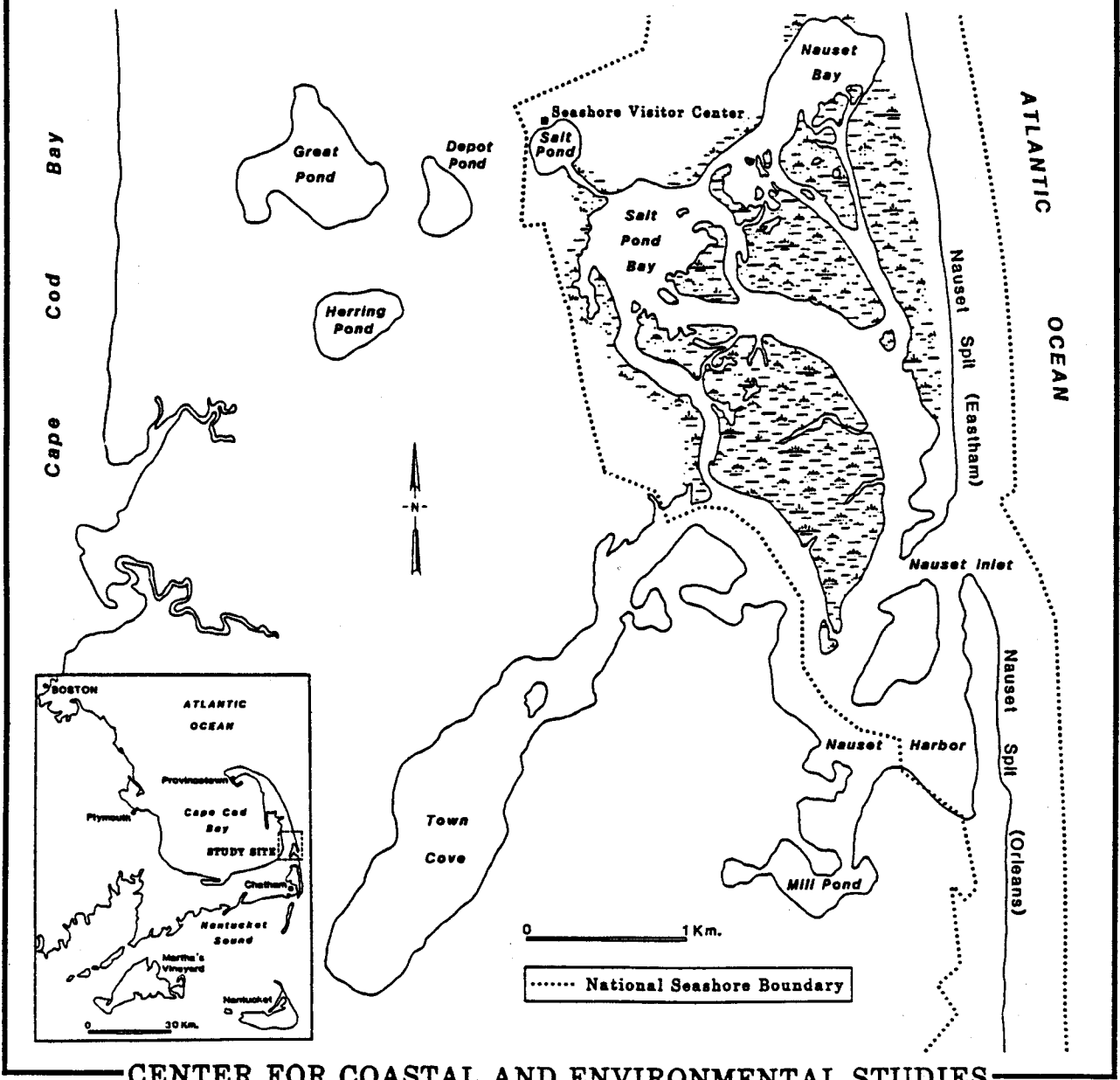


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AN ECOLOGICAL ANALYSIS of NAUSET MARSH

Cape Cod National Seashore



CENTER FOR COASTAL AND ENVIRONMENTAL STUDIES

NATIONAL PARK SERVICE COOPERATIVE RESEARCH UNIT

AN ECOLOGICAL ANALYSIS OF NAUSET MARSH

- Cape Cod National Seashore -

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85-88 5607 DI-NPS CRU Nauset Marsh

TABLE OF CONTENTS

	<u>page</u>
LIST OF FIGURES.....	v
LIST OF TABLES.....	vii
EXECUTIVE SUMMARY.....	ix
ACKNOWLEDGEMENTS.....	xiii
INTRODUCTION.....	1
Statement of Management Problem.....	1
Research Approach.....	1
Report Format.....	3
THE STUDY SITE.....	5
Inlet Dynamics.....	5
Physical Characteristics.....	5
Ecological Habitats.....	7
PRIMARY PRODUCTIVITY & BIOMASS DYNAMICS.....	13
Primary Production of Habitats.....	13
Remote Sensing Analysis.....	13
INVENTORY & HABITAT UTILIZATION OF FISHES AND MACROINVERTEBRATES.....	23
Fishes and Decapod Crustaceans.....	23
Benthic and Epibenthic Invertebrates.....	94
Habitat-Specific Studies.....	98
BIRD UTILIZATION.....	109
Introduction.....	109
Methods.....	110
Results and Discussion.....	117
Conclusions.....	143
RELATIONSHIPS BETWEEN WATER QUALITY & HABITATS.....	145
Introduction.....	145
Methods.....	145
Results and Discussion.....	149
Conclusions.....	161
LONG-TERM ENVIRONMENTAL MONITORING PROGRAM.....	165
Monitoring Objectives.....	165
Program Components.....	165
Program Implementation.....	172
LITERATURE CITED.....	175

APPENDICES (attached)

page

RESEARCH APPENDICES.....	A-1
A. Professional Manuscripts and Additional Literature.....	A-5
B. Abstracts of Professional Presentations.....	A-163
C. Student Thesis and Dissertation Research.....	A-175
D. Numerical Modeling of Nauset Inlet/Marsh.....	A-179
E. Nauset Reference Collection.....	A-223
DATA APPENDICES.....	A-239
A. Field Sampling Schedule.....	A-243
B. Inventory of Benthic and Epibenthic Invertebrates.....	A-247
C. Bird Inventory and Annelid Prey Abundance.....	A-283
D. Water Quality Study Data.....	A-319

LIST OF FIGURES

	<u>page</u>
1. Nauset Marsh regional location.....	2
2. Nauset Bay water temperature record.....	6
3. Habitat map.....	9
4. Macrophyte sampling locations.....	14
5. <u>S. alterniflora</u> live biomass estimates by harvest and radiance;	
a. sample means.....	17
b. standard deviations of means.....	17
6. <u>S. alterniflora</u> total biomass estimates by harvest and radiance;	
a. sample means.....	18
b. standard deviations of means.....	18
7. Difference between radiance and harvest <u>S. alterniflora</u> biomass estimates.....	20
8. Fauna sampling locations.....	26
9. Fauna species richness.....	30
10. Menhaden length-frequency.....	79
11. Atlantic herring length frequency.....	80
12. Pollack length frequency.....	82
13. Common mummichog length frequency.....	83
14. Atlantic silverside length frequency.....	84
15. Four-spined stickleback length frequency.....	85
16. Three-spined stickleback length frequency.....	86
17. Northern pipefish length frequency.....	88
18. Bluefish length frequency.....	89
19. Tautog length frequency.....	90
20. Cunner length frequency.....	91
21. Inshore sand lance length frequency.....	92
22. Winter flounder length frequency.....	93
23. Lobster length frequency.....	95
24. Sand shrimp length frequency.....	96
25. Green crab length frequency.....	97
26. Hard clam shell length growth in eelgrass vs. sand.....	100
27. Hard clam shell width growth in eelgrass vs. sand.....	101
28. Hard clam shell height growth in eelgrass vs. sand.....	102
29. Size selectivity in predation on tethered green crabs.....	107
30. Bird sampling locations.....	111
31. Effect of tidal stage on Nauset Bay bird use - May.....	118
32. Effect of tidal stage on Nauset Bay bird use - July.....	119
33. Effect of tidal stage on Nauset Bay bird use - October.....	120
34. Seasonal abundance of shorebirds.....	121
35. Effect of tidal stage on habitat use of Nauset Bay by;	
a. Herring Gull.....	128
b. Ring-billed Gull.....	128
c. American Black Duck.....	128
d. American Crow.....	128
e. Black-bellied Plover.....	129
f. Semipalmated Plover.....	129
g. Lesser and Greater Yellowlegs.....	129
h. Semipalmated Sandpiper.....	130

	<u>page</u>
i. Short-billed Dowitcher.....	130
j. Dunlin.....	130
36. Effect of tidal stage on habitat use of Skiff Hill marsh by;	
a. American Black Duck.....	131
b. Red-breasted Merganser.....	131
c. Great Blue Heron.....	131
d. Herring Gull.....	132
e. Ring-billed Gull.....	132
f. American Crow.....	132
37. Effect of tidal stage on habitat use of Salt Pond Bay by;	
a. American Black Duck.....	133
b. Red-breasted Merganser.....	133
c. Bufflehead.....	133
38. Water quality sample locations.....	146
39. Ebb and flood tide total suspended seston concentration.....	151
40. Ebb and flood tide inorganic suspended seston concentration.....	152
41. Ebb and flood tide organic suspended seston concentration.....	153
42. Ebb and flood tide ammonia concentration.....	154
43. Ebb and flood tide nitrate-nitrite concentration.....	156
44. Instantaneous volume flux.....	158
45. Tidal transport of total suspended seston.....	160
46. Tidal transport of ammonia.....	162
47. Tidal transport of nitrate-nitrite.....	163

LIST OF TABLES

	<u>page</u>
1. Predicted physical changes to system due to southerly inlet breach.....	8
2. Areal extent of habitats.....	10
3. Fauna sampling habitats and techniques.....	24
4. Description of otter trawl sampling stations.....	25
5. Ichthyoplankton sampling schedule.....	27
6. Fish and decapod species composition.....	31
7. Fish and decapod total abundance.....	37
8. Fish and decapod total abundance collected by trawl.....	42
9. Fish and decapod total abundance collected by seine.....	45
10. Fish and decapod mean abundance collected by seine.....	47
11. Fish and decapod mean abundance collected by trawl.....	48
12. Fish and decapod monthly abundance for Station 4.....	50
13. Fish and decapod monthly abundance for Station 6.....	51
14. Fish and decapod monthly abundance for Station 7.....	52
15. Fish and decapod total abundance collected at night by trawl.....	54
16. Fish and decapod monthly abundance collected in eelgrass by seine.....	56
17. Fish and decapod monthly abundance collected over gravel by seine.....	57
18. Fish and decapod monthly abundance collected over sand/mud by seine.....	58
19. Summary of fish and decapod abundance collected by trawl for habitats.....	60
20. Summary of fish and decapod abundance collected by seine for habitats.....	61
21. Fish and decapod monthly abundance for Station 1.....	63
22. Fish and decapod monthly abundance for Station 3.....	64
23. Fish and decapod monthly abundance for Station 2.....	65
24. Fish and decapod monthly abundance for Station 5.....	66
25. Mode of utilization of system by fishes and decapods.....	68
26. Number of fish eggs and larvae collected.....	74
27. Ichthyoplankton species collected.....	76
28. Fish and juvenile lobster collected by night lighting.....	78
29. Decapod species tethered in habitats for predation study.....	106
30. List of bird species sampled.....	112
31. Bird sampling intensity at;	
a. Nauset Bay.....	113
b. Skiff Hill.....	114
c. Salt Pond Bay.....	115
32. Nauset Bay habitat use by foraging birds.....	134
33. Skiff Hill habitat use by foraging birds.....	135
34. Salt Pond Bay habitat use by foraging waterfowl.....	136
35. Importance of habitat to bird use.....	137
36. Bird foraging at Nauset Bay.....	139
37. American Black Duck use of Salt Pond Bay and Skiff Hill.....	140
38. Benthic invertebrate densities in 10 cm cores.....	141
39. Benthic invertebrate densities in 30 cm cores.....	142
40. Infaunal shorebird prey.....	144
41. Water quality sample habitat descriptions.....	147
42. General water quality characteristics.....	150
43. Variability analyses of water quality between summer samplings.....	157
44. Flood and ebb tide volume flux.....	159
45. Summary of long-term monitoring program.....	174

EXECUTIVE SUMMARY

The 945 ha Nauset Marsh (Eastham and Orleans, Massachusetts) is a back-barrier estuary with direct exchange through an inlet to the Atlantic Ocean. Short form Spartina alterniflora marsh encompasses 35% of the system. Other important habitats include intertidal mudflats (12%), intertidal sandflats (11%), and eelgrass (Zostera marina) beds (6+ %). Thirty-three percent of the system is associated with tidal kettle ponds and shallow tidal channels (< 1 - 3m). A paucity of ecological information exists for Nauset Marsh, and thus, the objective of this study was to obtain a quantitative ecological data base of this Seashore system so that resource managers could more effectively assess significant adverse effects. Nauset Marsh is especially threatened by the cumulative effects of residential growth. Further, natural changes to the system's ecology will occur in association with migration of the geomorphically active Nauset Inlet. Our detailed data base and implementation of a long-term monitoring program, coupled with our interpretations of the functional ecology of major habitats, will provide the foundation for effective management and protection of Nauset's estuarine resources.

MACROPHYTE BIOMASS AND PRODUCTION

Net primary productivity estimates were made for the major macrophyte dominated habitats. Aboveground primary productivity of short form S. alterniflora was $664 \text{ g m}^{-2} \text{ y}^{-1}$. Productivity of Z. marina was estimated to range from $444 - 987 \text{ g m}^{-2} \text{ y}^{-1}$. The marsh creekbank habitat was dominated by an intertidal zone of furoid algae (Ascophyllum nodosum ecad. scorpioides, $1179 \text{ g m}^{-2} \text{ y}^{-1}$; Fucus vesiculosus, $426 \text{ g m}^{-2} \text{ y}^{-1}$), mixed intertidal filamentous algae ($91 \text{ g m}^{-2} \text{ y}^{-1}$), and a subtidal zone of assorted macroalgae ($68 \text{ g m}^{-2} \text{ y}^{-1}$). Intertidal mudflats were dominated by Cladophora gracilis, with net production ranging from $59 - 637 \text{ g m}^{-2} \text{ y}^{-1}$. These angiosperm and macrophyte dominated habitats produce over $3 \times 10^6 \text{ kg y}^{-1}$ of biomass ($1.2 \times 10^6 \text{ kg Carbon y}^{-1}$). A significant 28% of this carbon production is derived from the Z. marina and macroalgae habitats. Although S. alterniflora is considered the major macrophyte primary producer in Nauset Marsh and other north temperate salt marshes, it is concluded that other habitats also contribute significantly to total system carbon production.

FAUNAL INVENTORY AND HABITAT STUDIES

Forty-nine species of fish and 11 decapod crustacean species were collected during the 1 year inventory phase of the study. In trawl collections, six fishes, three-spined stickleback (Gasterosteus aculeatus), four-spined stickleback (Apeltes quadracus), Atlantic herring (Clupea harengus harengus), winter flounder (Pseudopleuronectes americanus) and inshore sand lance (Ammodytes americanus), made up 87.2% of the total fishes collected, with common mummichog (Fundulus heteroclitus, 3.5%) and northern pipefish (Syngnathus

fuscus, 3.3%) of somewhat less importance. In shallow waters, where collections were made by seine, the fishes were dominated by two killifishes (common mummichog and striped mummichog - Fundulus majalis), Atlantic silverside (Menidia menidia) and four-spined stickleback. These together made up 94.2% of the total number of individuals. Decapod crustaceans, in both trawl and seine collections, were dominated by sand shrimp (Crangon septemspinosa) and green crab (Carcinus maenas) which together made up 91.9 and 7.0%, respectively.

In terms of habitat distribution of fauna, the eelgrass habitat was found to support the greatest diversity for all fish and invertebrate groups collected (gastropods, bivalves, isopods, amphipods, decapods, fishes) except for polychaete worms (mud substrate preferred). To further evaluate habitat relationships we investigated habitat-specific survival rates of select species as a measure of relative habitat quality and nursery function. Based on tethering studies conducted in June 1988, greatest rates of predation were in eelgrass (25%), a high rate on tidal creek peat reefs (17%) and the lowest rate in mud (10%) and sand-bottom habitats (11%). Studies to determine the actual predators were not conducted. Eelgrass was not found to be an effective refuge from predation as found for more southern sites (e.g., Chesapeake Bay).

Aspects of the life history of select fish and decapod crustacean species were addressed in this study: American eel (Anquilla rostrata), menhaden (Brevoortia tyrannus), Atlantic herring, white hake (Urophycis tenuis), pollock (Pollachius virens), common mummichog, Atlantic silverside, three-spined stickleback, four-spined stickleback, northern pipefish, bluefish (Pomatomus saltatrix), tautog (Tautoga onitis), cunner (Tautoglabrus adspersus), inshore sand lance, grubby (Myoxocephalus aeneus), winter flounder, American lobster (Homarus americanus), sand shrimp, and green crab. Our studies of American lobster were most interesting as we discovered an undescribed habitat for juveniles. Juvenile lobster ($\bar{x}$ = 26.7 mm carapace length) density in peat reef habitat averaged 2.5 individuals m^{-2} (range 0 - 5.7). These reefs consisted of blocks of S. alterniflora that had separated from the marsh and fallen into the adjacent subtidal creek.

Habitat utilization by birds foraging at Nauset Marsh was quantified by bird species, habitat, tidal stage and season using weekly observations at three study sites. Habitats included both exposed and flooded intertidal mudflats, subtidal bottom, overwashed sand, open water, marsh surface and marsh pool. Most avian usage was by migrating shorebirds and wintering waterfowl. Shorebird use, dominated by Semipalmated Sandpipers (Calidris pusilla), Short-billed Dowitchers (Limnodromus griseus), Black-bellied Plovers (Pluvialis squatarola) and both Lesser and Greater Yellowlegs (Tringa flavipes and T. melanoleuca, respectively), was concentrated during the southward migratory passage from July through October. High Dunlin (Calidris alpina) counts continued into early December. Waterfowl usage was dominated by American Black Ducks (Anas rubripes) which wintered from October to early April, although Red-breasted Mergansers (Mergus serrator) and Buffleheads (Bucephala albeola) were also common during this period.

Avian habitat use was dependent upon physical accessibility through the tidal cycle; thus, most feeding by shorebirds, gulls and waterfowl occurred when mudflats could be reached by wading or swimming birds. By far, the most

intensively used habitats were intertidal mudflats, utilized by shorebirds at low tide and gulls at low and mid-tides. Open water and subtidal habitats, sampled at Salt Pond Bay, were most important for wintering waterfowl. American Black Ducks additionally fed on the S. alterniflora marsh surface during high tide, but this habitat was otherwise rarely used by foraging birds.

WATER QUALITY AND HABITAT RELATIONSHIPS

Water quality measurements were made over two study dates (August 1987, February 1988) and at several sites throughout the system, a) to serve as a baseline of water quality, and b) to evaluate relationships between water quality and different habitats (inlet-ocean, eelgrass, intertidal mudflat, salt marsh). Water quality parameters evaluated include: total, organic, and inorganic suspended seston; dissolved oxygen; nitrate-nitrite, ammonia, total dissolved nitrogen, and dissolved organic nitrogen; orthophosphate, total dissolved phosphorus, and dissolved organic phosphorus; and dissolved organic carbon.

For total and inorganic suspended seston there was an increase in concentration from the inlet to the more typical estuarine dominated sampling stations. This may be a reflection of bioturbation and wind-wave resuspension within the system. With respect to nutrients, the dominant form of dissolved inorganic nitrogen in summer and to a lesser degree in winter, was ammonia, as reported in other New England salt marshes. Ebb tide ammonia concentrations in August were consistently highest in the mudflat-dominated habitat as opposed to other parts of the system. Further, the mean ebb concentration was significantly greater than the flood at this station. This enrichment of mudflat ebb tide waters may be attributed to a combination of several factors including, diffusion or regeneration of ammonia from the sediments to the water column, runoff, seepage, leaching from the marsh surface and vegetation, and remineralization from decomposition of organics. Nitrate-nitrite concentration showed a similar trend with respect to habitat. No consistent concentration-habitat relationships were noted for the other water quality constituents studied.

Although the results were not clearly consistent, it was determined that the magnitude and direction of net nutrient exchange varies within different habitats, thus demonstrating that habitats within salt marsh/estuarine systems function differently with respect to nutrient processing.

NUMERICAL MODELING

A one-dimensional numerical model was developed to evaluate the system's tidal parameters for present conditions versus a system configuration with the inlet at a more southern location. Formation of a southern inlet increases tidal range and tidal prism in the deeper southern section while decreasing these parameters in the shallower northern section. It is predicted that residence time will decrease (i.e., circulation improves) in the southern end of the system by about 6% and increase by roughly 7% in the northern part. These predicted changes in tidal circulation parameters within the system are likely to influence

many ecological characteristics, most notably habitat boundaries and relative areal extent of habitats.

LONG-TERM MONITORING PROGRAM

The proposed Nauset Marsh monitoring program employs a simple and cost-effective approach to be coordinated by the National Park Service through close cooperation with local towns, state agencies, conservation-oriented interest groups and the university sector.

The monitoring program includes several components that can be implemented in a stepwise manner. Phase one of the program should include monitoring of physical parameters (water temperature and salinity), eelgrass wasting disease infection rates, shorebird counts and evaluation of habitat boundary changes. As the network of monitoring personnel becomes established and long-term funds are allocated to the Nauset monitoring effort, then the second phase should be implemented. The proposed program components include, annual evaluation of hard clam growth rate, eelgrass epiphyte biomass studies, and water quality analysis. The monitoring components of phases one and two have been carefully selected so that resource managers will be able to detect both subtle and dramatic changes in the system as imposed by human and natural influences.

It is recommended that the results of the monitoring program be reviewed and synthesized on at least an annual basis to evaluate potential changes to the ecological/environmental status of the system. Results of the monitoring program, coupled with the detailed ecological evaluations of our 3 year inventory and assessment, will enable resource managers to make scientifically-based management decisions concerning the maintenance of environmental quality in Nauset Marsh.

ACKNOWLEDGEMENTS

This study represents the collective efforts of numerous individuals. We extend thanks to Susan Kaiser and Barbara Baker for their dedicated assistance with field collections, laboratory analyses and report preparation. Additional assistance during many of our sampling trips was provided by Dave Able, Diana Barshaw, Loren Cohen, Steve Halterman, Joe Luczkovich, Richard Orson, I. Maiden, Jay Burnett, Andy Rowan, Wayne Spenser, Terry Westhead, and Kim Wilson. Michael Siegel provided cartographic expertise. Robert Connell, of the New Jersey Division of Water Resources, conducted much of the water quality analyses. With respect to species identification and/or verification, assistance was provided by Martine Villalard-Bohnsack (Roger Williams College), Ann Frame (National Marine Fisheries Service), Cindy Fuller (Rutgers University) and Kim Wilson (Rutgers University) for algae, polychaetes, bivalves and amphipods, respectively. Blair Nikula (Chatham, MA) graciously provided his long-term records of shorebird observations throughout the Nauset system. We thank Frederick T. Short (University of New Hampshire) for analyzing eelgrass samples for wasting disease and Michael Hardisky (University of Scranton) for working with us on analysis of S. alterniflora radiometer data.

Special thanks go to Superintendent Olsen and the Seashore staff for their full cooperation during all aspects of the study. We are grateful for the always present logistical support and advice provided by Henry Lind (Natural Resources Department, Eastham) and Sandy Macfarlane (Shellfish Department, Orleans). Also, thanks go to Cecil Newcomb for use of his fishing vessel during our winter water quality study. Finally, Capt. H. Morgan is gratefully acknowledged for advising our research team throughout.

This report was reviewed by the Superintendent and staff of Cape Cod National Seashore, by Michael Soukup (Chief Scientist, North Atlantic Region), P. A. Buckley (Director, NPS Cooperative Research Unit at Rutgers) and James A. Allen (North Atlantic Region). Further, anonymous reviewers provided comments on our published, in press and in review manuscripts. We thank them all for their input.

Major funding for this study was provided by the National Park Service, administered through the Cooperative Research Unit at Rutgers University. Additional funding was provided by the National Park Service North Atlantic Region and the Center for Coastal and Environmental Studies at Rutgers University. The Alabama Marine Environmental Sciences Consortium provided in-kind support.

INTRODUCTION

STATEMENT OF MANAGEMENT PROBLEM

Nauset Marsh is the most extensive and least disturbed salt marsh/estuarine system in Cape Cod National Seashore (Fig. 1). The overall objective of our three year study, initiated in July 1985, was to obtain a quantitative ecological data base and understanding of the functional ecology of this Seashore resource so that resource managers can effectively assess significant adverse effects on the system. For example, Nauset Marsh is especially threatened by the cumulative effects of encroaching residential development. The mere detection of these often subtle and long-term impacts requires a baseline characterization and, as important, an understanding of ecosystem interaction and dynamics. Further, a complete assessment of the system is needed to evaluate the ecological effects of serious oil spills. The Cape Cod Planning and Economical Development Commission (1981) has designated Nauset Marsh as being particularly vulnerable to oil spill impacts.

Ecological changes related to natural processes can also be evaluated upon establishment of a quantitative understanding of the system's functional ecology. As the geomorphology of Nauset Inlet is altered by storms, long-term sea level rise, and other events/processes, the ecology of the marsh/estuarine system will certainly respond to subsequent changes in circulation and hydrology, salinity structure and net sedimentation rate.

RESEARCH APPROACH

The research approach employed in our investigation focuses on the system's major habitats including, salt marshes, eelgrass beds, intertidal mudflats, mussel beds, tidal channels, and tidal kettle ponds. Within this habitat-specific framework, this Final Report includes;

- 1) an assessment of primary production and biomass dynamics of the macrophyte-dominated habitats,
- 2) a seasonal inventory of fishes, decapod crustaceans, benthos and birds, including select species life history studies and habitat-specific studies, and
- 3) an evaluation of circulation and water quality dynamics throughout the system.

In addition to evaluating the general ecological and nursery functions of Nauset Marsh, a major objective of this study was to recommend a long-term environmental monitoring program. Implementation of the monitoring program presented in this Final Report, coupled with our detailed ecological evaluations, will enable resource managers to make scientifically-based management decisions concerning the maintenance of environmental quality in Nauset Marsh.

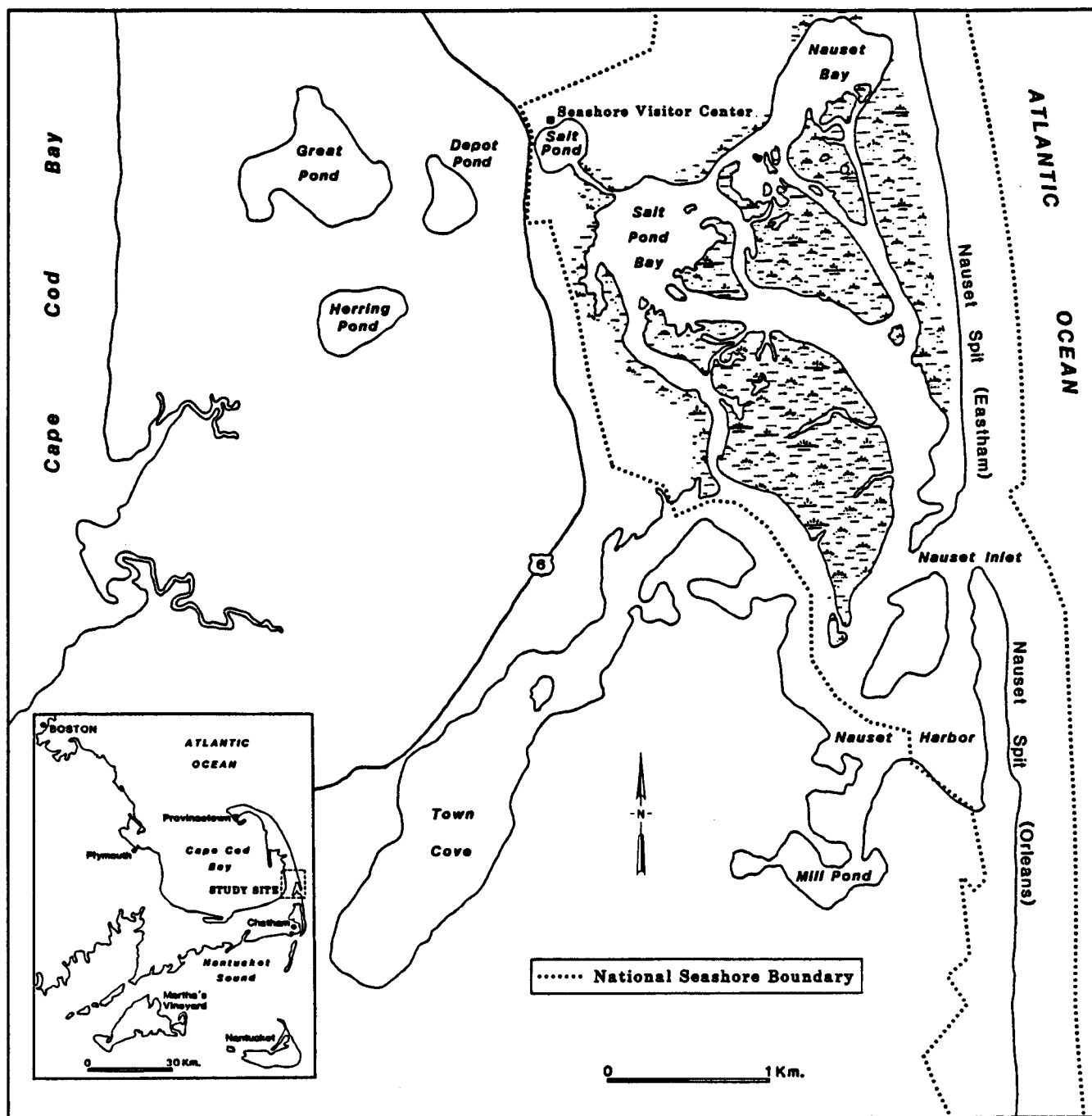


Figure 1. The Nauset Marsh-barrier beach complex, Cape Cod National Seashore. Redrawn from USGS 7.5 minute topographic map (Orleans quadrangle, 1974).

REPORT FORMAT

The Nauset Marsh ecological study has been ongoing for over 3 years. During that period extensive amounts of data have been collected and interpreted. Much of this information is now in professional manuscript format (i.e., published, in press, in review, or in preparation). These manuscripts and associated products (i.e., abstracts from professional meetings, theses abstracts and technical research and progress reports) from our research efforts are included in the RESEARCH APPENDICES. These appendices are a major part of this Final Report. Data from various aspects of the study are presented in the DATA APPENDICES.

THE STUDY SITE

INLET DYNAMICS

The 945 ha Nauset Marsh (Eastham and Orleans, Massachusetts) is a back-barrier estuary with direct exchange through a tidal inlet (Fig. 1). The barrier spit system fronting Nauset Marsh has a history of dynamic geomorphology associated with inlet migration (Aubrey and Speer 1984) and overwash dynamics (Zaremba and Leatherman 1984, 1986; Leatherman and Zaremba 1986). Based on an analysis of historical charts (from 1779) and aerial photography (from 1938), Aubrey and Speer (1984) note that the preferred location of Nauset Inlet is at the southern end of the system at Nauset Harbor. Beginning in the 1950's, perhaps in response to an increased storm frequency, the Inlet began an active northward migration. Then, in the late 1950's and early 1960's numerous storms resulted in re-establishment of the Inlet to the south. Since 1965 the Inlet has again been steadily extending northward at a rate of approximately 100 m y^{-1} . The Inlet is now at its northernmost location, when compared to historical records. This northward migration will likely end when a storm creates a breach at the energetically preferred southern location. Because of deeper channels and a greater tidal volume to the south, as opposed to the shallow frictionally-dominated northern channels, an Inlet location to the south is predicted (Aubrey and Speer 1984, 1985; Speer and Aubrey 1985).

PHYSICAL CHARACTERISTICS

The Nauset Marsh estuary is an ocean-dominated system. During the course of our study mean salinity ranged from 24 - 33 ppt. This range is represented by water column measurements taken during all seasons, at numerous stations throughout the system, and over a range of tidal stages. Freshwater input from surface flow and groundwater seepage appears to be negligible. Based on a 1 1/2 year record, water temperature in Nauset Bay ranged from -2°C to 27°C (Fig. 2).

Tides in the system are flood dominated, being characterized by, a) flood tides of shorter duration than ebb, and b) flood velocities greater than ebb (Aubrey and Speer 1985). Tidal duration is asymmetric. The ocean tide just outside of Nauset Inlet floods and ebbs for equal durations (average of 6 + hrs), while in Nauset Bay the average flood duration is 3 hours less than the ebb. Further, because the estuary's tidal channels are relatively shallow ($< 1 - 3 \text{ m}$) and highly dissected, there is a strong frictional component resulting in tidal energy dissipation. For instance, tidal range at an ocean tide gauge (Aubrey and Speer 1985) was about 2 m, while being reduced to 1 m at Nauset Bay. The reach from the Inlet to Nauset Bay is defined by extremely shallow channels and extensive intertidal sand flats.

Tidal parameters in Nauset Marsh, such as tidal range, tidal prism, and particle residence times, are influenced by the location of the Inlet. A one-dimensional, multi-branch numerical model was developed for the Nauset Marsh system to compare these tidal circulation factors for the present inlet location and the previously discussed southern inlet location (see Research Appendix D for complete model). The numerical model clearly demonstrates the effect of

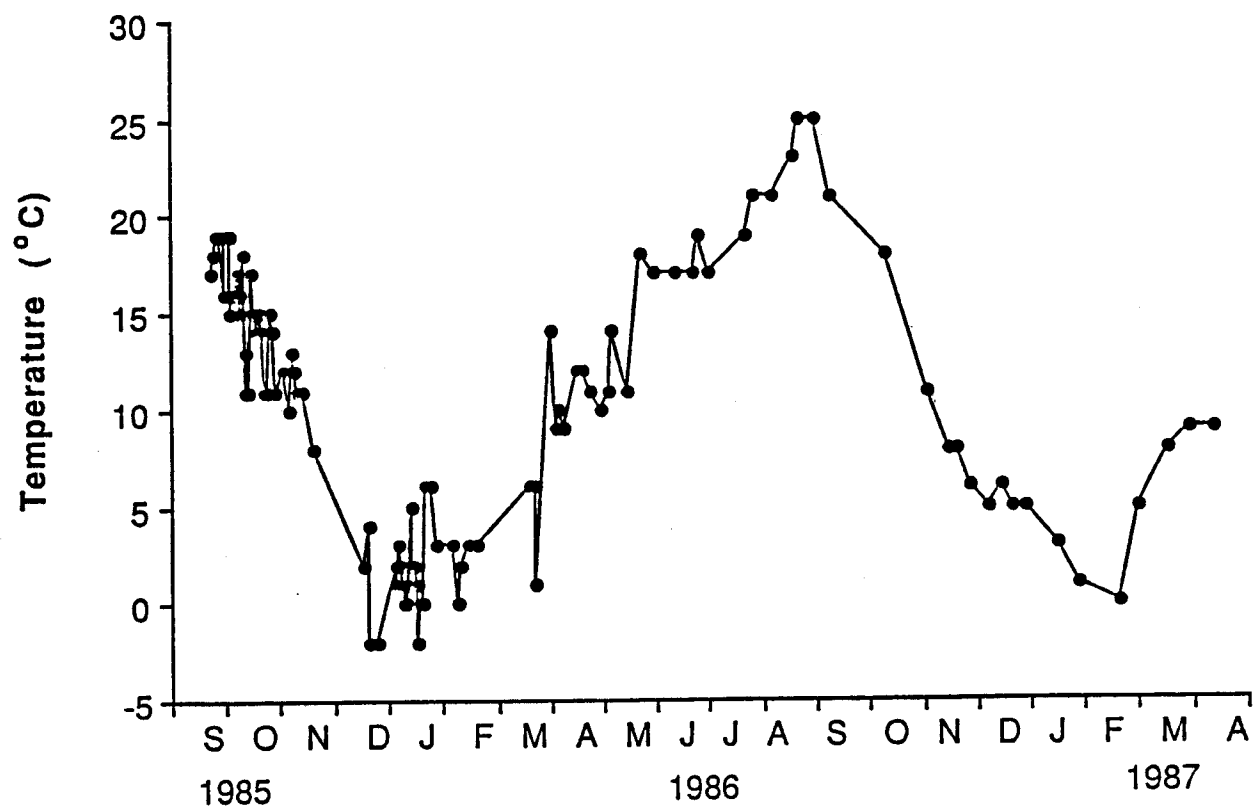


Figure 2. Water temperature from Nauset Bay taken at 2 - 10 day intervals from September 1985 to April 1987. Measurements were taken during daytime hours and near high tide.

frictional dampening in the system as tidal range is consistently smaller in the shallow northern section (Table 1). However, particle residence time is shorter in the northern section because it is shallower and tidal prism is reduced (Table 1).

Formation of an inlet at the southern end of the barrier spit (in the vicinity of Nauset Harbor; see Fig. 3) increases tidal range and tidal prism in the deeper southern section while decreasing these parameters in the shallower northern section (Table 1). It is predicted that residence time will decrease (i.e., circulation improves) in the southern end of the system by about 6% and increase by roughly 7% in the northern part with creation of a more southern inlet (Table 1). These predicted changes in tidal circulation parameters within the system are likely to influence many ecological characteristics, most notably habitat boundaries and relative areal extent of habitats. Eelgrass habitats will most likely be altered (i.e., lost) as the flood tidal delta associated with a more southern inlet may effectively cover the now extensive meadows.

ECOLOGICAL HABITATS

True-color vertical aerial photographs (scale 1:18,000; date - October 22, 1982) were used to map the major habitat types of the system. Pseudo-vertical aerial photographs (true-color) from an August 1985 flight were used to detect any significant habitat changes which may have occurred since the October 1982 flight. These aeriels were taken from a small fixed wing aircraft with a hand-held camera, and thus are not true verticals, although adequate for detecting major boundary changes (i.e., inlet and barrier spit locations).

The habitats mapped included Spartina alterniflora-dominated marsh and associated creeks and pools, intertidal sand flats, intertidal mud flats, eelgrass (Zostera marina) beds, blue mussel (Mytilus edulis) beds, barrier beach/dune and freshwater wetlands. Open water, such as major tidal creeks and tidal kettle ponds, was also included. All habitat boundaries were delineated from the aerial photographs, except for the eelgrass and mussel beds. These habitats were poorly discernable on the aeriels, and therefore location and approximate boundaries were obtained from the Town of Orleans Shellfish Department. Ground-truthing of the entire habitat map was performed in spring-summer 1986.

Salt marsh dominates, encompassing 35% of the system (Fig. 3; Table 2). Extensive areas of short form S. alterniflora characterize the marsh, with the tall form occasionally found as narrow bands (< 1 - 3 m) along tidal creeks. Patches of S. patens and Distichlis spicata are rarely encountered. Nauset Marsh is not mosquito-ditched except for a small area adjacent to the barrier spit, and thus marsh pools are numerous and an intricate network of small tidal creeks exists. Salt Pond Bay and Nauset Bay contain most of the system's 115 ha (12%) of intertidal mudflat habitat. Patches of the green alga, Cladophora gracilis, occur throughout this habitat. Intertidal sand flats (105 ha, 11%) are a dynamic component of the system and mostly associated with the inlet's flood tidal delta. New Island is dominated by supratidal sand flat habitat. Created after a 1972 storm, it is the remnant of a southernmost extension of Nauset spit - Eastham (Zaremba and Leatherman 1984). Eelgrass beds occupy 55 ha or 6% of the system; however, recent observations indicate that this habitat has expanded, especially in Nauset Harbor, since the aerial flight and subsequent ground truthing. Open water accounts for 33% (315 ha) of the system and is associated with tidal kettle ponds

Table 1. Summary of results from the numerical model predicting changes in the system's physical parameters with an inlet breach to the southern location (see Research Appendix D for details of the model and results).

Location	<u>Tidal Range (m)</u>		<u>Particle Residence Time (hrs)</u>		<u>Tidal Prism (m³ x 1000)</u>	
	Present	Southern	Present	Southern	Present	Southern
Ocean (1,1) ¹	1.97	1.97	27.4	27.0	5630	5710
Inlet (3,3)	1.87	1.87	28.9	24.1	-	-
<u>Southern Section</u>						
Nauset Harbor (27,29)	1.48	1.54	34.4	32.3	2220	2470
Town Cove (41,43)	1.28	1.32	48.7	46.3	976	1030
Town Cove Channel (32,34)	1.39	1.44	34.9	37.5	1530	1610
<u>Northern Section</u>						
North Channel (54,54)	1.33	1.31	20.3	21.3	375	385
Salt Pond Bay (58,58)	1.10	1.06	17.5	18.4	122	115
Nauset Bay (68,68)	1.10	1.06	24.4	25.2	147	139

¹ Numbers refer to the grid points of the numerical model (see model in Research Appendix D). Key: (present configuration grid point number, southern grid point number).

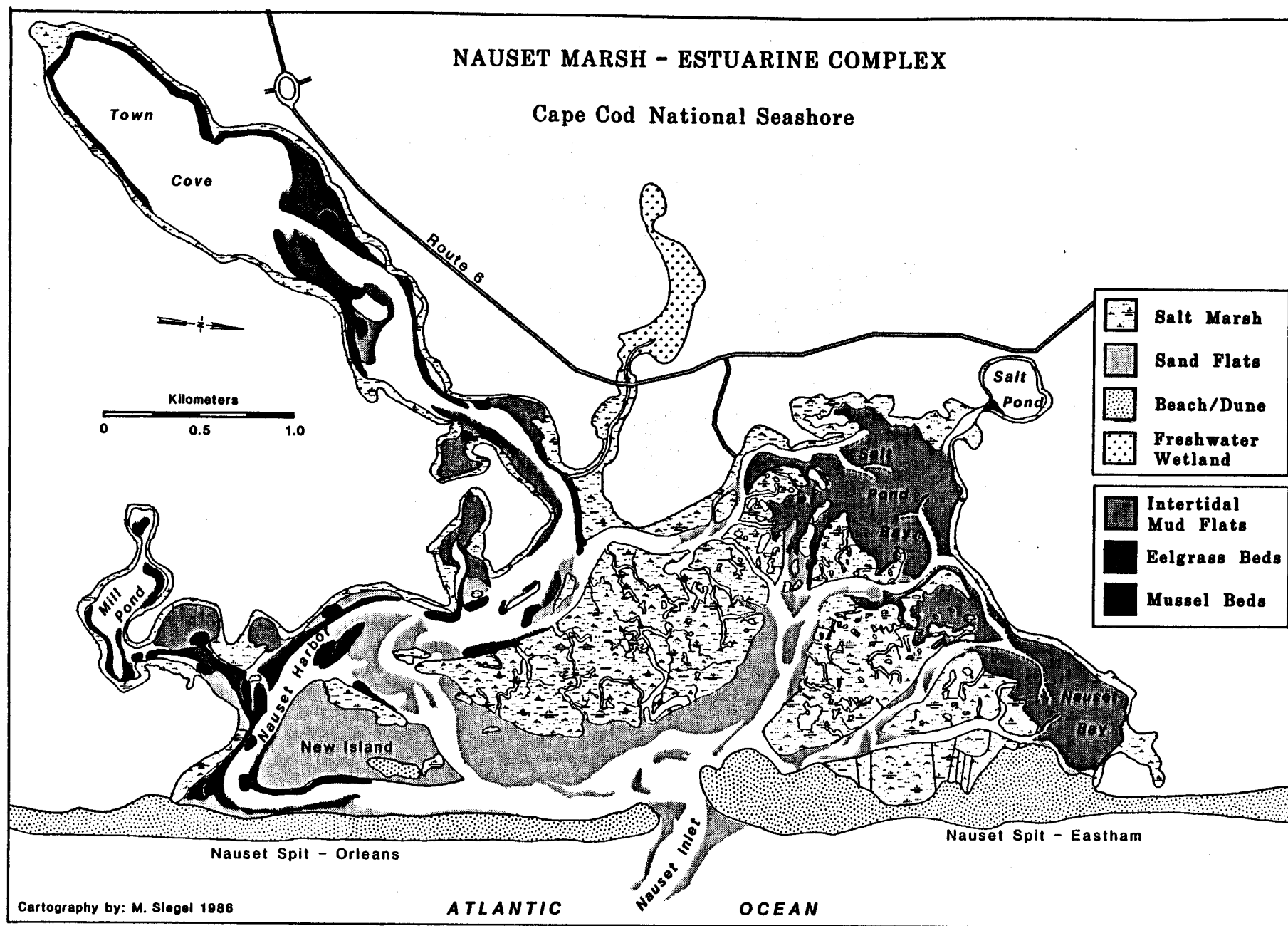


Figure 3. Habitat map of the Nauset Marsh system. Based on 1982 aerial photographs with 1986 ground-truth.

