyllus ingiorata
Polydora ligni
Potamilla neglecta
Prionospio malmgreni
Sabella microphthalmus
Sabellidae
Scolepidis virides
Scoloplos acutus
Scoloplos fragalis
Scoloplos robustus
Scoloplos sp.
Serpulidae
Spio filicornis
Spio setosa
Spionidae
Scolepidis virides
Scoloplos acutus
Scoloplos fragalis
Scoloplos robustus
Scoloplos sp.
Serpulidae
Spio filicornis
Spio setosa
Spionidae
Spiochaetopterus oculatus
Stenolais boa
Streblospio benedicti
Syllidae
Terebellidae
Tharyx acutus

Other polychaetes:

Brania clavata
Diopatra cuprea
Eteone lactea
Eumida sanguinea
Petaloproctus tenuis
Unidentified polychaete

Nemertea:

Amphiporus bioculatus
Amphiporus ochraceus
Amphiporus sp.
Euplana gracilis
Paleonemertea A
Paleonemertea B
Nemerteans unidentified

Nematoda:

Tetrastemmatidae
Unidentified nematodes

Crustaceans:

Ampelisca abidita
Ampelisca agassizi
Ampelsica vadorum
Amphithoe longimana
Batea catharinensis
Caprellidae
Cerapus tubularis
Corophium insidiosum
Corophium simile
Corophium sp.

Table 5. Continued.

Corophium tuberculatum
Cymadusa compta
Gammarus daiberi
Gammarus mucronatus
Gammarus palustris
Gammarus sp.
Leptocheirus pinguis
Leptocheirus plumulosus
Lysianopsis alba
Melita nitida
Microdeutopus gryllotalpa
Mellitidae
Podoceridae
Unidentified amphipod

Isopoda:

Cyathurd polita
Edotea triloba
Erichsonella attenuata
Idotea baltica
Leptochelia savigni
Chirodotea sp.
Sphaeromidae
Unidentified isopod

Other Crustaceans:

Balanus balanoides
Balanus sp.
Callinectes sapidus
Campanularidae
Brachyuran crabs
Copepoda
Collembolla
Crangon septemspinosa
Cumacea
Cyclaspis varians
Mysidopsis bigelowi
Neomysis americana
Palaemonetes pugio
Palaemonetes vulgaris
Neopanope texana
Nymphon longitarse
Ostracod
Oxyurostylis smithi
Xanthid crabs

Molluscs:

Bivalvia:

Anadara ovalis
Acteon punctostriatus
Ensis directus
Gemma gemma
Lyonsia hyalina
Macoma balthica
Mercenaria mercenaria
Modiolus demissus
Mulinia lateralis
Mya arenaria
Mytilus edulis
Solemya velum
Spisula solidissima
Tagelus plebeius
Tellina agilis
Unidentified bivalves

Gastropoda:

Anachis avara
Bittium alternatum
Cerithiopos sp.
Corambella
Crepidula fornicata
Crepidula converxa
Crepidula sp.
Eupleura caudata
Melampus bidentatus
Mitrella lunata
Ilyanassa obsoleta
Nassarius vibex
Polinices duplicatus
Odostomia
Retusa canaliculata
Turbonilla
Unidentified gastropods
Urosalpins cinereus

Miscellaneous:

Anthozoans
Anguilla rostrata
Asterias forbesii
Ascidian
Botryllus sp.
Mnemiopsis leidyi
Amathia sp.
Hirudinea
Hydrozoan
Holothurian
Hydractinia

Table 5. Continued.

Insect larvae
Lysidice sp.
Medusa
Membranipora sp.
Metridium sp.
Microciona prolifera
Microporella sp.
Molgula manhattensis
Nematostella vectensis
Notella sp.
Platyhelminthes
Pycnogonid
Oligochaeta
Vorticella
Clione sp.

Table 6. List of marsh surface invertebrates observed during August 1974.