Table 2. Areal extent of habitat types in the Nauset Marsh estuary as of 1986.

Habitat	Area		Percent of Total Area
	acres	hectares	
Salt Marsh ¹	815	330	35
Intertidal Mud Flats	290	115	12
Sand Flats	255	105	11
Eelgrass Beds	140	55	6
Freshwater Wetland	40	15	2
Mussel Beds	20	10	1
Water (Subtidal) ²	775	315	33
Nauset Marsh Total	<u>2335</u>	<u>945</u>	<u>100</u>

¹Includes network of minor tidal creeks and marsh pools.

²Includes subtidal portions of major channels and tidal kettle ponds. Eelgrass beds are also associated with subtidal channels and ponds, but area of this habitat is determined separately.

(Town Cove, Mill Pond and Salt Pond) and major tidal channels throughout the system.

Salt marsh creekbanks are another habitat focused on in this study. A typical vertical creekbank profile at Nauset Marsh contains an intertidal zone of furoid algae (Ascophyllum nodosum ead. scorpioides, Fucus vesiculosus) usually associated with tall S. alterniflora, an intertidal zone of filamentous algae attached to the substrate of exposed creekbank peat, and a subtidal zone of assorted macroalgae growing on chunks of marsh peat that have fallen into the tidal creek. These irregularly sized peat blocks, settled along the margins of deeper tidal channels, are referred to as peat reef habitat (Able et al. 1988, reprinted in Research Appendix A-1a).

Peat blocks generally range from 1 - 4 m long and 1 m wide. In a study of peat reef formation in Nauset Marsh, Rowan (1988) counted 60 submerged blocks, often in 2 or 3 coexisting layers, along an 80 m length of channel (see Research Appendix C for Rowan's thesis abstract). We surveyed the entire system by boat and found over 6 km linear distance of peat reef habitat, thus demonstrating its potential significance.

PRIMARY PRODUCTIVITY & BIOMASS DYNAMICS OF ANGIOSPERM AND MACROALGAE DOMINATED HABITATS

PRIMARY PRODUCTION OF HABITATS

Primary production and biomass estimates of the major macrophyte-dominated habitats in Nauset Marsh will provide a baseline for long-term monitoring and provide background data relative to our studies of habitat utilization by estuarine fauna and nutrient interactions. In this study we provide seasonal estimates of biomass and net primary production for S. alterniflora (tall and short form, aboveground and belowground), eelgrass (aboveground only), and macroalgae-dominated habitats (intertidal mudflats, intertidal/subtidal peat reefs).

Sample areas and frequency of sample collections are included in Fig. 4 and Data Appendix A, respectively. Presentation of the data and appropriate interpretations are included as professional manuscripts (Research Appendix A-1). Findings relative to the eelgrass study are in a manuscript entitled "Production ecology of eelgrass (Zostera marina L.) in a Cape Cod salt marsh - estuarine system, Massachusetts," Aquatic Botany (Roman and Able 1988). A second manuscript submitted for consideration in Estuarine, Coastal and Shelf Science includes results from the other macrophyte-dominated habitats. The entire macrophyte data set, including biomass and productivity estimates and species composition, is found in these manuscripts.

ANALYSIS OF SPARTINA ALTERNIFLORA PRODUCTION BY REMOTE SENSING¹

INTRODUCTION

Recent studies have demonstrated the utility of monitoring salt marsh primary production by remote sensing from both ground (Hardisky et al. 1983, 1984) and satellite (Gross et al. 1987) levels. The objective of this aspect of the study was to determine the scientific feasibility of introducing remote sensing techniques to the Nauset Marsh long-term monitoring program.

METHODS

A hand-held Mark II radiometer, on extended loan from the NASA Goddard Space Flight Center, was used to estimate canopy reflectance from the abovementioned short S. alterniflora study area (see Fig. 4). Canopy reflectance of tall S. alterniflora was not evaluated in this study. Measurements were taken in summer on 7 dates from August 1985 to June 1987. At each sample date, and immediately prior to harvesting, the radiometer was leveled approximately 1.5 m above the top of the plant canopy for each of the 10 randomly selected quadrats. At this height the field of view of the radiometer is approximately 0.25 m², the size

¹Prepared by Michael A. Hardisky, Biology Department, University of Scranton, Scranton, PA.

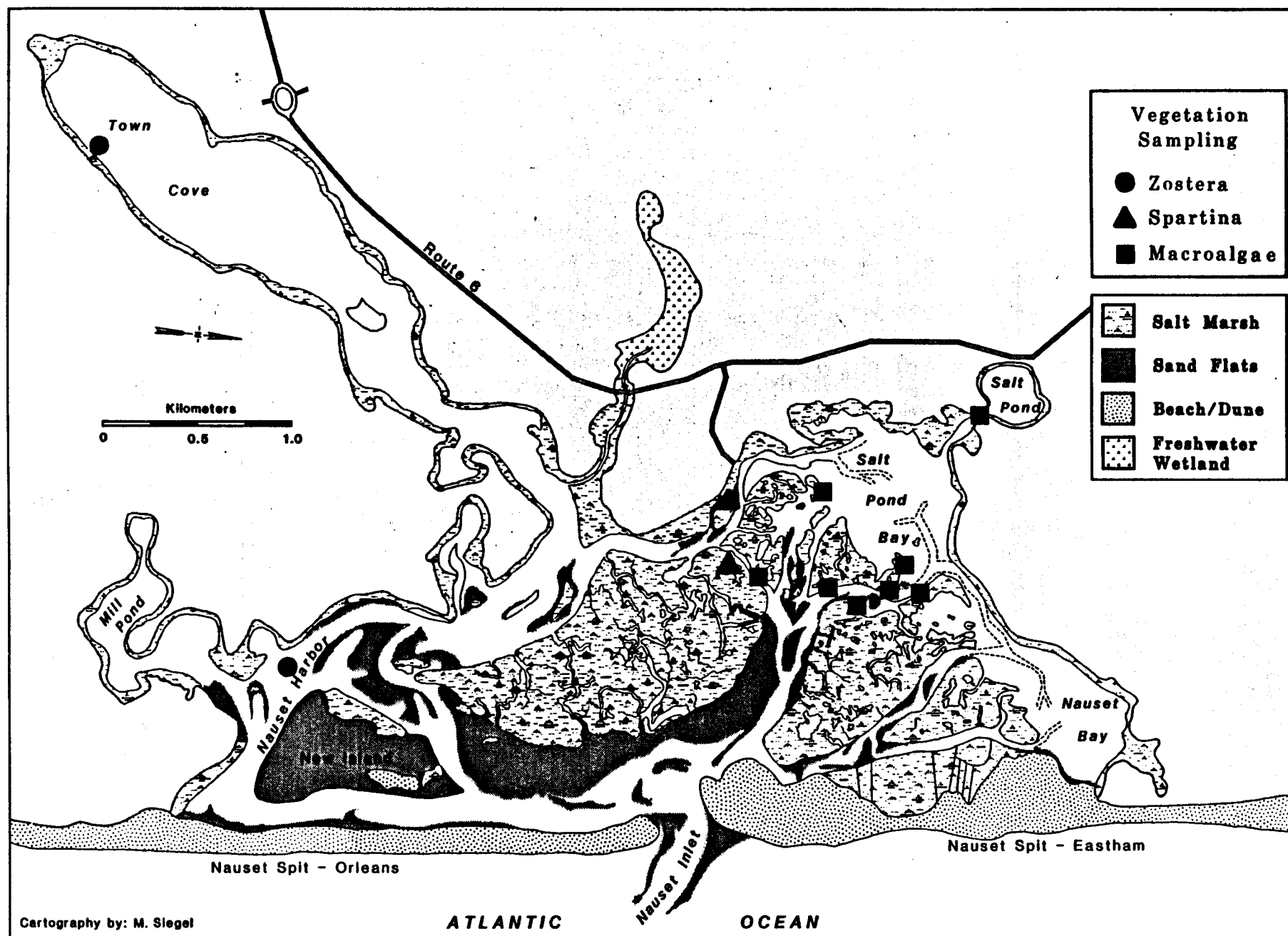


Figure 4. Macrophyte sampling locations.

of the harvest sample. Radiance was measured three times over each quadrat. Radiance data were not collected under cloudy, hazy or windy conditions and were always measured within 2 hours of local solar noon. Standing water was avoided, when possible, due to potential reflectance from the water surface. The quadrats were harvested immediately after collecting radiance data. Harvest and laboratory processing methods are described in Research Appendix A-1h.

Raw radiance values were converted to percent of incident solar radiance for each waveband. Incoming solar radiation was measured in the field as reflectance from a Halon reference panel. The spectral characteristics of Halon (tetrafluoroethelene) are described by Schutt et al. (1984). Radiance of the S. alterniflora target divided by radiance of the reference panel equals % reflectance. This conversion was applied to each of the 3 measured wavebands independantly.

The % reflectance values were then used to compute the vegetation index (V.I.) in the following equation: $V.I. = \frac{\text{infrared reflectance} - \text{red reflectance}}{\text{infrared reflectance} + \text{red reflectance}}$. The hand-held radiometer was configured with filters which matched bands 3 (0.63 - 0.69 μm), 4 (0.76 - 0.90 μm) and 5 (1.55 - 1.75 μm) of the Thematic Mapper; the remote sensing device carried on the satellite, LANDSAT. Thematic Mapper bands 3 and 4 were used in the above transformation equation. This transformation is useful because it combines the information about a target for two spectral bands and it helps to smooth high frequency variations in the solar irradiance.

The vegetation index was then corrected for solar elevation. The solar elevation angle was computed for each sampling period using the following equation: $(\sin^{-1}(\cos \theta_{\text{latitude}} \cos \theta_{\text{declination angle}} \cos \theta_{\text{hour angle}})) + (\sin \theta_{\text{latitude}} \sin \theta_{\text{declination angle}})$. The above equation was solved for solar elevation angle. Declination angle was computed based upon date and location. Hour angle was computed using the following information: during the summer months solar noon at 75.0° west longitude is 1300 DST. For every degree of longitude east of this point, 4 minutes are subtracted from 1300 hours. Thus at the Nauset Marsh study site, solar noon was at 1240 hours. Hour angle is 0° at local solar noon. For every 4 minutes difference between solar noon and actual sampling time, 1 degree of hour angle is added.

Once solar elevation angle was computed, it was used to correct vegetation index values to conform to the solar elevation angle of the model. For the present data, a model developed for a solar elevation angle of 61.8° was used. Two considerations allow for the conversion of observed vegetation index values to those for a 61.8° solar elevation; 1) for each degree of change in the observed solar elevation angle compared to the model solar elevation angle, the vegetation index changes 0.0035 units, and 2) as solar elevation angle increases over the model value, vegetation index decreases by the appropriate units.

The vegetation index value was then plugged into the model to predict total live biomass (g dry wt m^{-2}). The model used was $(V.I.)(5.287 + 2.786) = \ln \text{ live biomass}$. This model was developed for short and medium S. alterniflora in Delaware marshes from 1985 through 1987. The coefficient of determination was 0.75 and $n = 228$. The computed biomass estimates could then be compared to the harvest estimates.

RESULTS AND DISCUSSION

Fig. 5a compares total live areal biomass estimates by sampling date computed from radiance data and from manual harvest techniques. Sampling dates where remote sensing (radiance) estimates were not very similar to harvest estimates occurred in August 1985, twice in August 1986 and in September 1986. The remaining samplings showed rather close agreement. The similarity of the results of the two estimation methods, however, is supported by a comparison of standard deviations of the means for harvest and radiance estimates (Fig. 5b). If the standard deviations of the two means are similar but the estimated biomass deviates substantially, some systematic error in the model is suggested which can easily be corrected. This may be the case for September 1986, during which time S. alterniflora canopies experience very rapid senescence and significant changes in canopy geometry. These phenomena are probably accelerated at Cape Cod as compared to Southern Delaware, where the model was developed. The standard deviations for several other pairs of means (e.g., August 1986) differed significantly. This indicates allowance for a canopy architecture, or a mixture of live and dead vegetation, which is unique to the model. For instance, inflorescence formation, a significant characteristic of August canopies at Nauset which alters spectral reflectance, is not accounted for in the Delaware model.

Some documentable changes in S. alterniflora canopies with latitude have been reported (Bartlett et al. 1988). It appears that northern canopies have a greater horizontal leaf area (to maximize light interception during a short growing season with the sun at low zenith angles) than southern canopies (light interception is maximized on either side of solar noon to reduce transpiration during the hottest part of the day yet be able to photosynthesize maximally at slightly lower sun angles). The canopy geometries associated with each of these adaptations significantly alters the nadir reflectance measured by remote sensing instruments. Because harvest and radiance biomass estimates were similar for several of the samplings, it is suggested that a closer look at canopy geometry, especially in August, would yield a very reliable technique for nondestructive estimation of Nauset salt marsh biomass.

Total (live and dead) aboveground biomass was also estimated (Fig. 6a). Agreement between harvest and radiance estimates is not as close for total biomass as for live biomass alone. This is not surprising as dead biomass is difficult to estimate accurately. Because dead biomass reflects both red and near-infrared radiation very strongly, the measurable difference between them is minimized and the ability to quantify biomass is impaired. In most cases, the radiance estimated biomass was greater than the harvest estimated biomass. This suggests an overall increase in the measured vegetation index as compared to Delaware marshes. This phenomenon could be a result of; 1) large quantities of dead biomass located in the lower part of the canopy, or 2) a greater horizontal leaf area index in Nauset Marsh than in Delaware marshes such that a higher vegetation index results from a lower density of biomass. Both of these hypotheses are viable and could be modelled with a small amount of additional site specific research.

Fig. 6b compares the standard deviations of the radiance and harvest total biomass estimates. There was very good agreement between the estimation techniques. August 1985 and the two August 1986 samplings were most different, indicating the existence of some unique canopy characteristic to have caused the great variability in the radiance biomass estimates.

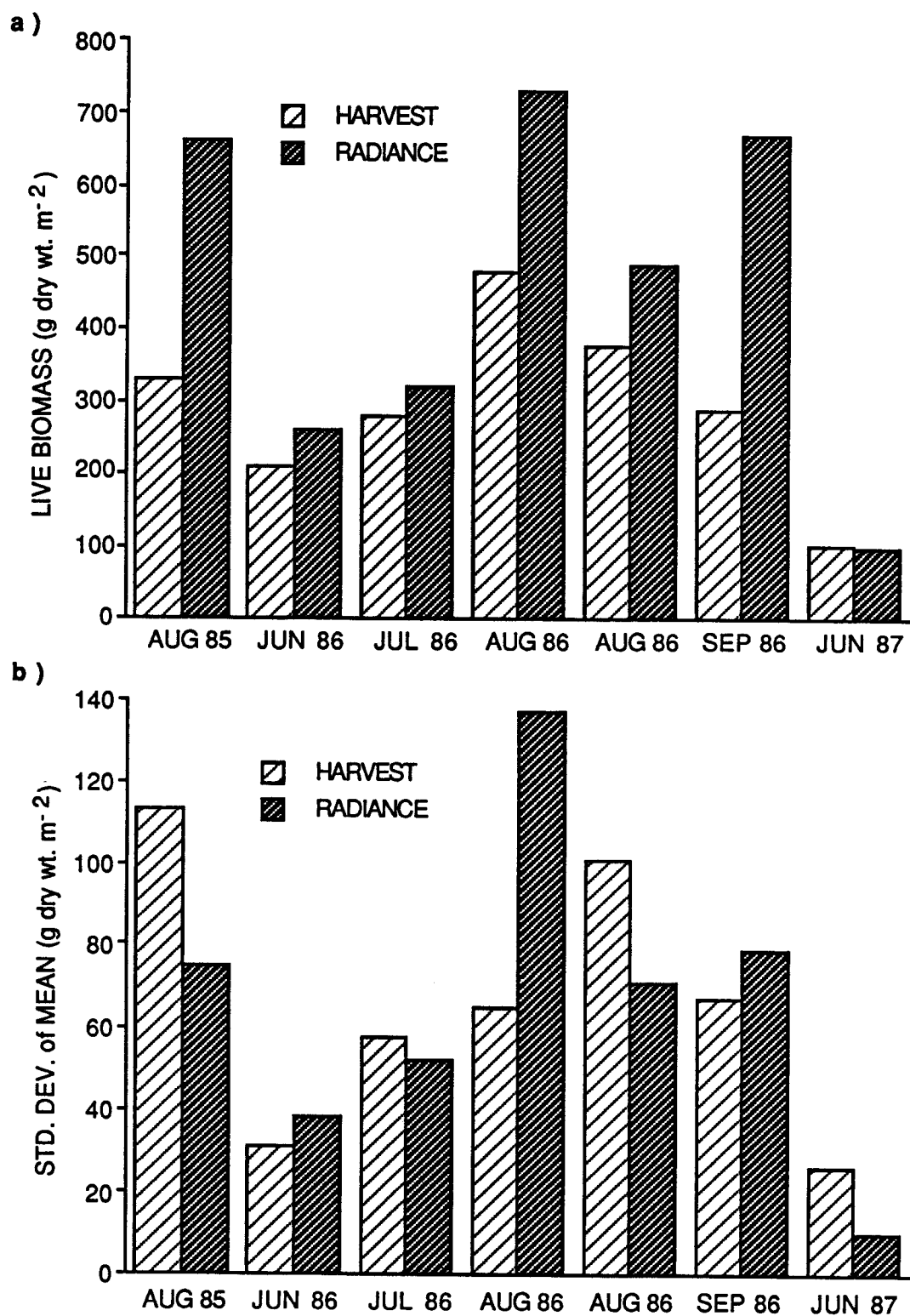


Figure 5. Comparison of *S. alterniflora* live aboveground biomass estimated by the harvest and hand-held radiometer methods: a) mean, $n = 10$; b) standard deviation

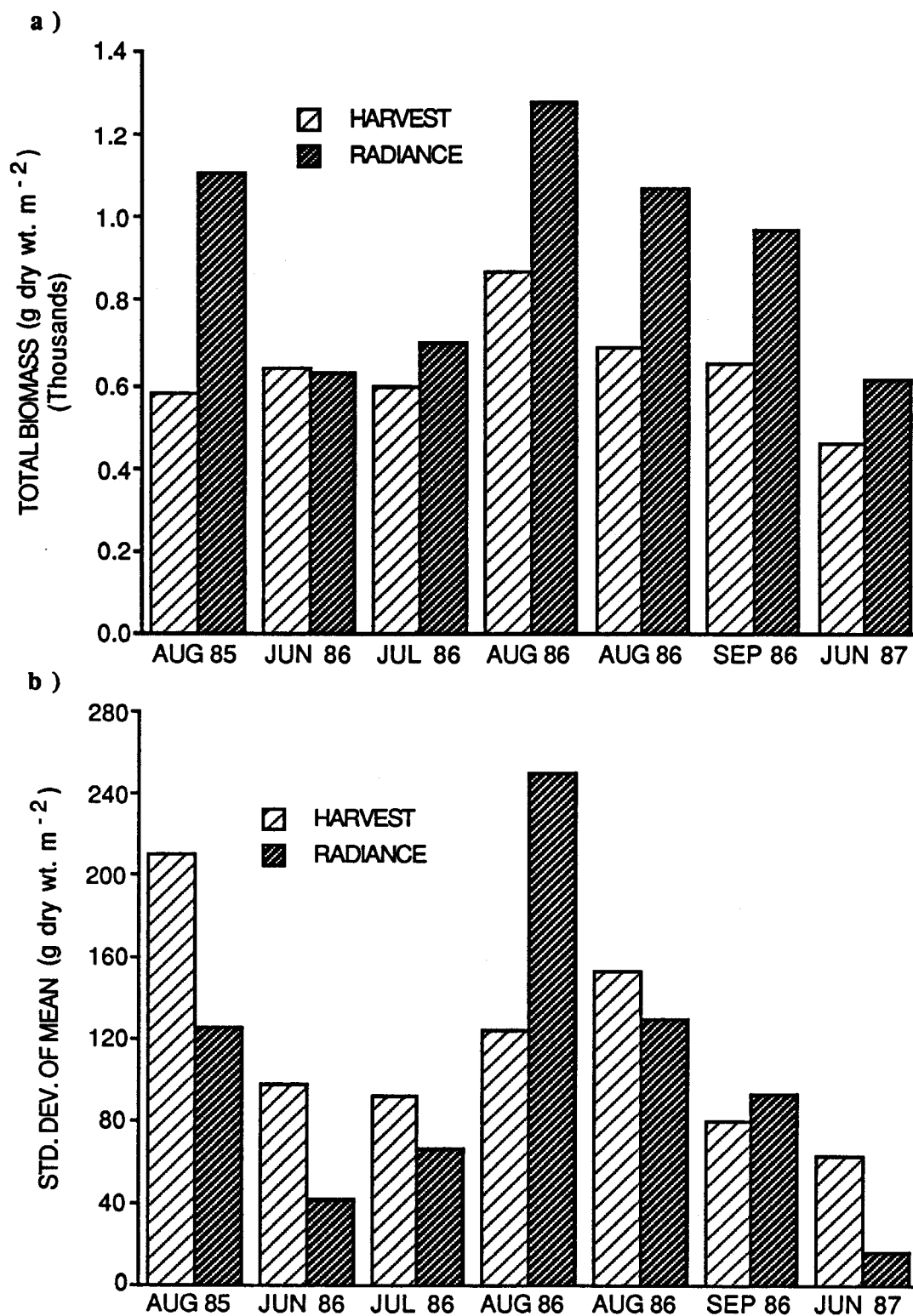


Figure 6. Comparison of *S. alterniflora* total aboveground biomass estimated by harvest and hand-held radiometer methods: a) mean, $n = 10$; b) standard deviation.

Fig. 7 provides a comparison based upon percent difference between harvest and radiance estimates of biomass for both live and total biomass. For August 1985, both live and total estimates showed large differences. September 1986 also showed a large variation between harvest and radiance estimated live biomass. For all other samplings, the agreement between the two estimates was reasonable, with several estimates being very similar (total biomass in June and July 1986 and live biomass in June 1987). When considering the tremendous savings in time by using the remote sensing technique and the fact that rarely is one seeking absolute biomass quantities but rather documenting trends in biomass change, the spectral technique for nondestructive biomass estimation has great potential as a monitoring tool.

RECOMMENDATIONS

These data indicate that models which are sensitive to regional variations in canopy morphology are required to generate reasonable estimates of biomass at Nauset Marsh. Small data sets, such as the one described here, along with limited additional data collection, as alluded to above, can be used to modify existing models such that they reflect seasonal changes in canopy geometry and reflectance. Such adjustments need only be done for a single growing season with occasional checks of accuracy thereafter.

The models and data used in this study were developed specifically for hand-held radiometry. Similar data and models from Delaware marshes have been used to develop models for predicting salt marsh biomass from satellite radiance (Gross et al. 1987). This extrapolation is essentially a correction for atmospheric attenuation of the signal and variations in the response curves of the sensors. Hand-held radiometry is a reliable, nondestructive technique for estimating marsh biomass, however, one is limited by the physical distance needed for representative coverage of a marsh. A satellite image can accomplish the same task superiorly for two reasons. First, the entire marsh is sampled. This means no subsample or randomization errors will influence the data. Second, satellite data can be used to initiate a long-term database for a particular site. The advantages of this type of database include historic data availability and total automation in data processing. In addition, other types of information can be extracted from the satellite image such as species or community distributions, and evapotranspiration and chlorophyll density for angiosperms and aquatic algae. For example, in the Great Marsh at Lewes, Delaware, a comparison of several satellite images over 2 - 3 years indicated an area to have been developing low productivity (increased areal extent of die-out areas). Subsequent field checks confirmed that the satellite radiance patterns had indeed been useful in detecting interannual variations in marsh productivity (Gross et al. in prep.). Presently, the National Science Foundation's long-term ecological research group is implementing the use of satellite imagery as the template for geographic and biological information systems. Other types of ground data can be added to the data base with relative ease and these can then be compared directly to other data.

To summarize, the hand-held radiometer is a very inexpensive means by which to quickly assess the health and vigor of S. alterniflora in Nauset Marsh. Further, the use of satellite data should be considered. Two remote sensing satellites are presently in orbit. The United States satellite, LANDSAT, contains the

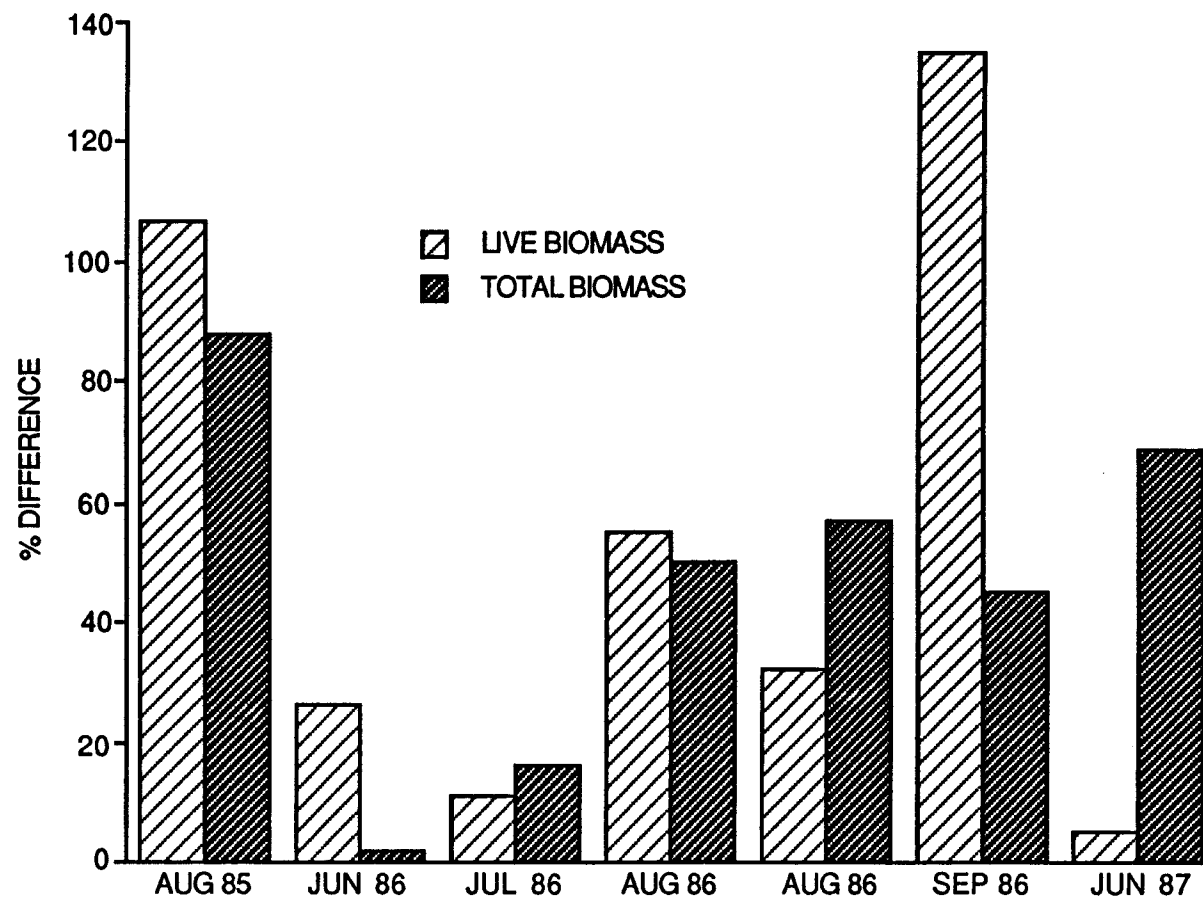


Figure 7. Percent difference between harvest and radiance methods for both live and total aboveground *S. alterniflora* biomass estimates.

Thematic Mapper, which is capable of 30 m resolution, and the French satellite, SPOT, is equipped for 20 m resolution. Models have been developed which can be used with radiance data from either satellite.

INVENTORY AND HABITAT UTILIZATION OF FISHES AND MACROINVERTEBRATES

FISHES AND DECAPOD CRUSTACEANS

METHODS

Extensive sampling throughout the Nauset Marsh Complex began in August 1985 and was continued through September 1988 (see Data Appendix A). Regular sampling has been conducted with a variety of gears (trawl, seine, suction sampler, and plankton nets; see Table 3) and in a variety of habitats (Tables 3 and 4) characteristic of the Nauset Marsh system. Sample station locations are shown in Fig. 8. At most habitats more than one type of conventional gear was used for sampling. The exception is the "peat reef" habitat. Peat reefs are irregular, elongate blocks of marsh peat that have broken off from the marsh surface and fallen into creek channels. Typically, the living *S. alterniflora* dies and decays if the reefs are completely subtidal. Eventually the former marsh surface becomes colonized by algae, invertebrates, and fish. The irregular nature of these habitats made underwater observations by "hookah" assisted divers and suction sampling the only possible way of sampling them.

Most gears, with the exception of suction sampling, were used to make quantitative or representative collections of decapod crustaceans and fishes. In deeper habitats (Table 4) a small otter trawl (4.9 m, 0.6 cm codend mesh) was towed for two minutes. After extensive sampling in August 1985 we determined that four two-minute replicate tows were appropriate based on species accumulation curves. Replicate samples were kept separate, sorted live, and discarded except for species of particular interest, which were preserved in 10% formalin. All decapod crustaceans and fish were identified, counted and measured.

At intertidal and subtidal habitats (Table 3) three replicate seine (7.7 m, 0.6 cm mesh) collections were made by sweeping over the study site while one end of the seine remained stationary at the water's edge. All decapod crustaceans and fish were identified, enumerated, and a representative subsample measured and then discarded.

Qualitative ichthyoplankton sampling, to determine the reproductive seasonality of the species spawning and utilizing Nauset Marsh as a nursery area, occurred from December 1985 through June 1987 (Table 5). Preliminary sampling was conducted with an epibenthic sled, a 0.5 m hoop net and 20 cm bongo nets, all with 0.505 micron mesh. The tows were variable in duration until standardized tows of 5 minutes with the 20 cm bongo nets were begun in September 1986. Six locations were sampled and nine samples collected (Table 5) in September, October 1986 and March, April, May and June 1987. Inlet flood and ebb samples and day and night samples at two stations were collected in all these months except March.

In addition, 17 night light samples were collected on 13 dates in 1986 and 7 samples were collected on 7 dates in 1987. Night light sampling involved illuminating the water surface after dark for 30 to 60 minutes with a battery powered 50 watt light bulb and dip netting larval and juvenile fishes attracted by the light. Fishes were sampled by night lighting in Mill Pond, Town Cove,

Table 3. Major habitat types and number of regular faunal sampling techniques employed in the Nauset Marsh study, August 1985 - August 1987.

Sampling Activity	Subtidal	Intertidal	Intertidal	Subtidal	Subtidal	Inter- tidal	Sub- tidal	Salt
	Eelgrass Bed (Sta. #4, 6 & 7)	Macroalgal Mudflat (Sta. #2)	Sand Substrate	Sand/Gravel Substrate (Sta. #1 & 3)	Drift Algal (Sta. #5)	Mussel Bed	Peat Reef	Marsh Pools
Trawling	78	25		51	41			
Seining	24 ^a		27 ^b	40 ^c				
Suction Sampling	12	12	12			8 ^d	27	12
Ichthyoplankton	24	13	10	28	14			
Diving ^e	x			x			x	

^aSampled in Salt Pond inlet

^bSampled in Salt Pond Inlet

^cSampled in Salt Pond Bay and Inlet

^dSampled with 0.051m² quadrat by hand

^eSampling frequency has not been presented because diving was conducted supplementally to major efforts, when possible, and yielded qualitative as opposed to quantitative data. This does not include, however, the diving conducted for suction sampling peat reef habitat.

Table 4. Description of the otter trawl stations sampled in Nauset Marsh from August 1985 through October 1986.

Station	Mean Depth (m)	Substrate Type	Vegetation	Temperature Range (°C)	Salinity Range (‰)
1 (Marsh Creek)	2	sand	none	4.5-19.0	26-31
2 (Nauset Bay)	1	mud	<u>Cladophora</u> <u>gracilis</u>	4.0-19.0	27-31
3 (Inlet)	3	sand/gravel	none	5.0-18.0	26-34
4 (Hopkins Island)	2	mud	<u>Zostera</u> <u>marina</u>	13.0	30
5 (Town Cove)	5	mud	<u>Gracilaria</u> sp.	2.0-20.0	24-30
6 (Fort Hill)	2	sand	<u>Zostera</u> <u>marina</u>	4.0-16.5	27-30
7 (Nauset Harbor)	2	mud/sand	<u>Zostera</u> <u>marina</u>	4.5-16.5	26-30

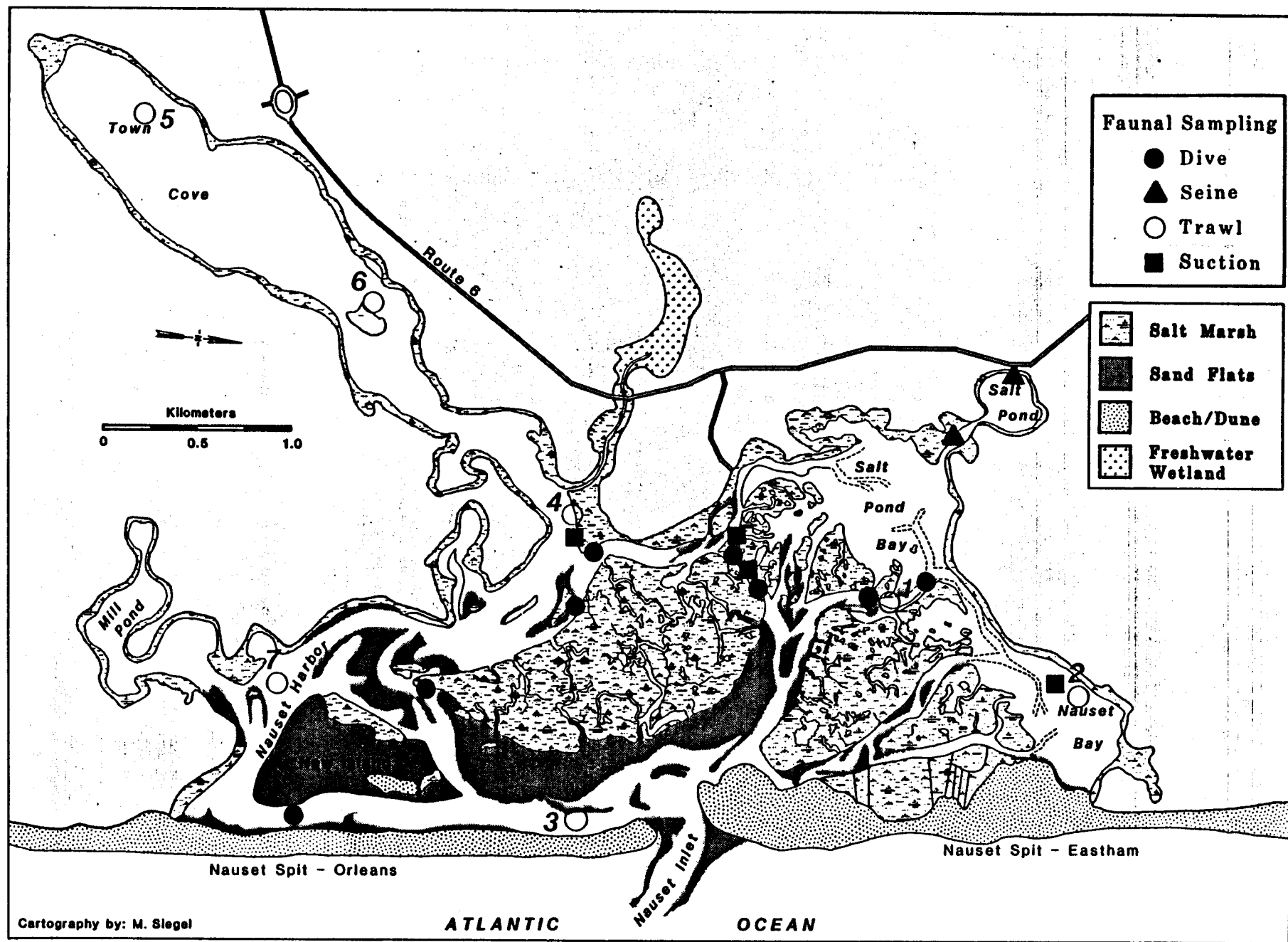


Figure 8. Sampling locations and methods used for the fauna study.

Table 5. Ichthyoplankton sampling locations and dates during August 1985 through August 1987. Tows were of 5 minute duration unless otherwise noted (see parentheses).

Location	December 1985		3 April 1986			2-5 June 1986		31 July-1 Aug 1986	
	20cm	0.5m	2 min	20cm	0.5m	2 min	20cm	2 min	20cm
	Bongo	Hoop	Episled	Bongo	Hoop	Episled	Bongo	Episled	Bongo
Salt Pond			x						
Salt Pond Bay						x			
Salt Pond Inlet to Nauset Bay					x(12)				x(10)
Nauset Bay	x		x						
Nauset Bay to Station 1					x				x(10)
Station 1	x		x						
Station 1 to Inlet					x				
Inlet -ebb -flood	x		x		x(12)				x(10)
Inlet to Nauset Harbor							x(15) x(20)		
Nauset Harbor -day -night	x		x						
Mill Pond						x			
Nauset Harbor to Fort Hill					x(13)		x(15)		x(24)
Fort Hill	x								
Fort Hill to Hopkins Island					x(15)				
Town Cove Eelgrass			x		x			x	
Town Cove -day -night	x						x(15)		x(10)
Salt Pond Inlet (Stationary)						x(60)	x(60)		
Greenhead Channel (Stationary)						x(34)		x(163)	

<u>10 Sept 1986</u>		<u>16 Oct 1986</u>		<u>11 March 1987</u>		<u>14 Apr 1987</u>		<u>May 1987</u>		<u>June 1987</u>	
2 min	20cm*	20cm*		20cm*		20cm*		20cm*		20cm*	
Episled	Bongo	Bongo		Bongo		Bongo		Bongo		Bongo	
	x	x		x		x		x		x	
	x	x		x		x		x		x	
	x	x		x		x		x		x	
	x	x		x		x		x		x	
	x	x				x		x		x	
x	x	x		x		x		x		x	
	x	x				x		x		x	
	x	x		x		x		x		x	
	x	x				x		x		x	

*tows standardized at 5 minutes.

Hemenway Landing and Salt Pond (see Data Appendix A).

Nektonic and benthic organisms were collected at four habitats (intertidal algal mudflat, subtidal eelgrass, intertidal sand substrate, and salt marsh pools; Table 3) with a suction sampling technique. At each study site a plastic cylinder (0.85 m²) was deployed to capture a column of water 1 m or less in depth and the associated fish and epibenthos. Rotenone was added to the cylinder in sufficient quantity to allow capture of fish with dipnets. After fish captures reached zero (usually within 10 min), the remaining contents were sucked up with a gasoline powered pump and screened through a bag (1.6 mm mesh). The entire sample in the mesh bag was preserved in 10% formalin for later sorting in the laboratory.

In situ visual observations were made in eelgrass and peat reef habitats to complement information from previously mentioned sampling gears. At the peat reef habitats, qualitative and quantitative samples were obtained with a diver operated suction sampler. For the quantitative samples, a metal cylinder (0.14 m²) was pressed into the substrate and the contents of three replicate suction samples combined. These samples were examined for the presence of juvenile lobsters and discarded. All juvenile lobsters were enumerated, measured and preserved.

Several types of gear were used at irregular intervals to augment our regular sampling in order to obtain a more complete inventory of fishes and as part of student exercises during Rutgers University's Ichthyology and Estuarine Ecology class visits to Nauset Marsh. During October 1985 and September 1986 (Data Appendix A) experimental gill nets were deployed overnight in Salt Pond. The dominant fishes were collected, enumerated, measured, and discarded. Conical fish traps were deployed to collect fish at peat reef habitats. Similarly, additional trawl and seine collections were made for specific class projects.

SPECIES COMPOSITION

Our comprehensive sampling during 1985 - 1987, captured over 11,976 fishes and 39,740 decapods with a variety of sampling techniques. Fish and decapod species richness, compared by habitat, is included in Fig. 9.

The fish (49 species) fauna is generally similar to that of Pleasant Bay (Fiske et al. 1967, Table 6), a back-barrier estuarine system immediately south of Nauset Marsh. While a number of species reported by Fiske et al. (1967), including big skate (*Raja ocellata*), little skate (*Raja erinacea*), ocean pout (*Macrozoarces americanus*), longshore sculpin (*Myoxocephalus octodecimspinosus*), and yellowtail flounder (*Limanda ferruginea*), did not appear in Nauset Marsh samples, these species apparently were collected at otter trawl stations several miles offshore of Pleasant Bay rather than in the estuary itself. Trawl samples collected from the ocean immediately outside of the Nauset Marsh system by the Massachusetts Division of Marine Fisheries included several of these same species (Table 6). These nearshore ocean trawl collections shared few species with the typically inshore fauna of Nauset Marsh (Table 6).

The decapod fauna (11 species) also closely resembled that of Pleasant Bay (Table 6). The presence of Jonah crab (*Cancer borealis*) in the Pleasant Bay collection may be explained by the deeper otter trawl collections, while the same study did not report hermit crab (*Pagurus acadianus*) as we did for Nauset Marsh.