Common Name	Species	Order:Family
Ribbed mussels	*Modiolus demissus*	Prionodesmacea:Mytilidae
Salt marsh snails	*Melampus bidentatus*	Basommatophora:Ellobiidae
Fiddler crabs	*Uca pugnax*	Decopoda:Ocypodidae
Ants		Hymenoptera:Formicidae
True bugs		Hempitera
Crickets		Orthoptera:Gryllidae
Grasshoppers		Orthoptera:Locustidae
Leaf-hoppers		Homoptera:Cicadellidae
Sow bugs	*Philoscia vittata*	Isopoda:Oniscidae
Beach fleas	*Orchestia grillus* (=*palustris*)	Amphipoda:Orchestiidae
Spiders		Araneida:Lycosidae

Table 7. Common and scientific names of fish taken in the Manahawkin Bay - Little Egg Harbor system.

Alewife	*Alosa pseudoharengus*
American eel	*Anguilla rostrata*
American sand lance	*Ammodytes americanus*
American shad	*Alosa sapidissima*
Atlantic croaker	*Micropogon undulatus*
Atlantic menhaden	*Brevoortia tyrannus*
Atlantic needlefish	*Strongylura marina*
Atlantic silverside	*Menidia menidia*
Banded killifish	*Fundulus diaphanus*
Bay anchovy	*Anchoa mitchilli*
Black sea bass	*Centropristes striatus*
Blueback herring	*Alosa aestivalis*
Bluefish	*Pomatomus saltatrix*
Blue runner	*Caranx crysos*
Bluespotted cornetfish	*Fistularia tabacaria*
Brown bullhead	*Ictalurus nebulosus*
Butterfish	*Peprilus triacanthus*
Crevalle jack	*Caranx hippos*
Cunner	*Tautogolabrus adspersus*
Fourspine stickleback	*Apeltes quadracus*
Golden shiner	*Notemigonus crysoleucas*
Gray snapper	*Lutjanus griseus*
Hogchoker	*Trinectes maculatus*
Inshore lizardfish	*Synodus foetens*
Lined seahorse	*Hippocampus erectus*
Lookdown	*Selene vomer*
Mojarra	*Eucinostomus* sp.
Mummichog	*Fundulus heteroclitus*
Naked goby	*Gobiosoma bosci*
Northern kingfish	*Menticirrhus saxatilis*
Northern pipefish	*Syngnathus fuscus*
Northern puffer	*Sphoeroides maculatus*
Northern sea robin	*Prionotus carolinus*
Northern sennet	*Sphyraena borealis*

Table 7. Continued.

Oyster toadfish	*Opsanus tau*
Permit	*Trachinotus falcatus*
Pinfish	*Lagodon rhomboides*
Planehead filefish	*Monacanthus hispidus*
Pollock	*Pollachius virens*
Pumpkinseed	*Lepomis gibbosus*
Rainwater killifish	*Lucania parva*
Red hake	*Urophycis chuss*
Redfin pickerel	*Esox americanus americanus*
Scup	*Stenotomus chrysops*
Sheepshead minnow	*Cyprinodon variegatus*
Silver perch	*Bairdiella chrysura*
Smallmouth flounder	*Etropus microstomus*
Smooth dogfish	*Mustelus canis*
Spot	*Leiostomus xanthurus*
Spotted hake	*Urophycis regius*
Striped anchovy	*Anchoa hepsetus*
Striped burrfish	*Chilomycterus schoepfi*
Striped killifish	*Fundulus majalis*
Striped mullet	*Mugil cephalus*
Striped sea robin	*Prionotus evolans*
Summer flounder	*Paralichthys dentatus*
Tautog	*Tautoga onitis*
Threespine stickleback	*Gasterosteus aculeatus*
Tidewater silverside	*Menidia beryllina*
Weakfish	*Cynoscion regalis*
White mullet	*Mugil curema*
White perch	*Morone americana*
Windowpane	*Scophthalmus aquosus*
Winter flounder	*Pseudopleuronectes americanus*
Herring	*Alosa* sp.
Shiner	*Notropis* sp.