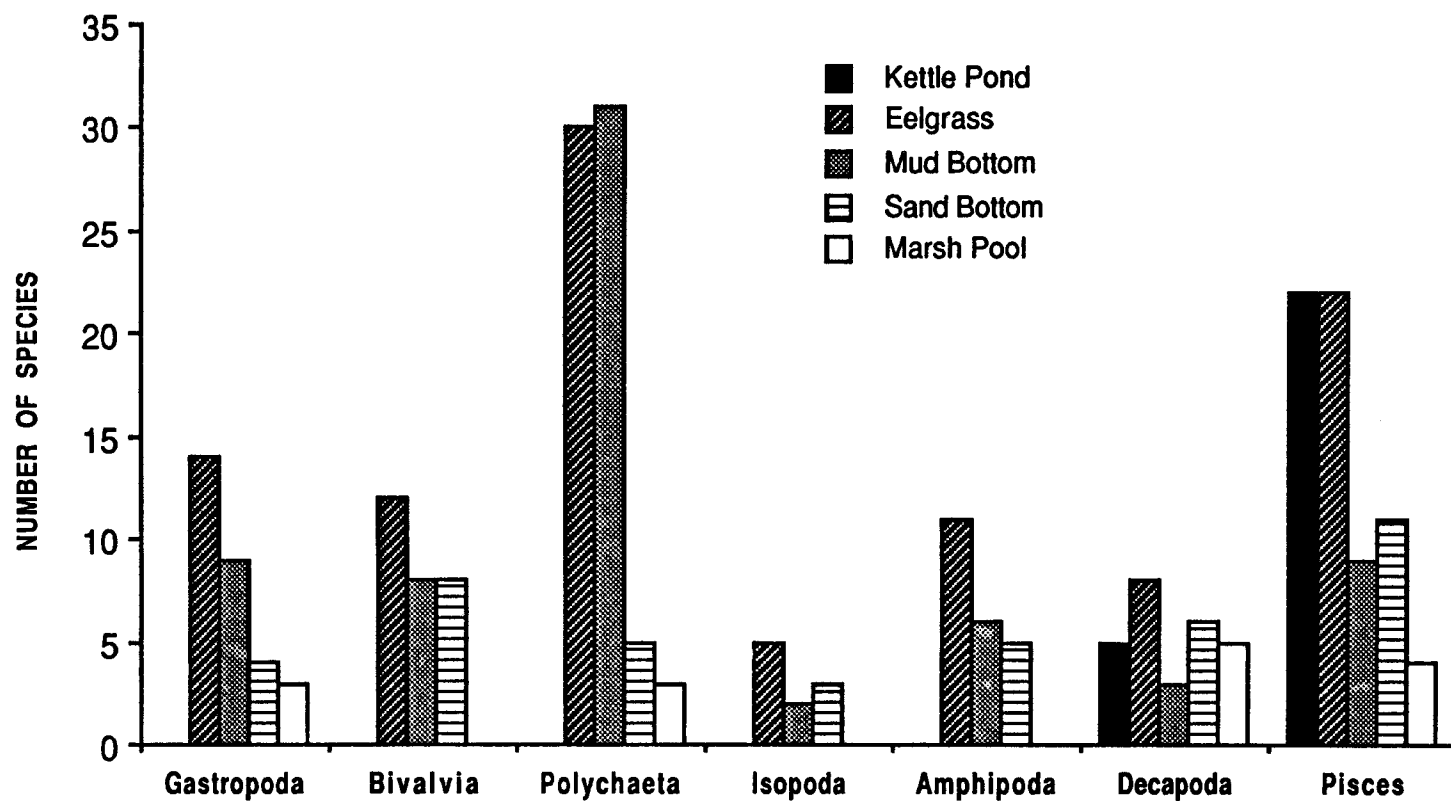


Figure 9. Species richness of major faunal groups compared by habitat (Decapoda and Pisces collected by 4.9 m otter trawl, 8.3 m seine; all others collected by suction sampling).

Table 6. Species composition of fishes and decapod crustaceans from the Nauset Marsh study during August 1985 to October 1987, the adjacent Atlantic Ocean during 1978 to 1985 (based on trawl surveys by the Massachusetts Division of Marine Fisheries) and Pleasant Bay (based on Fiske et al. 1967).

	NAUSET MARSH	ADJACENT ATLANTIC OCEAN	PLEASANT BAY
SPECIES			
Class Crustacea			
Order Decapoda			
<u>Cancer borealis</u> - Jonah crab		x	x
<u>Cancer irroratus</u> - Rock crab	x	x	x
<u>Carcinus maenas</u> - Green crab	x		x
<u>Libinia</u> sp. - Spider crab	x	x	x
<u>Ovalipes ocellatus</u> - Lady crab	x	x	
<u>Pagurus acadianus</u> - Hermit crab	x		
<u>Eurypanopeus depressus</u> - Mud crab	x		x
<u>Neopanopeus sayi</u>	x		
<u>Neopanope texana</u>			x
<u>Crangon septemspinosa</u> - Sand shrimp	x		x
<u>Hippolyte zostericola</u> - Grass shrimp	x		x
<u>Homarus americanus</u> - American lobster	x	x	x
<u>Palaemonetes vulgaris</u> - Shore shrimp	x		x
<u>Palaemonetes pugio</u>			x
Class Chondrichthyes			
Order Squaliformes			
Family Squalidae			
<u>Squalus acanthias</u> - Spiny dogfish		x	
Order Rajiformes			
Family Rajidae			
<u>Raja ocellata</u> - Big skate		x	x
<u>Raja erinacea</u> - Little skate		x	x

Table 6 (continued).

	NAUSET MARSH	ADJACENT ATLANTIC OCEAN	PLEASANT BAY
Class Osteichthyes			
Order Anguilliformes			
Family Anguillidae			
<u>Anguilla rostrata</u> - American eel	x		x
Family Congridae			
<u>Conger oceanicus</u> - Conger eel	x ^c		
Order Clupeiformes			
Family Clupeidae			
<u>Alosa aestivalis</u> - Blueback herring	x	x	x
<u>Alosa pseudoharengus</u> - Alewife	x ^d	x	x
<u>Clupea harengus harengus</u> - Atlantic herring			x
<u>Brevoortia tyrannus</u> - Atlantic menhaden	x ^d		x
Family Engraulidae			
<u>Anchoa mitchilli</u> - Bay anchovy	x ^d	x	
<u>Anchoa hepsetus</u> - Striped anchovy	x ^c		
Family Osmeridae			
<u>Osmerus mordax</u> - American smelt			x
Order Lophiiformes			
Family Lophiidae			
<u>Lophius americanus</u> - Goosefish		x	
Order Batrachoididae			
Family Batrachoididae			
<u>Opsanus tau</u> - Oyster toadfish			x
Order Gadiformes			
Family Gadidae			
<u>Gadus morhua</u> - Atlantic cod	x	x	x
<u>Melanogrammus aeglefinus</u> - Haddock		x	
<u>Merluccius bilinearis</u> - Silver hake		x	
<u>Microgadus tomcod</u> - Atlantic tomcod	x		x
<u>Pollachius virens</u> - Pollock	x	x	
<u>Urophycis chuss</u> - Red hake	x	x	

Table 6 (continued).

	NAUSET MARSH	ADJACENT ATLANTIC OCEAN	PLEASANT BAY
<u>Urophycis regius</u> - Spotted hake		x	
<u>Urophycis tenuis</u> - White hake	x	x	x
<u>Enchelyopus cimbrius</u> - Fourbeard rockling	x		
Family Zoarcidae			
<u>Macrozoarces americanus</u> - Ocean pout		x	x
Order Atheriniformes			
Family Belonidae			
<u>Strongylura marina</u> - Atlantic needlefish			x
Family Cyprinodontidae			
<u>Fundulus heteroclitus</u> - Common mummichog	x		x
<u>Fundulus majalis</u> - Striped mummichog	x		x
<u>Cyprinodon variegatus</u> - Sheepshead minnow			x
Family Atherinidae			
<u>Menidia</u> sp. - Silversides	x ^f	x	
<u>Menidia beryllina</u> - Tidewater silverside	x		
<u>Menidia menidia</u> - Atlantic silverside	x		x
Order Gasterosteiformes			
Family Gasterosteidae			
<u>Apeltes quadracus</u> - Four-spined stickleback	x ^f		x
<u>Gasterosteus aculeatus</u> - Three-spined stickleback	x		x
<u>Gasterosteus wheatlandi</u> - Black-spotted stickleback	x		x
Family Syngnathidae			
<u>Syngnathus</u> sp. - Pipefish		x	
<u>Syngnathus fuscus</u> - Northern pipefish	x		x
Order Perciformes			
Family Serranidae			
<u>Centropristis striata</u> - Black sea bass	x	x	
<u>Morone saxatilis</u> - Striped bass			x
Family Pomatomidae			
<u>Pomatomus saltatrix</u> - Bluefish	x		x
Family Carangidae			
<u>Decapterus macarellus</u> - Mackerel scad		x	

Table 6 (continued).

	NAUSET MARSH	ADJACENT ATLANTIC OCEAN	PLEASANT BAY
<u>Decapterus punctatus</u> - Round robin	x		
<u>Selene vomer</u> - Lookdown	x		
<u>Caranx hippos</u> - Crevalle jack	x		x
Family Labridae			
<u>Tautoga onitis</u> - Tautog	x	x	x
<u>Tautoglabrus adspersus</u> - Gunner	x	x	x
Family Mugilidae			
<u>Mugil cephalus</u> - Striped mullet	x		
Family Pholidae			
<u>Pholis gunnellus</u> - Rock gunnel	x		
Family Stichaeidae			
<u>Ulvaria subbifurcata</u> - Radiated shanny	x		
Family Anarhichadidae			
<u>Anarhichas</u> sp. - Wolffish		x	
Family Ammodytidae			
<u>Ammodytes</u> sp. ^a - Sand lance	x ^d	x	
<u>Ammodytes americanus</u> - Inshore sand lance			x
Family Gobiidae			
<u>Gobiosoma boscii</u> - Naked goby	x		
Family Stromatidae			
<u>Peprilus triacanthus</u> - Butterfish	x	x	
Family Triglidae			
<u>Prionotus carolinus</u> - Northern sea robin		x	
<u>Prionotus evolans</u> - Striped sea robin	x	x	
Family Sparidae			
<u>Stenotomus chrysops</u> - Scup	x		x
Family Sciaenidae			
<u>Leiostomus xanthurus</u> - Spot	x		
Family Cottidae			
<u>Hemitripterus americanus</u> - Sea raven	x ^b	x	x

Table 6 (continued).

	NAUSET MARSH	ADJACENT ATLANTIC OCEAN	PLEASANT BAY
<u>Myoxocephalus aeneus</u> - Grubby	x ^d		x
<u>Myoxocephalus octodecemspinosus</u> - Longhorn sculpin		x	x
Family Cyclopteridae			
<u>Cyclopterus lumpus</u> - Lumpfish	x		
Order Pleuronectiformes			
Family Bothidae			
<u>Citharichthys arctifrons</u> - Gulf stream flounder			x
<u>Etropus microstomus</u> - Small mouth flounder	x		
<u>Paralichthys dentatus</u> - Summer flounder	x	x	
<u>Paralichthys oblongus</u> - Fourspot flounder		x	
<u>Scophthalmus aquosus</u> - Windowpane	x ^e	x	x
Family Pleuronectidae			
<u>Limanda ferruginea</u> - Yellowtail flounder		x	x
<u>Hippoglossoides platessoides</u> - American plaice	x		
<u>Pseudopleuronectes americanus</u> - Winter flounder	x ^d	x	x
Family Soleidae			
<u>Trinectes maculatus</u> - Hogchoker			x
Order Tetraodontiformes			
Family Monacanthidae			
<u>Monacanthus hispidus</u> - Planehead filefish	x		
Family Tetraodontidae			
<u>Sphaeroides</u> sp. - Puffer		x	
<u>Sphaeroides maculatus</u> - Northern puffer	x		

^a taxonomic studies ongoing

^b visual observation while diving

^c night lighting (larvae or juveniles)

^d larvae and adults

^e eggs and adults

^f eggs, larvae and adults

Lady crab (Ovalipes ocellatus) was rare in our collections.

Over the study period both the decapod and fish faunas were dominated by a relatively few species but the temporal and spatial patterns of abundance varied considerably. In trawl collections, six fishes, three-spined stickleback (Gasterosteus aculeatus), four-spined stickleback (Apeltes quadracus), Atlantic herring (Clupea harengus harengus), winter flounder (Pseudopleuronectes americanus) and inshore sand lance (Ammodytes americanus), made up 87.2% of the total fishes collected, with common mummichog (Fundulus heteroclitus, 3.5%) and northern pipefish (Syngnathus fuscus, 3.3%) of some what less importance (Tables 7, 8). In shallow waters, where collections were made by seine (Table 9), the fishes were dominated by two killifishes (common mummichog and striped mummichog - Fundulus majalis), Atlantic silverside (Menidia menidia) and four-spined stickleback which together made up 94.2% of the total number of individuals (Tables 9, 10). Decapod crustaceans, in both trawl and seine collections, were dominated by sand shrimp (Crangon septemspinosa) and green crab (Carcinus maenas) which together made up 91.9 and 7.0%, respectively (Tables 8, 9).

HABITAT-SPECIFIC DISTRIBUTION

The patterns of fish and decapod abundance, as reflected in trawl collections, varied strikingly between habitats (Table 11). Fish abundance ranked highest in eelgrass, followed by collections in deep water that was often dominated by red drift algae (Gracilaria sp.). Fish in sand and mud substrates were much less abundant. In almost direct contrast, the mud substrate harbored an order of magnitude greater abundance of decapod crustaceans, while sand was ranked next.

The ranking of fishes and decapods differed in seine collections (Table 10). Fishes were of similar abundance in eelgrass and the sand/mud habitat and much less abundant over gravel. Decapod crustaceans were poorly represented but most occurred over sand/mud substrate.

The habitat specific abundance patterns for fishes can be discerned by examining the collections from each station (habitat) (Table 8). The high mean abundance levels observed in the eelgrass habitats are the result of the extremely abundant three- and four-spined sticklebacks, particularly the former at Station 7 (mean number/tow = 83), and the latter at Station 4 (mean number/tow = 71). The relatively large numbers of fishes taken in the deep water/drift algae habitat was the result of large collections (mean number/tow = 36) of Atlantic herring. In the sand habitats, inshore sand lance was the most abundant form. These numbers are probably significant underestimates because the trawl is not efficient at collecting either of these pelagic fishes and we observed large schools, especially of inshore sand lance, over sand substrates while diving and from the surface on numerous occasions. The most abundant forms over mud bottom were winter flounder and Atlantic herring. In shallow water habitats (Table 9), fish species composition varied but less than in the deeper trawl collections (Table 8). Across all habitats, the most abundant species were common mummichog, four-spined stickleback, and Atlantic silverside.

For decapods, which were dominated numerically by two species (sand shrimp and green crab), the abundance in the deeper habitat was variable (Table 8). Sand shrimp occurred in all habitats but was most abundant over mud bottoms in

Table 7. Total abundance of fishes and decapod crustaceans collected from the Nauset Marsh study, from July 1985 to October 1986. See Data Appendix A for sampling effort.

	Total Abundance (Trawl) day (night)	Total Abundance (Seine)	Total Abundance (Ichthyoplankton)	
				<u>Eggs</u> <u>Larvae</u>
SPECIES				
Class Crustacea				
Order Decapoda				
Family Cancridae				
<u>Cancer irroratus</u> - Rock crab	276 (734)	1		
Family Portunidae				
<u>Carcinus maenas</u> - Green crab	2379 (459)	53		
<u>Ovalipes ocellatus</u> - Lady crab	6			
Family Majidae				
<u>Libinia emarginata</u> - Spider crab	27 (9)			
Family Paguridae				
<u>Pagurus acadianus</u> - Hermit crab	20 (7)			
Family Xanthidae				
<u>Eurypanopeus depressus</u> - Mud crab		1		
<u>Neopanopeus savi</u>	1			
Family Cragonidae				
<u>Crangon septemspinosa</u> - Sand shrimp	31546 (3891)	258		
Family Hippolytidae				
<u>Hippolyte zostericola</u> - Green shrimp	2			
Family Nephropidae				
<u>Homarus americanus</u> - American lobster	12 (11)			21

Table 7 (continued).

	Total Abundance (Trawl) day (night)	Total Abundance (Seine)	Total Abundance (Ichthyoplankton)	
				<u>Eggs</u> <u>Larvae</u>
Family Palaemonidae				
<u>Palaemonetes vulgaris</u> - Shore shrimp	58	5		
Class Osteichthyes				
Order Anguilliformes				
Family Anguillidae				
<u>Anguilla rostrata</u> - American eel	17	(2)		475
Family Congridae				
<u>Conger oceanicus</u> - Conger eel				2
Order Clupeiformes				
Family Clupeidae				
<u>Alosa aestivalis</u> - Blueback herring	2	1		6
<u>Alosa pseudoharengus</u> - Alewife		2		
<u>Alosa</u> sp.				5
<u>Clupea harengus harengus</u> - Atlantic herring	1276			66
<u>Brevoortia tyrannus</u> - Atlantic menhaden	2	24		35
Family Engraulidae				
<u>Anchoa mitchilli</u> - Bay anchovy	1	(1)		2
<u>Anchoa hepsetus</u> - Striped anchovy				1
Order Gadiformes				
Family Gadidae				
<u>Gadus morhua</u> - Atlantic cod	(2)			
<u>Microgadus tomcod</u> - Atlantic tomcod	1	(4)		1
<u>Pollachius virens</u> - Pollock	19	(9)	1	1

Table 7 (continued).

	Total Abundance (Trawl) day (night)	Total Abundance (Seine)	Total Abundance (Ichthyoplankton)		
				<u>Eggs</u>	<u>Larvae</u>
<u>Urophycis chuss</u> - Red hake	1 (2)				
<u>Urophycis tenuis</u> - White hake	52 (17)				
<u>Enchelyopus cimbrius</u> - Fourbeard rockling					20
Order Atheriniformes					
Family Cyprinodontidae					
<u>Fundulus heteroclitus</u> - Common mummichog	282 (15)	1432			3
<u>Fundulus majalis</u> - Striped mummichog	3	261			
Family Atherinidae					
<u>Menidia beryllina</u> - Tidewater silverside		3			
<u>Menidia menidia</u> - Atlantic silverside	41 (30)	545	3		31
Order Gasterosteiformes					
Family Gasterosteidae					
<u>Apeltes quadracus</u> - Four-spined stickleback	2094 (408)	502	9		34
<u>Gasterosteus aculeatus</u> - Three-spined stickleback	2592 (1089)	4			33
<u>Gasterosteus wheatlandi</u> - Black-spotted stickleback	14				
Family Syngnathidae					
<u>Syngnathus fuscus</u> - Northern pipefish	267 (363)	20			52
Order Perciformes					
Family Serranidae					
<u>Centropristis striata</u> - Black sea bass	(1)				

Table 7 (continued).

	Total Abundance (Trawl) day (night)	Total Abundance (Seine)	Total Abundance (Ichthyoplankton)	
				<u>Eggs</u> <u>Larvae</u>
Family Pomatomidae				
<u>Pomatomus saltatrix</u> - Bluefish	(2)	1		
Family Carangidae				
<u>Decapterus punctatus</u> - Round robin		1		
<u>Selene vomer</u> - Lookdown	1			
<u>Caranx hippos</u> - Crevalle jack		6		
Family Labridae				
<u>Tautoga onitis</u> - Tautog	18 (12)	1		
<u>Tautoglabrus adspersus</u> - Gurner	48 (26)	2		1
Family Mugilidae				
<u>Mugil cephalus</u> - Striped mullet		11		
<u>Mugil curema</u> - White mullet				1
Family Pholidae				
<u>Pholis gunnellus</u> - Rock gummel				3
Family Gobiidae				
<u>Gobiosoma</u> sp.	1			
Family Stichaeidae				
<u>Ulvaria subbifurcata</u> - Radiated shanny	(1)			9
Family Ammodytidae				
<u>Ammodytes americanus</u> - Inshore sand lance	549	1		533
Family Stromatidae				
<u>Peprilus triacanthus</u> - Butterfish	5			

Table 7 (continued).

	Total Abundance (Trawl) day (night)	Total Abundance (Seine)	Total Abundance (Ichthyoplankton)
			<u>Eggs</u> <u>Larvae</u>
Family Triglidae			
<u>Prionotus evolans</u> - Striped sea robin	1 (2)		
Family Sparidae			
<u>Stenotomus chrysops</u> - Scup	167 (92)	30	
Family Sciaenidae			
<u>Leiostomus xanthurus</u> - Spot		2	
Family Cottidae			
<u>Myoxocephalus aeneus</u> - Grubby	84 (65)	5	20
Family Cyclopteridae			
<u>Cyclopterus lumpus</u> - Lumpfish	1 (1)		1
Order Pleuronectiformes			
Family Bothidae			
<u>Etropus microstomus</u> - Smallmouth flounder	1 (4)		
<u>Paralichthys dentatus</u> - Summer flounder	1 (1)		
<u>Scophthalmus aquosus</u> - Windowpane	8 (2)		2
Family Pleuronectidae			
<u>Hippoglossoides platessoides</u> - American plaice			3 3
<u>Pseudopleuronectes americanus</u> - Winter flounder	575 (175)	52	40
Order Tetradonotiformes			
Family Monacanthidae			
<u>Monacanthus hispidus</u> - Planehead filefish	0 (1)		
Family Tetraodontidae			
<u>Sphaeroides maculatus</u> - Northern puffer	5 (4)	3	

Table 8. Number of fishes and decapod crustaceans collected during the day with 4.9 m otter trawl by station in Nauset Marsh from August 1985 through October 1986. See Fig. 8 for station locations.

Station	STATION							TOTAL
	1	2	3	4	5	6	7	
Number of tows	26	25	25	9	33	25	28	171

PISCES

<u>Gasterosteus aculeatus</u>		3	1	10	7	253	2318	2592
<u>Apeltes quadracus</u>	1	4		650	90	787	562	2094
<u>Clupea harengus harengus</u>	14	65			1195	1	1	1276
<u>Pseudopleuronectes americanus</u>	36	86	19	64	187	134	49	575
<u>Ammodytes americanus</u>	412	10	121		4	2		549
<u>Fundulus heteroclitus</u>		7		50		214	11	282
<u>Syngnathus fuscus</u>	2	8		115	59	42	41	267
<u>Stenotomus chrysops</u>					167			167
<u>Myoxocephalus aeneus</u>				34	3	12	35	84
<u>Urophycis tenuis</u>				5	14	15	18	52
<u>Tautogolabrus adspersus</u>			1	14	9	11	13	48
<u>Menidia menidia</u>	6	19	2	4	5			36
<u>Pollachius virens</u>							19	19
<u>Tautoga onitis</u>				11	7			18

Table 8 (continued).

Station	STATION							TOTAL
	1	2	3	4	5	6	7	
Number of tows	26	25	25	9	33	25	28	171
<u>Anguilla rostrata</u>		1		2	1	10	3	17
<u>Gasterosteus wheatlandi</u>	1	13						14
<u>Scophthalmus aquosus</u>	2		3		3			8
<u>Peprilus triacanthus</u>					5			5
<u>Sphaeroides maculatus</u>					5			5
<u>Fundulus majalis</u>				2			1	3
<u>Brevoortia tyrannus</u>					2			2
<u>Anchoa mitchilli</u>					1			1
<u>Urophycis chuss</u>						1		1
<u>Microgadus tomcod</u>				1				1
<u>Selene vomer</u>			1					1
<u>Prionotus evolans</u>					1			1
<u>Gobiosoma boscii</u>				1				1
<u>Cyclopterus lumpus</u>							1	1
<u>Etropus microstomus</u>					1			1
<u>Paralichthys dentatus</u>					1			1

Table 8 (continued).

Station	STATION							TOTAL
	1	2	3	4	5	6	7	
Number of tows	26	25	25	9	33	25	28	171

DECAPODA

<u>Crangon septemspinosus</u>	5748	23768	310	247	299	955	219	31546
<u>Carcinus maenas</u>	65	1321	17	79	99	673	125	2379
<u>Cancer irroratus</u>	2	1	19	34	112	27	81	276
<u>Palaeomonetes vulgaris</u>				36	15	7		58
<u>Libinia dubia</u>				2	9	16		27
<u>Pagurus acadianus</u>	1	1	7	1	3	4	3	20
<u>Homarus americanus</u>	3		1	1	1	1	5	12
<u>Ovalipes ocellatus</u>	5		1					6
<u>Hippolyte zostericoli</u>					1		1	2
<u>Neopanopeus sayi</u>				1				1

Table 9. Fishes and decapod crustaceans collected with 8.3 m seine in Nauset Marsh from August 1985 through October 1986. Eelgrass disappeared at sampling site after October 1985.

Habitat	Salt Pond			Creeks and marsh pools		
	Eelgrass	Gravel	Sand/Mud	Oct. 85	Sept.-Oct. 86	Total
Number of tows	18	18	21	21	15	
PISCES						
<u>Fundulus heteroclitus</u>	66	125	441	793	7	1432
<u>Menidia menidia</u>		191	293	56	5	545
<u>Apeltes quadracus</u>	150	34	53	265		502
<u>Fundulus majalis</u>	2	15	39	205		261
<u>Pseudopleuronectes americanus</u>	2		34	5	11	52
<u>Stenotomus chrysops</u>			30			30
<u>Brevoortia tyrannus</u>				5	19	24
<u>Syngnathus fuscus</u>	14	3	3			20
<u>Mugil cephalus</u>				2	9	11
<u>Girella jack</u> <u>Caranx hippos</u>			6			6
<u>Myoxocephalus aeneus</u>		1	4			5
<u>Gasterosteus aculeatus</u>			1	3		4
<u>Menidia beryllina</u>		1	2			3
<u>Sphaeroides maculatus</u>			3			3
<u>Alosa pseudoharengus</u>			1		1	2
<u>Leiostomus xanthurus</u>			2			2
<u>Tautoglabrus adspersus</u>			2			2
<u>Alosa aestivalis</u>		1				1
<u>Ammodytes americanus</u>				1		1

Table 9 (continued).

Habitat	Salt Pond			Creeks and marsh pools		
	Eelgrass	Gravel	Sand/Mud	Oct. 85	Sept.-Oct. 86	Total
Number of tows	18	18	21	21	15	
<u>Decapterus punctatus</u>					1	1
<u>Pomatomus saltatrix</u>			1			1
<u>Tautoga onitis</u>	1					1
DECAPODA						
<u>Crangon septemspinosa</u>	1	2	252	3		258
<u>Carcinus maenas</u>	5	8	26	14		53
<u>Palaemonetes vulgaris</u>	4	1	1			5
<u>Cancer irroratus</u>			1			1
<u>Eurypanopeus depressus</u>		1				1

Table 10. Mean number of fishes and decapod crustaceans collected per 8.3 m seine in the different habitats in Nauset Marsh from August 1985 through October 1986.

Habitat	Mean number per seine	
	PISCES	DECAPODA
Eelgrass	39	2
Gravel	21	1
Sand/Mud	44	13

Table 11. Mean number of fishes and decapod crustaceans collected per 4.9 m otter trawl in the different habitats in Nauset Marsh from August 1985 through October 1986. See Fig. 8 for station locations.

Habitat (Stations)	Mean number per trawl	
	PISCES	DECAPODA
Eelgrass (St-4,6,7)	79	36
Deep Water (St-5)	54	16
Sand (St-1,3)	12	121
Mud (St-2)	9	1004

Nauset Bay (Station 2) where they averaged 951 individuals/tow. The next most abundant collections of sand shrimp (221 individuals/tow) were over sand in a nearby marsh creek (Station 1). Green crab was also most abundant in the mud substrate at Nauset Bay (Station 2), where it averaged 53 individuals/tow, but we also collected fairly large numbers (27 individuals/tow) in the eelgrass habitat near Fort Hill. In shallow waters, where collections were made by seine, relatively few decapods were found (Table 9). Sand shrimp was clearly more abundant in the sand/mud substrate as was green crab.

The sampling effort expended at the eelgrass habitats (Stations 4, 6, 7; Tables 12, 13, 14) varied by station with most effort expended at Stations 6 and 7. These latter two stations provided the basis for the following comments. For most of the dominant species in these habitats (three- and four-spined sticklebacks) the greatest collections were made during the summer and fall, although this varied somewhat between stations. At Station 6, which was immediately adjacent to a salt marsh habitat, common mummichog was abundant, but only during July and August. Winter flounder was collected in all months with nearly equal abundance in each collection.

In general our intensive sampling from eelgrass and nearby unvegetated areas showed the expected patterns of greater species richness in eelgrass meadows relative to unvegetated areas and greatest summer abundance for decapod crustaceans and fishes in eelgrass (Research Appendix A-1d). The composition of eelgrass-associated decapods and fishes was dominated by cold-water taxa and was strikingly different from that of the better studied eelgrass meadows of the mid-Atlantic coast. For example, four of the eight decapod species collected, including the second and third most abundant taxa, did not even appear in collections reported from Chesapeake Bay eelgrass meadows. Similarly, 10 of the 22 fish species taken, including the first and sixth most abundant species, were not reported from Chesapeake Bay eelgrass samples.

In an attempt to discern diurnal patterns of utilization in eelgrass (Stations 6 and 7) and deep water/drift algae (Station 5) habitats we made night trawls during the fall of 1985 and 1986 (Table 15). At the drift algae habitat there was no major difference in the relative ranking or abundance of the dominant forms in day and night collections, although the number of sand shrimp collected at night in September 1986 was much greater than that during the day. In the comparisons for eelgrass (Station 6 in 1985), a number of species, four-spined stickleback, winter flounder, grubby, sand shrimp, and green crab, were much more abundant at night than during the day. At Station 7, northern pipefish, sand shrimp, rock crab, and green crab were more abundant at night while the reverse was true for three- and four-spined sticklebacks.

For the shallow water habitats, which were sampled by seine (Tables 16, 17, 18), all species were most abundant during July through October except at the eelgrass station where no fishes were collected in July 1986 when eelgrass was absent.

SOME SEASONAL CONSIDERATIONS

The temporal utilization of Nauset Marsh indicates clearly that fish and decapod crustaceans were most abundant during the summer and least abundant during the winter (Tables 19, 20). This pattern probably reflects either movement

Table 12. Number of fishes and decapod crustaceans collected during the day with 4.9 m otter trawl by month at Station 4 (eelgrass) from August through October 1985. See Fig. 8 for location.

	1985		TOTAL
	Aug	Oct	
Number of tows	5	4	9
PISCES			
<u>Apeltes quadracus</u>	253	397	650
<u>Syngnathus fuscus</u>	46	69	115
<u>Psuedopleuronectes americanus</u>	37	27	64
<u>Fundulus heteroclitus</u>	3	47	50
<u>Myoxocephalus aeneus</u>	10	24	34
<u>Tautogolabrus adspersus</u>	5	9	14
<u>Tautoga onitis</u>	1	10	11
<u>Gasterosteus aculeatus</u>	2	8	10
<u>Urophycis tenuis</u>	5		5
<u>Menidia menidia</u>	1	3	4
<u>Anguilla rostrata</u>		2	2
<u>Fundulus majalis</u>		2	2
<u>Microgadus tomcod</u>		1	1
<u>Gobiosoma boscii</u>	1		1
DECAPODA			
<u>Crangon septemspinosa</u>	58	189	247
<u>Carcinus maenas</u>	20	59	79
<u>Palaemonetes vulgaris</u>	27	9	36
<u>Cancer irroratus</u>	8	26	34
<u>Libinia dubia</u>	2		2
<u>Pagurus acadianus</u>		1	1
<u>Homarus americanus</u>		1	1
<u>Neopanopeus sayi</u>		1	1

Table 13. Number of fishes and decapod crustaceans collected during the day with 4.9 m otter trawl by month at Station 6 (eelgrass) from August 1985 through July 1986. See Fig. 8 for location.

	1985			1986			TOTAL
	Aug	Oct	Dec	Apr	Jun	Jul	
Number of tows	5	4	4	4	4	4	25
PISCES							
<u>Apeltes quadracus</u>	161	16		7	55	548	787
<u>Gasterosteus aculeatus</u>	4			1	156	92	253
<u>Fundulus heteroclitus</u>	109					105	214
<u>Pseudopleuronectes americanus</u>	23	5	12	24	55	15	134
<u>Syngnathus fuscus</u>	18	10		1	1	12	42
<u>Urophycis tenuis</u>	3				6	6	15
<u>Myoxocephalus aeneus</u>	10	2					12
<u>Tautoglabrus adspersus</u>	4	3	1			3	11
<u>Anguilla rostrata</u>	2					8	10
<u>Ammodytes americanus</u>			2				2
<u>Clupea harengus harengus</u>						1	1
<u>Urophycis chuss</u>					1		1
DECAPODA							
<u>Crangon septemspinosa</u>	15	81	2	106	506	245	955
<u>Carcinus maenas</u>	141	45	22	36	242	187	673
<u>Cancer irroratus</u>	4	11		1	4	7	27
<u>Libinia dubia</u>	15	1					16
<u>Palaeomonetes vulgaris</u>	3					4	7
<u>Pagurus acadianus</u>			1	1	2		4
<u>Homarus americanus</u>		1					1

Table 14. Number of fishes and decapod crustaceans collected during the day with 4.9 m otter trawl by month at Station 7 (eelgrass) from December 1985 through October 1986. See Fig. 8 for location.

	1985	1986					
	Dec	Apr	Jun	Jul	Sept	Oct	TOTAL
Number of tows	4	4	4	4	4	4	28
PISCES							
<u>Gasterosteus aculeatus</u>	9	6	164	20	878	1241	2318
<u>Apeltes quadracus</u>	35	33	127	56	89	222	562
<u>Pseudopleuronectes americanus</u>	4	8	13	9	9	6	49
<u>Syngnathus fuscus</u>	5				13	23	41
<u>Myoxocephalus aeneus</u>	17	1	2	4	1	10	35
<u>Pollachius virens</u>		2	17				19
<u>Urophycis tenuis</u>			4	5	6	3	18
<u>Tautoglabrus adspersus</u>				1	2	10	13
<u>Fundulus heteroclitus</u>						11	11
<u>Anguilla rostrata</u>			2			1	3
<u>Clupea harengus harengus</u>		1					1
<u>Fundulus majalis</u>	1						1
<u>Cyclopterus lumpus</u>	1						1

Table 14 (continued).

	1985	1986					
	Dec	Apr	Jun	Jul	Sept	Oct	TOTAL
Number of tows	4	4	4	4	4	4	28
DECAPODA							
<u>Crangon septemspinosus</u>	30	6	30	4	4	145	219
<u>Carcinus maenas</u>	38	28	28	7	5	19	125
<u>Cancer irroratus</u>	12	4	1	1	9	54	81
<u>Homarus americanus</u>			5				5
<u>Pagurus acadianus</u>	1	1	1				3
<u>Hippolyte zostericola</u>	1						1

Table 15. Number of fishes and decapod crustaceans collected at night with 4.9 m otter trawl in October 1985 and September and October 1986. See Fig. 8 for station locations.

	<u>Oct. 1985</u>		<u>Sept. 1986</u>		<u>Oct. 1986</u>		
Station	6	7	5	7	5	7	Total
Number of tows	4	4	4	4	4	4	24

PISCES

<u>Gasterosteus aculeatus</u>		761		161		167	1089
<u>Apeltes quadracus</u>	72	299		8		29	408
<u>Syngnathus fuscus</u>	3	152		47		161	363
<u>Pseudopleuronectes americanus</u>	75	44	9	11	21	15	175
<u>Stenotomus chrysops</u>			40	2	50		92
<u>Myoxocephalus aeneus</u>	21	12		9		23	65
<u>Menidia menidia</u>	3	13		12		2	30
<u>Tautogolabrus adspersus</u>		23				3	26
<u>Urophycis tenuis</u>		8		4		5	17
<u>Fundulus heteroclitus</u>	1	9				5	15
<u>Tautoga onitis</u>		11		1			12
<u>Pollachius virens</u>				5		4	9
<u>Microgadus tomcod</u>		1		1		2	4
<u>Etropus microstomus</u>			4				4
<u>Sphaeroides maculatus</u>			2		2		4
<u>Anguilla rostrata</u>				1		1	2
<u>Alosa aestivalis</u>					2		2
<u>Gadus morhua</u>		2					2

Table 15 (continued).

Station	<u>Oct. 1985</u>		<u>Sept. 1986</u>		<u>Oct. 1986</u>		Total
	6	7	5	7	5	7	
Number of tows	4	4	4	4	4	4	24
<u>Urophycis chuss</u>	2						2
<u>Pomatomus saltatrix</u>			2				2
<u>Prionotus evolans</u>					2		2
<u>Scophthalmus aquosus</u>			1		1		2
<u>Anchoa mitchilli</u>					1		1
<u>Cyclopterus lumpus</u>						1	1
<u>Monocanthus hispidus</u>					1		1
<u>Centropristis striata</u>						1	1
<u>Ulvaria subbifurcata</u>						1	1
<u>Paralichthys dentatus</u>			1				1
DECAPODA							
<u>Crangon septemspinosa</u>	1437	22	909	436	138	949	3891
<u>Cancer irroratus</u>	16	3	5	463	3	244	734
<u>Carcinus maenas</u>	307	8	11	27	4	102	459
<u>Homarus americanus</u>	7	2				2	11
<u>Libinia dubia</u>		2	7				9
<u>Pagurus acadianus</u>	4	2		1			7

Table 16. Number of fishes and decapod crustaceans collected in eelgrass with 8.3 m seine by month in Salt Pond Inlet August and October 1985. See Fig. 8 for location.

	1985		TOTAL
	Aug	Oct	
Number of tows	3	3	18
PISCES			
<u>Apeltes quadracus</u>	92	58	150
<u>Fundulus heteroclitus</u>	35	31	66
<u>Syngnathus fuscus</u>	12	2	14
<u>Fundulus majalis</u>		2	2
<u>Pseudopleuronectes americanus</u>		2	2
<u>Tautoga onitis</u>	1		1
DECAPODA			
<u>Carcinus maenas</u>	5		5
<u>Palaemonetes vulgaris</u>	4		4
<u>Crangon septemspinosa</u>		1	1

Table 17. Number of fishes and decapod crustaceans collected with 8.3 m seine by month over gravel substrate in Salt Pond Inlet from August 1985 through July 1986. See Fig. 8 for location.

	1985			1986			
	Aug	Oct	Dec	Apr	Jun	Jul	TOTAL
Number of tows	3	3	3	3	3	3	18
PISCES							
<u>Menidia menidia</u>	1	2				188	191
<u>Fundulus heteroclitus</u>	9	14			1	101	125
<u>Apeltes quadracus</u>		25				9	34
<u>Fundulus majalis</u>		15					15
<u>Syngnathus fuscus</u>	3						3
<u>Menidia beryllina</u>		1					1
<u>Alosa pseudoharengus</u>						1	1
<u>Myoxocephalus aeneus</u>						1	1
DECAPODA							
<u>Carcinus maenas</u>		1			2	5	8
<u>Crangon septemspinosa</u>	1			1			2
<u>Palaemonetes vulgaris</u>		1					1
<u>Eurypanopeus depressus</u>		1					1

Table 18. Number of fishes and decapod crustaceans collected with 8.3 m seine by month over sand/mud substrate at the Salt Pond boat ramp from August 1985 through September 1986. See Fig. 8 for location.

	1985			1986				TOTAL
	Aug	Oct	Dec	Apr	Jun	Jul	Sept	
Number of tows	3	3	3	3	3	3	3	21
PISCES								
<u>Fundulus heteroclitus</u>	109	302				28	2	441
<u>Menidia menidia</u>	2	25				266		293
<u>Apeltes quadracus</u>	5	8		2		38		53
<u>Fundulus majalis</u>		39						39
<u>Pseudopleuronectes americanus</u>	16					1	17	34
<u>Stenotomus chrysops</u>							30	30
<u>Crevalle jack</u>							6	6
<u>Myoxocephalus aeneus</u>							4	4
<u>Syngnathus fuscus</u>	2					1		3
<u>Sphaeroides maculatus</u>							3	3
<u>Menidia beryllina</u>		2						2
<u>Leiostomus xanthurus</u>							2	2
<u>Tautogolabrus adspersus</u>							2	2
<u>Alosa pseudoharengus</u>							1	1
<u>Gasterosteus aculeatus</u>				1				1
<u>Pomatomus saltatrix</u>							1	1

Table 18 (continued).

	1985			1986				
	Aug	Oct	Dec	Apr	Jun	Jul	Sept	TOTAL
Number of tows	3	3	3	3	3	3	3	21
DECAPODA								
<u>Crangon septemspinosus</u>	133			3			116	252
<u>Carcinus maenas</u>	16	3				7		26
<u>Palaemonetes vulgaris</u>	1							1
<u>Cancer irroratus</u>				1				1

Table 19. Number of fishes and decapod crustaceans collected by month at the seven otter trawl stations from August 1985 through October 1986.
(NS = not sampled.) See Fig. 8 for station locations.

Station Number (Habitat)	1985			1986					Total
	Aug	Oct	Dec	Aug	June	July	Sept	Oct	
PISCES									
1 (sand)	26	215	2	3	147	24	57	NS	474
3 (sand)	12	33	1	9	90	3	NS	NS	148
2 (mud)	52	24	0	51	59	30	NS	NS	216
5 (deep)	2	108	105	10	1113	213	92	124	1767
4 (eelgrass)	364	599	NS	NS	NS	NS	NS	NS	963
6 (eelgrass)	334	36	15	33	274	790	NS	NS	1482
7 (eelgrass)	<u>NS</u>	<u>NS</u>	<u>72</u>	<u>51</u>	<u>329</u>	<u>95</u>	<u>989</u>	<u>1527</u>	<u>3072</u>
	790	1015	195	157	2012	1155	1147	1651	8122
DECAPODA									
1 (sand)	5310	354	1	1	1	157	0	NS	5824
3 (sand)	294	9	6	4	3	39	NS	NS	355
2 (mud)	344	57	3	29	163	24495	NS	NS	25091
5 (deep)	34	131	53	23	54	11	93	140	539
4 (eelgrass)	115	286	NS	NS	NS	NS	NS	NS	401
6 (eelgrass)	178	139	25	144	754	443	NS	NS	1683
7 (eelgrass)	<u>NS</u>	<u>NS</u>	<u>82</u>	<u>39</u>	<u>65</u>	<u>12</u>	<u>18</u>	<u>218</u>	<u>434</u>
	6275	976	170	240	1040	25157	111	358	34327

Table 20. Number of fishes and decapod crustaceans collected by month at the three 8.3 m seine stations from August 1985 through September 1986. See Fig. 8 for habitat locations.

Habitats	1985			1986				Total
	Aug	Oct	Dec	Aug	June	July	Sept	
PISCES								
Eelgrass	140	95	0	0	0	0	NS	235
Gravel	13	57	0	0	1	300	NS	371
Sand/Mud	<u>134</u>	<u>376</u>	<u>0</u>	<u>3</u>	<u>0</u>	<u>334</u>	<u>68</u>	<u>915</u>
	287	528	0	3	1	634	68	1521
DECAPODS								
Eelgrass	9	1	0	0	0	0	NS	10
Gravel	1	3	0	1	2	5	NS	12
Sand/Mud	<u>150</u>	<u>3</u>	<u>0</u>	<u>4</u>	<u>0</u>	<u>7</u>	<u>116</u>	<u>280</u>
	160	7	0	5	2	12	116	302

out of Nauset Marsh by a large number of species in winter, or lack of vulnerability to the collecting gear for some of the resident species.

The temporal pattern of abundance at each station/habitat was species specific. At the sand habitats (Stations 1, 3; Tables 21, 22), inshore sand lance was abundant from July through October. The dominant decapod was abundant from July through August or October depending on the station. At the mud habitat (Station 2, Table 23), winter flounder was most abundant in July and August while Atlantic herring was only found in April and June. Collections of sand shrimp were large in July and August while green crab was fairly abundant June through October with a pronounced peak in July. At the deep, drift algae habitat (Station 5; Table 24) Atlantic herring peaked in June, was present in July and was virtually absent from the rest of the collections. Winter flounder was most abundant from June through October while scup (Stenotomus chrysops) only occurred in September and October. Sand shrimp was found in abundance in September and October while rock crab appeared to be most abundant in the cooler months, October through June.

CATEGORIES OF UTILIZATION

In general, the fish and decapod fauna can be characterized as consisting of a small number of resident species and a larger number of migratory species (anadromous, catadromous and transients) (Table 25). Most of the migratory forms use the marsh as a nursery area, indicated by the preponderance of juvenile stages. Many of these are of commercial or recreational importance including American eel (Anguilla rostrata), river herrings (alewife - Alosa pseudoharengus, and blueback herring - A. aestivalis), Atlantic herring, menhaden (Brevoortia tyrannus), pollock (Pollachius virens), white hake (Urophycis tenuis), bluefish (Pomatomus saltatrix), winter flounder, and American lobster (Homarus americanus). Others are important prey for some of the above species including menhaden, bay anchovy (Anchoa mitchilli), Atlantic silverside, inshore sand lance, and sand shrimp. Further, these juveniles are undoubtedly prey for the system's shorebird populations.

The habitats utilized by these forms may be classified by the degree of fidelity to a specific habitat (Table 25). Some of the pelagic forms, such as Atlantic herring and inshore sand lance, occur over a variety of substrates (i.e., habitat generalists) and this may occur in some benthic forms as well (e.g., winter flounder). Others appear more restricted in the habitats they utilize. The best examples are those that appear to require three-dimensional structures such as white hake (peat reef, eelgrass, drift algae), three- and four-spined sticklebacks (eelgrass), cunner - Tautoglabrus adspersus (peat reef, eelgrass), and American lobster (peat reef, eelgrass).

The composition of the fauna generally reflects the location of Nauset Marsh at the limits of two zoogeographic provinces. A northern, or boreal fauna, is well represented by numerous cold water forms (e.g., Atlantic herring, Atlantic cod - Gadus morhua, pollack, rock gunnel - Pholis gunnellus) while southern components are represented by such forms as common mummichog, tidewater silverside (Menidia beryllina), and numerous southern transients (Table 25) that were collected during late summer when water temperatures peaked. These zoogeographic differences may be occurring on a smaller scale on outer Cape Cod as

Table 21. Number of fishes and decapod crustaceans collected during the day with 4.9 m otter trawl by month at Station 1 (sand) from August 1985 through September 1986. See Fig. 8 for location.

	1985			1986				TOTAL
	Aug	Oct	Dec	Apr	Jun	Jul	Sept	
Number of tows	5	4	4	4	4	4	1	26
PISCES								
<u>Ammodytes americanus</u>		202			134	20	56	412
<u>Pseudopleuronectes americanus</u>	26	4	2		1	3		36
<u>Clupea harengus harengus</u>				2	11	1		14
<u>Menidia menidia</u>		6						6
<u>Syngnathus fuscus</u>		1		1				2
<u>Scophthalmus aquosus</u>		1					1	2
<u>Gasterosteus wheatlandi</u>					1			1
<u>Apeltes quadracus</u>		1						1
DECAPODA								
<u>Crangon septemspinosa</u>	5288	331		1		128		5748
<u>Carcinus maenas</u>	20	18	1		1	25		65
<u>Ovalipes ocellatus</u>	1	4						5
<u>Homarus americanus</u>						3		3
<u>Cancer irroratus</u>	1					1		2
<u>Pagurus acadianus</u>		1						1

Table 22. Number of fishes and decapod crustaceans collected during the day with 4.9 m otter trawl by month at Station 3 (inlet, sand) from August 1985 through July 1986. See Fig. 8 for location.

	1985			1986			TOTAL
	Aug	Oct	Dec	Apr	Jun	Jul	
Number of tows	5	4	4	4	4	4	25
PISCES							
<u>Ammodytes americanus</u>		24	1	7	89		121
<u>Pseudopleuronectes americanus</u>	11	3		2	1	2	19
<u>Scophthalmus aquosus</u>		3					3
<u>Menidia menidia</u>		2					2
<u>Gasterosteus aculeatus</u>						1	1
<u>Tautogolabrus adspersus</u>	1						1
<u>Selene vomer</u>		1					1
DECAPODA							
<u>Crangon septemspinosus</u>	269	5	5	1	1	29	310
<u>Cancer irroratus</u>	12	3	1	1	1	1	19
<u>Carcinus maenas</u>	7			2		8	17
<u>Pagurus acadianus</u>	5				1	1	7
<u>Ovalipes ocellatus</u>		1					1
<u>Homarus americanus</u>	1						1

Table 23. Number of fishes and decapod crustaceans collected during the day with 4.9 m otter trawl by month at Station 2 (mud) from August 1985 through July 1986. See Fig. 8 for location.

	1985			1986			TOTAL
	Aug	Oct	Dec	Apr	Jun	Jul	
Number of tows	5	4	4	4	4	4	25
PISCES							
<u>Pseudopleuronectes americanus</u>	44	5		9	4	24	86
<u>Clupea harengus harengus</u>				39	26		65
<u>Menidia menidia</u>		14				5	19
<u>Gasterosteus wheatlandi</u>					13		13
<u>Ammodytes americanus</u>					10		10
<u>Syngnathus fuscus</u>	6			2			8
<u>Fundulus heteroclitus</u>	1	5				1	7
<u>Apeltes quadracus</u>				1	3		4
<u>Gasterosteus aculeatus</u>					3		3
<u>Anguilla rostrata</u>	1						1
DECAPODA							
<u>Crangon septemspinosa</u>	295	18	2	20	52	23381	23768
<u>Carcinus maenas</u>	49	39	1	9	110	1113	1321
<u>Cancer irroratus</u>					1		1
<u>Pagurus acadianus</u>						1	1

Table 24. Number of fishes and decapod crustaceans collected during the day with 4.9 m otter trawl by month at Station 5 (deep) from August 1985 through October 1986. See Fig. 8 for location (* = Gracilaria sp. present.)

	1985			1986					TOTAL
	Aug	Oct	Dec	Apr	Jun	Jul	Sept	Oct	
Number of tows	5	4*	4*	4	4	4	4	4	33

PISCES

<u>Clupea harengus harengus</u>				1	1049	145			1195
<u>Pseudopleuronectes americanus</u>		30	5	4	56	54	3	35	187
<u>Stenotomus chrysops</u>							81	86	167
<u>Apeltes quadracus</u>		4	82	3		1			90
<u>Syngnathus fuscus</u>		56		2		1			59
<u>Urophycis tenuis</u>		1			5	7	1		14
<u>Tautogolabrus adspersus</u>	1	4	4						9
<u>Gasterosteus aculeatus</u>			6		1				7
<u>Tautoga onitis</u>		3	4						7
<u>Menidia menidia</u>	1	4							5
<u>Peprilus triacanthus</u>						2	3		5
<u>Sphaeroides maculatus</u>							4	1	5
<u>Ammodytes americanus</u>		3	1						4
<u>Myoxocephalus aeneus</u>			3						3

Table 24 (continued).

	1985			1986					TOTAL
	Aug	Oct	Dec	Apr	Jun	Jul	Sept	Oct	
Number of tows	5	4*	4*	4	4	4	4	4	33
<u>Scophthalmus aquosus</u>		2						1	3
<u>Brevoortia tyrannus</u>						2			2
<u>Anguilla rostrata</u>					1				2
<u>Anchoa mitchilli</u>		1							1
<u>Prionotus evolans</u>								1	1
<u>Etropus microstomus</u>						1			1
<u>Paralichthys dentatus</u>					1				1
DECAPODA									
<u>Crangon septemspinosa</u>	20	56	15	5	8		63	132	299
<u>Cancer irroratus</u>	12	40	20	10	21	2	4	3	112
<u>Carcinus maenas</u>	2	33	4	5	24	6	21	4	99
<u>Palaemonetes vulgaris</u>		2	13						15
<u>Libinia dubia</u>				1	1	3	4		9
<u>Pagurus acadianus</u>				1			1	1	3
<u>Homarus americanus</u>				1					1
<u>Hippolyte zostericola</u>			1						1

Table 25. Utilization of Nauset Marsh by fishes and decapod crustaceans from July 1985 through October 1986.

Mode of utilization as follows: R = resident, A = anadromous, C = catadromous, T = transient (S-southern, N-northern), and N = nursery. Habitat utilization as follows: D = dominant, C = common and O = infrequent occurrence. Life history stages as follows: E = eggs, L = larvae, J = juvenile and A = adult.

	Mode of Utilization	Habitat				Life History Stage
		Sand	Mud	Deep	Eelgrass	
PISCES						
Family Anguillidae						
<u>Anguilla rostrata</u>	C		O	O	C	J,A
Family Congridae						
<u>Conger oceanicus</u>	T-S			O		L
Family Clupeidae						
<u>Alosa aestivalis</u>	A	O		O		J
<u>Alosa pseudoharengus</u>	A	O				J
<u>Clupea harengus harengus</u>	N	O	C	D	O	L,J
<u>Brevoortia tyrannus</u>	N	O		O		L,J
Family Engraulidae						
<u>Anchoa mitchilli</u>	T-S	O		O		J
<u>Anchoa hepsetus</u>	T-S	O				J
Family Gadidae						
<u>Gadus morhua</u>	T-N				O	J
<u>Microgadus tomcod</u>	T				O	J
<u>Pollachius virens</u>	N				C	L,J

Table 25 (continued).

	Mode of Utilization	Habitat				Life History Stage
		Sand	Mud	Deep	Eelgrass	
<u>Urophycis chuss</u>	T			O	O	J
<u>Urophycis tenuis</u>	N			C	C	J
<u>Enchelyopus cimbrius</u>	T		O			L
Family Cyprinodontidae						
<u>Fundulus heteroclitus</u>	R	D	O		C	L,J,A
<u>Fundulus majalis</u>	R	O			O	J,A
Family Atherinidae						
<u>Menidia beryllina</u>	R	O				A
<u>Menidia menidia</u>	N	O	O	O	O	E,L,J,A
Family Gasterosteidae						
<u>Apeltes quadracus</u>	R	O	O	C	D	E,L,J,A
<u>Gasterosteus aculeatus</u>	N	R	O	O	D	L,J,A
<u>Gasterosteus wheatlandi</u>	N	O	O			A
Family Syngnathidae						
<u>Syngnathus fuscus</u>	N	O	O	C	C	J,A
Family Serranidae						
<u>Centropristes striata</u>	T-S				O	J
Family Pomatomidae						
<u>Pomatomus saltatrix</u>	N	O		O		J

Table 25 (continued).

	Mode of Utilization	Habitat				Life History Stage
		Sand	Mud	Deep	Eelgrass	
Family Carangidae						
<u>Decapterus punctatus</u>	T-S				O	J
<u>Selene vomer</u>	T-S	O				J
<u>Caranx hippos</u>	T-S	O				J
Family Labridae						
<u>Tautoga onitis</u>	T			O	C	J,A
<u>Tautogolabrus adspersus</u>	R	O		C	C	L,J,A
Family Mugilidae						
<u>Mugil cephalus</u>	T-S	O				J
<u>Mugil curema</u>	T-S	O				L
Family Pholidae						
<u>Pholis gunnellus</u>	R				O	J,A
Family Gobiidae						
<u>Gobiosoma boscii</u>	T-S				O	A
Family Stichaeidae						
<u>Ulvaria subbifurcata</u>	R				O	L,J
Family Ammodytidae						
<u>Ammodytes americanus</u>	R	D	O	C	O	L,J,A

Table 25 (continued).

	Mode of Utilization	Habitat				Life History Stage
		Sand	Mud	Deep	Eelgrass	
Family Stromatidae						
<u>Peprilus triacanthus</u>	T			O		J
Family Triglidae						
<u>Prionotus evolans</u>	T-S	O		O		J
Family Sparidae						
<u>Stenotomus chrysops</u>	T-S	O		C	O	J
Family Sciaenidae						
<u>Leiostomus xanthurus</u>	T-S	O				J
Family Cottidae						
<u>Myoxocephalus aeneus</u>	R	O		O	C	L,J,A
Family Cyclopteridae						
<u>Cyclopterus lumpus</u>	T				O	J
Family Bothidae						
<u>Etropus microstomus</u>	T-S			O		A
<u>Paralichthys dentatus</u>	T-S			O		A
<u>Scophthalmus aquosus</u>	T	O		O		E,A
<u>Hippoglossoides platessoides</u>	T	O	O	O	O	E,L

Table 25 (continued).

	Mode of Utilization	Habitat				Life History Stage
		Sand	Mud	Deep	Eelgrass	
Family Pleuronectidae						
<u>Pseudopleuronectes americanus</u>	R	C	C	C	C	L,J,A
Family Monacanthidae						
<u>Monacanthus hispidus</u>	T-S			O		J
Family Tetraodontidae						
<u>Sphaeroides maculatus</u>	T-S	O		O		J
DECAPODA						
<u>Cancer irroratus</u>	R	C	O	C	C	J,A
<u>Carcinus maenas</u>	R	C	D	C	D	J,A
<u>Ovalipes ocellatus</u>	R	O				A
<u>Libinia emarginata</u>	R			O	O	J,A
<u>Pagurus acadianus</u>	R	O	O	O	O	J,A
<u>Eurypanopeus depressus</u>	R	O				J
<u>Neopanopeus sayi</u>	R				O	J
<u>Crangon septemspinosa</u>	R	D	D	D	D	J,A
<u>Hippolyte zostericola</u>	T-S				O	A
<u>Homarus americanus</u>	R	O		O	O	L,J,A
<u>Palaemonetes vulgaris</u>	R			C	O	J,A

well. Our collections suggest that the fauna of Nauset Marsh may vary from that of Pleasant Bay immediately to the south (Table 6). Nauset Marsh lacks several southern fishes that have been collected from Pleasant Bay. These include oyster toadfish (Opsanus tau), Atlantic needlefish (Strongylura marina), sheepshead minnow (Cyprinodon variegatus), and hogchoker (Trinectes maculatus). A species not reported in these studies, but of some interest is blue crab (Callinectes sapidus). It is known to occur in Pleasant Bay and in some years is even abundant (Sargent 1981). It was not collected in our intensive efforts in Nauset Bay during 1985 - 1986 but we observed several adult individuals that were part of a "fish kill" in Salt Pond Bay in 1987.

Collections of the early life history stages (eggs and larvae) of fishes resulted in representatives of 24 species from ichthyoplankton collections (Tables 26, 27) and night light sampling (Table 28). American lobster postlarvae (Stage IV) were also represented in both collections. The eggs or larvae of some species (Fourbeard rockling - Enchelyopus cimbrius, striped anchovy - Anchoa hepsetus, Conger eel - Conger oceanicus, plaice - Hippoglossoides platessoides) occurred in these samples which were not collected with other techniques or in other developmental stages. Most eggs and larvae were collected from April through August (Table 26) but this range was extended by the earlier occurrence (March) of inshore sand lance and winter flounder.

LIFE HISTORY OF SELECT SPECIES

The following treatments address aspects of the life history for select species that were abundant in the collections used to characterize the fauna of Nauset Marsh. Treatment follows in a phylogenetic order.

American Eel (Anquilla rostrata)

Small numbers of large juveniles were observed around peat reefs and were collected in a variety of habitats but most frequently in eelgrass meadows. The most abundant collections by far, however, were of glass eels (48 - 68 mm TL) that occurred in large numbers in night light samples in June and, to a lesser extent, in July (Tables 26, 28).

Menhaden (Brevoortia tyrannus)

Both juvenile and adult menhaden utilize Nauset Marsh. Juveniles (15 - 80 mm) were collected in July and August (Table 26) and larger juveniles in September 1986 and October 1985 by gill net (Fig. 10). Adults (20 cm) were taken at the same time and visual inspection of the gonads indicated they were ripe at this time.

Atlantic Herring (Clupea harengus harengus)

Small juvenile Atlantic herring appear to utilize Nauset Marsh as a nursery area during the spring (Fig. 11). A single mode, presumably representing recently spawned individuals, first appeared in collections in April 1986. These may be the result of spawning along outer Cape Cod or adjacent Georges Bank because no small larvae were collected within Nauset Marsh. Further collections in May 1987, June and July 1986, indicate the presence of a single cohort that attained sizes of 41 - 74 mm before disappearing after July.

Table 26. Number of fish eggs and larvae and lengths of fish larvae collected in Nauset Marsh. Includes data from all sampling gears (plankton nets and night lighting). Indicated as number of larvae followed by range in length (TL) in parentheses.

SPECIES	MONTH						
	Mar	Apr	May	June	Jul	Aug	Sept
<u>Anguilla rostrata</u>		1 (50)	2 (57-58)	379 (48-68)	86 (53-66)	7 (58-62)	
<u>Conger oceanicus</u>				2 (91-102)			
<u>Alosa</u> sp.						5 26-32	
<u>Brevoortia tyrannus</u>					29 (19-80)	5 (15-49)	1 (54)
<u>Clupea harengus</u> <u>harengus</u>		5 (26-42)	31 (39-52)	30 (46-55)			
<u>Anchoa hepsetus</u>							1 (24)
<u>Anchoa mitchilli</u>					1 (17)		1 (21)
<u>Enchelyopus cimbrius</u>			20 eggs				
<u>Microgadus tomcod</u>					1 (20)		
<u>Pollachius virens</u>			1 (28)				
<u>Fundulus heteroclitus</u>				3 (48-64)			
Atherinidae				3 eggs	1 (14)		
<u>Menidia menidia</u>				19 (3-111) & egg mass	2 (56-62)	8 (13-60)	
<u>Apeltes quadracus</u>			2 (23-35)	30 (3-38) 9 eggs			2 (31-36)

Table 26 (continued).

SPECIES	MONTH						
	Mar	Apr	May	June	Jul	Aug	Sept
<u>Gasterosteus</u> <u>aculeatus</u>			27 38-72		2 18-?	2 17-17	2 33-40
<u>Syngnathus fuscus</u>				1 176	24 36-81	27 53-124	
<u>Tautogolabrus adspersus</u>					1 14		
<u>Mugil curema</u>						1 34	
<u>Ulvaria subbifurcata</u>			1 35	8 9-15			
<u>Pholis gunnellus</u>		2 19-26			1 47		
<u>Ammodytes</u> sp.	60 5-7	482 4-23					
<u>Myoxocephalus</u> <u>aeneus</u>		20 6-9					
<u>Cyclopterus</u> <u>lumpus</u>				1 8			
<u>Scophthalmus</u> <u>aquosus</u>							
<u>Hippoglossoides</u> <u>platessoides</u>	2 eggs		3 eggs				
<u>Psuedopleuronectes</u> <u>americanus</u>	4 2-4	30 3-4		9 4-7			
Unid. eggs	2	15	1	217			

Table 27. Ichthyoplankton collected with 20 cm bongo nets, 0.5 m hoop and 0.5 m epibenthic sled in Nauset Marsh from April 1986 - June 1987. (ns = no samples collected * = only eggs collected, ** = both eggs and larvae collected).

1986								1987					
Apr	May	Jun	J-Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
3	ns	3	31-1	10	14	ns	ns	ns	ns	11	14	7	2

DECAPODA

Homarus americanus ---

PISCES

Anguilla rostrata ---

Clupea harengus harengus ---

Pollachius virens ---

Enchelyopus cimbrius ---

Menidia menidia** ---

Apeltes quadracus** ---

Gasterosteus aculeatus -----

Syngnathus fuscus ---

Tautogolabrus adspersus ---

Pholis gunnellus ---

Ulvaria subbifurcata ---

Table 27 (continued).

	1986								1987					
	Apr	May	Jun	J-Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
	3	ns	3	31-1	10	14	ns	ns	ns	ns	11	14	7	2
<u>Ammodytes americanus</u>	---										-----			
<u>Myoxocephalus aeneus</u>	---													
<u>Cyclopterus lumpus</u>			---											
<u>Hippoglossoides platessoides**</u>										---		---		
<u>Scophthalmus aquosus*</u>						---								
<u>Pseudopleuronectes americanus</u>	---										-----			---

Table 28. Occurrence of fishes and stage IV lobsters collected by night lighting in Nauset Marsh June 2, 1986 - August 20, 1987.

	1986														1987							
	Jun				Jul				Aug				Sept	/	May	Jun		Jul			Aug	
	2	4	17	18	6	7	17	31	1	2	3	4	12	10	4	16	8	9	15	20		
DECAPODA																						
<u>Homarus americanus</u>																						

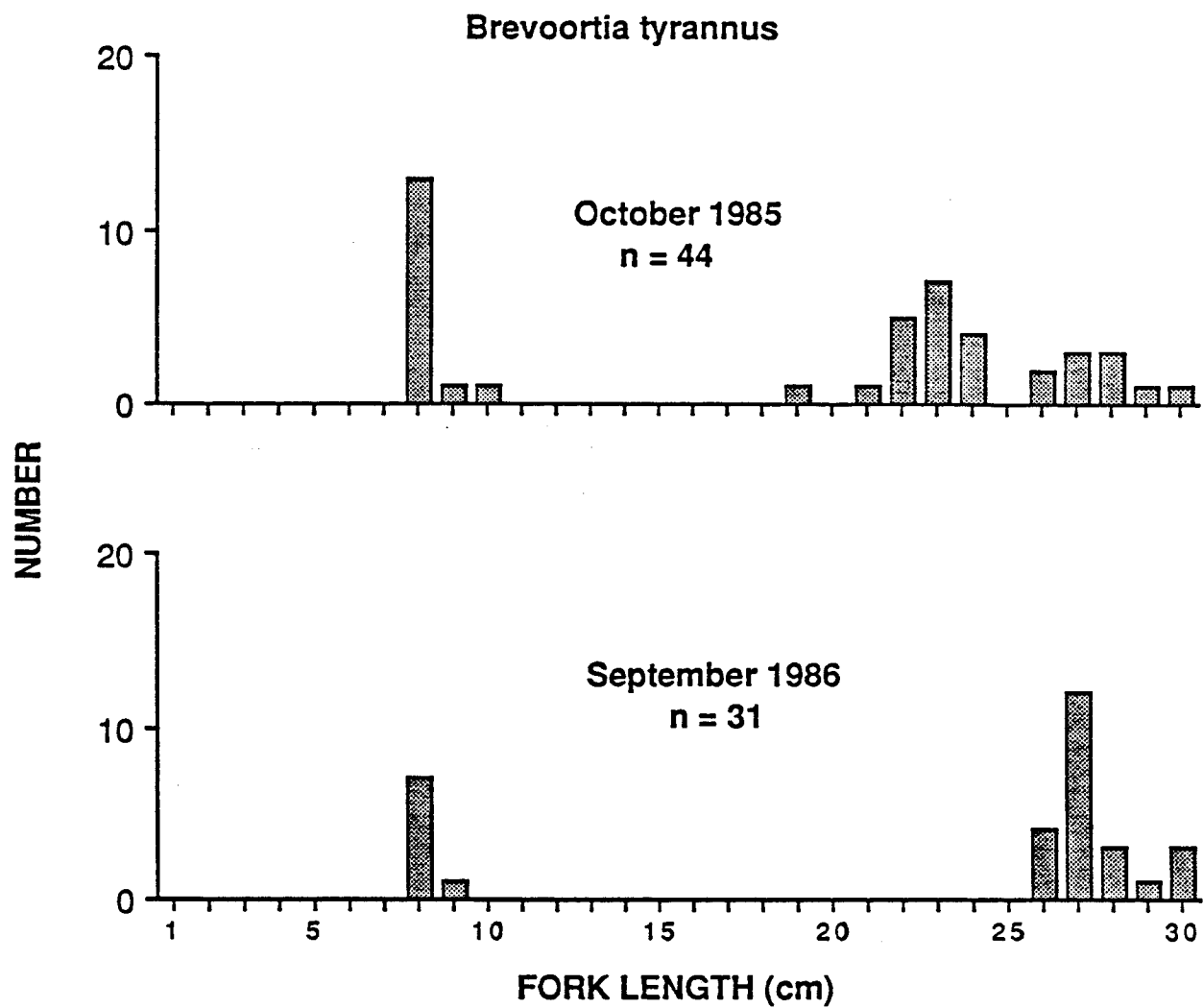


Figure 10. Length frequency distribution of menhaden, Brevoortia tyrannus, collected in Nauset Marsh with gill nets.

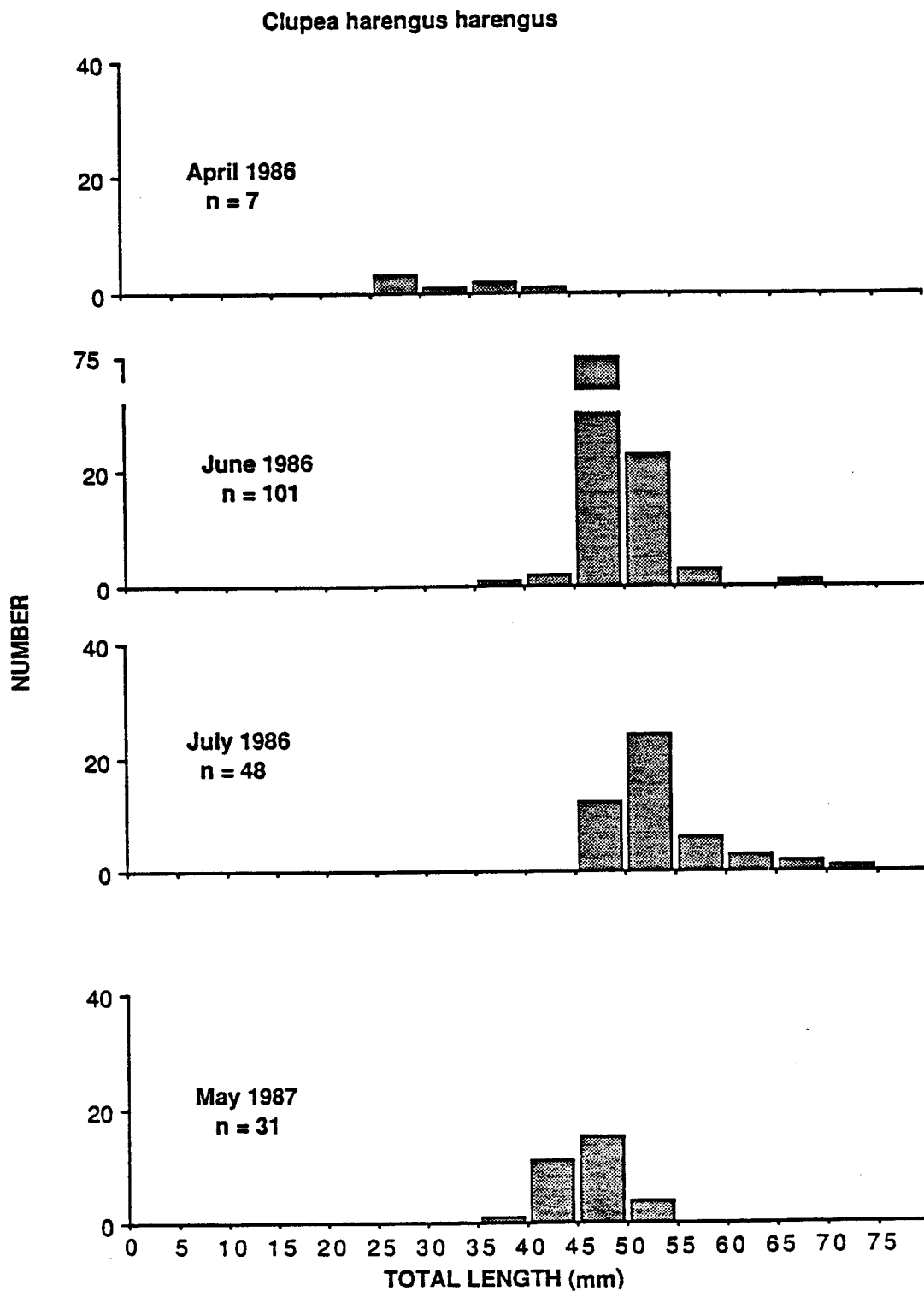


Figure 11. Length frequency distribution of Atlantic herring, Clupea harengus harengus, collected in Nauset Marsh with 4.9 m otter trawl and ichthyoplankton nets.

White Hake (Urophycis tenuis)

White hake was of interest because, although it is commercially important, virtually nothing is known of the juvenile habitat. We have discovered white hake to be common components of eelgrass and peat reef habitats (Research Appendix A-1c). It appears that they move into these habitats during late spring-early summer at sizes of 50 - 100 mm total length. They are resident and continue to grow at least through October, when they reach 200 - 300 mm before disappearing in early winter.

Pollock (Pollachius virens)

Juvenile pollock utilize Nauset Marsh as a nursery from spring through fall (Fig. 12). Small individuals first appeared in April and this year class can be followed through October. Examination of otoliths also indicated that larger fish collected in October are young of the year, thus they grow very quickly during the first year. Caution must be used in interpreting these data because of the small sample size for larger fish. Reduced catches are presumably the result of gear avoidance by the larger fish in the day because night collections were much more successful (Table 15).

Common Mummichog (Fundulus heteroclitus)

Several age classes appear to be represented in our collections (Fig. 13) of this resident fish. This is most obvious in July when three groups (20 - 45, 60 - 85, 110 - 120 mm TL), which probably represent three year classes, were evident. These and subsequent collections in August (approximately 10 - 50 mm) and October (approximately 20 - 60 mm TL) are dominated by presumed young of the year. Common mummichogs were absent from our collections during the winter and early spring.

Atlantic Silverside (Menidia menidia)

Nauset Marsh is considered a nursery area for this species based on the occurrence of small juveniles in July and October (Fig. 14). Large juveniles and adults presumably leave the system and overwinter offshore as reported for other Massachusetts populations (Conover and Murawski 1982).

Four-spined Stickleback (Apeltes quadracus)

This species is resident in Nauset Marsh as evidenced by its presence during every collecting period (Fig. 15). There is little variation in size for this small species in our collections. Spawning likely occurs in the spring and early summer as the smallest individuals appear in July and August.

Three-spined Stickleback (Gasterosteus aculeatus)

This species uses Nauset Marsh as a nursery area (Fig. 16). Although they were collected every sampling period, most individuals are offshore during the winter and migrate into Nauset Marsh in the spring. These adults are represented by larger individuals (approximately 50 - 75 mm TL) collected in June and July. Young of the year (approximately 15 - 30 mm TL) occur in July as well but are less

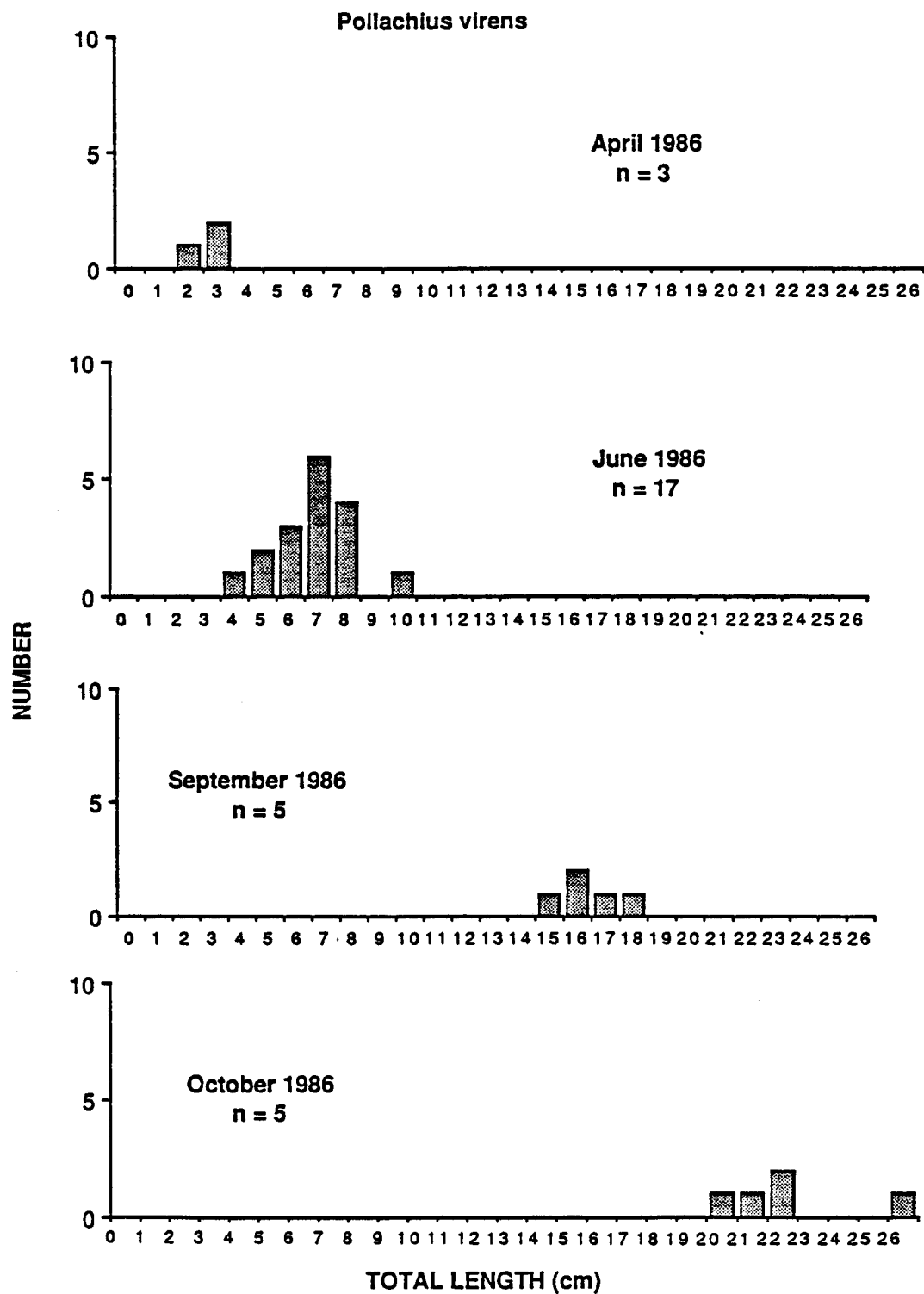


Figure 12. Length frequency distribution of pollock, Pollachius virens, collected in Nauset Marsh with 4.9 m otter trawl and ichthyoplankton nets.

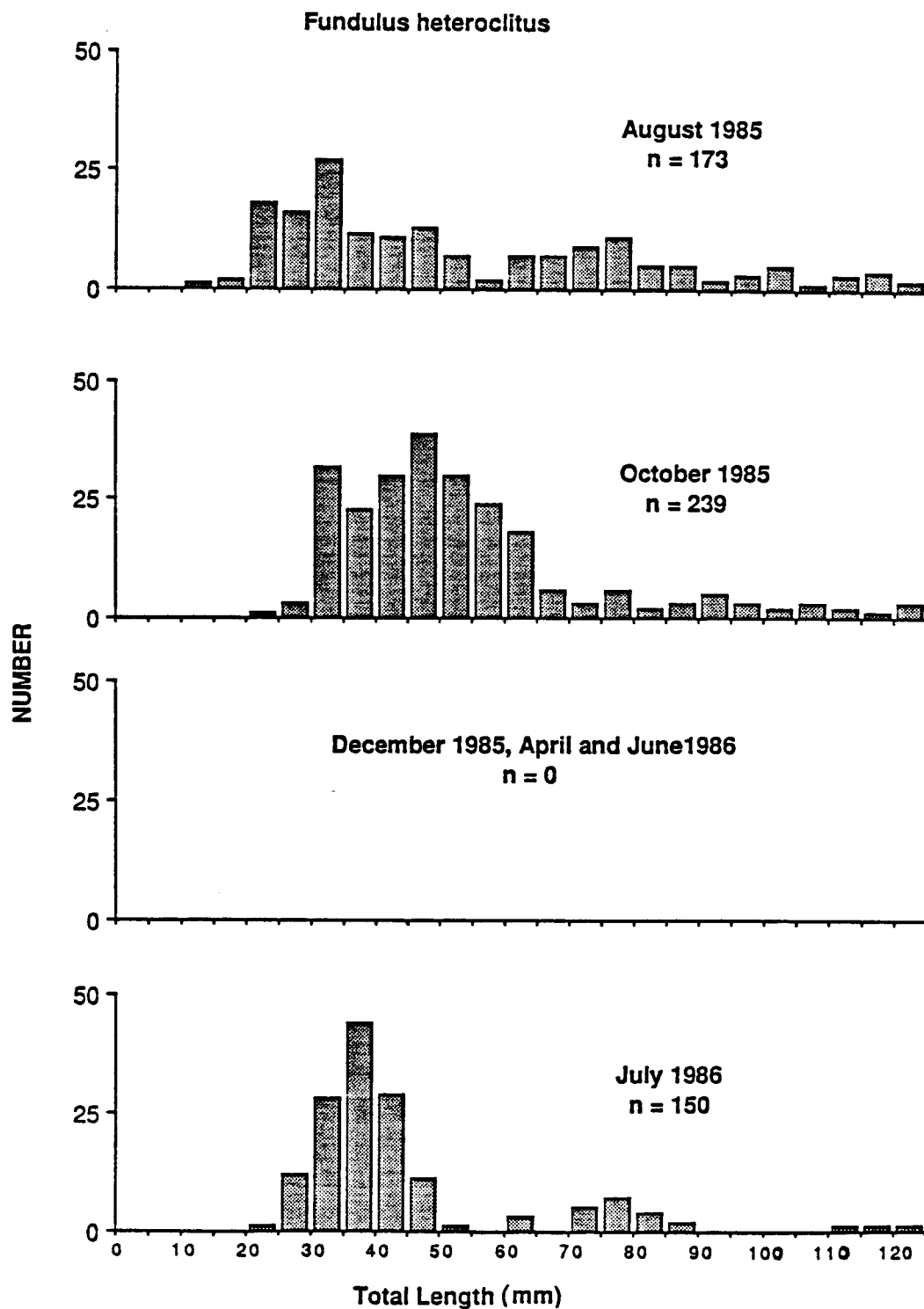


Figure 13. Length frequency distribution of common mummichog, Fundulus heteroclitus, collected in Nauset Marsh with 4.9 m otter trawl and 8.3 m seine.

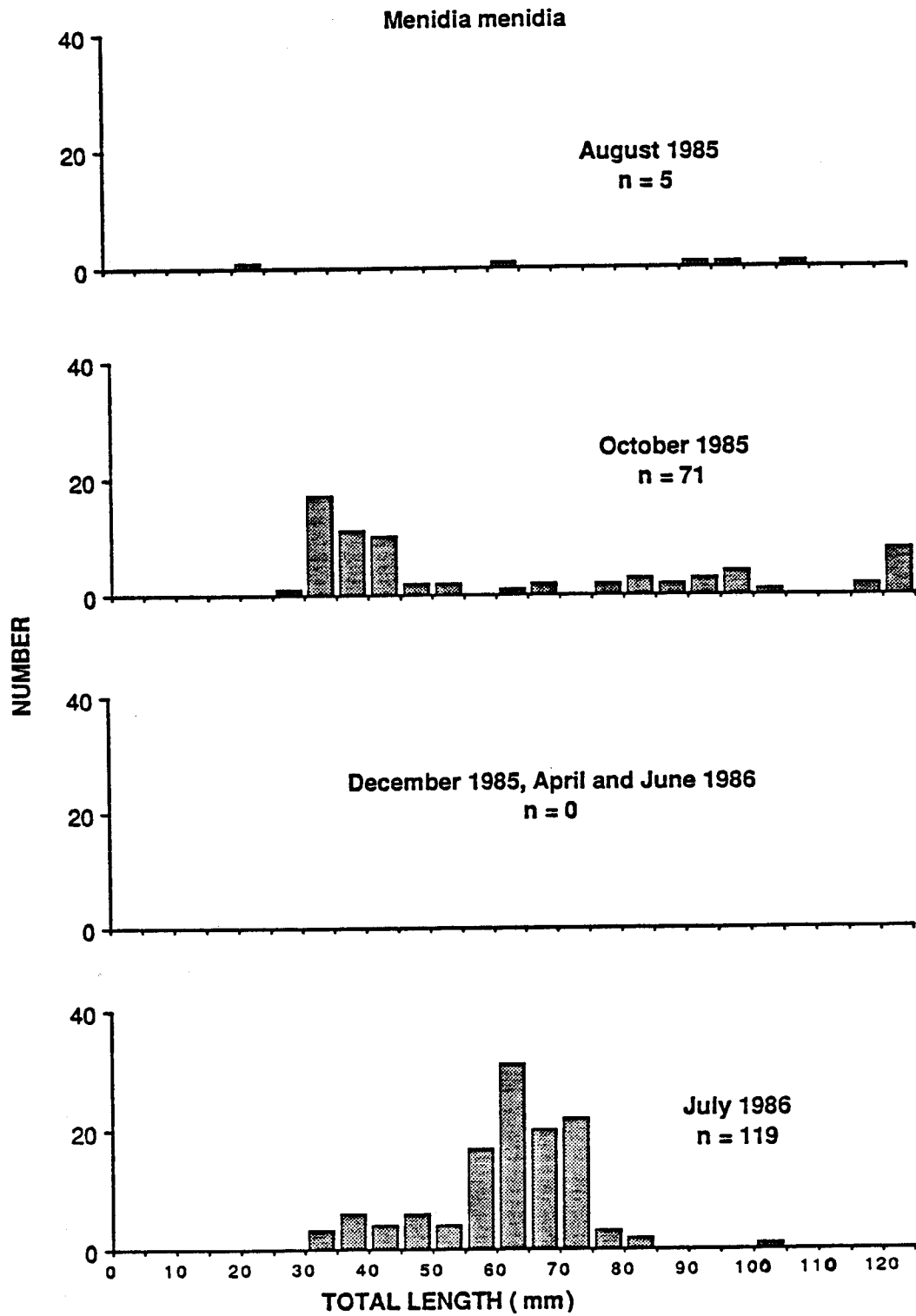


Figure 14. Length frequency distribution of Atlantic silverside, Menidia menidia, collected in Nauset Marsh with 4.9 m otter trawl and 8.3 m seine.