Table 8. Mammals observed and those likely to occur in the study area (including marsh and upland habitat).*

SCIENTIFIC AND COMMON NAMES#

ORDER MARSUPIALIA

Family Didelphiidae

Didelphis marsupialis (Opossum)

ORDER INSECTIVORA

Family Soricidae

Sorex cinereus (Masked shrew)
Blarina brevicauda (Shorttail shrew)
Cryptotis parva (Least shrew)

Family Talpidae

Scalopus aquaticus (Eastern mole)
Condylura cristata (Starnose mole)

ORDER CHIROPTERA

Family Vespertilionidae

Myotis lucifugus (Little brown myotis)
Lasionycteris noctivagans (Silver-haired bat)
Pipistrellus subflavus (Eastern pipistrel)
Eptesicus fuscus (Big brown bat)
Lasiurus borealis (Red bat)
Lasiurus cinereus (Hoary bat)

ORDER CARNIVORA

Family Procyonidae

Procyon lotor (Racoon)

Family Mustelidae

Mustela frenata (Longtail weasel)
Mephitis mephitis (Striped skunk)

Family Canidae

Vulpes fulva (Red fox)
Urocyon cinereoargenteus (Gray fox)

Table 8. Continued.

ORDER RODENTIA

Family Sciuridae

Marmota monax (Woodchuck)
Tamias striatus (Eastern chipmunk)
Sciurus carolinensis (Eastern gray squirrel)
Tamiasciurus hudsonicus (Red squirrel)
Glaucomys volans (Southern flying squirrel)

Family Cricetidae

Peromyscus leucopus (White-footed mouse)
Clethrionomys gapperi (Boreal redback vole)
Microtus pennsylvanicus (Meadow vole)†
Pitymys pinetorum (Pine vole)
Ondatra zibethica (Muskrat)†

Family Muridae

Rattus norvegicus (Norway rat)†
Mus musculus (House mouse)†

Family Zapodidae

Zapus hudsonius (Meadow jumping mouse)†

ORDER LAGOMORPHA

Family Leporidae

Sylvilagus floridanus (Eastern cottontail)

ORDER ARTIODACTYLA

Family Cervidae

Odocoideus virginianus (Whitetail deer)

*Sources used were this study, "Mammals of Brigantine National Wildlife Refuge", Fish and Wildl. Serv., USDI (1976), and Pokras and Pokras (1973).

#Nomenclature and order of listing according to Burt and Grossenheider (1964).

†Rodents trapped in this study.

Table 9. Bird species observed in the Manahawkin salt marsh and in Village Harbour lagoon development.* Unless noted species was observed in the marsh area.

COMMON AND SCIENTIFIC NAMES

ORDER GAVIIFORMES
  FAMILY GAVIIDAE
    Common loon *(Gavia immer)*#

ORDER PODICIPEDIFORMES
  FAMILY PODICIPEDIDAE
    Horned grebe *(Podiceps auritus)*
    Pied-billed grebe *(Podilymbus podiceps)*#

ORDER PELECANIFORMES
  FAMILY PHALACROCORACIDAE
    Double-crested cormorant *(Phalacrocorax auritus)*#

ORDER ANSERIFORMES
  FAMILY ANATIDAE
    Mute swan *(Cygnus olor)*
    Whistling swan *(Olor columbianus)*
    Canada goose *(Branta canadensis)*#
    Brant *(Branta bernicla)*
    Snow goose *(Chen hyperborea)*
    Mallard *(Anas platyrhynchos)*#
    Black duck *(Anas rubripes)*#
    Pintail *(Anas acuta)*
    Gadwall *(Anas strepera)*
    Blue-winged teal *(Anas discors)*#
    Green-winged teal *(Anas carolinensis)*#
    American widgeon *(Mareca americana)*
    Shoveler *(Spatula clypeata)*
    Wood duck *(Aix sponsa)*#
    Canvasback *(Aythya valisineria)*#
    Ring-necked duck *(Aythya collaris)*
    Greater scaup *(Aythya marila)*#
    Lesser scaup *(Aythya affinis)*#
    Common goldeneye *(Bucephala clangula)*
    Bufflehead *(Bucephala albeola)*#
    Oldsquaw *(Clangula hyemalis)*#
    Surf scoter *(Melanitta perspicillata)*
    Ruddy duck *(Oxyura jamaicensis)*
    Common merganser *(Mergus merganser)*
    Red-breasted merganser *(Mergus serrator)*
    Hooded merganser *(Lophodytes cucullatus)*