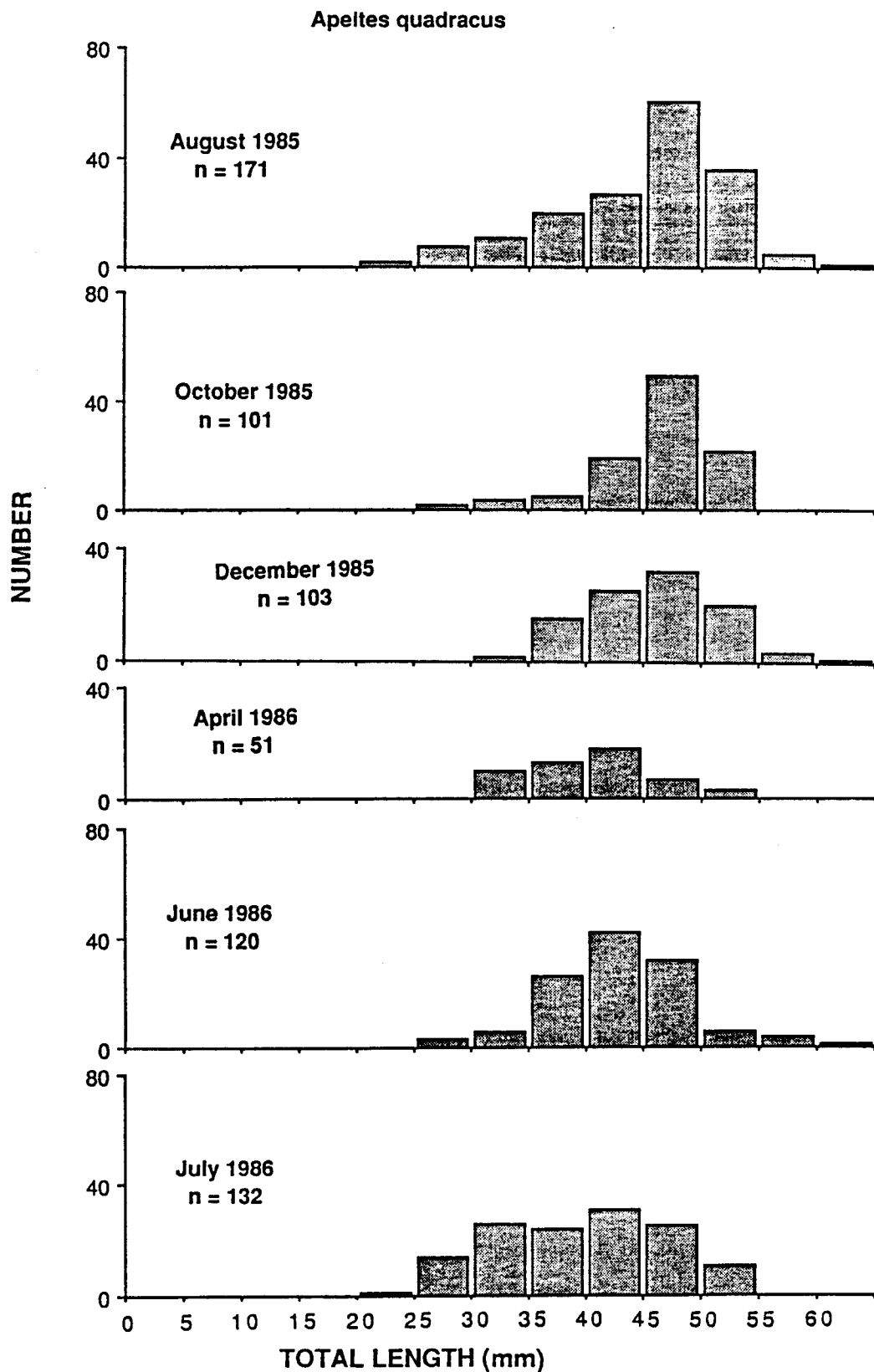


Figure 15. Length frequency distribution of four-spined stickleback, Apeltes quadracus, collected in Nauset Marsh with 4.9 m otter trawl and ichthyoplankton nets.

Gasterosteus aculeatus

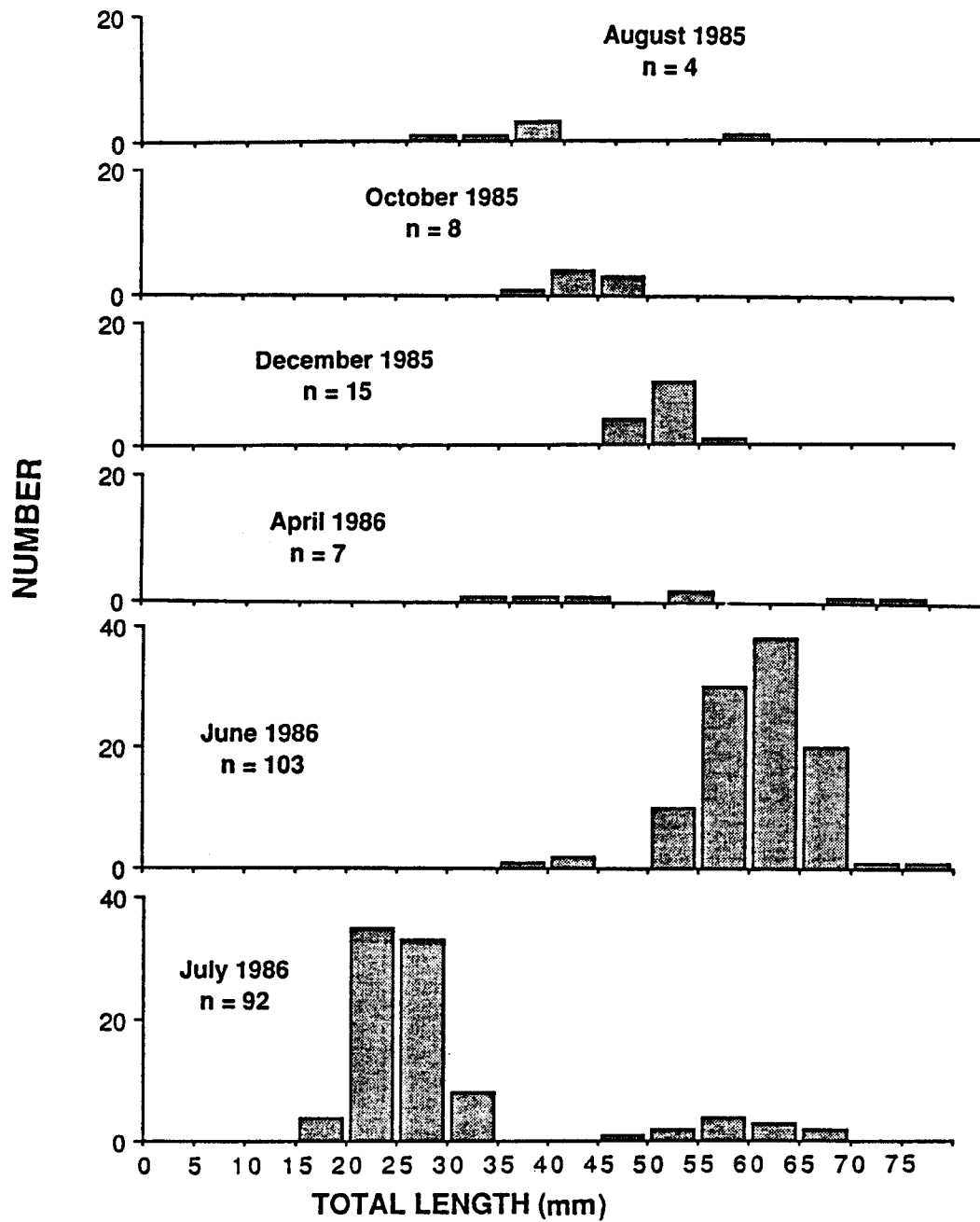


Figure 16. Length frequency distribution of three-spined stickleback, *Gasterosteus aculeatus*, collected in Nauset Marsh with 4.9 m otter trawl and ichthyoplankton nets.

abundant during late summer and fall.

Northern Pipefish (Syngnathus fuscus)

This species is a seasonal visitor to Nauset Marsh. Adults are found offshore in the winter (Research Appendix A-1f), then move into the system during the summer to spawn. Young-of-the-year first appeared in July (Fig. 17) collections, were abundant through October, and then disappeared.

Bluefish (Pomatomus saltatrix)

This species was only collected by gill nets during the fall of 1985 and 1986 (Fig. 18) but were also observed while night lighting in August 1986.

Tautog (Tautoga onitis)

This species is not abundant in Nauset Marsh but some juveniles (approximately 20 - 45 mm TL) utilize the system as a nursery area, at least during the fall (Fig. 19).

Cunner (Tautoglabrus adspersus)

This species is probably more abundant than our collections indicate (Fig. 20) because we have observed them consistently around peat reefs where they are unavailable to our usual collecting gear. Presumed young of the year were most abundant in October 1985.

Inshore Sand Lance (Ammodytes americanus)

This is one of the most abundant species in Nauset Marsh but is not always well represented in our collections (Fig. 21). Spawning presumably occurs in early spring because recently hatched larvae were collected in April. Individuals of a similar size range (50 - 120 mm TL) were collected during almost all other collecting periods.

Grubby (Myoxocephalus aeneus)

The grubby is a year-round resident of Nauset Marsh where it occurs primarily in eelgrass beds (Research Appendix A-1e). Five gravid females, a running ripe male and two egg masses were collected. Larvae hatch in mid winter and occur in plankton collections throughout the estuary in April. Juveniles first appear in summer collections. Grubbies of all sizes feed primarily on crustaceans, particularly sand shrimp. Amphipods and isopods are more important in juveniles' diets while fishes are a minor component found only in adult stomachs.

Winter Flounder (Pseudopleuronectes americanus)

This species appears to be a year round resident of Nauset Marsh (Fig. 22). Spawning presumably occurs in late winter because recently hatched larvae were collected in April 1986. This same year class is probably represented by 30 - 90 mm individuals in July and 70 - 110 mm individuals in October. One year old fish may be represented by 100 - 140 mm individuals in July 1986. Individuals larger than 300 mm (presumably adults) were collected in every sampling period.

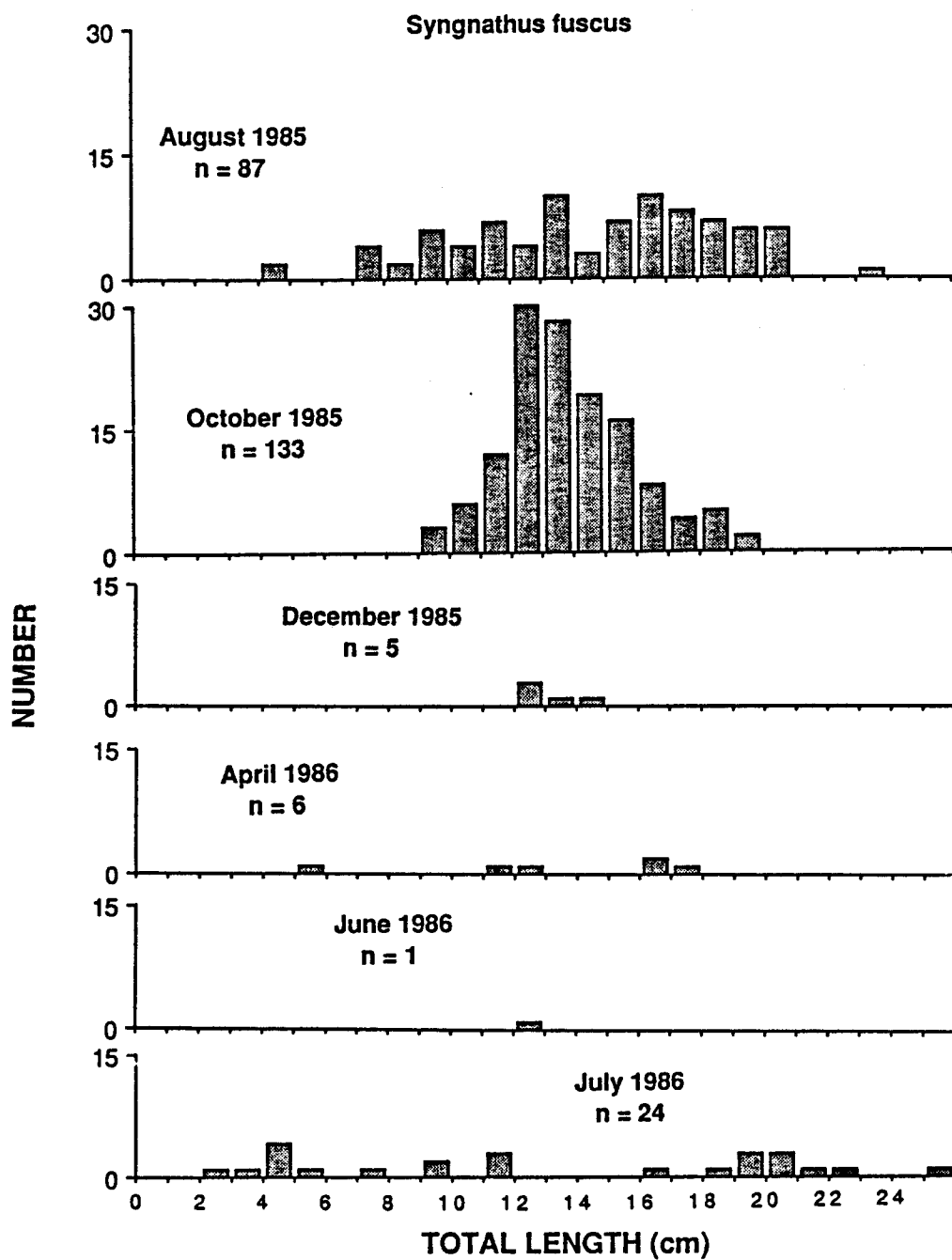


Figure 17. Length frequency distribution of northern pipefish, Syngnathus fuscus, collected in Nauset Marsh with 4.9 m otter trawl and ichthyoplankton nets.

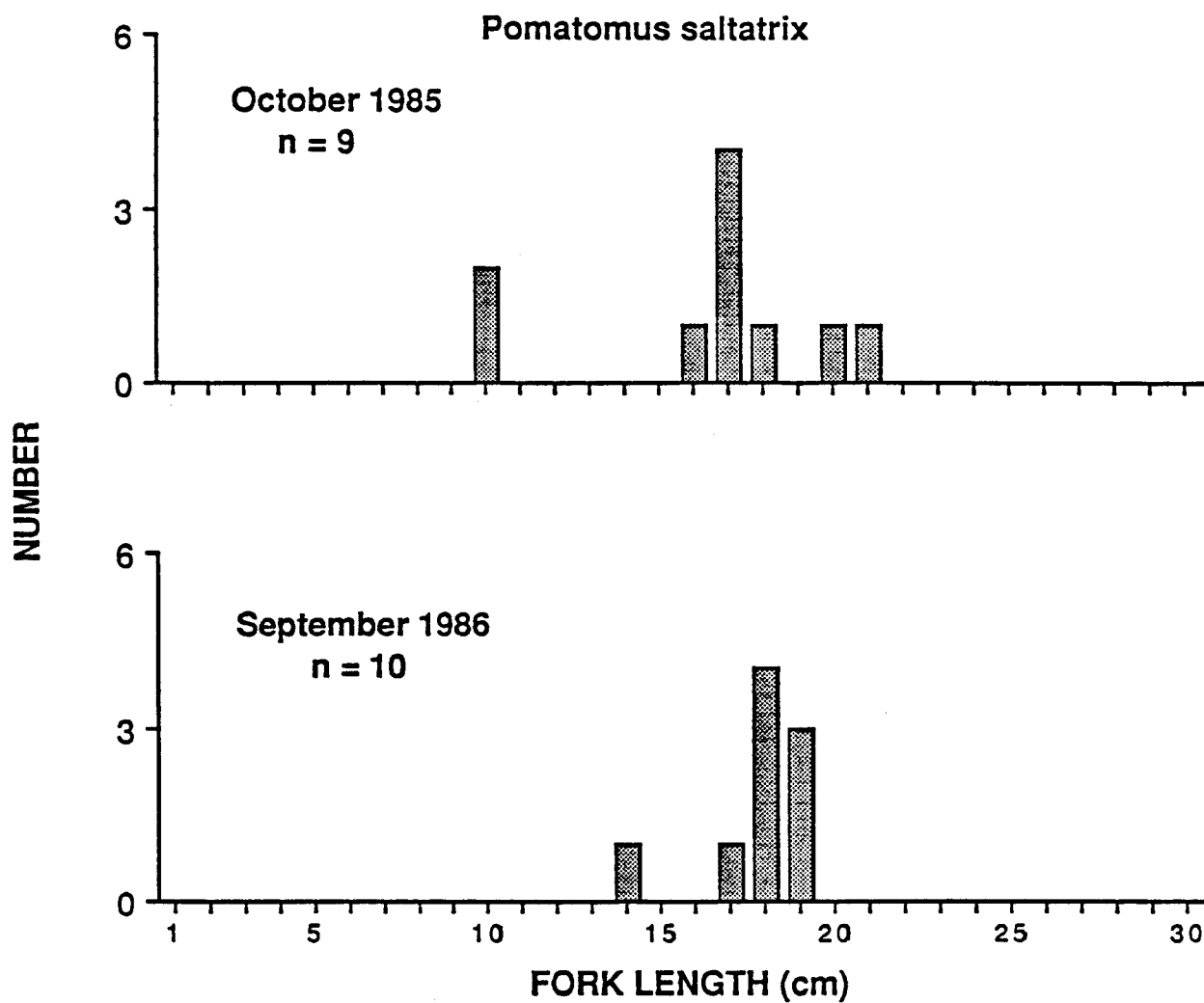


Figure 18. Length frequency distribution of bluefish, Pomatomus saltatrix, collected in Nauset Marsh with gill nets.

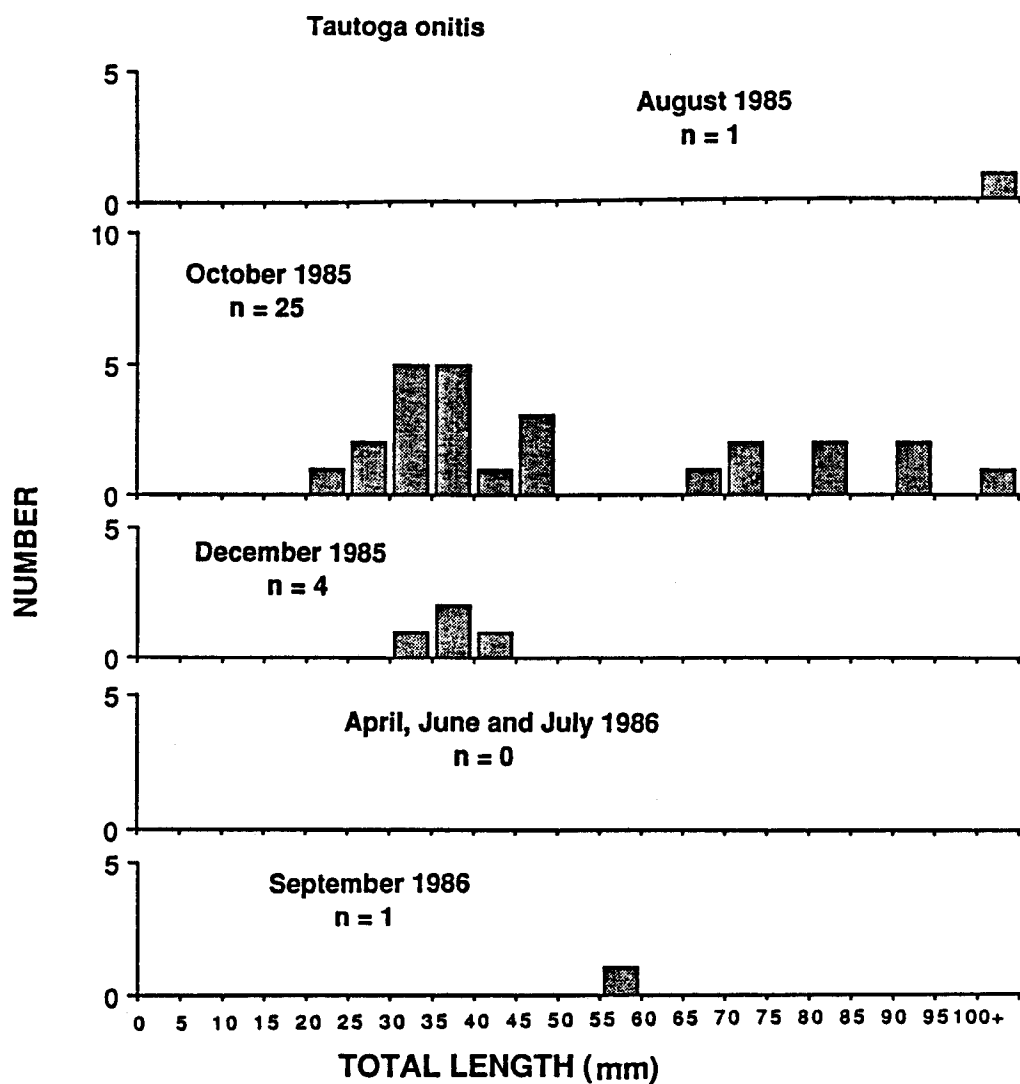


Figure 19. Length frequency distribution of tautog, *Tautoga onitis*, collected in Nauset Marsh with 4.9 m otter trawl.

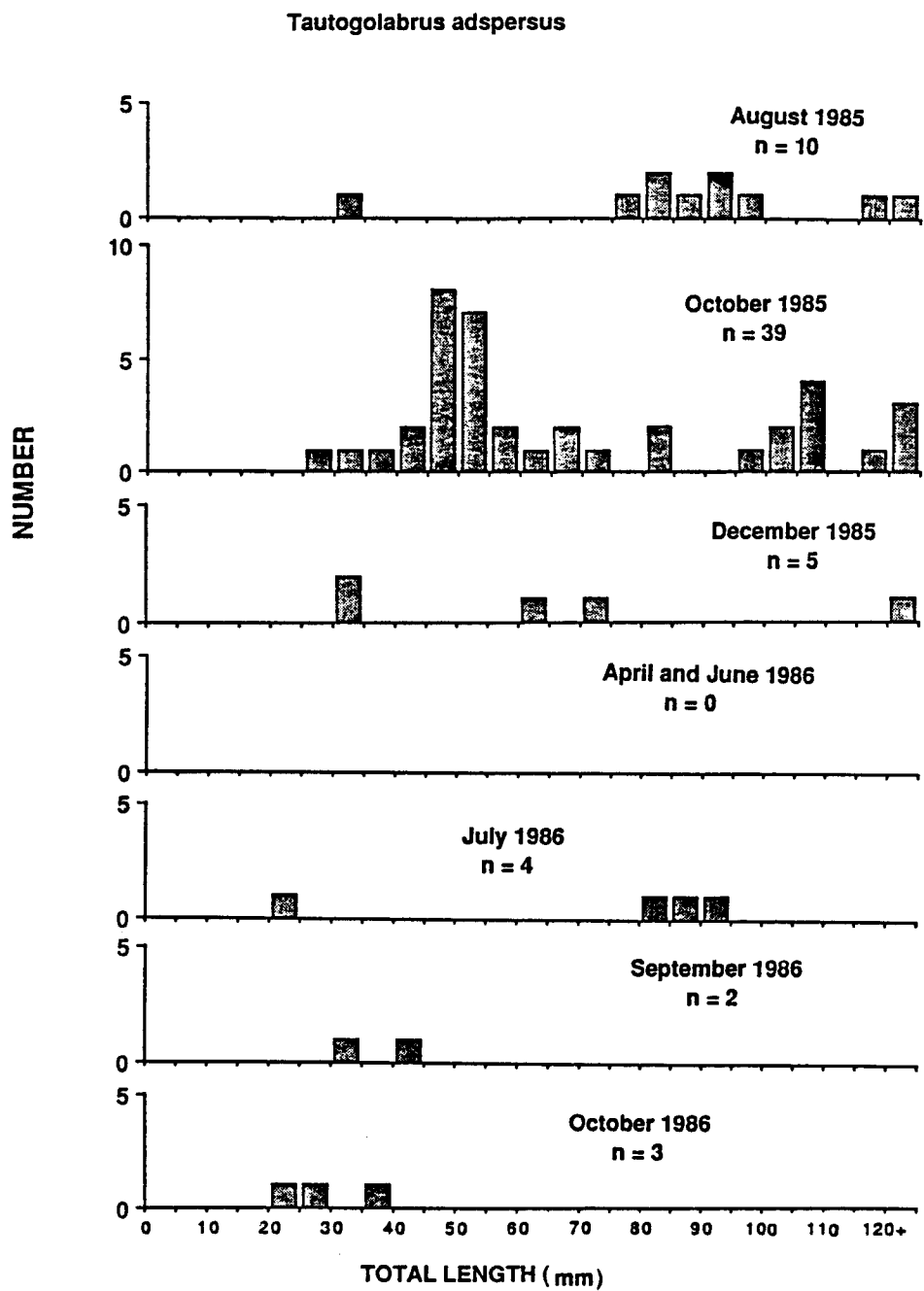


Figure 20. Length frequency distribution of cunner, Tautogolabrus adspersus, collected in Nauset Marsh with 4.9 m otter trawl.

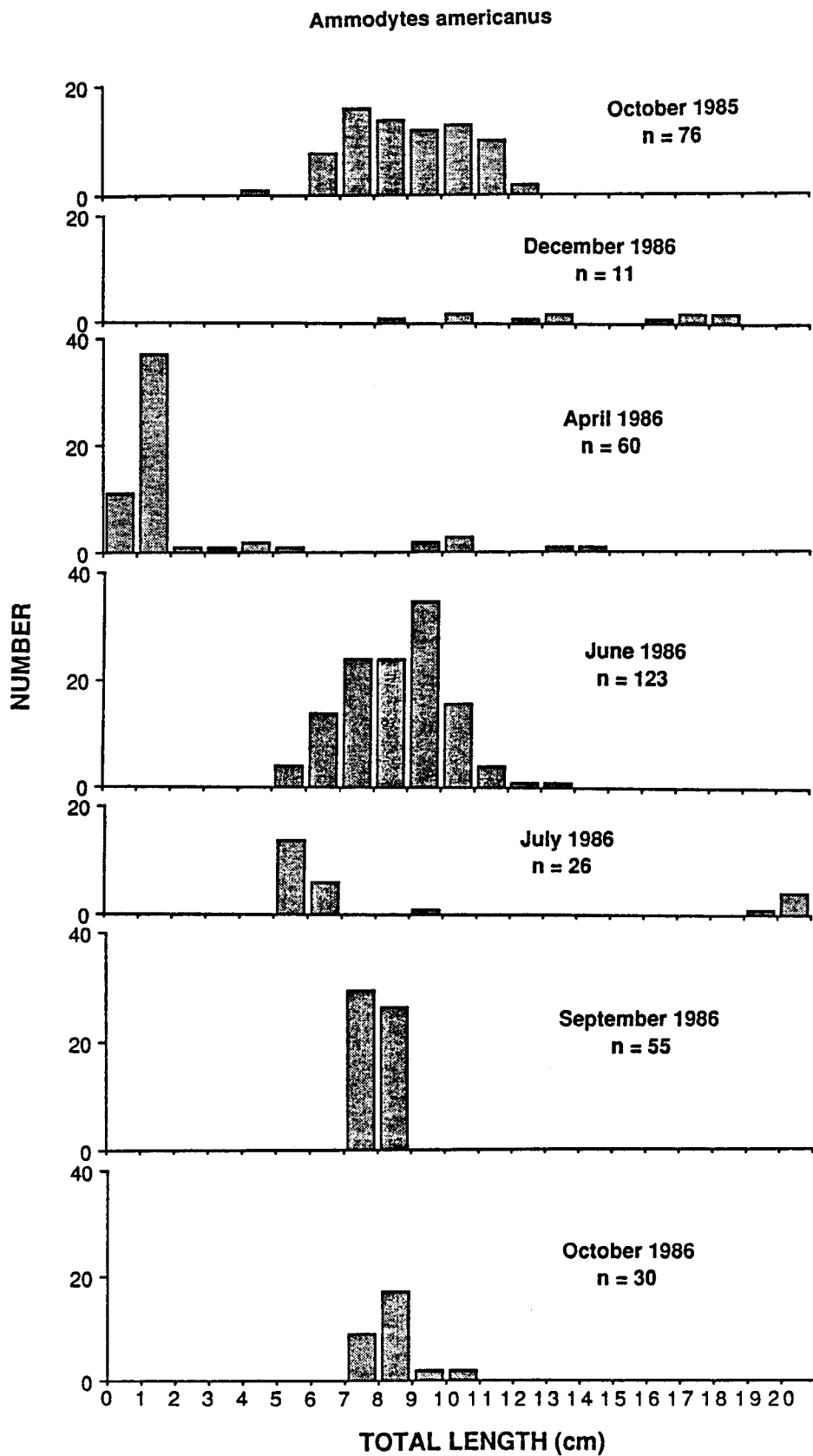


Figure 21. Length frequency distribution of inshore sand lance, *Ammodytes americanus*, collected in Nauset Marsh with 4.9 m otter trawl and ichthyoplankton nets.

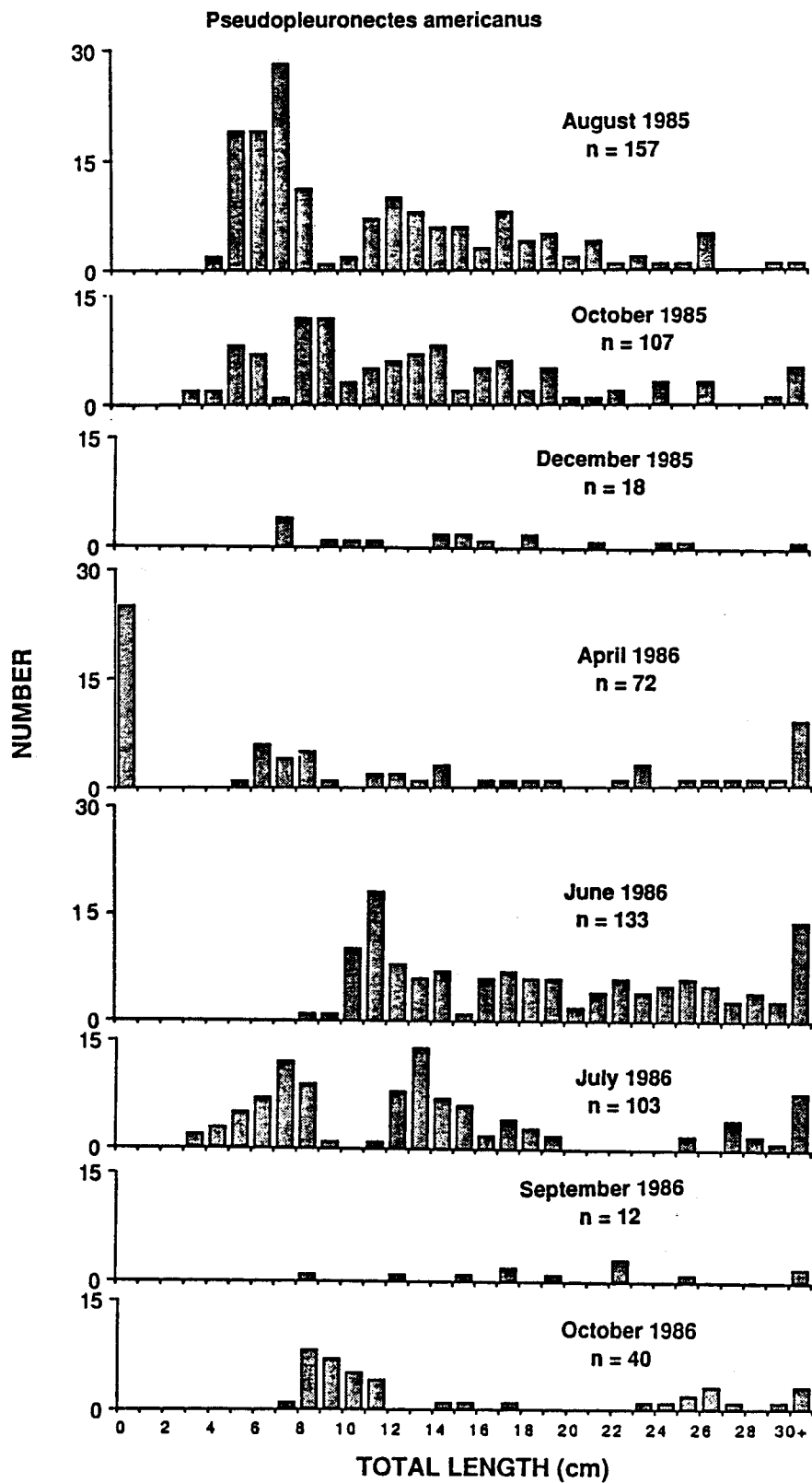


Figure 22. Length frequency distribution of winter flounder, *Pseudopleuronectes americanus*, collected in Nauset Marsh with 4.9 m otter trawl, 8.3 m seine and ichthyoplankton nets.

American Lobster (Homarus americanus)

The American lobster is abundant in Nauset Marsh (Research Appendix A-1a) and was collected consistently in our samples except during December, perhaps in part due to reduced sampling effort. The size of lobsters collected was gear dependent, as larger individuals (greater than 50 mm carapace length) were taken by trawl and smaller individuals were collected only by suction sampling (Fig. 23). Prior knowledge of the habitat of juvenile lobsters, less than 50 mm carapace length was virtually lacking prior to our studies. Both suction sampling and *in situ* observations found small juvenile lobsters only in peat reef habitats. Smaller individuals (less than 10 mm carapace length) had apparently settled in these habitats only recently.

Sand Shrimp (Crangon septemspinosa)

The sand shrimp is a resident of Nauset Marsh and was abundant especially in the summer and fall (Fig. 24). The largest numbers of small individuals (15 - 19 mm) occurred during July 1986 and August and October 1985.

Green Crab (Carcinus maenas)

This species was resident year round based on large collections (Fig. 25). Recruitment of small individuals (5 - 9 mm carapace width) apparently occurred during the fall based on their occurrence in October 1985.

BENTHIC AND EPIBENTHIC INVERTEBRATES

METHODS

Quantitative collection of benthic and epibenthic invertebrates was conducted by suction sampling as described in the section "Fishes and Decapod Crustaceans-Methods" (Table 2). All major shallow water habitats, except for mussel beds, were sampled from August 1985 - August 1986 while mussel bed habitat was sampled from April 1986 - October 1986. Samples were preserved in 10% formalin, stained with rose bengal, and subsamples were sorted in the laboratory. Members of the classes Gastropoda, Bivalvia and Polychaeta, and those of the orders Isopoda and Amphipoda were identified to species or genus and their abundances recorded (Data Appendix B). Two phyla of benthic worms, Rhynchocoela and Oligochaeta, were minimally represented in these samples and were not identified to species or genus. Following identification, subsamples of each group were dried at 60°C to a constant weight then burned for five hours at 550°C to yield dry weight and ash-free dry weight measurements for biomass and secondary production estimates.

ABUNDANCE AND SPECIES RICHNESS

Abundance data for benthic and epibenthic invertebrates appear in Data Appendix B-1. Graphic summaries of these data, in Data Appendix B-2, provide an overview of habitat preference and seasonality for these organisms.

Species richness is compared across major habitats in Fig. 9. Eelgrass

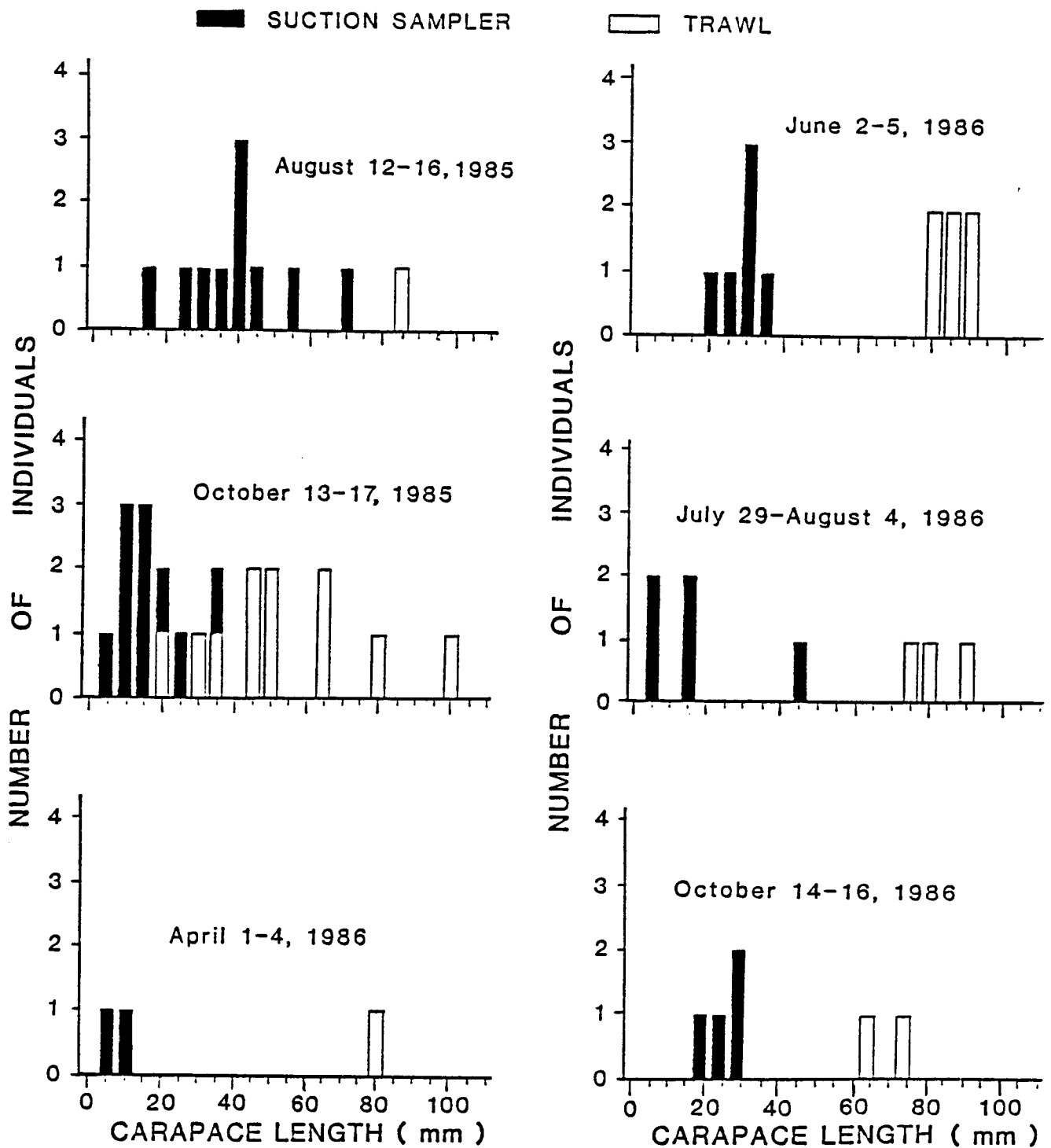


Figure 23. Length frequency distribution of American lobster, Homarus americanus, collected in Nauset Marsh with 4.9 m otter trawl and suction sampler.

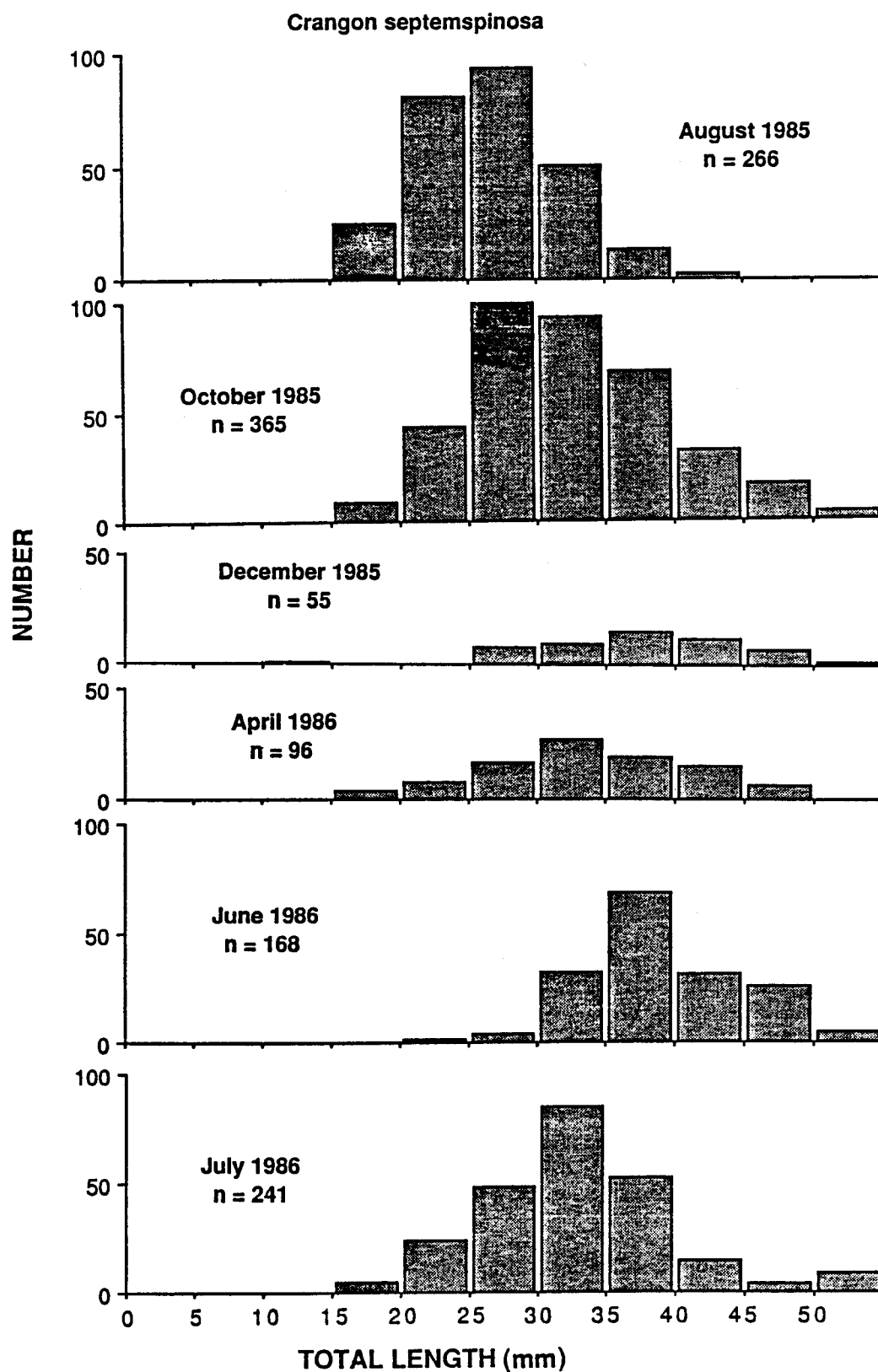


Figure 24. Length frequency distribution of sand shrimp, Crangon septemspinosa, collected in Nauset Marsh with 4.9 m otter trawl.

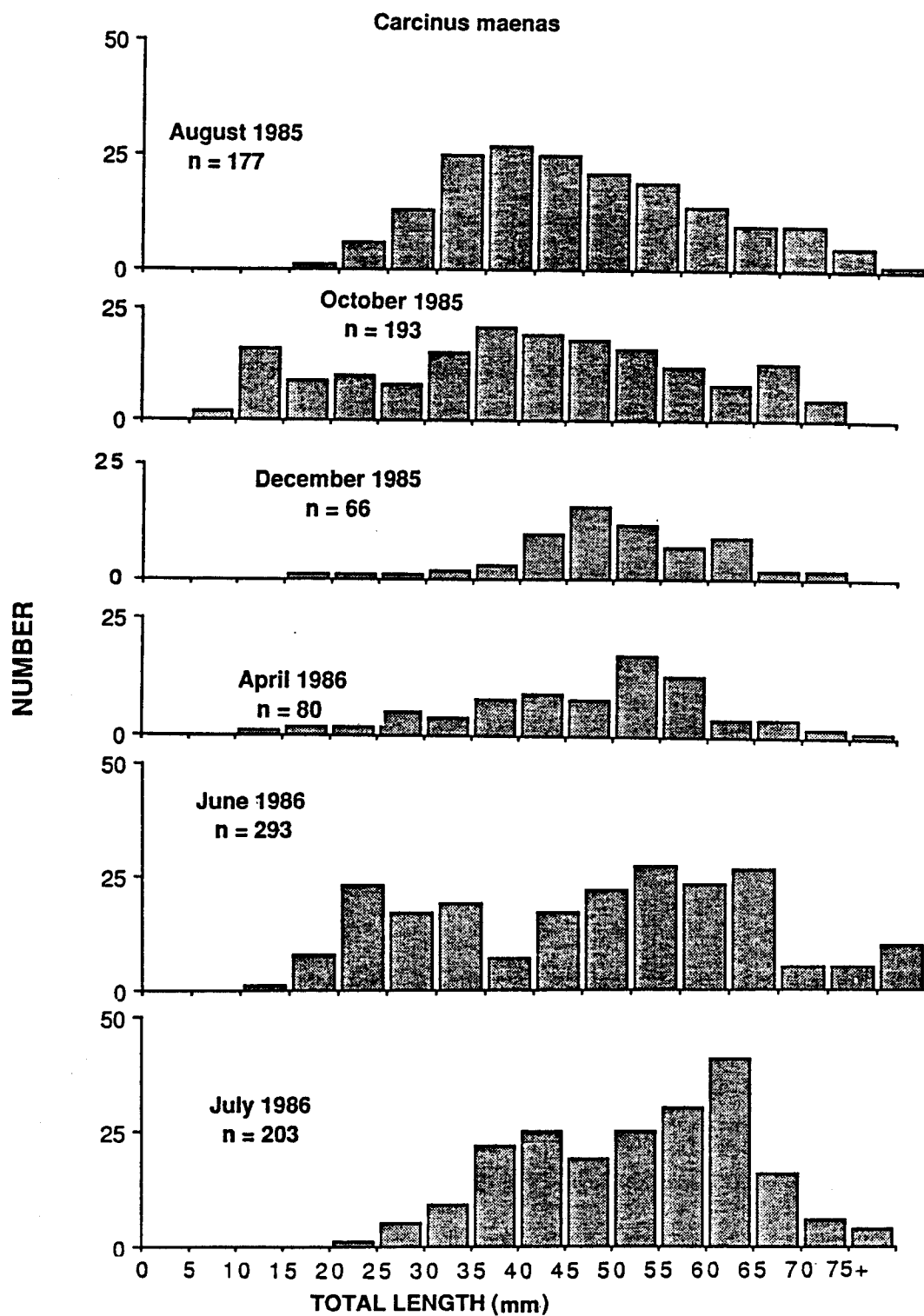


Figure 25. Length frequency distribution of green crab, Carcinus maenas, collected in Nauset Marsh with 4.9 m otter trawl.

habitat is shown to support the greatest richness of benthic and epibenthic invertebrates for all groups examined except for the polychaete worms; the mudflat habitat supported one more polychaete species than did the eelgrass.

SECONDARY PRODUCTION

Benthic and epibenthic invertebrates are primary consumers within the Nauset Marsh system and these, by feeding directly on plants and organic detritus, provide the essential energy link between those constituents and the majority of fishes, larger invertebrates and birds. Secondary production of these organisms combines, in a single measurement, estimates of their individual growth and survivorship which can be used to compare rates of energy production among habitats.

In ongoing analyses (Research Appendix A-1d), four major habitats are being examined for secondary production rate comparisons: eelgrass bed, mud bottom, sand bottom and marsh pool. Production/biomass ratios are calculated from the following equation, $\log_{10} P/B = K_1 + K_2 \log_{10} L$, where; P = specific estimates of secondary production, B = mean biomass of the taxon of interest, K1 and K2 are constants determined from the literature, and L = taxon-specific mean life span in years (Robertson 1979). Rates of secondary production per unit area of each habitat can be multiplied by the total amount of area of each habitat in the Nauset system to directly compare the total amount of system secondary production by habitat.

HABITAT-SPECIFIC STUDIES

HARD CLAM GROWTH

This aspect of the study focuses on the commercially important hard clam (*Mercenaria mercenaria*) in an attempt to better understand the environmental factors and habitat effects that control its growth in the Nauset Marsh estuary. One-time samples (May 10 - 12, 1987) of clam populations were made in Nauset Harbor and the collections were analyzed by Marc Wilson as part of a master's thesis research project (University of South Alabama; advisor - Kenneth Heck).

Methods

Clams were collected by treading (detecting clams with feet) from both vegetated and unvegetated habitats so that the relationship between habitat and growth rate could be tested. The clams were placed on ice and returned to the lab for processing. Sediment cores were taken from each habitat using a 5.5 cm (2 1/8 in) diameter metal corer. Sediment cores were placed in "ziplock" bags and stored on ice until returned to the laboratory. Clams were removed from the freezer in groups of 10 - 30 and allowed to partially thaw overnight in a refrigerator. The meat was then removed from the shell. Clam shells were washed, measured for height (widest distance between the two valves), width (greatest distance parallel to the ventral margin) and length (distance from the umbo to the ventral margin along the axis of maximum growth). The first one hundred clams in each of the respective study sites were utilized for the shell growth analyses. One valve was embedded in resin and

sectioned from the umbo to the ventral margin along the axis of greatest growth (Clark 1980; Kennish et al. 1980). This section was polished and then aged by counting and measuring annual growth increments (Fritz and Haven 1983; Rhoads and Pannella 1970).

Results and Discussion

Growth rates, as indicated by length, width and height measurements show similar overall patterns (Figs. 26, 27, 28), including substantial amounts of variation among individual clams. Despite this variation, correlations between length and age are significant for both eelgrass ($r = 0.86$; $n = 17$; $p < 0.001$) and sand ($r = 0.77$; $n = 28$; $p < 0.001$) collections. Significant correlations also exist between width and age ($r = 0.86$; $p < 0.001$ for eelgrass; $r = 0.77$; $p < 0.001$ for sand) and between height and age ($r = 0.83$; $p < 0.001$ for eelgrass; $r = 0.75$; $p < 0.001$ for sand). Regression equations describing the relationship between length and age are $y = 1.78 + 0.399x$ for eelgrass and $y = 1.30 + 0.625x$ for sand, between width and age $y = 2.01 + 0.426x$ for eelgrass and $y = 1.35 + 0.701x$ for sand, and between height and age $y = 1.32 + 0.195x$ for eelgrass and $y = 0.967 + 0.344x$ for sand. Growth rates described by these equations are intermediate compared to those reported from both north and south of the study area along the Atlantic coast. For example: Kersiwill (1949) found the lengths of 5 year old clams on Prince Edward Island, Canada, to average between 20 and 40 mm, while in North Carolina, Peterson et al. (1984) found clams of this age class to be, on average, between 50 and 60 mm in length; at Nauset, 5 year old clams were between 30 and 50 mm in length.

Slopes, and hence growth rates, are greatest for clams collected from sand. This agrees with results presented by Kersiwill (1949) who found greater growth of clams in sand than in eelgrass in Nova Scotian waters, but contrasts with results presented by Peterson et al. (1984) who found higher hard clam growth in eelgrass than sand in North Carolina. One possible explanation for these results is that eelgrass densities varied significantly between the geographically separated study sites and that clam growth varies as a function of eelgrass density. Another explanation is that there are latitudinal differences in the influence of vegetation on hard clam growth, with the value of vegetation being greatest in low latitudes. Mechanistically, this could work if the amount of sublethal predation (siphon nipping), which may significantly reduce clam growth (de Vlas 1985; Peterson and Quammen 1982), is much greater in lower latitudes. Because the presence of vegetation should make siphon nipping more difficult, this may more than offset reductions in food availability that result from vegetation causing particle deposition and thereby reducing food supply.

The regression equations shown above provide baseline estimates for rates of hard clam growth in both vegetated and unvegetated substrates in the Nauset Marsh, and should be useful as a standard of comparison for future studies of the health of the system. Any significant shifts in growth rate identified by future studies should serve as a warning that further investigation of the causes of these shifts is warranted.

HABITAT SPECIFIC HETEROZYGOSITY AND GROWTH OF HARD CLAMS

Previous studies have shown that growth in the hard clam is regulated by a suite of environmental factors such as current speed, substrate composition, and

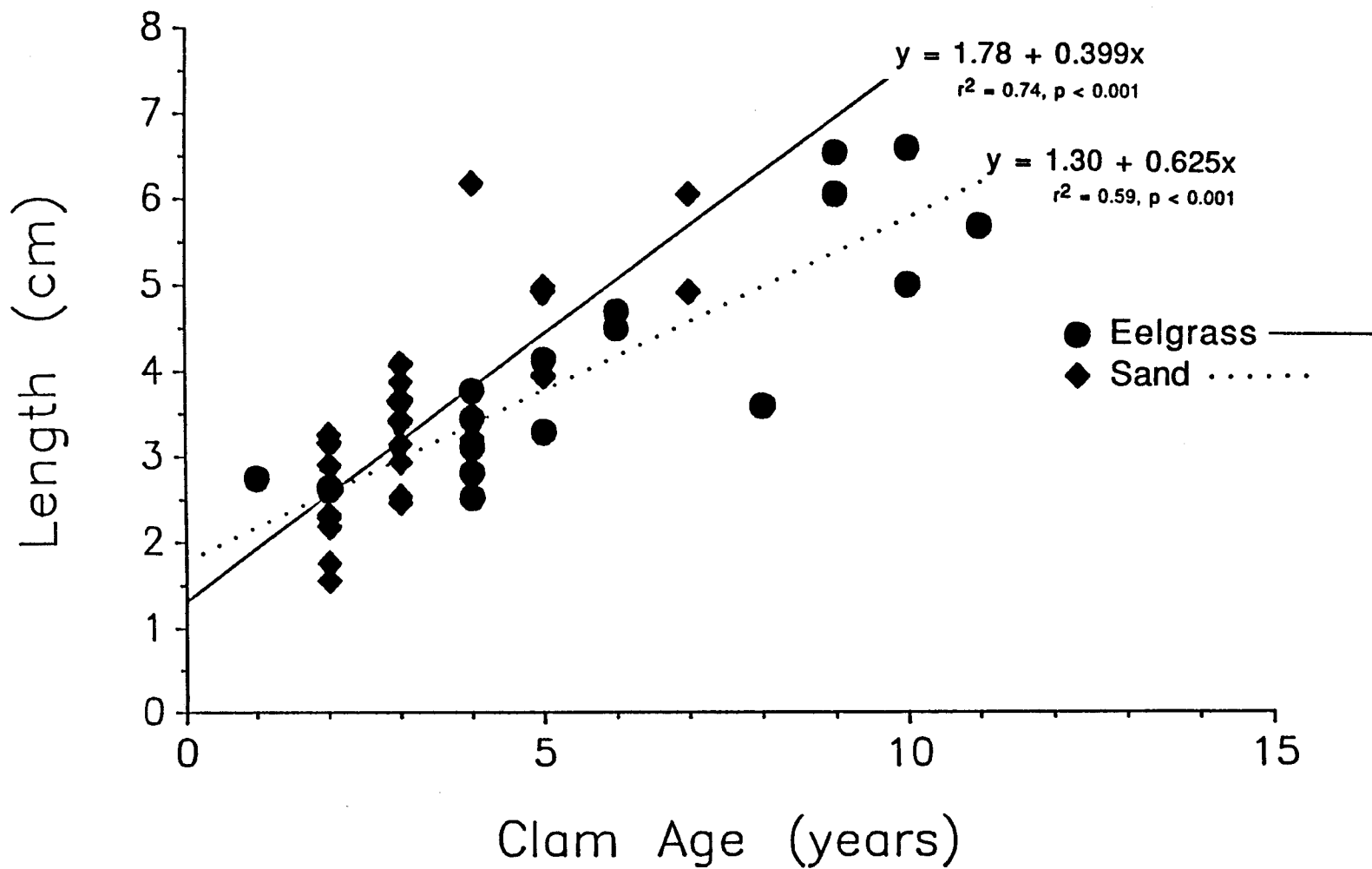


Figure 26. Hard clam shell length growth in eelgrass and sand habitats.

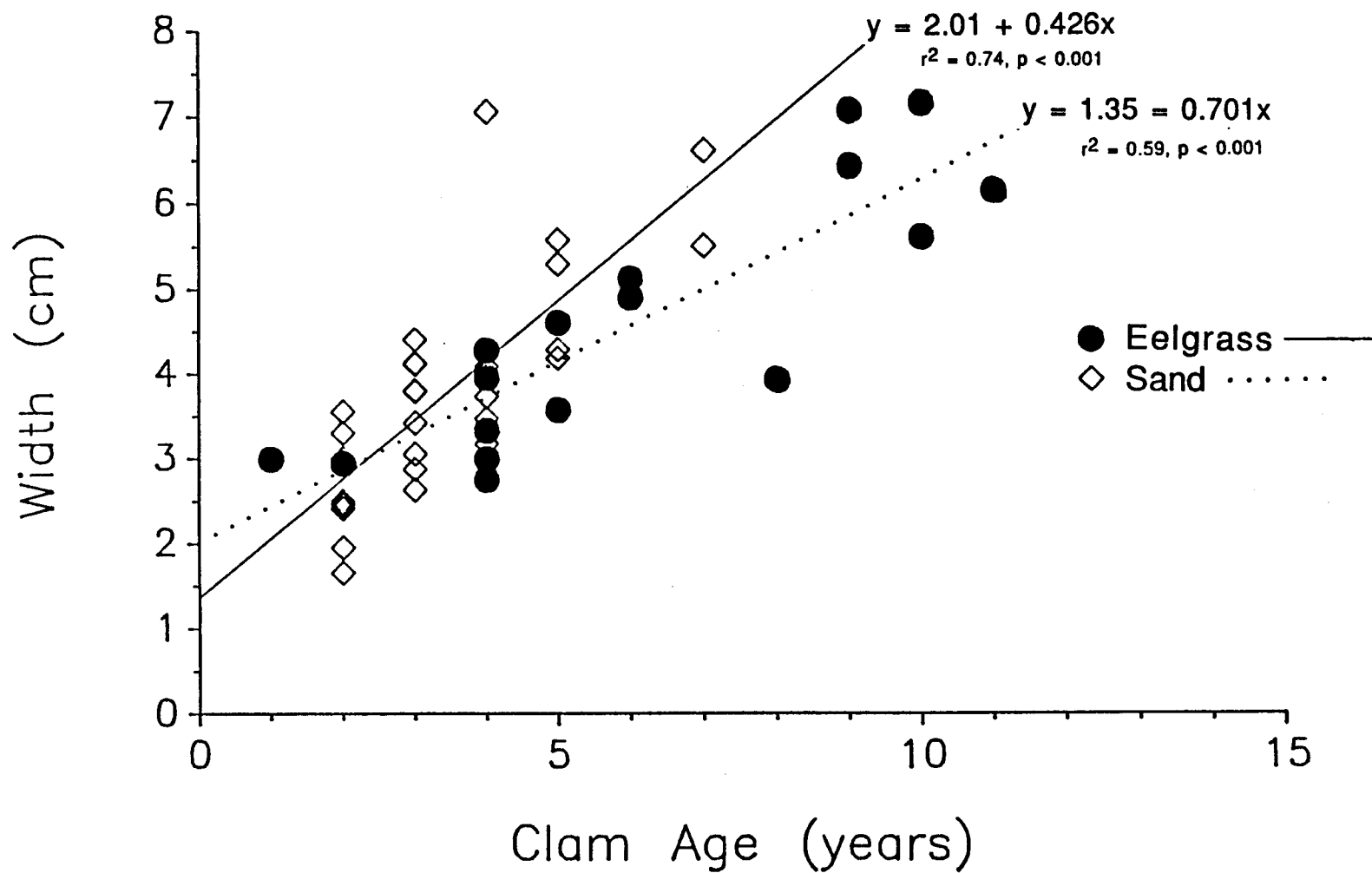


Figure 27. Hard clam shell width growth in eelgrass and sand habitats.

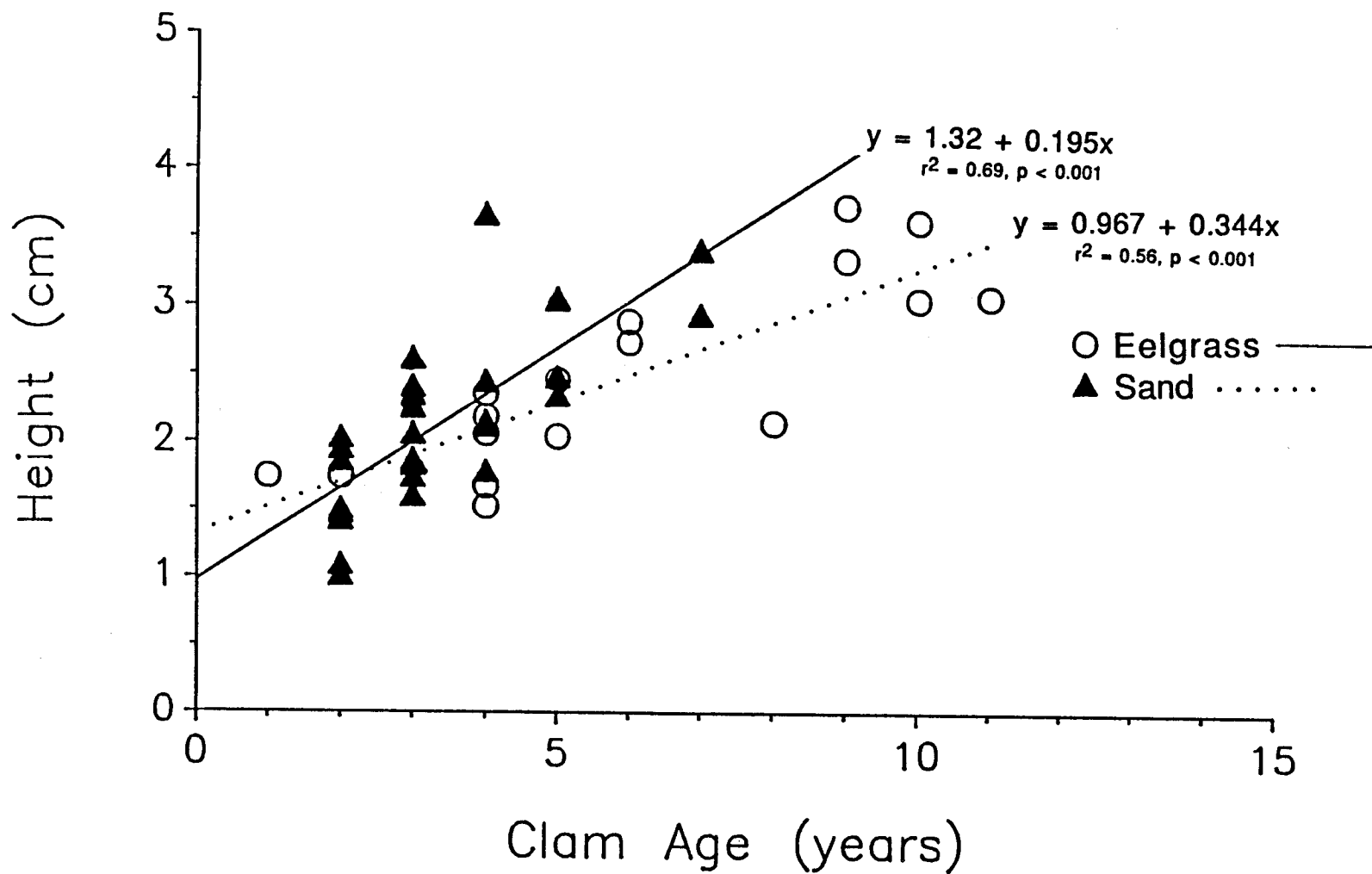


Figure 28. Hard clam shell height growth in eelgrass and sand habitats.

nutrient levels in the seston. Furthermore, Peterson et al. (1984) found that clams situated in eelgrass beds grew faster than those in adjacent unvegetated areas. In other species of marine bivalves, growth is positively correlated with the genetic parameter of heterozygosity. In this study, as part of a dissertation research project by Jill Pecon (Rutgers University), the heterozygosity and growth of clams found in an eelgrass bed and adjacent sand flat located in Nauset Marsh was compared.

Methods

One hundred clams from each habitat were collected in October 1987 from Nauset Harbor. Tissues were excised and analyzed by starch gel electrophoresis. The age of each individual was determined by counting the number of annual bands deposited in the inner shell layer.

Results and Discussion

The results show differences in both heterozygosity and growth between the two habitats. First, the frequency distributions of size and age are significantly different. The sand flat population is dominated by the age classes of 3 - 5 years. However, the eelgrass population is bimodal with maxima for ages 3 - 5 years and 8 - 12 years. Similarly, as size is closely correlated with age, the distribution of clam size classes had a pronounced peak at the 50 - 59 mm class in the sand flat and a more broad distribution in the eelgrass. Second, the mean value of heterozygosity is identical for clams found in the eelgrass site and those in the sand flat. Also, the mean heterozygosity increases with age class. This trend is found in both populations, but the sand flat clams have a steeper increase in heterozygosity. Similarly, as seen in other bivalve species, natural populations are deficient in heterozygous individuals. Interestingly, this deficiency declines with age in both populations. The two differ in that the data suggest the heterozygote deficiency is consistently less for those clams inhabiting the sand bed. The preceding conclusions are preliminary and must be substantiated with further analyses.

HABITAT-SPECIFIC PREDATION RATES

Studies in laboratory microcosms (Nelson 1979; Heck and Thoman 1981; Stoner 1982; Main 1985, 1987) and in the field (Heck and Thoman 1981; Leber 1985; Heck and Wilson 1987; Wilson et al. 1987) have documented that survival rates of many crustacean species may vary greatly from habitat to habitat. Estimates of habitat specific survival rate have been used as a measure of habitat quality for the species being investigated, and thereby allow habitats to be ranked against each other with regard to their "nursery function" (Wilson et al. 1987).

In a series of preliminary field experiments we have evaluated survival rates of juvenile lobsters, green crabs, rock crabs and hermit crabs in a variety of habitats in the Nauset Marsh system: eelgrass beds, mud flats, sand flats, and peat reefs. The species and the habitats were chosen because of: their abundance in the Nauset Marsh system; their commercial importance; or the ability to compare results with studies elsewhere. Our goal has been to determine the functional significance of each of these habitats for the decapods tested.

Methods

Tethering experiments were conducted during June 2 - 7, 1988 in eelgrass beds in Mill Pond, mud flats containing green macroalgae in Nauset Bay, and sand flats and adjacent peat reefs in a channel near Hemenway Landing. Hermit crabs, green crabs, rock crabs and American lobsters were collected by hand, by seine and by trawling for use in the tethering experiments. No ovigerous or recently molted crabs were retained.

Tethering was accomplished by tying one end of an approximately one meter length of monofilament fishing line (20 lb. test) around the width of the body of rock crabs and green crabs and fastening the line with a few drops of "superglue" (cyanoacrylate cement) placed on the dorsal surface of the carapace. Hermit crabs were tethered by wrapping the monofilament line around the crab's shell and securing the line to the shell with "superglue". Juvenile lobsters (Stage V) were tethered by placing a small knot in the end of a one meter piece of nylon sewing thread and placing this knot in a drop of "superglue" and then in the middle of the lobster's carapace. All tethered animals were allowed to dry until the glue had hardened and they were then placed in holding tanks until the experiments were initiated.

In the field the free end of the tether was tied in a loop and placed around a J-shaped piece of clotheswire, then the carapace width of brachyuran crabs, the carapace length of lobsters or the total length (and identity) of hermit's shells was measured and recorded before the clotheswire was pushed completely into the sediments in each of the four habitats studied. Tethered animals were placed in the field at low water (subtidal depth, < 1 m). No more than three animals (all of the same species) were placed on a single piece of clotheswire. Heck and Thoman (1981), Heck and Wilson (1987) and Wilson et al. (1987) provide additional descriptions of the tethering technique.

Animals were placed in the habitats for a period of approximately 25 hours (two tidal cycles) and recovered. Predation was indicated only if a piece of carapace or a damaged shell remained on the tether. Empty lines were eliminated from consideration even though it is likely that some of these lines represented predation losses. A total of 93 animals were successfully tethered in peat reef habitat, 90 in sand, 87 in eelgrass, and 78 in macroalgae dominated mudflat.

The density, biomass and mean blade height of eelgrass was determined at Mill Pond from five 0.051 m² cores taken on the final day of the study. Before weighing at 60°C to a constant weight, all epiphytic material was scraped from the eelgrass leaves. Ten randomly chosen blades from four of the samples were measured to provide an estimate of average blade height. Salinity was measured daily with a temperature compensated refractometer and temperature was measured daily with a stick thermometer.

Results and Discussion

Salinity was about 34 ppt and temperature was approximately 14°C during the study period. Eelgrass mean biomass was 69.89 g dry wt m⁻² (s.d. = 19.21), mean shoot density was 526 m⁻² (s.d. = 74) and mean blade height was 27.85 cm (s.d. = 10.77).

Tethering results showed greatest rates of predation in eelgrass (25%), a high rate on the peat reef (17%), and lowest rate in the mud (10%) and sand (11%) (Table 29). This would seem to indicate that eelgrass does not provide an effective refuge for predation for the species taken, a conclusion totally at odds with previous work in the laboratory (e.g., Nelson 1979; Heck and Thoman 1981; Stoner 1982) and in the field (Heck and Thoman 1981; Heck and Wilson 1987; Wilson et al. 1987). However, the densities of eelgrass present at the Mill Pond site were quite low compared to densities in previous studies. For example, Wilson et al. (1987; see their Table 1) used eelgrass densities in their field studies that ranged from 197 g dry wt m^{-2} to 1275 g dry wt m^{-2} . Thus, their eelgrass densities were 2.8 - 18.2 times greater than the Mill Pond eelgrass densities. It would be instructive to repeat the Mill Pond tethering experiments when eelgrass densities are higher to see how predation rates vary.

An interesting overall result of these tethering studies is the relatively low mean predation rates observed. Our highest rate, 25% in eelgrass, is about the same as the lowest rates experienced by blue crabs in New Jersey eelgrass meadows (Wilson et al. 1987). The highest rates seen in New Jersey were on sand and averaged nearly 50% (Wilson et al. 1987; their Fig. 3). In the Gulf of Mexico and Bermuda lowest and highest mean rates were 8% and 67%, and 59% and 100%, respectively. Again, it is apparent that the rates measured in Nauset Marsh are quite low with respect to rates measured in similar habitats at other, more southern, coastal locations.

There are also striking differences in vulnerability among taxa. For example, no hermit crabs were preyed upon, while nearly 82% of the lobsters offered were eaten during the 25 hour exposure period (Table 29). The magnitude of these differences among taxa are similar to those found by Heck and Wilson (1987) in Bermuda, where hermit crabs were the least vulnerable taxa tested.

From the data in Table 29 it is clear that tethered juvenile lobsters are at great risk in the habitats tested. It is unusual that the lowest rates of predation should be found on sand, since juvenile lobsters do not frequently occur on sandy substrate. However, each of the lobsters tethered in sand managed to grasp pieces of algae (such as sea lettuce, Ulva lactuca and filamentous green algae) and were totally encased by algae when they were retrieved. Thus, we actually did not have a true bare sand treatment. In addition, because we tethered only 4 lobsters on sand it is premature to draw too many conclusion from this small data set. This is, however, the first field test of the survival of juvenile lobsters that has been accomplished and it provides some evidence of the feasibility of future studies of lobster survival under natural conditions.

In Fig. 29 it is evident that there was some size selectivity involved in green crab predation losses, with those crabs over 30 mm carapace width (CW) experiencing very low loss rates. These differences in the percent taken versus the percent offered in each size class are, however, only marginally significant ($0.05 < p < 0.10$) according to the Kolmogorov-Smirnov test. There is no statistical evidence for size selectivity for any of the other taxa tethered.

In summary, these results showed relatively low rates of mean predation losses for all taxa combined, although juvenile lobsters were at great risk in all the habitats investigated (with the possible exception of sand flats). They also indicated that eelgrass meadows, low in eelgrass densities, did not confer any advantage to the

Table 29. Results of June 1988 study of decapod species tethered in four habitats. Number of predation events / total number of tethered individuals = predation rate.

	Green crabs	Rock crabs	Hermit crabs	Lobsters	Total
Mill Pond (Eelgrass)	9/45=20%	6/18=33%	0/17=0%	7/7=100%	22/87=25%
Nauset Bay (Mud/Algae)	3/44=7%	0/4=0%	0/25=0%	5/5=100%	8/78=10%
Greenhead Channel (Peat Reef)	4/51=7%	2/18=11%	0/12=0%	10/12=83%	16/93=17%
Greenhead Channel (Sand)	3/57=5%	6/21=29%	0/8=0%	1/4=25%	10/90=11%
TOTAL	19/197=10%	14/61=23%	0/62=0%	23/28=82%	56/348=16%

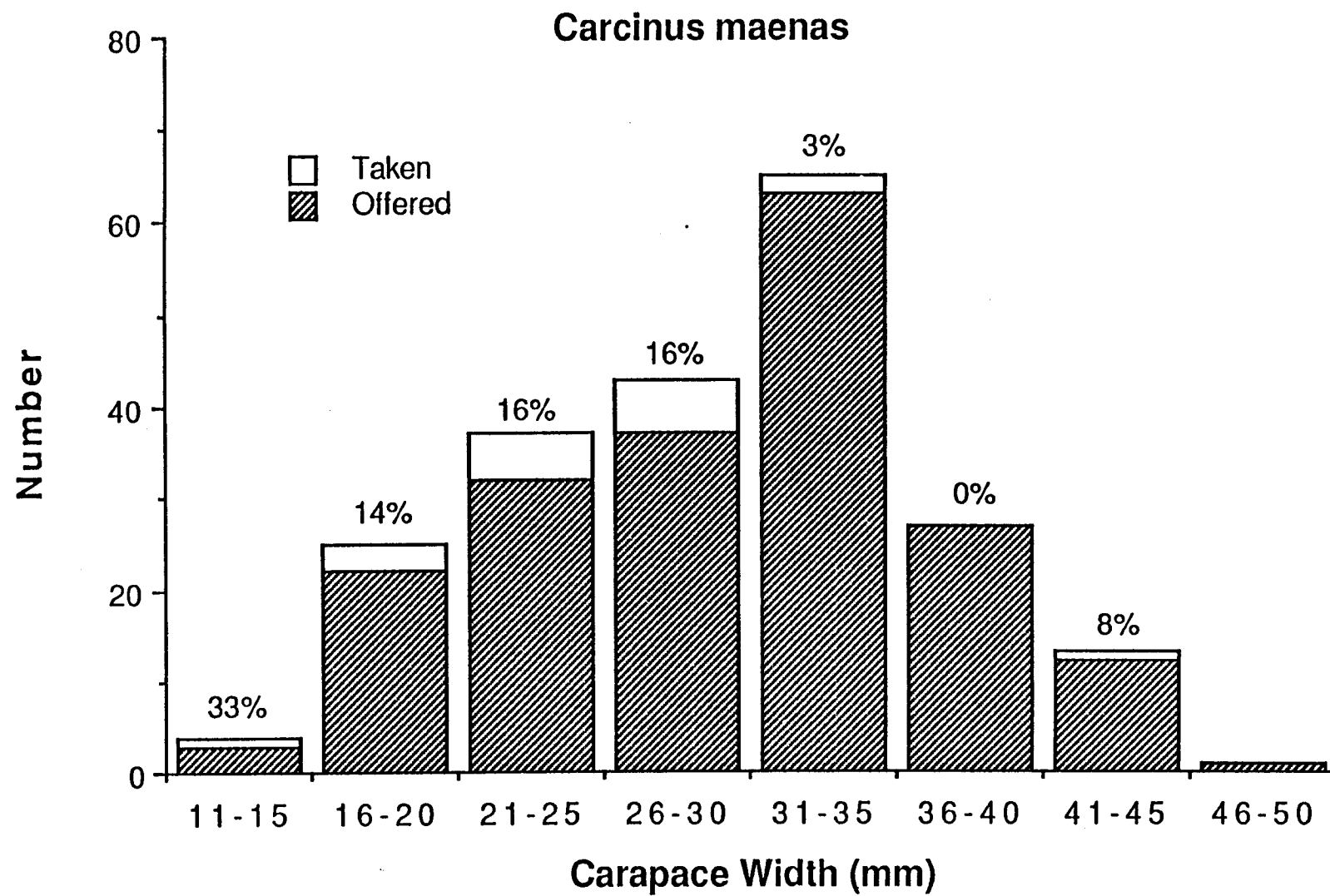


Figure 29. Size selectivity in predation on tethered green crabs.

prey taxa tested, but were actually the most risky habitats evaluated. Finally, there was weak statistical support for an escape from vulnerability to predators by green crabs over 30 mm CW.

BIRD UTILIZATION²

INTRODUCTION

Migratory shorebirds and waterfowl are the most conspicuous animal components of the Nauset Marsh ecosystem. Its productive and expansive intertidal and subtidal habitats comprise important, perhaps critical, feeding areas for large numbers of coastal migrants and wintering waterfowl. These populations are obviously a great attraction to the public, many of whom visit the Seashore with a special interest in sighting rare species. Quantitative observations of the more common, and thus ecologically more important, species have been limited, however, to American Black Duck (Anas rubripes) studies by J.W. Grandy IV during the late 1960's (1972) and shorebird counts by Blair Nikula from 1976 to the present (International Shorebird Survey, Manomet Bird Observatory, Manomet, MA). The latter study combined both feeding and roosting flocks and was restricted to the Nauset Harbor vicinity primarily during peak migration.

Despite their seasonal abundance, the role that marsh-dependent birds play in net nutrient and energy flux within coastal systems may be minimal (Bildstein et al. 1982; Duffy et al. 1981); nevertheless, several studies have shown that shorebirds in particular can substantially deplete local prey populations and especially vulnerable life stages of size classes (Goss-Custard 1969; Goss-Custard et al. 1977, Schneider 1978; Quammen 1982) with potentially far-reaching effects within complex estuarine food webs. Quammen (1984) showed that shorebirds significantly reduced infaunal densities, especially at typically muddy intertidal sites, and had a much greater influence in this regard than fish. Differential avian predation pressures in uniform vs. heterogeneous microhabitats may even influence the spatial distribution of sedentary invertebrate prey populations in intertidal habitats (Marsh 1986).

The first step in understanding the specific roles of migrant avifauna in the Nauset ecosystem is to quantify the temporal and spatial use of preferred habitats. The conspicuousness of coastal waterbirds and their apparent dependency on Nauset habitats make them useful indicators of overall habitat quality. Importantly, Nauset represents only one of many key habitats that are "critical" to the annual cycles of migrant and wintering species. Thus, the abundance of migratory birds using Nauset Marsh is affected by a multitude of environmental factors acting throughout these animals' extensive annual ranges. This aspect of the Nauset Marsh study focussed on the establishment of a baseline inventory of avian usage by species, season, tidal stage and habitat type. The intent was not to document the occurrence of as many species as possible, but to quantify densities of most common species within primary Nauset habitats. A secondary goal was to contribute to the ecosystem analysis with estimates of bird foraging rates and invertebrate prey densities.

²Prepared by John W. Portnoy, Biologist, Cape Cod National Seashore.

METHODS

STUDY SITES

Three study areas were selected within the Nauset Marsh system to represent the most heavily used habitat types: 1) Nauset Bay, 27 ha of intertidal and subtidal mudflats and open water; 2) Salt Pond Bay, 40 ha of open water and subtidal bottom; and 3) 19 ha of intertidal marsh, including marsh pools, referred to for the purpose of this study as Skiff Hill marsh (Fig. 30).

OBSERVATIONS

Instantaneous counts were conducted for all species visible within study sites through a 20x telescope positioned at least 50 m from feeding birds. Emphasis was placed on including most common and conspicuous species feeding in largely open habitat. Therefore, rarities or cryptic birds feeding amongst vegetation (e.g., Least Sandpiper - Calidris minutilla) were likely overlooked. Lesser and Greater Yellowlegs (Tringa flavipes and T. melanoleuca, respectively) could not be confidently distinguished at a distance and in the time available while counting large and transient feeding flocks; thus, these two species were combined as "Unidentified Yellowlegs". (See Table 30 for a species list.)

In general, foraging coastal waterbirds were inventoried on an approximately weekly basis at Nauset Bay from March 1986 through November 1987, at Salt Pond Bay (waterfowl only) from October 1986 through April 1987 and January to April 1988, and at Skiff Hill marsh from September 1986 through November 1987 and January through April 1988. Special effort was directed at obtaining shorebird counts from May through November during low-ebb tidal periods, when the number of feeding birds should have been most stable (Recher 1966). Whenever possible, daily counts were extended into flood-tide periods. Although staff time limitations often interfered with a regular weekly observation schedule, especially for winter waterfowl, the extension of the study in 1988 allowed sufficient data collection to describe seasonal population trends and habitat utilization.

Field observations were restricted to daylight hours due to time constraints and the lack of a night-vision telescope. Although scolopacid shorebirds (e.g., Short-billed Dowitchers - Limnodromus griseus, and Dunlin - Calidris alpina) can be expected to feed at night by tactile probing, they also feed actively during the day in Nauset Bay. Evidence from studies elsewhere in Massachusetts (B. Harrington, pers. comm.) and in Great Britain (Evans 1976) indicates that, in tidal areas, shorebird foraging activity is concentrated within daylight hours. American Black Ducks, however, are known to feed at night (Grandy 1972).

For each observation period, instantaneous counts of foraging birds by species and habitat were conducted by panning across feeding groups with a 20x telescope. Time, tide height and tide direction were also recorded. Counts were made on an hourly basis during low tide at Nauset Bay, and less frequently during high tide at Nauset Bay and at all tides at the other two study sites. Importantly, only foraging birds were counted; roosting flocks were excluded from the study. Tables 31a, b, and c document sampling intensity by tidal stage and season for the three Nauset sites. Note that emphasis at Salt Pond Bay was on wintering waterfowl, thus the lack of summertime sampling.

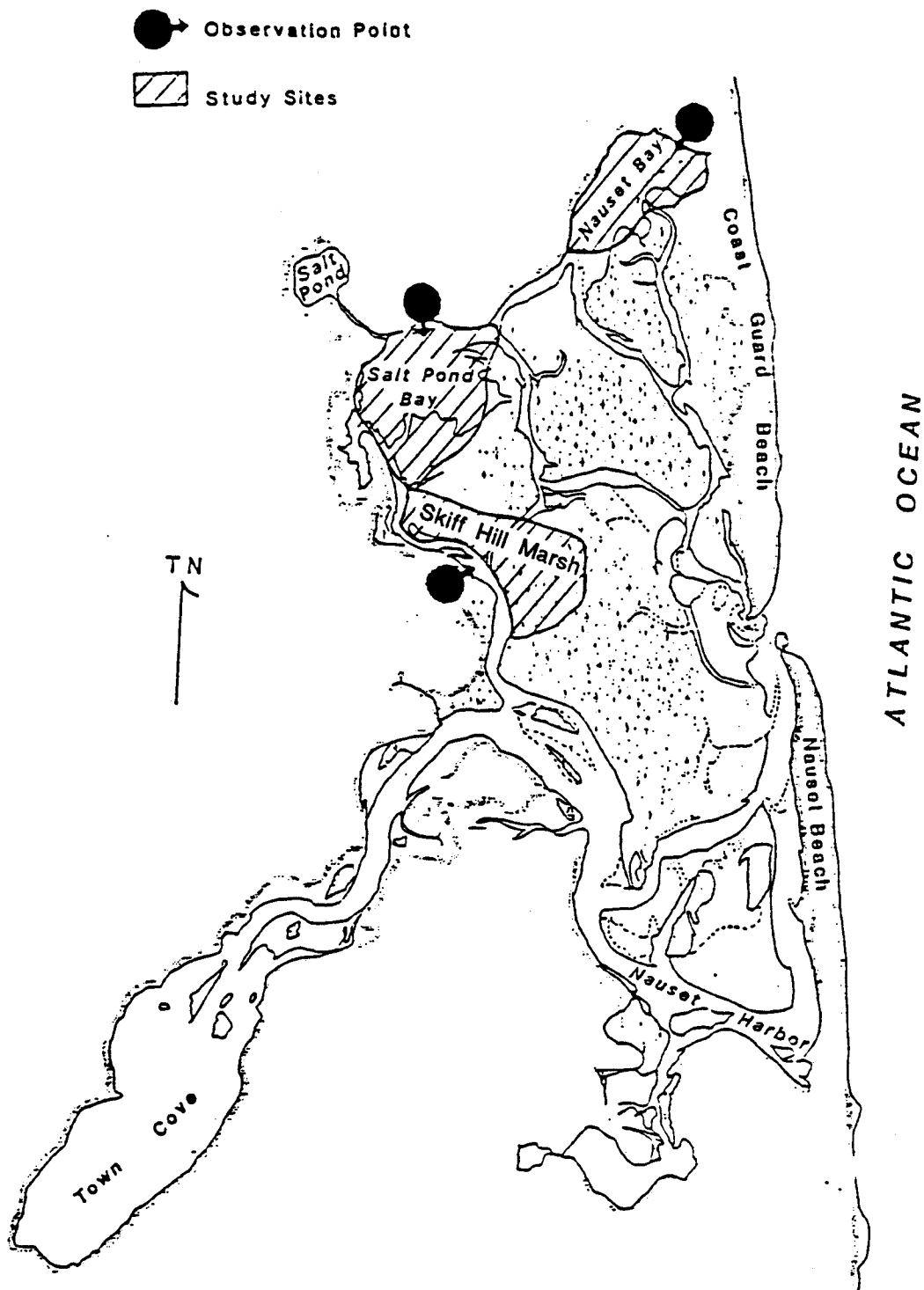


Figure 30. Bird observation points and boundaries of study sites.

Table 30. American Ornithologists' Union (AOU) number, alpha codes, common and scientific names of birds observed in Nauset Marsh.