ORDER FALCONIFORMES
  FAMILY CATHARTIDAE
    Turkey vulture *(Cathartes aura)*#

Table 9. Continued

FAMILY ACCIPITRIDAE	
Marsh hawk *(Circus cyaneus)*	
Red-tailed hawk *(Buteo jamaicensis)*	
Broad-winged hawk *(Buteo platypterus)*	
FAMILY PANDIONIDAE	
Osprey *(Pandion haliaetus)*#	
FAMILY FALCONIDAE	
Peregrine falcon *(Falco peregrinus)*	
Sparrow hawk *(Falco sparverius)*#	
ORDER GALLIFORMES	
FAMILY PHASIANIDAE	
Bobwhite *(Colinus virginianus)*#	
ORDER CICONIIFORMES	
FAMILY ARDEIDAE	
Common egret *(Casmerodius albus)*#	
Snowy egret *(Leucophoyx thula)*#	
Great blue heron *(Ardea herodias)*#	
Louisiana heron *(Hydranassa tricolor)*	
Little blue heron *(Florida caerulea)*	
Green heron *(Butorides virescens)*#	
Black-crowned night heron *(Nycticorax nycticorax)*#	
American bittern *(Botaurus lentiginosus)*	
Least bittern *(Ixobrychus exilis)*	
FAMILY THRESKIORNITHIDAE	
Glossy ibis *(Plegadis falcinellus)*	
ORDER GRUIFORMES	
FAMILY RALLIDAE	
Virginia rail *(Rallus limicola)*	
Clapper rail *(Rallus longirostris)*	
Sora *(Porzana carolina)*	
Black rail *(Laterallus jamaicensis)*	
Purple gallinule *(Porphyrula martinica)*	
American coot *(Fulica americana)*#	
ORDER CHARADRIIFORMES	
FAMILY HAEMATOPODIDAE	
American oystercatcher *(Haematopus palliatus)*#	
FAMILY CHARADRIIDAE	
American golden plover *(Pluvialis dominica)*	
Black-bellied plover *(Squatarola squatarola)*	
Semipalmated plover *(Charadrius semipalmatus)*	
Killdeer *(Charadrius vociferus)*	

Table 9. Continued.

FAMILY SCOLOPACIDAE
- Whimbrel *(Numenius phaeopus)*
- Buff-breasted sandpiper *(Tryngites subruficollis)*
- Spotted sandpiper *(Actitis macularia)*
- Willet *(Catoptrophorus semipalmatus)*#
- Greater yellowlegs *(Totanus melanoleucus)*#
- Lesser yellowlegs *(Totanus flavipes)*
- Stilt sandpiper *(Micropalama himantopus)*
- Short-billed dowitcher *(Limnodromus griseus)*
- Ruddy turnstone *(Arenaria interpres)*
- Pectoral sandpiper *(Erolia melanotos)*
- Knot *(Calidris canutus)*
- Dunlin *(Erolia alpina)*
- White-rumped sandpiper *(Erolia fuscicollis)*
- Baird's sandpiper *(Erolia bairdii)*
- Least sandpiper *(Erolia minutilla)*
- Semipalmated sandpiper *(Ereunetes pusillus)*
- Western sandpiper *(Ereunetes mauri)*
- Common snipe *(Capella gallinago)*