AOU#	Alpha code	Common name	Scientific name
0470	GBBG	Great Black-backed Gull	<u>Larus marinus</u>
0510	HERG	Herring Gull	<u>Larus argentatus</u>
0540	RBGU	Ring-billed Gull	<u>Larus delawarensis</u>
0580	LAGU	Laughing Gull	<u>Larus atricilla</u>
0650	ROYT	Royal Tern	<u>Sterna maxima</u>
0700	COTE	Common Tern	<u>Sterna hirundo</u>
0740	LETE	Least Tern	<u>Sterna antillarum</u>
0770	BLTE	Black Tern	<u>Chlidonias niger</u>
0800	BLSK	Black Skimmer	<u>Rynchops niger</u>
1200	DCCO	Double-crested Cormorant	<u>Phalacrocorax auritus</u>
1300	RBME	Red-breasted Merganser	<u>Mergus serrator</u>
1320	MALL	Mallard	<u>Anas platyrhynchos</u>
1330	ABDU	American Black Duck	<u>Anas rubripes</u>
1370	AMWI	American Wigeon	<u>Anas americana</u>
1390	AGWT	Green-winged Teal	<u>Anas crecca</u>
1400	BWTE	Blue-winged Teal	<u>Anas discors</u>
1430	NOPI	Northern Pintail	<u>Anas acuta</u>
1510	COGO	Common Goldeneye	<u>Bucephala clangula</u>
1530	BUFF	Bufflehead	<u>Bucephala albeola</u>
1660	SUSC	Surf Scoter	<u>Melanitta perspicillata</u>
1720	CAGO	Canada Goose	<u>Branta canadensis</u>
1730	ATBR	Brant	<u>Branta bernicla</u>
1782	MUSW	Mute Swan	<u>Cygnus olor</u>
1900	AMBI	American Bittern	<u>Botaurus lentiginosus</u>
1940	GTBH	Great Blue Heron	<u>Ardea herodias</u>
1970	SNEG	Snowy Egret	<u>Egretta thula</u>
2010	GNBH	Green-backed Heron	<u>Butorides striatus</u>
2020	BCNH	Black-crowned Night Heron	<u>Nycticorax nycticorax</u>
2310	SBDO	Short-billed Dowitcher	<u>Limnodromus griseus</u>
2340	REKN	Red Knot	<u>Calidris canutus</u>
2420	LESA	Least Sandpiper	<u>Calidris minutilla</u>
2430	DUNL	Dunlin	<u>Calidris alpina</u>
2460	SESA	Semipalmated Sandpiper	<u>Calidris pusilla</u>
2480	SAND	Sanderling	<u>Calidris alba</u>
	UNYE	Unidentified Yellowlegs includes the two following:	
2540	GRYE	Greater Yellowlegs	<u>Tringa melanoleuca</u>
2550	LEYE	Lesser Yellowlegs	<u>Tringa flavipes</u>
2700	BBPL	Black-bellied Plover	<u>Pluvialis squatarola</u>
2740	SEPL	Semipalmated Plover	<u>Charadrius semipalmatus</u>
2770	PIPL	Piping Plover	<u>Charadrius melodus</u>
2830	RUTU	Ruddy Turnstone	<u>Arenaria interpres</u>
3310	NOHA	Northern Harrier	<u>Circus cyaneus</u>
3560	PEFA	Peregrine Falcon	<u>Falco peregrinus</u>
4880	AMCR	American Crow	<u>Corvus brachyrhynchos</u>
4980	RWBL	Red-winged Blackbird	<u>Agelaius phoeniceus</u>
5110	COGR	Common Grackle	<u>Quiscalus quiscula</u>
3900	BEKI	Belted Kingfisher	<u>Ceryle alcyon</u>

Table 31a. Bird sampling intensity at Nauset Bay, March 1986 through November 1987 by month and tidal stage.

Month	Number of Counts								Totals
	HS ¹	HE	ME	LE	LS	LF	MF	HF*	
J	0	0	3	1	2	0	1	0	7
F	0	0	1	1	0	0	0	1	3
M	1	3	0	1	1	2	2	1	11
A	0	1	4	6	4	1	0	2	18
M	0	0	2	11	7	5	2	2	29
J	1	1	3	11	9	7	6	0	38
J	0	0	2	11	7	6	3	0	29
A	0	0	3	10	6	7	4	0	30
S	0	0	3	6	8	11	2	0	30
O	1	1	5	4	5	2	7	1	26
N	0	0	3	5	2	2	2	4	18
D	1	1	1	3	4	3	2	2	17
Totals	4	7	30	70	55	46	31	13	256

¹ tide height: H = high; L = low; M = mid-tide
 tide direction: E = ebb; F = flood; S = slack water.

Table 3lb. Bird sampling intensity at Skiff Hill marsh, September 1986 to April 1988, by month and tidal stage.

Month	Number of Counts								Totals
	HS ¹	HE	ME	LE	LS	LF	MF	HF	
J	0	1	3	3	1	2	0	1	11
F	1	1	2	3	3	1	0	2	13
M	0	3	1	2	2	2	2	3	15
A	1	0	1	1	1	2	0	2	8
M	0	0	0	2	1	1	0	2	6
J	0	1	0	1	1	0	1	0	4
J	0	0	1	2	0	0	0	0	3
A	0	1	0	0	1	0	1	0	3
S	0	0	1	2	1	2	0	0	6
O	0	2	2	3	2	2	5	3	19
N	2	2	2	1	2	1	2	2	14
D	1	1	0	3	2	1	1	2	11
Totals	5	12	13	23	17	14	12	17	113

¹ tide height: H = high; L = low; M = mid tide
 tide direction: E = ebb; F = flood; S = slack water.

Table 3lc. Waterfowl sampling intensity at Salt Pond Bay, October 1986 through March 1988, by month and tidal stage.

Month	Number of Counts								Totals
	HS ¹	HE	ME	LE	LS	LF	MF	HF	
J	0	1	4	2	1	2	1	1	12
F	1	0	2	2	2	1	1	0	9
M	0	3	1	2	2	2	2	3	15
A	0	0	0	1	1	1	0	2	5
M	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0
A	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0
O	0	1	1	1	2	0	1	2	8
N	2	1	2	1	1	1	2	1	11
D	1	1	0	3	2	1	1	1	10
Totals	4	7	10	12	11	8	8	10	70

¹ tide height: H = high; L = low; M = mid-tide
 tide direction: E = ebb; F = flood; S = slack water.

Principal foraging habitats were first identified by preliminary field observations. Because intertidal and subtidal habitat availability was dependent upon tide height, the habitat classification of any given location in the marsh changed with tide time. As the tide level increased, "exposed flats" became "flooded flats" and eventually "open water;" areas of subtidal bottom were classified as open water habitats at high tide. Recorded habitat types were as follows:

Exposed intertidal mudflat (EIM) - unvegetated or algae-covered (*Cladophora* sp.) substrates composed of highly organic sediments, usually exposed at low tide and exposed at the time of observation.

Flooded intertidal mudflat (FIM) - as above but flooded at the time of observation.

Subtidal bottom (SUB) - flats and creek channels flooded throughout a mean tidal cycle.

Overwashed sand (SAN) - sandy deposits above mean high water left by barrier-island overwash events.

Open water (OPW) - deep (generally > 0.5 m) water habitat during mid- to high tide.

Marsh surface (MSF) - intertidal *S. alterniflora* marsh.

Marsh pool (MRP) - isolated small pools or pannes (3 - 20 m diameter) connected to adjacent creeks and larger embayments only during high tide.

The tidal stage of each observation period was characterized functionally in terms of habitat availability relative to bird foraging habits. "Low tide" was defined by relative water heights at and below 0.22 m, encompassing all times when mudflats are exposed. At mid-tide, 0.23 to 0.90 m, all mudflats in Nauset Bay were flooded but the intertidal *S. alterniflora* marsh was exposed. Tide was "high" whenever the marsh surface was flooded.

INVERTEBRATE SAMPLING

To document benthic invertebrate prey densities in those subtidal and intertidal habitats most used by shorebirds, sediment cores were collected from Nauset Bay in September 1987. Six 10 cm and three 30 cm cores were randomly located at each of four intertidal and two subtidal flats, where shorebird feeding was observed to be most concentrated. The deeper cores were intended to sample large nereid polychaetes which borrow below 10 cm (R. Grizzle, Univ. of New Hampshire, pers. comm.). Core diameter was 10 cm. All material retained in 0.6 mm mesh (for shallow cores) and 2.0 mm mesh (for the deep cores) was fixed in 5% buffered formalin and stained with rose bengal in the field. [Note that the deep cores (30 cm) were intended to sample large, deep-burrowing nereids which may have been missed by the 10 cm deep grabs. These large nereids were retained on the 2.0 mm mesh seive, making finer sieving unnecessary.] Fixed collections were later sorted and stored in 70% ethanol. All specimens were identified to the family level.

RESULTS AND DISCUSSION

SEASONAL USAGE OF NAUSET MARSH

Most of the shorebirds and waterfowl that use Nauset Marsh are highly migratory. The vast majority breed elsewhere, the marsh serving as an important (if not critical) seasonal feeding ground for shorebirds in passage, and for wintering waterfowl; thus, their populations at Nauset fluctuate dramatically with season.

As predators, these birds comprise a morphologically and behaviorally diverse group, ranging from generalist Herring Gulls (Larus argentatus) to highly specialized scolopacid shorebirds. Anatomical limitations and differences in foraging strategies (and tide-dependent prey behaviors - Evans 1979) segregate bird species in terms of habitat use both temporally (relative to tide), and spatially (relative to habitat type within the marsh complex). For this reason, and in lieu of intensive studies beyond the scope of this inventory, a daily maximum count was chosen as the best indication of specific habitat use (see Data Appendix C). Hourly observations indicated that these maxima are quite stable through that portion of the tidal cycle (several hours for most species) when a given species is most abundantly feeding. For example, note the stability of Semipalmated Sandpiper (Calidris pusilla) numbers during low ebb tide at Nauset Bay (Figs. 31, 32, 33). Shorebird migratory movements probably occur in successive and overlapping waves of individuals rather than as entire populations passing through an area like Nauset in synchrony (Recher 1966; B.A. Harrington, Manomet Bird Observatory, pers. comm.). Thus, foraging bird counts presented here are representative densities only; the total of any species that annually utilizes Nauset remains undetermined.

General seasonal trends in bird usage, irrespective of habitat, are depicted in Figure 34: shorebird counts are from Nauset Bay and American Black Duck counts are from Salt Pond Bay. As expected, peak shorebird counts occurred during the brief spring and more protracted autumn migratory passages. From January through early April, the marsh was devoid of shorebird use except for sporadic appearances of small, 30- to 50-bird flocks of dunlin in early January (recorded at Skiff Hill marsh). Spring migrants, beginning with Yellowlegs (mostly Greater Yellowlegs) in late April, generally passed through in May and early June. The study sites were evidently used by only 5 to 10 Dunlin and no Short-billed Dowitchers during their northward migration. Semipalmated Sandpipers and Black-bellied Plovers were dominant at this time, their flock sizes peaking in late May. By mid- to late-June, the marsh's intertidal habitats were again nearly devoid of shorebird activity, most individuals having reached their northern breeding areas.

"Fall" migration was first marked by the return of large numbers of Semipalmated Sandpipers and Short-billed Dowitchers beginning in early July; these two species peaked in late July and August. Yellowlegs (most closely observed individuals were Lesser Yellowlegs) reached population peaks in late July to early August and again in October. Black-bellied Plovers appeared in greatest numbers in late August to early September.

Short-billed Dowitchers were the first of the common shorebirds to disappear, except for a few stragglers, in mid-August. By late September their

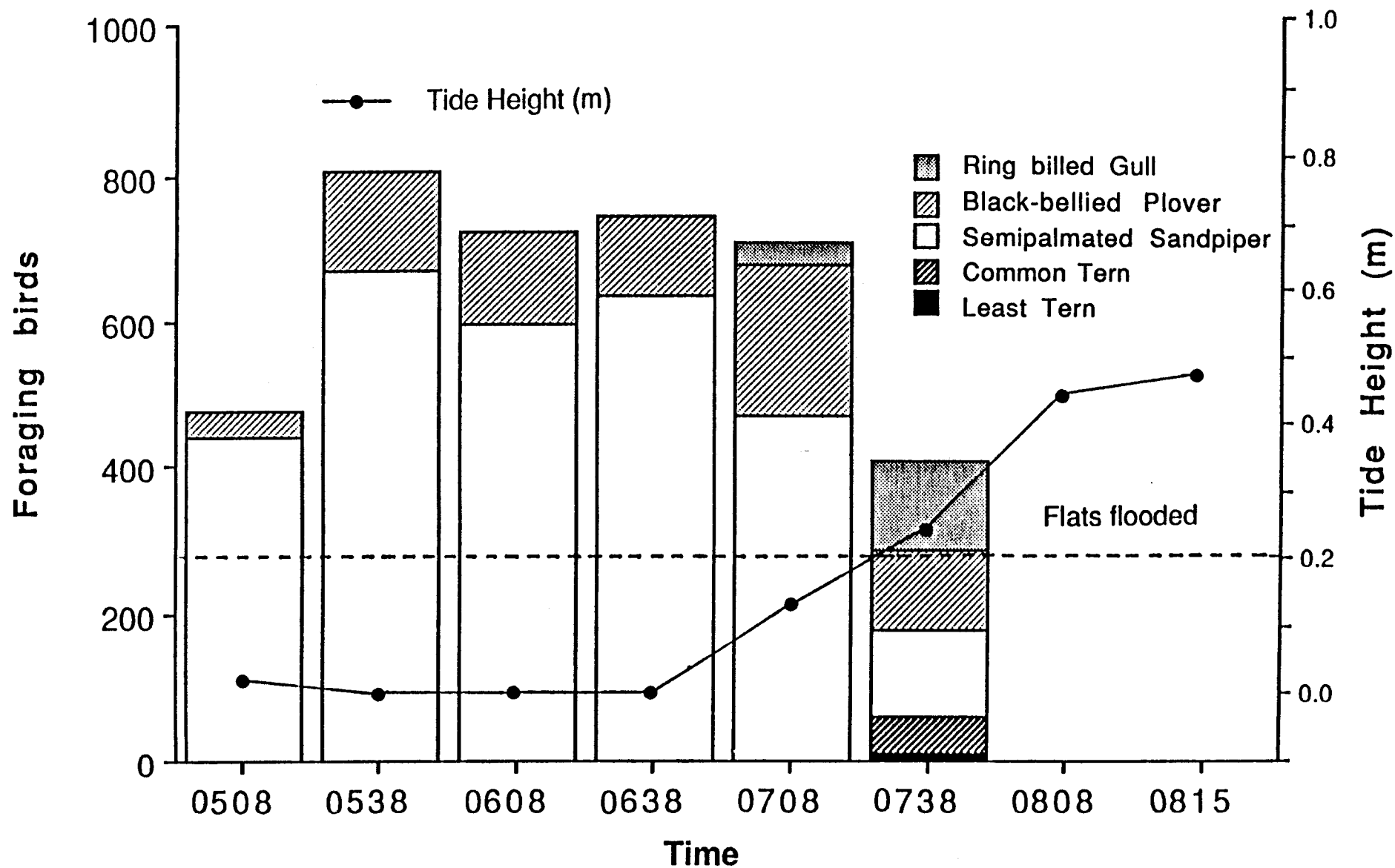


Figure 31. Effect of tidal stage on Nauset Bay bird use, 20 May 1986.

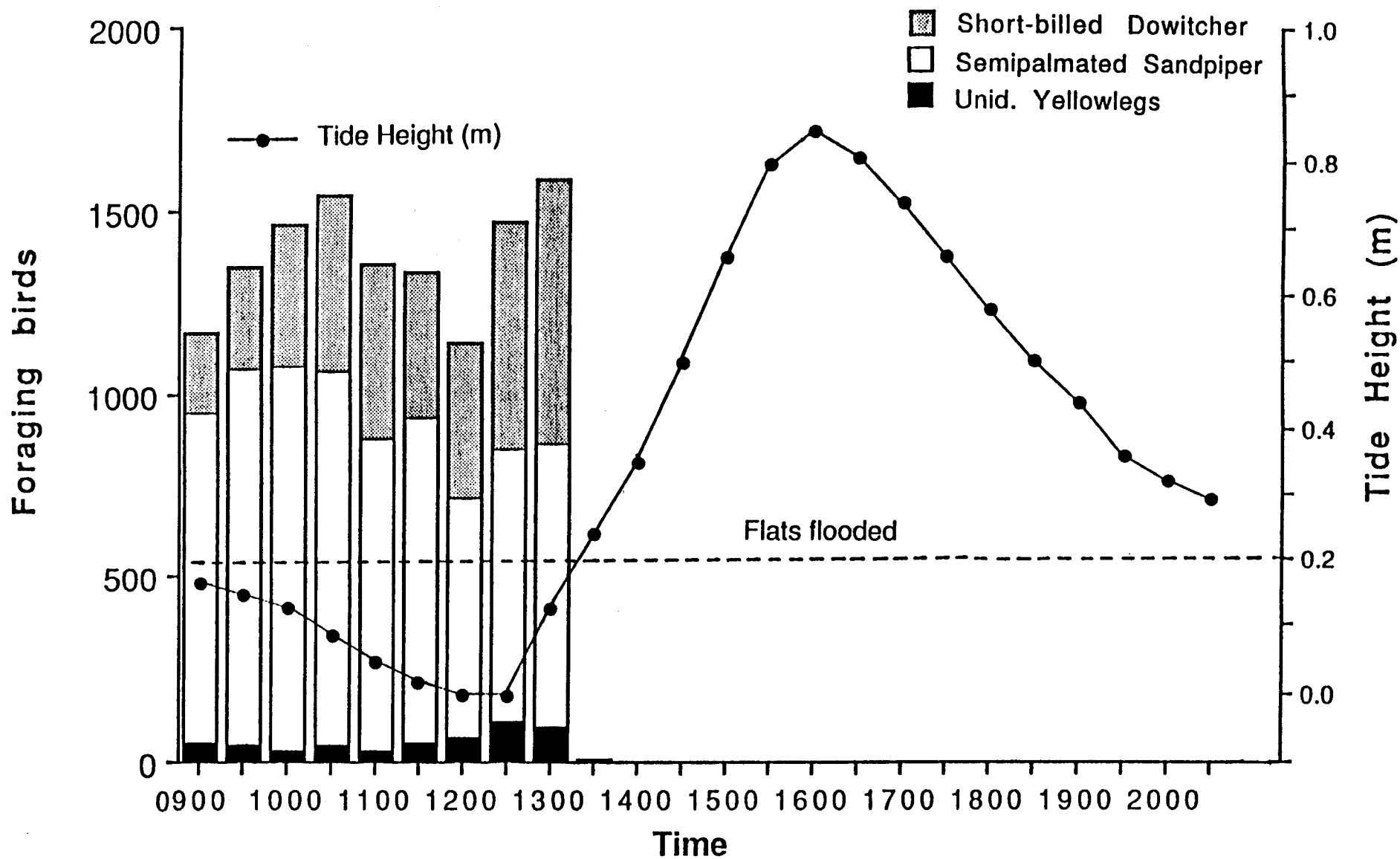


Figure 32. Effect of tidal stage on Nauset Bay bird use, 24 July 1986.

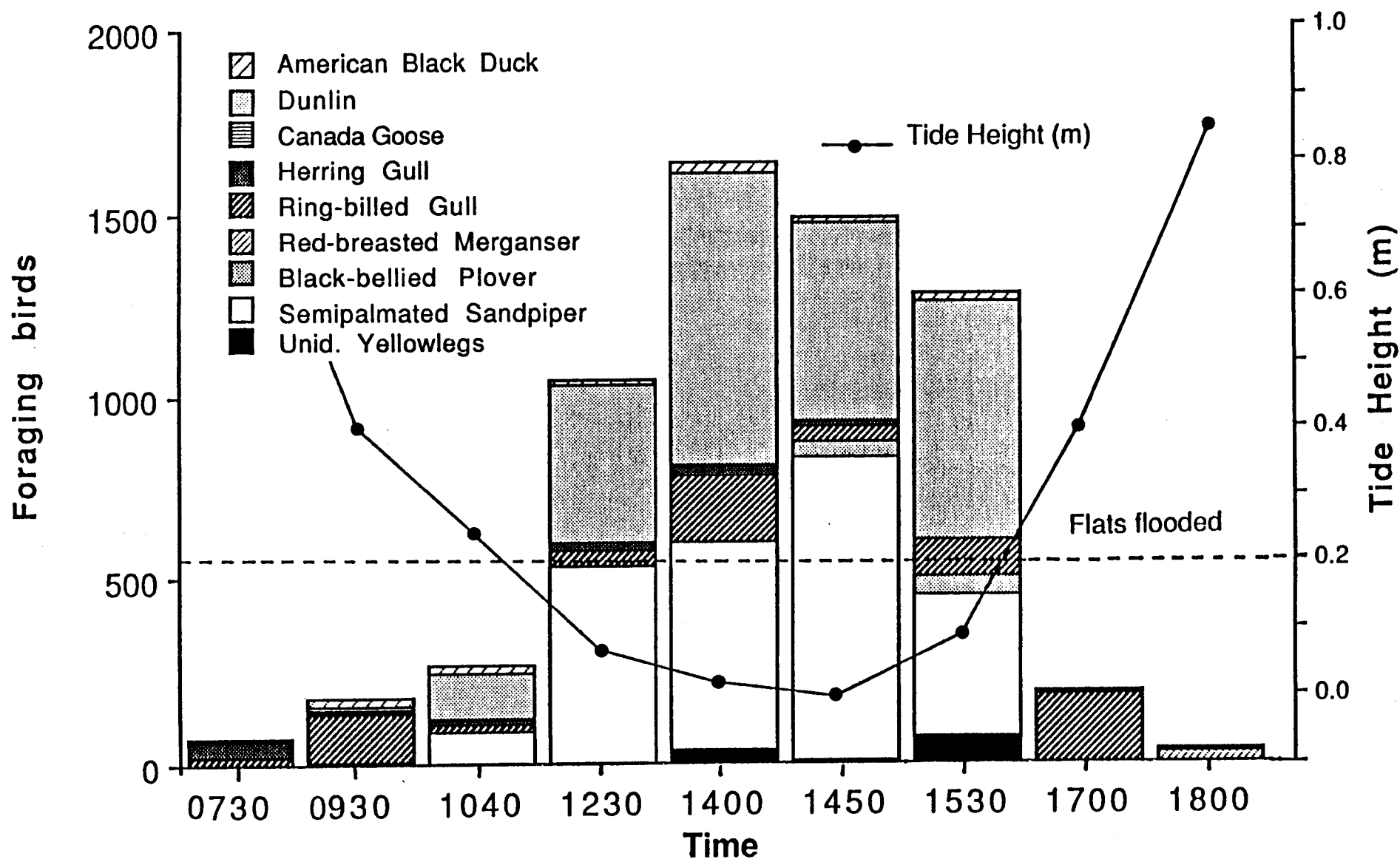


Figure 33. Effect of tidal stage on Nauset Bay bird use, 10 October 1986.

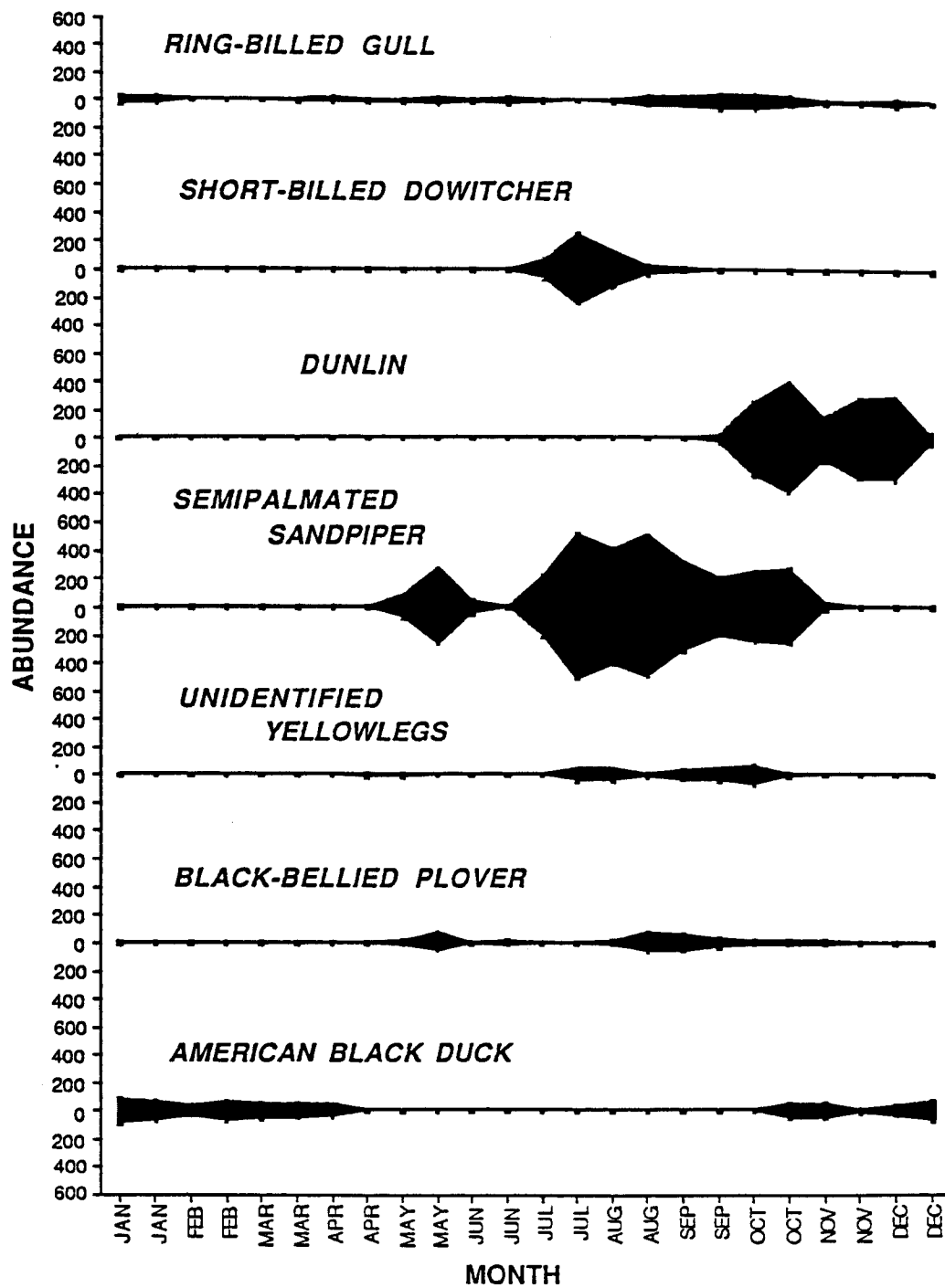


Figure 34. Seasonal abundance of most common shorebirds (Nauset Bay) and American Black Ducks (Salt Pond Bay). Data are two-week averages of maximum daily counts.

feeding areas were occupied by Dunlin, possibly representing the replacement of one deeply-probing scolopacid wader with another and demonstrating Recher's (1966) contention that competition among morphologically similar species may be reduced by the staggering of peak population densities. In any case, Dunlin became the numerically dominant shorebird, exceeding even Semipalmated Sandpiper counts almost immediately after the former species' first arrival in late September. Dunlin persisted in flocks of nearly 600 individuals into December; flocks of 5 to 150 were observed near Skiff Hill throughout January 1988. The other common species which remained after Short-billed Dowitcher departure into the early fall, Semipalmated Sandpipers, Yellowlegs and Black-bellied Plovers, gradually declined in flock size in late October and November.

Wintering American Black Ducks arrived in Nauset Marsh in October of both 1986 and 1987. Numbers observed at Salt Pond Bay (100 to 150) approximate those tallied by Grandy (1972) in the late 1960s. They remained at Nauset until early April. Both their arrival and departure appeared fairly abrupt and synchronous.

Gulls, mostly Ring-billed Gulls (Larus delawarensis), comprise a more constant annual component of the local avifauna, foraging on intertidal flats and in shallow water throughout the year.

SELECT SPECIES ACCOUNTS

Great Black-backed Gull (Larus marinus)

Great Black-backed Gulls are primarily scavengers on exposed intertidal mudflats and on the marsh surface throughout the year.

Herring Gull (Larus argentatus)

Like the previous species, Herring Gulls scavenge on exposed substrates but also capture crabs, fish and large polychaetes while wading in flooded intertidal mudflats. Herring and Great Black-backed Gulls loaf by the thousands at Nauset Inlet and Nauset Harbor.

Ring-billed Gull (Larus delawarensis)

This gull is the predominant larid of the intertidal flats, feeding most actively when water depths range from a few to 20 cm. Ring-billed Gulls wade or swim out over flooding flats during flood tide and were regularly observed to prey upon large nereid polychaetes in Nauset Bay. This and the two preceding species probably remove substantial numbers of these annelids (Ambrose 1986). At nearby Plymouth flats, sand shrimp were important prey (Schneider and Harrington 1981).

Laughing Gull (Larus atricilla)

Laughing Gulls feed infrequently during the breeding season on intertidal substrates and over open water within the marsh proper. Foraging by local breeders is concentrated in the high energy littoral zone outside Nauset Inlet.

Common Tern (Sterna hirundo)

Common Terns regularly prey on marsh-dwelling Atlantic silverside and killifish, especially during the rapid flood over normally intertidal substrates of Nauset Bay and in creek channels beyond. Casual observations at Nauset Inlet indicated at least sporadic use by feeding flocks of this species.

Least Tern (Sterna antillarum)

This tern, regularly nesting along the barrier beach of Coast Guard Spit and Nauset Heights, frequently fishes Nauset and Salt Pond Bays at high water. Local Salt marsh habitats are probably important to Least Tern reproductive success at colonies on either side of Nauset Inlet.

Double-crested Cormorant (Phalacrocorax auritus)

Double-crested Cormorants fish in small numbers throughout the marsh at high tide, being most frequent in creek channels. They are most common in September and October.

Red-breasted Merganser (Mergus serrator)

Red-breasted Mergansers also feed at high tide in open water and marsh pools, regularly wintering in Nauset Marsh. The 1986-87 inventory coincided with unusually high numbers (R. Prescott, pers. comm.) during that winter with 80 to 100 individuals in Salt Pond Bay.

American Black Duck (Anas rupripes)

American Black Ducks, intensively studied at Nauset by Grandy (1972) in the late 1960's, are the most abundant wintering waterfowl, feeding primarily on subtidal blue mussel beds at low tide and on the marsh surface (on marsh snails - Melampus sp.) at high tide.

Bufflehead (Bucephala albeola)

Buffleheads are regular winter residents, feeding in open water especially in the smaller embayments and occasionally in marsh pools.

Canada Goose (Branta canadensis)

Canada Geese appear intermittently from October through March as a small flock of 15 to 40 individuals feeding on the marsh surface or alternately on subtidal substrates.

Great Blue Heron (Ardea herodias)

Great Blue Herons are most common in fall (up to 50 birds observed across the entire marsh surface in October 1986), but a few individuals wintered over in 1986-87 and 1987-88. They feed on both exposed and flooded intertidal and subtidal flats, and in marsh pools.

Snowy Egret (Egretta thula)

Snowy Egrets occur throughout their May to August breeding season. They are most abundant, feeding with Yellowlegs and Ring-billed Gulls on flooded intertidal and subtidal flats, during post-breeding dispersal in late summer. Prey include killifish (pers. observ.) and probably shrimp (Schneider and Harrington 1981).

Short-billed Dowitcher (Limnodromus griseus)

These birds are highly seasonal, occurring in large numbers as migrants in July and August on the intertidal flats of Nauset Bay. A spring passage was not recorded in either 1986 or 1987, suggesting that it occurred between weekly sampling dates or that Short-billed Dowitchers fed elsewhere during the northward migration. Maldanid polychaetes and amphipods were important foods at a Plymouth stopover (Schneider and Harrington 1981).

Red Knot (Calidris canutus)

Red Knots used Nauset Bay intertidal substrates only infrequently and in very low numbers. Casual observation since 1987 indicated their activity in Nauset Marsh is centered beyond my study sites, i.e., around Nauset Harbor and near the Inlet.

Least Sandpiper (Calidris minutilla)

Least Sandpipers, although regularly feeding within the S. alterniflora marsh, were not readily visible in dense grass or along the seaward marsh edge and were therefore not recorded during standard counts. This species may have been included in some Semipalmated Sandpiper (SESA) counts, but periodic close inspections of "SESA-types" on open flats showed them all to be of the latter species. K. Jones (pers. comm.) reports counts of 3 to 11 Least Sandpipers foraging in marsh fringes around Nauset Bay during August and early September.

Dunlin (Calidris alpina)

Dunlin were present briefly in very low numbers during spring migration in May; flocks of 500 to 700 are common during fall migration in October through early December. They appear to make equal use of both flooded and exposed mudflats, probably feeding on polychaetes (Recher 1966; Evans et al. 1979).

Semipalmated Sandpiper (Calidris pusilla)

This sandpiper is the numerically dominant shorebird throughout Nauset Marsh during both spring and fall migrations, concentrating foraging efforts on exposed mudflats. In July and August, flocks of over 1000 spread out to feed across the exposed mudflats of Nauset Bay throughout the protracted low tide. Foods at nearby Plymouth flats were primarily shrimp (Schneider and Harrington 1981), amphipods and spionid polychaetes (B.A. Harrington, pers. comm.).

Sanderling (Calidris alba)

Sanderlings are most common along the high energy ocean beach but, in fall and winter, 10 to 20 birds occasionally foraged along sandy substrates, especially overwashed areas, on the west (marsh) side of the barrier.

Greater and Lesser Yellowleg (Tringa melanoleuca and T. flavipes)

Yellowlegs were counted together due to difficulty in distinguishing the two species at a distance in large multi-species flocks. Feeding observations at Nauset indicate that these species take large polychaetes from exposed mudflats, and fish from pools (at low water), especially killifish, during the early flood tide period. The late April and early May influx of 10 to 30 individuals at Nauset Bay appeared to include mostly Greater Yellowlegs. Later, larger peaks (90 to 130 birds) in late-July/early-August and again in late-September/early-October included both species.

Black-bellied Plover (Pluvialis squatarola)

Black-bellied Plovers appeared abundantly (up to 150 birds at Nauset Bay) during both May and August/September migratory periods. They consistently foraged on exposed intertidal mudflats, probably feeding upon gastropods, gem clams (Gemma sp.) and polychaetes (Recher 1966, Schneider and Harrington 1979, 1981). The "autumn" (August) migratory peak occurred about a month after that of Semipalmated Sandpipers, the other abundant shorebird of exposed intertidal flats.

Semipalmated Plover (Charadrius semipalmatus)

This plover, probably feeding on polychaete worms (Recher 1966), is widely distributed across exposed intertidal mudflats and sandy overwashed areas in May and again in July and August. Numbers were consistently low, but probably underestimated during this study due to confusion with similarly-sized but much more abundant Semipalmated Sandpipers in mixed-species flocks.

Piping Plover (Charadrius melodus)

Piping Plovers regularly foraged on sandy substrates, especially overwash deposits, on the east side of Nauset Bay beginning with their spring arrival in March and throughout their summer breeding season. Typically 2 to 4 birds were seen there in the summers of 1986 and 1987. The local breeding population is under currently intensive study (L. McIvor unpubl.; E. Hoopes, unpubl.).

Ruddy Turnstone (Arenaria interpres)

Ruddy Turnstones were represented at Nauset Bay by only a few individuals appearing on sandy overwash deposits in May and August.

Northern Harrier (Circus cyaneus)

Apparently Northern Harriers do not nest within the Nauset Marsh complex, but 1 to 2 birds were regularly seen hunting the open intertidal marsh and marsh/upland borders in summer, autumn and early winter.

Peregrine Falcon (Falco peregrinus)

Peregrine Falcons sporadically appeared during peak shorebird migrations in July through September. Only one individual was ever observed during a given observation period. Most predation attempts were directed toward flocks of Semipalmated Sandpipers.

American Crow (Corvus brachyrhynchos)

Four to ten American Crows, probably comprising a resident flock, were almost always visible foraging on exposed intertidal mudflats at low tide, or on the marsh surface. Recorded foods included exposed crabs, stranded fish and carrion (especially dead birds). They also forage in dune habitats along the barrier beach.

Other Passerines

With the exception of American Crows, passerines were generally infrequent in the marsh proper, i.e. below mean high tide, but no attempt was made to inventory small passerines in the marsh/upland ecotone or in intertidal S. alterniflora. Only small flocks of Common Grackles (Quiscalus quiscula) and Red-winged Blackbirds (Agelaius phoeniceus) (8 to 20 individuals) foraged sporadically on the marsh surface east of Skiff Hill.

TIDE AND HABITAT USE

At all seasons, tidal stage constantly affects the availability of all habitats below high water. Tidal stage also profoundly affects fish and benthic invertebrate distributions and behaviors. Thus, tidal stage and habitat usage variables are interdependent.

Figures 31, 32, and 33 describe typical tidally-induced changes in the foraging abundance of dominant species during spring, summer and autumn at Nauset Bay. Dates were chosen to represent peak migration periods for Semipalmated Sandpipers (Fig. 31, 32, 33), Black-bellied Plovers (Fig. 31, 33), Short-billed Dowitchers (Fig. 32), Yellowlegs (Fig. 32, 33), and Dunlin (Fig. 33).

Regardless of season, general trends in habitat use relative to tide time are apparent. During the ebb, little feeding activity occurred until tide height reached 0.4 m, corresponding with water depths of 30 cm over intertidal flats. At this point Ring-billed Gulls began feeding, apparently upon large polychaetes captured by dipping over the shoaling muddy substrate. As the tide continued to fall, Semipalmated Sandpipers and Black-bellied Plovers quickly flew in from beyond Nauset Bay to utilize newly exposed flats and those covered with less than 3 cm of water. Ring-billed Gulls remained to forage and rest on exposed flats, but the number feeding declined toward low slack water. Short-billed dowitchers, in July and August, or Dunlin, in October through December, arrived along with other shorebirds, but usually settled to feed on more deeply flooded (estimated 3 to 5 cm) substrates. Feeding flocks tended to disperse as more intertidal mudflats became exposed over the prolonged Nauset Bay ebb period.

During the rapid flood tide, flocks quickly concentrated, retreating before the flooding tide, and feeding activity appeared to increase. Black-bellied Plover

and Semipalmated Sandpiper feeding quickly ended as flats became flooded; Short-billed Dowitchers (or Dunlin in fall) feeding in deeper water left the flooded flats shortly after the Plovers and Sandpipers. Ring-billed Gull and Yellowleg foraging activity dramatically increased as the flats became flooded. These two species, often in mixed-species flocks with Common and Least Terns and Snowy Egrets in July, probably exploited killifish schools at the leading edge of the advancing tide. Later into the flood (water depths of 5 to 20 cm), the gulls regularly captured large (4 to 10 cm) nereid polychaetes. All foraging activity usually ended as the tide again reached 0.4 m.

Winter waterfowl usage of all three study sites was also influenced in a consistent way by tidal stage. As documented by Grandy (1972), American Black Ducks most actively fed in subtidal bottom at low water and on the marsh surface at extreme high tide, resting on the water or marsh surface at mid-tides. Piscivorous Buffleheads and Red-breasted Mergansers were most active during mid-tide to high flood tide.

Species-specific influences of tidal stage on foraging densities and habitat usage are summarized in Figs. 35, 36 and 37 for most common species. Species-specific habitat usage, similarly quantified by tallying the total number of peak daily counts that were recorded for each habitat type, are presented in Tables 32, 33 and 34. Table 35 is a summary of the relative importance of the various habitats at Nauset Bay, Skiff Hill marsh, and Salt Pond Bay to all bird species combined.

Gulls in general, and particularly Herring and Ring-billed Gulls, made extensive use of flooded mudflats during low ebb tide and exposed flats during low slack water (Figs. 35a, 35b). However, usually only Ring-billed Gulls continued to feed on mudflats as these substrates became submerged during the flood. Fifty-four percent of maximum Ring-billed Gull counts at Nauset Bay were recorded from exposed or flooded intertidal mudflats; another 26% were recorded for "open water" habitats, probably including submerged intertidal substrates accessible to swimming gulls early in the flood.

Black-bellied Plovers, along with Semipalmated Plovers and Semipalmated Sandpipers, use predominantly visual cues in locating their prey; they are thus highly dependent upon exposed intertidal mudflats for foraging (Figs. 35e, 35f, 35h). About 78% of the former species' maximum daily counts were recorded on this substrate; another 20% was observed on overwashed sand. Semipalmated Plovers were never observed to feed in flooded habitats. About 78% of Semipalmated Sandpiper peak counts were recorded on exposed intertidal mud, with 17% on flooded flats.

As expected, Dunlin and Short-billed Dowitchers, which feed largely by tactile probing well below the sediment surface, used flooded habitats much more extensively than visually oriented surface feeders (Figs. 35i, 35j). About 50% and 33% of daily peak counts for Dunlin and Short-billed Dowitchers, respectively, were tallied on flooded intertidal and subtidal substrates.

The two Yellowleg species were also strongly associated with flooded intertidal and subtidal habitats, with 34% and 43% of daily peak counts recorded for these respective habitats. These long-legged, long-billed waders both fish and probe in water that is too deep for foraging by the other common shorebirds.

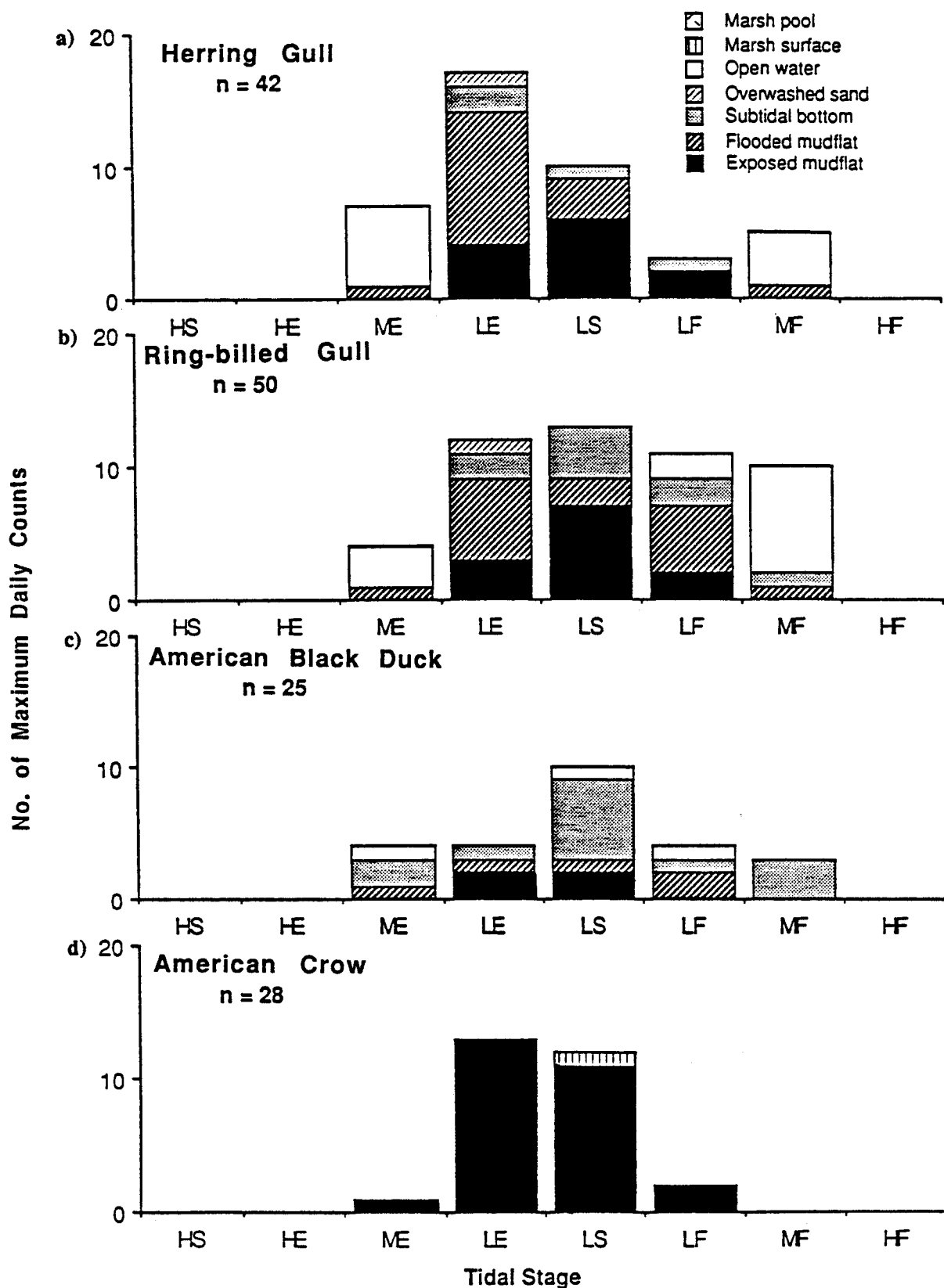


Figure 35. Effect of tidal stage on habitat use of Nauset Bay by select bird species; a) Herring Gull, b) Ring-billed Gull, c) American Black Duck, d) American Crow, e) Black-bellied Plover, f) Semipalmated Plover, g) Lesser and Greater Yellowlegs, h) Semipalmated Sandpiper, i) Short-billed Dowitcher, j) Dunlin (n = days observed).