FAMILY LARIDAE
- Great black-backed gull *(Larus marinus)*#
- Herring gull *(Larus argentatus)*#
- Ring-billed gull *(Larus delawarensis)*
- Laughing gull *(Larus atricilla)*#
- Least tern *(Sterna albifrons)*#
- Common tern *(Sterna hirundo)*#
- Forster's tern *(Sterna forsteri)*

FAMILY RYNCHOPIDAE
- Black skimmer *(Rynchops nigra)*

ORDER COLUMBIFORMES

FAMILY COLUMBIDAE
- Rock dove *(Columba livia)*#
- Mourning dove *(Zenaidura macroura)*#

ORDER STRIGIFORMES

FAMILY TYTONIDAE
- Barn owl *(Tyto alba)*

FAMILY STRIGIDAE
- Short-eared owl *(Asio flammeus)*

ORDER CAPRIMULGIFORMES

FAMILY CAPRIMULGIDAE
- Whip-poor-will *(Caprimulgus vociferus)*

ORDER CORACIIFORMES

FAMILY ALCEDINIDAE
- Belted kingfisher *(Megaceryle alcyon)*#

Table 9. Continued.

ORDER PICIFORMES
FAMILY PICIDAE
Yellow-shafted flicker *(Colaptes auratus)*
Hairy woodpecker *(Dendrocopos villosus)*
Downy woodpecker *(Dendrocopos pubescens)*

ORDER PASSERIFORMES
FAMILY TYRANNIDAE
Eastern kingbird *(Tyrannus tyrannus)*
Eastern phoebe *(Sayornis phoebe)*
Eastern wood pewee *(Contopus virens)*

FAMILY HIRUNDINIDAE
Barn swallow *(Hirundo rustica)*#
Tree swallow *(Iridiprocne bicolor)*
Rough-winged swallow *(Stelgidopteryx ruficollis)*
Purple martin *(Progne subis)*#

FAMILY CORVIDAE
Blue Jay *(Cyanocitta cristata)*
Common crow *(Corvus brachyrhynchos)*#
Fish crow *(Corvus ossifragus)*

FAMILY PARIDAE
Carolina chickadee *(Parus carolinensis)*
Tufted titmouse *(Parus bicolor)*

FAMILY TROGLODYTIDAE
Long-billed marsh wren *(Telmatodytes palustris)*
Short-billed marsh wren *(Cistothorus platensis)*

FAMILY MIMIDAE
Mockingbird *(Mimus polyglottos)*#
Catbird *(Dumetella carolinensis)*

FAMILY TURDIDAE
Robin *(Turdus migratorius)*#

FAMILY STURNIDAE
Starling *(Sturnus vulgaris)*#

FAMILY PARULIDAE
Yellow warbler *(Dendroica petechia)*
Yellowthroat *(Geothlypis trichas)*

FAMILY PLOCEIDAE
House sparrow *(Passer domesticus)*#†

Table 9. Continued.

FAMILY ICTERIDAE
Bobolink *(Dolichonyx oryzivorus)*
Eastern meadowlark *(Sturnella magna)*
Red-winged blackbird *(Agelaius phoeniceus)*#
Common grackle *(Quiscalus quiscula)*#
Brown-headed cowbird *(Molothrus ster)*#
FAMILY FRINGILLIDAE
Pine siskin *(Spinus pinus)*
American goldfinch *(Spinus tristis)*
Rufous-sided towhee *(Pipilo erythrophthalmus)*
Sharp-tailed sparrow *(Ammospiza caudacuta)*
Seaside sparrow *(Ammospiza maritima)*
Swamp sparrow *(Melospiza georgiana)*
Song sparrow *(Melospiza melodia)*

*Sources used were this study, Figley (1974), Natural and Historic Resource Associates (1973), and Fish and Wildlife Service (1977).

#Observed in the lagoon complex.

†Not observed on the marsh, upland ecotone, or adjacent bay shore.