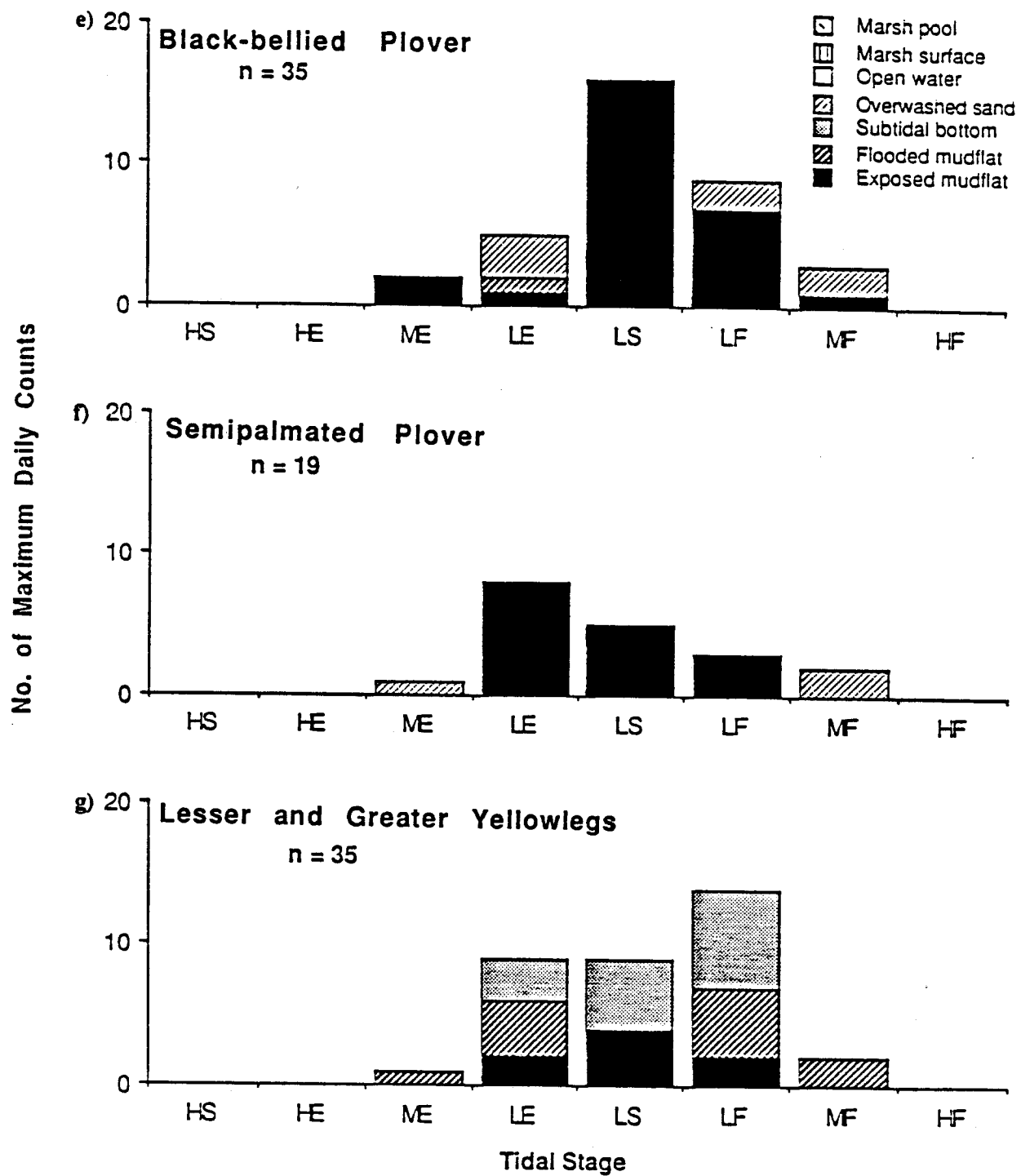


Figure 35 (continued).

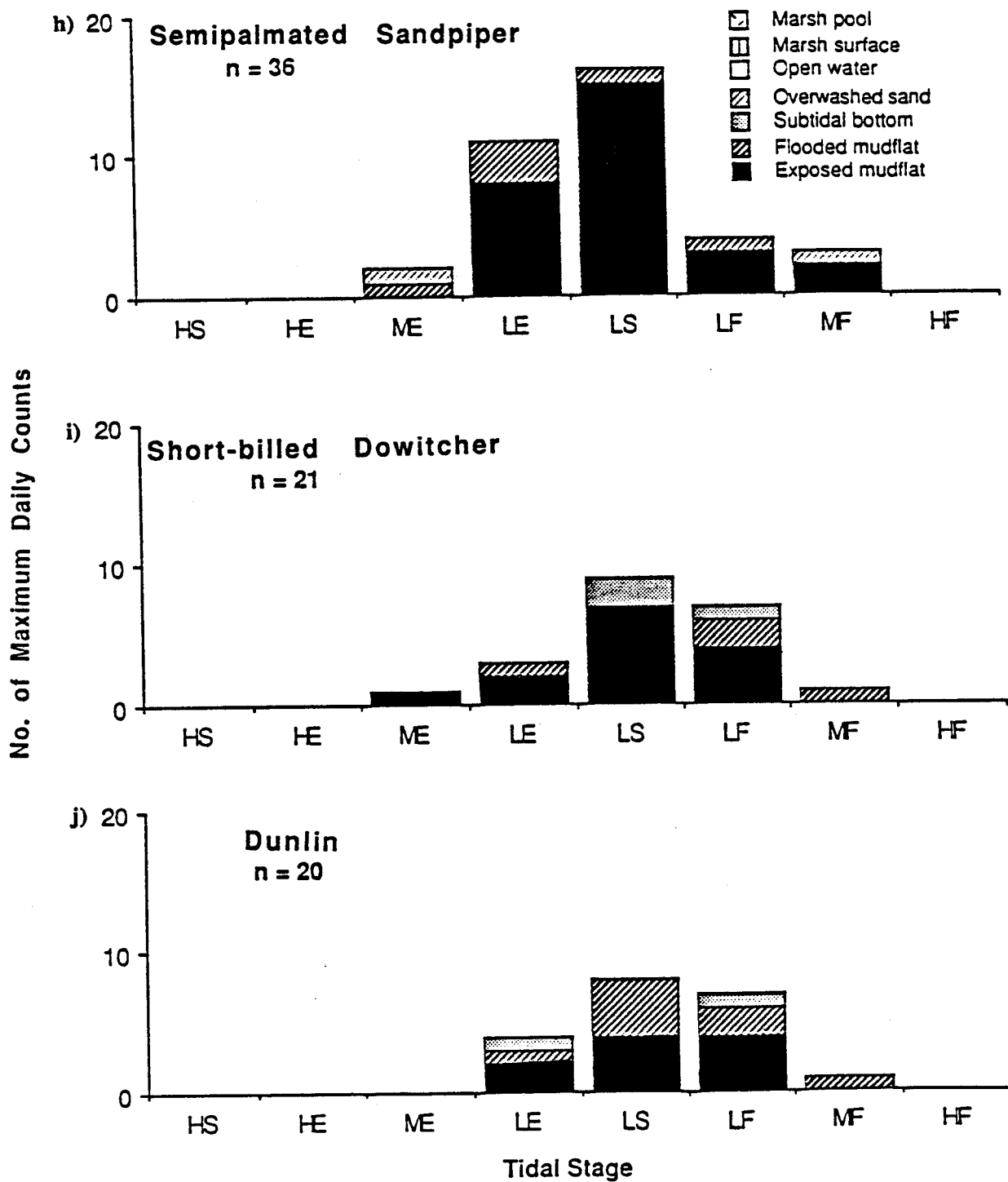


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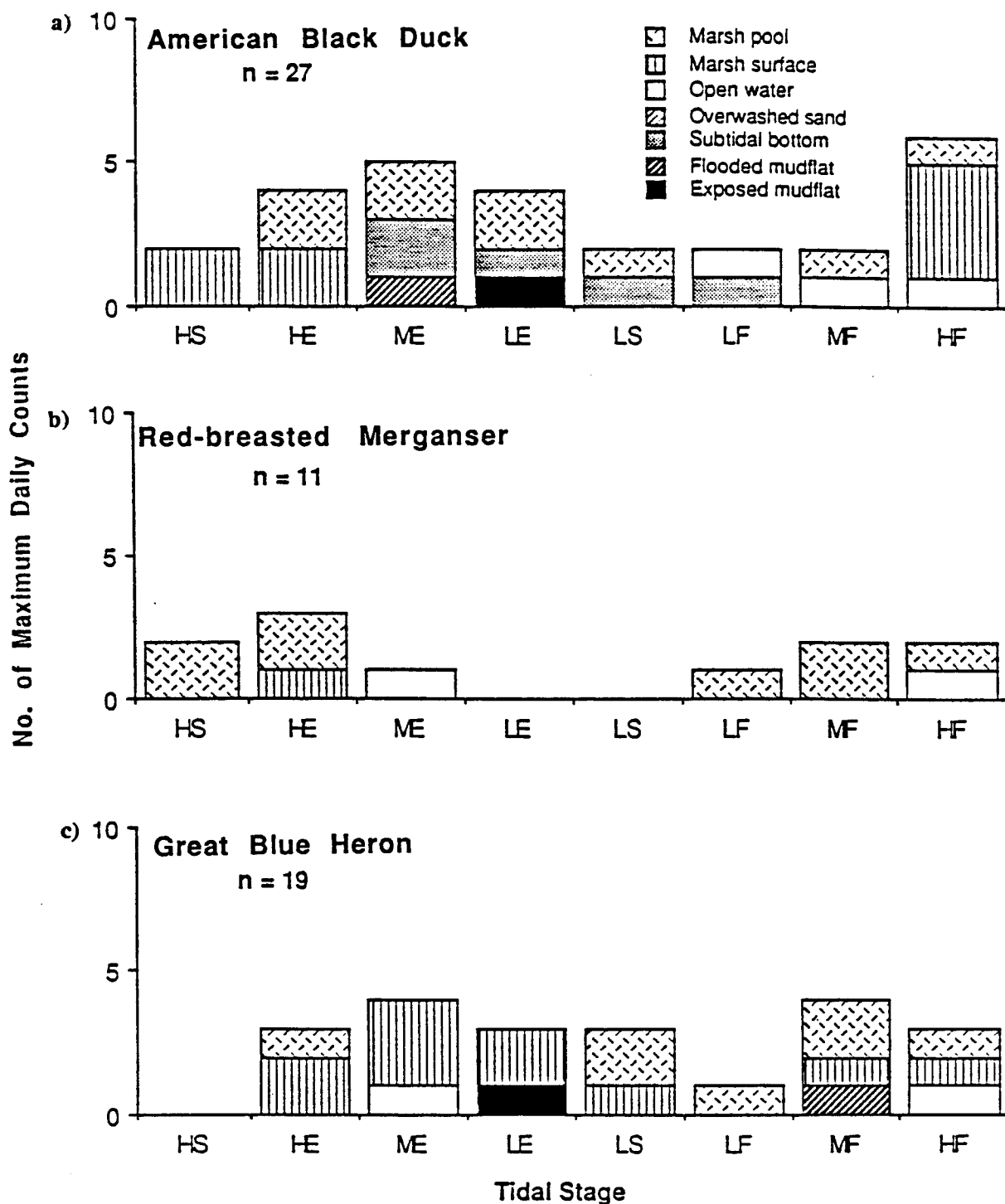


Figure 36. Effect of tidal stage on habitat use of Skiff Hill marsh by select bird species; a) American Black Duck, b) Red-breasted Merganser, c) Great Blue Heron, d) Herring Gull, e) Ring-billed Gull, f) American Crow (n = days observed).

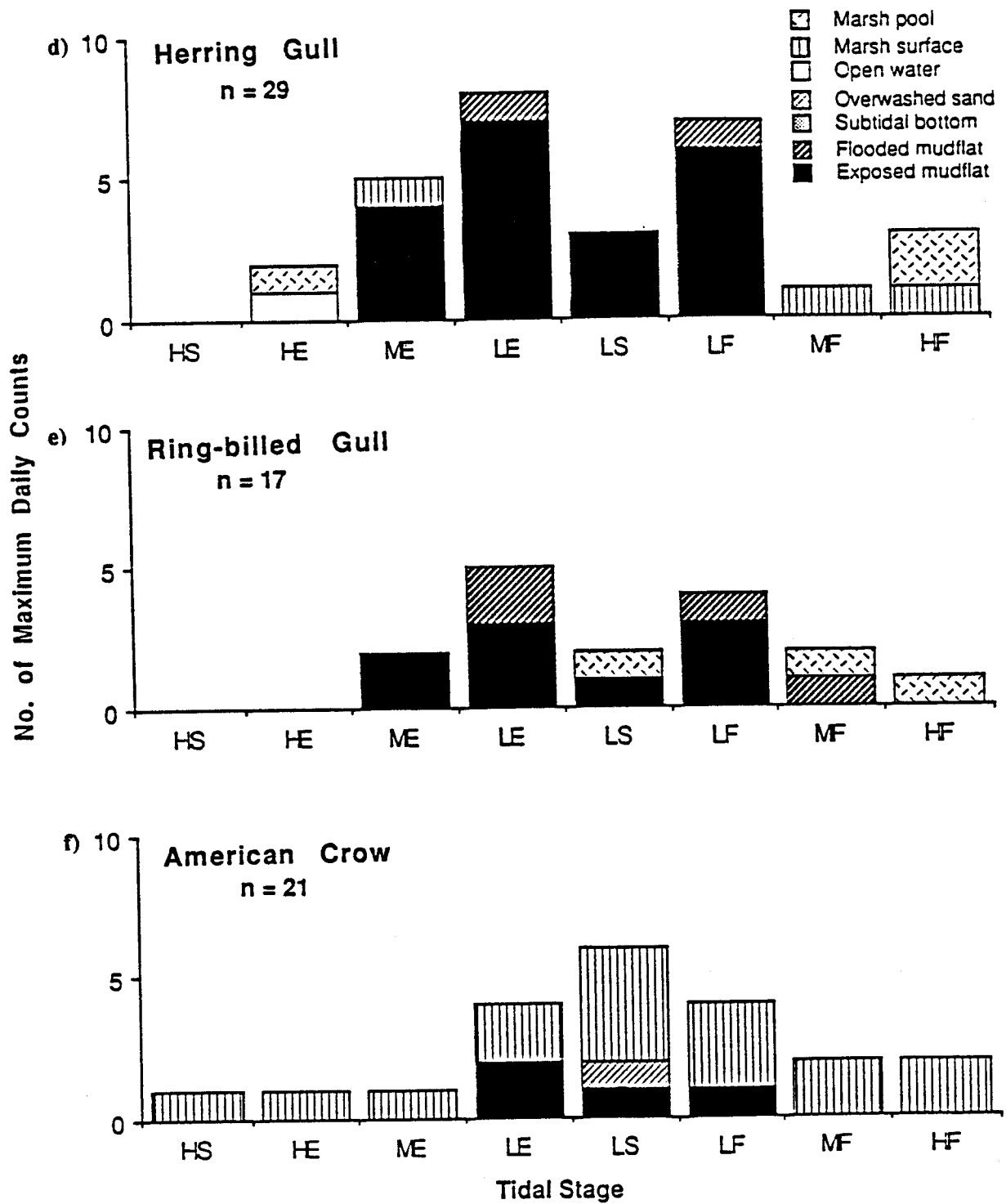


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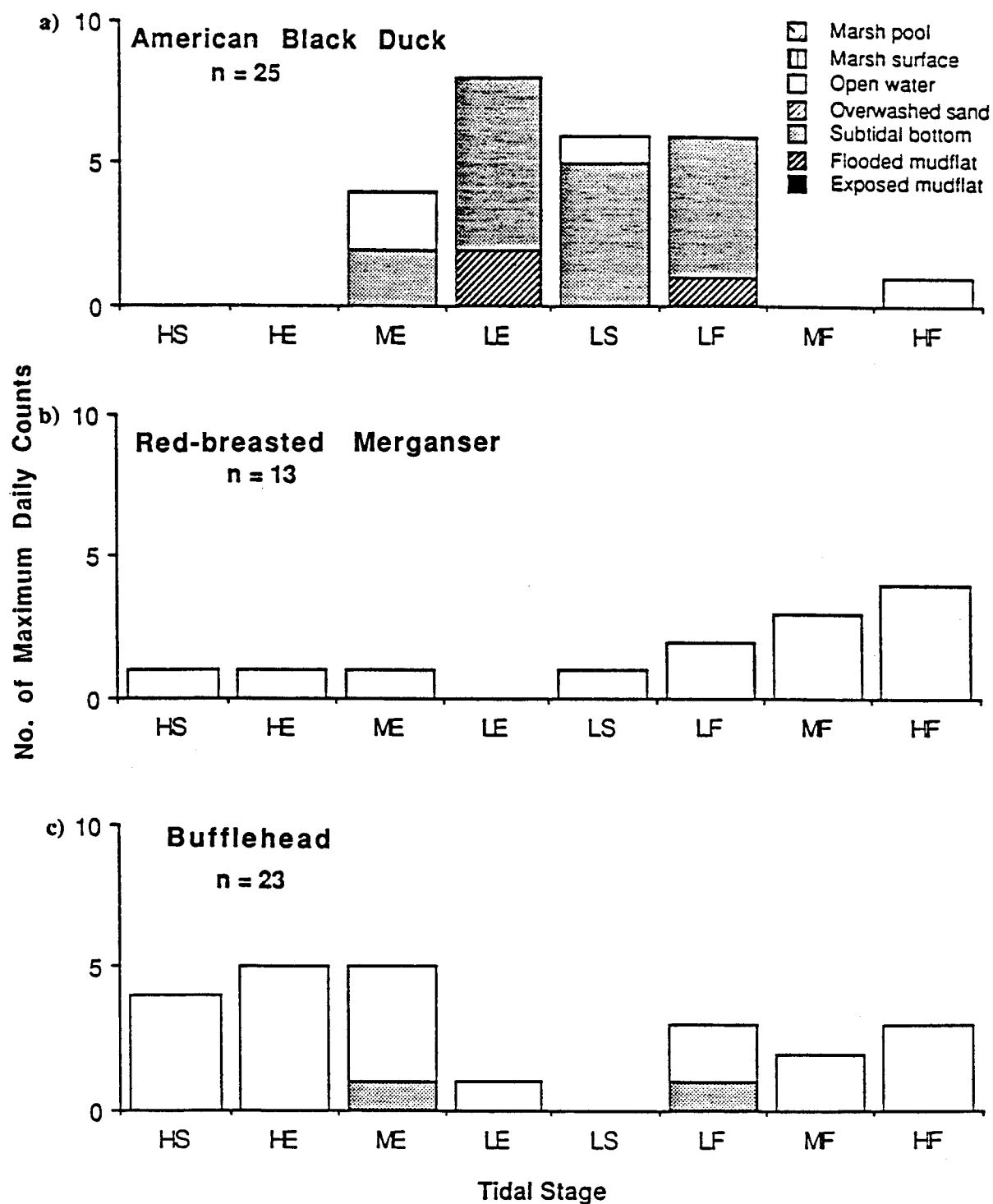


Figure 37. Effect of tidal stage on habitat use of Salt Pond Bay by select waterfowl species; a) American Black Duck, b) Red-breasted Merganser, c) Bufflehead (n = days observed).

Table 32. Habitat use by foraging birds at Nauset Bay. See Table 30 for species codes.

Number of Maximum counts by habitat							
Species	Days observed	Open water	Exposed intertidal	Flooded intertidal	Subtidal bottom	Marsh surface	Overwash
<u>Shorebirds</u>							
SESA	36	0	28	6	0	0	0
DUNL	20	0	10	8	2	0	0
SAND	3	0	1	0	0	0	2
SBDO	21	0	14	4	3	0	0
UNYE	35	0	8	12	15	0	0
SEPL	19	0	16	0	0	0	3
BBPL	35	0	27	1	0	0	7
RUTU	6	0	4	0	0	0	2
<u>Gulls & Terns</u>							
GBBG	16	0	9	3	0	0	4
HERG	42	10	12	15	4	0	1
RBGU	50	13	12	15	9	0	1
LAGU	11	3	1	3	2	0	2
COTE	14	14	0	0	0	0	0
LETE	6	6	0	0	0	0	0
<u>Hérons</u>							
GTBH	12	0	3	4	2	3	0
SNEG	22	1	4	6	11	0	0
<u>Waterfowl</u>							
ABDU	24	3	3	5	13	0	0
RBME	17	17	0	0	0	0	0
BUFF	18	18	0	0	0	0	0
CAGO	6	1	2	1	0	2	0
<u>Other species</u>							
ACRO	28	0	27	0	0	1	0
DCCO	6	6	0	0	0	0	0

Table 33. Habitat use by foraging birds at Skiff Hill Marsh. See Table 30 for species codes.

Number of maximum counts by habitat								
Species	Days observed	Open water	Exposed intertidal	Flooded intertidal	Subtidal bottom	Marsh surface	Marsh pool	Overwash sand
<u>Shorebirds</u>								
SESA	6	0	4	2	0	0	0	0
DUNL	4	0	1	3	0	0	0	0
SEDO	4	0	1	0	3	0	0	0
UNYE	10	0	3	4	3	0	0	0
SEPL	3	0	3	0	0	0	0	0
BBFL	4	0	3	1	0	0	0	0
<u>Gulls & Terns</u>								
GBBG	9	0	5	0	0	4	0	0
HERG	29	1	20	2	0	3	3	0
RBGU	17	0	9	4	0	0	3	1
LAGU	3	0	2	0	0	1	0	0
COTE	1	0	0	1	0	0	0	0
LETE	1	0	1	0	0	0	0	0
<u>Hérons</u>								
GTBH	19	0	1	1	0	10	7	0
SNEG	8	0	0	2	1	2	3	0
<u>Waterfowl</u>								
ABDU	27	3	1	1	5	8	9	0
REME	11	2	0	0	0	1	8	0
BUFF	6	2	0	0	0	0	4	0
CAGO	3	1	2	0	0	0	0	0
<u>Other species</u>								
AMCR	21	0	4	0	0	16	0	1
DCCO	3	3	0	0	0	0	0	0

Table 34. Habitat use by foraging waterfowl at Salt Pond Bay. See Table 30 for species codes.

Species	Days observed	Number of maximum counts			
		Open water	Exposed intertidal	Flooded intertidal	Subtidal bottom
ABDU	25	3	0	4	18
RBME	13	13	0	0	0
BUFF	23	21	0	0	2
BWTE	1	0	0	0	0
AGWT	1	0	0	0	1
CAGO	4	1	3	0	0
ATBR	2	0	1	0	1
MUSW	2	0	0	0	2
DCCO	1	1	0	0	0

Table 35. Relative importance of the various habitat types to bird utilization at three study sites.

Habitat	Number of maximum counts (% of total)		
	Nauset Bay	Salt Pond Bay	Skiff Hill Marsh
Open water	97 (20.0)	40 (50.0)	16 (7.8)
Intertidal mudflat (exposed)	194 (40.1)	5 (5.0)	61 (29.8)
Intertidal mudflat (flooded)	90 (18.6)	5 (6.2)	23 (11.2)
Subtidal bottom	63 (13.0)	31 (38.8)	12 (5.8)
Marsh surface	10 (2.1)	-	51 (24.9)
Marsh pool	-	-	38 (18.5)
Overwashed sand	30 (6.2)	0 (0.0)	4 (2.0)

Peak daily counts of American Black Ducks were most common at low tide in subtidal bottom habitat at Salt Pond Bay, i.e., 72% of total maxima (Fig. 37a). At Skiff Hill marsh, daily peaks probably including some of the same individuals were commonly recorded for the marsh surface at high tide, although marsh pools were used to some extent at low water (Fig. 36a). Marsh pools were also important habitat for fishing Red-breasted Mergansers (Fig. 36b) from low flood to high ebb tides, but evidently not for Buffleheads.

TEMPORAL ESTIMATES OF SHOREBIRD AND WATERFOWL USAGE

Very rough approximations of total foraging usage of Nauset by most common avian species are listed in Table 36 (shorebirds and American Black Ducks of Nauset Bay) and Table 37 (American Black Ducks of Salt Pond Bay and Skiff Hill marsh). Total annual bird-hours are the multiplication product of the seasonal period of use, the hours per day in which appropriate tidal habitat is accessible, and the average daily peak count for each species. It is assumed that the daily maximum count for a species represents a fairly constant density throughout the tidal period of active feeding; data are not sufficient to verify this for all species. Also assumed is only one suitable tidal period during daylight hours per day of use; some species, especially nocturnal feeders, could have foraged during two appropriate tidal stages in a 24 hour period. Another consideration is the expectedly high sampling error inherent in the small number of (hourly) observations of highly mobile populations. The resulting bird-use determinations, therefore, are included here for comparative value and should be considered only order-of-magnitude estimates. Note that Ring-billed Gulls were omitted from the analysis entirely because of high month to month variation in peak counts.

The estimate of American Black Duck usage (Table 37) is partitioned into three habitats corresponding with the discrete daily activity patterns detailed by Grandy (1972) and corroborated during this study. Actual feeding was observed only on the marsh surface and on subtidal bottom. At mid-tides American Black Ducks rested on the marsh and/or water surface. Nocturnal feeding in this species (Grandy 1972) probably makes these calculations of foraging utilization gross underestimates.

DENSITIES OF BENTHIC INVERTEBRATE PREY

Intertidal and subtidal benthic invertebrates are prominent foods in the diets of all the shorebirds that forage in Nauset Marsh. Although macrobenthos were sampled by suction dredge in typical Nauset habitats outside the primary Nauset Bay bird study sites, some level of site-specific invertebrate sampling at Nauset Bay seemed justified given the observed intensity of shorebird utilization. The specific intent was to document infaunal densities and species composition (to the family level) in specific habitats most utilized by feeding shorebirds. To improve retention and collection of small macroinvertebrates (especially spionid polychaetes) important in shorebird diets, sieving was through 0.6 mm mesh, as opposed to the 1.6 mm mesh used for suction dredge collections.

Data are summarized by most common major taxa in Tables 38 and 39 for 10 cm deep cores (sieved through 0.6 mm mesh) and 30 cm cores (sieved through 2.0 mm mesh), respectively. (Data Appendix C tabulates annelid data by species from 10 cm deep collections.) Most striking are the high density and low variability in total

Table 36. Estimates of shorebird and waterfowl foraging at Nauset Bay.

Species ¹	Est. dates of use	Days x hours/day ²		Average x max. count	Bird-hours = (x 10 ³)	N ³
BBPL	10 May - 30 May	20	3	91	5.5	5
	1 Aug - 1 Nov	90	3	73	19.7	20
SESA	10 May - 30 May	20	4	287	23.0	5
	10 Jun - 10 Nov	150	4	614	368.4	29
DUNL	15 Sep - 15 Dec	120	5	437	262.2	17
SBDO	15 Jul - 10 Sep	55	5	174	47.8	14
UNYE	15 Apr - 30 May	45	4	12	2.2	5
	10 Jul - 1 Nov	110	4	62	27.3	25
ABDU	15 Sep - 15 Dec	90	10	53	47.7	15
	15 Jan - 30 Mar	75	10	125	93.8	5

¹

See Table 30 for species codes.

²

Presumes one suitable tidal period, during daylight hours, per day of use.

³

Apr. 1986 through Apr. 1988 observations were pooled.

Table 37. Estimates of diurnal American Black Duck use of Salt Pond Bay and Skiff Hill Marsh, based on 25 observation days from 10 October 1986 to 1 April 1988.

Habitat (behavior)	Use days x hours/day x max. count		Average	Bird hours (x 10 ³)
Marsh surface (feeding)	180	2	17	6.1
Open water (resting)	180	5	112	100.8
Subtidal bottom (feeding)	180	5	95	85.5
Total annual use				192.4

Table 38. Benthic invertebrate densities in substrates heavily used by shorebirds at Nauset Bay, September 1987, 10-cm-deep cores. Sieve mesh was 0.6 mm. N = 6 per station.

STA-habitat	Animals/m ² ± SE				
	Oligochaetes	Large nereids ¹	Total polychaetes	<u>Gemma</u> clams	Amphipods
1-Intertidal mud	191 ± 108	318 ± 157	11,189 ± 554	13,334 ± 1165	127 ± 57
2-Subtidal mud	0	0	8,063 ± 1526	15,925 ± 1113	0
7-Intertidal mud	2973 ± 1171	42 ± 27	9,746 ± 1596	13,037 ± 1045	0
8-Intertidal sandy mud	1720 ± 985	0	15,861 ± 1740	3,440 ± 1213	0

¹Longer than 30 mm.

Table 39. Benthic invertebrate densities in substrates heavily used by shorebirds at Nauset Bay, September 1987; 30 cm deep cores. Sieve mesh was 2.0 mm.

STA-habitat	N	Animals/m ² ± SE		
		Large nereids ¹	Total polychaetes	<u>Gemma</u> clams
1-Intertidal mud	3	170 ± 42	4374 ± 626	10,149 ± 1823
2-Subtidal mud	3	0	4501 ± 1529	14,141 ± 2906
7-Intertidal mud	3	127 ± 74	2421 ± 368	8,493 ± 810
8-Intertidal sandy mud	3	0	3864 ± 595	2,548 ± 588
9-Subtidal mud	5	0	2038 ± 647	76 ± 76
10-Intertidal mud	6	127 ± 33	3546 ± 522	1,316 ± 338

¹Longer than 30 mm.

polychaetes and gem clams in intertidal mudflats. Amphipods were comparatively rare. Large nereid polychaetes (length > 30 mm) were not collected in subtidal areas.

The uniformity of invertebrate densities across intertidal mudflats seems to explain the wide and apparently uniform dispersion of shorebird feeding flocks. Even the large nereids seem to be fairly evenly distributed over three intertidal stations sampled by deep (30 cm) cores in Nauset Bay, in part explaining the tendency of foraging Ring-billed Gulls to disperse widely across intertidal flats during the flood tide.

Food habits were not directly determined. The likelihood of sampled benthic species occurring in specific shorebird diets (Table 40) is based upon published sources and causal observations made during daily counts. Despite their relative abundance, gem clams are probably of little nutritive value to scolopacids, who may ingest the small clams incidentally and excrete their unopened valves intact (Schneider 1978).

CONCLUSIONS

The intertidal habitats of Nauset Marsh represent one of several rich and consistent sources of energy along the flight path of a large and diverse contingent of shorebirds during their migrations between Arctic breeding grounds and southern U.S. and South American wintering areas. For this reason, shorebird feeding at Nauset may be of hemisphere-wide importance to populations of Semipalmated Sandpipers, Short-billed Dowitchers, Black-bellied Plovers, Dunlin, and perhaps several other less common species. The importance of physically preserving these habitats and protecting these transient populations from anthropic disturbances should be placed in this context. The Seashore's enabling legislation and other federal and state laws at least ensures protection of coastal wetlands from physical destruction; however, the results of developments beyond Park boundaries (e.g., offshore petrochemical pollution or ground water contamination from adjacent residential and commercial activities) may degrade Nauset habitats in ways that passive protections can not avert.

Table 40. Potential infaunal prey of the five most abundant shorebirds of Nauset Bay. The table lists likely prey from those taxa found to be abundant at Nauset and for which species-specific shorebird predation is confirmed in lit. or by personal observations.

Invertebrate taxa	Black-bellied Plover	Semipalmated Sandpiper	Dunlin	Short-billed Dowitcher	Yellowlegs
<u>Gemma gemma</u>	x ^{1,5}		x ⁵	x ⁵	
Polychaeta	x ^{1,2,5}	x ^{1,2,3,4}	x ⁵	x ^{1,2,5}	x ²
Nereidae	x ^{1,2,5}	x ^{2,4}		x ^{1,2,5}	x ²
Large nereids	x ^{1,2,5}	x ²		x ^{1,2,5}	x ²
Maldanidae				x ¹	
Spionidae		x ^{1,3}			
Amphipoda		x ^{1,3}		x ¹	

¹Schneider and Harrington 1981.

²pers. observ., this study.

³B.A. Harrington, pers. comm.

⁴Schneider and Harrington 1979.

⁵Recher 1966.

RELATIONSHIPS BETWEEN WATER QUALITY AND HABITATS

INTRODUCTION

Numerous investigators have estimated the net exchange of nutrients, and other constituents from entire salt marsh systems (see review by Nixon 1980). Essentially, water quality concentrations and water volume estimates have been taken from the mouth of salt marsh systems. However, little is known about the relative contribution of individual habitats to total system nutrient dynamics. The few investigators studying nutrient interactions between habitats (e.g., mudflat, S. alterniflora marsh) have reported that the spatial arrangement and biogeochemical function of these habitats are critical to our interpretation and understanding of total system nutrient dynamics (Welsh 1980; Wolaver et al. 1980).

Nauset Marsh, with a diversity of habitats, provides an ideal site to study water quality habitat relationships. Key questions to be addressed in this first objective of the water quality study were: a) do water column nutrient concentrations vary with respect to different habitats?, and b) does the direction and magnitude of exchange vary within different habitats?

The second objective of this aspect of the Nauset Marsh study was to provide a water quality baseline throughout the system. These baseline data will provide the foundation for evaluating future changes.

METHODS

FIELD PROCEDURES

Six sample stations were established throughout the system, each dominated by one or a combination of habitats (Fig. 38, Table 41). Sampling was not conducted in Town Cove as Teal (1983) recently characterized the nutrient dynamics of this major portion of the system. Two seasonal studies were conducted. The summer study was on August 25 and 27, 1987. Two summer dates were sampled to document day-to-day variability. A winter study was conducted on February 28, 1988. The August and February study dates corresponded to the time of peak spring tides. Aubrey and Speer (1985) suggest that mass flux studies should be performed over peak spring or peak neap tides in order to minimize the potential for large net water flows in a landward or seaward direction, and thus introduce bias to exchange determinations.

In August, water samples were collected from each sample station over complete tidal cycles on the two dates. Because of logistical constraints in February, only 4 stations (1, 2, 4, 6) were sampled. Water samples were collected at hourly intervals with submersible pumps at Stations 1 - 5 and with a water sampler at Station 6. Sampling began at approximately 0600 hours and continued until the starting tide height was again reached (approximately a 13 hr period). In the August studies, collections were from mid-depth, except at 4 hour intervals when collections were from three depths (0.25 m below surface, mid-depth, 0.25 m above bottom) to determine if the water column was well-mixed or stratified. Water depth at the Nauset Bay station (6) was shallow (range 20 - 100 cm), and thus only mid-depth was sampled. In February, mid-depth collections were made at all stations

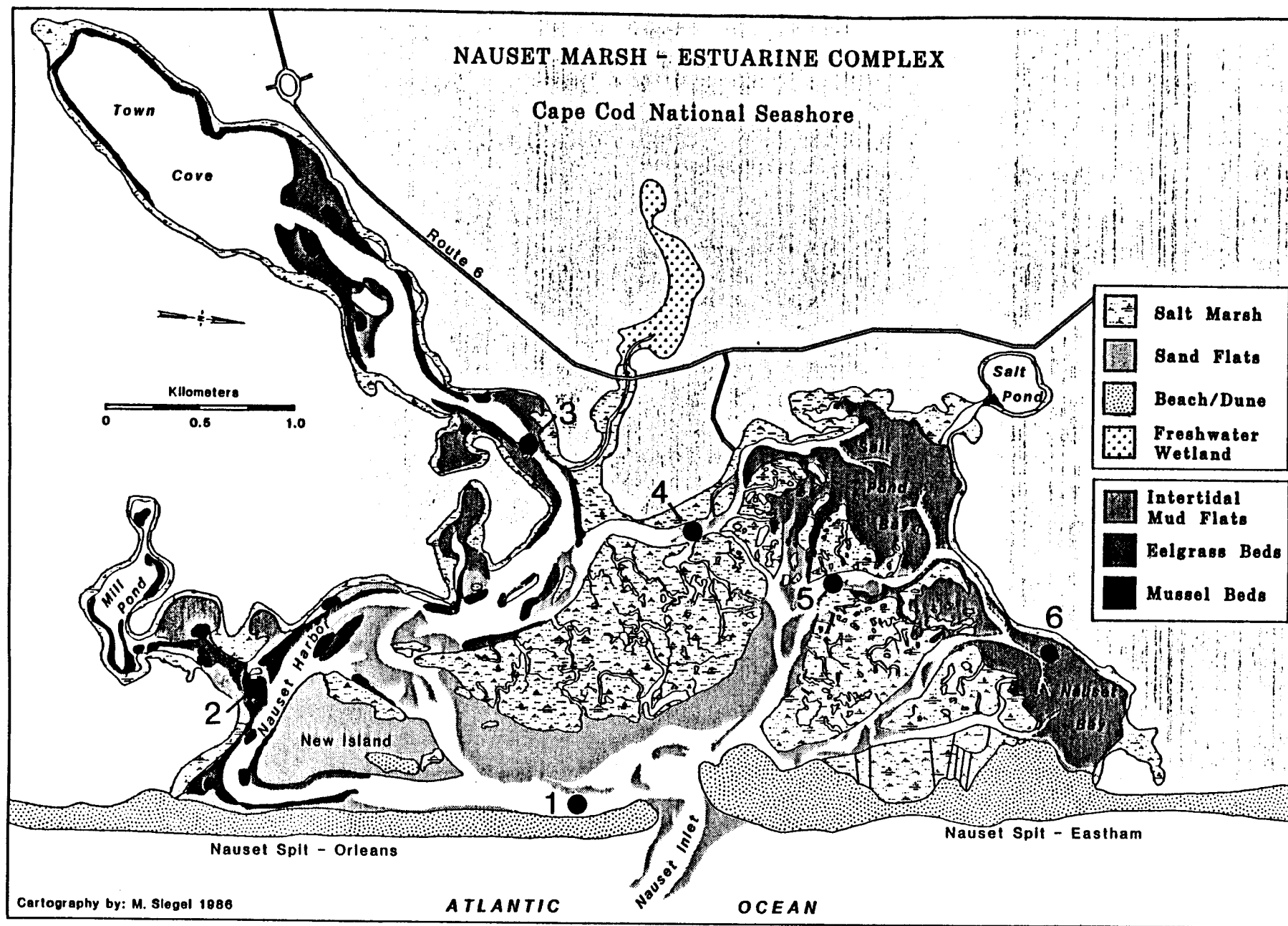


Figure 38. Habitat map with locations of six water quality sampling stations indicated.

Table 41. Habitat description of the six stations sampled for the water quality study.

Station	Dominant Habitats
1. Inlet	Oceanic, Intertidal Sand
2. Nauset Harbor	Eelgrass, Intertidal Mudflat
3. Mouth of Town Cove	Eelgrass, Intertidal Mudflat, Tidal Kettle Pond
4. Hemenway Channel	Salt Marsh, Intertidal Mudflat
5. North Channel	Salt Marsh, Intertidal Mudflat
6. Nauset Bay	Intertidal Mudflat

because analysis of the summer data revealed well-mixed conditions. Data for each August study were analyzed separately and ANOVA ($p < 0.05$, $n = 23 - 41$) revealed no significant differences among surface, middle and bottom for particulate (i.e., total suspended seston, organic suspended seston, inorganic suspended seston) and dissolved (i.e., dissolved organic carbon) parameters. Therefore, the data presented in this section of the Final Report and associated Appendices are from mid-depth collections.

At hourly intervals, water was collected for the following analyses: total suspended seston, organic suspended seston, inorganic suspended seston, nitrate-nitrite, ammonia, orthophosphate, total dissolved nitrogen, total dissolved phosphorus and total dissolved organic carbon. Dissolved oxygen samples were collected at bihourly intervals (every other hour). Salinity (refractometer) and temperature (stick thermometer) were monitored hourly. Tide height was also recorded hourly to assist with application of the water quality data to the Nauset numerical model.

Water samples for the dissolved parameters were filtered in the field through pre-muffled 2.4 cm diameter Whatman GF/C filters. In the field, ammonia water samples were fixed with 2 ml of phenol solution per 50 ml of sample (Degobbis 1973). All water samples for dissolved parameters were frozen within 1 - 3 hours of collection.

LABORATORY PROCEDURES

Dissolved oxygen was determined by Winkler titration (Strickland and Parsons 1972). Upon return to the laboratory, 1-liter of water was filtered through pre-tared 4.25 cm diameter GF/C Whatman filters, and dried to a constant weight at 60°C for total suspended seston determination. The filters were then combusted at 550°C for 2.5 h and weighed for determination of inorganic and organic fractions.

Ammonia was determined by the Solorzano (1969) technique. Nitrate-nitrite, orthophosphate and total dissolved phosphorus were analyzed on an autoanalyzer according to methods described by the U.S. Environmental Protection Agency (1979). Total dissolved nitrogen was by the persulfate oxidation technique (D'Elia et al. 1977). Dissolved organic carbon determinations were by a UV-persulfate oxidation technique (Dohrmann DC-80 total carbon analyzer). For quality control, replicates were run on at least 10% of the samples. Coefficients of variation were as follows; nitrate-nitrite $\pm 20\%$, orthophosphate $\pm 12\%$, total dissolved phosphorus $\pm 15\%$, total dissolved nitrogen $\pm 3\%$, dissolved organic carbon $\pm 9\%$. For ammonia and dissolved oxygen, duplicates were run for each sample with the following coefficients of variation; $\pm 1\%$ and $\pm 4\%$, respectively.

RESULTS AND DISCUSSION

PHYSICAL CHARACTERISTICS

Attenuation of tidal range from Station 1 near the Inlet to Nauset Bay (Station 6) was clearly apparent for the three tidal cycles sampled (Table 42). Aubrey and Speer (1985) attribute this attenuation to frictional characteristics of the system. Salinity variability over the sampled tidal cycles was minimal, indicating a strong oceanic influence with little freshwater input.

With respect to dissolved oxygen, there was a consistent trend of higher concentrations in winter, primarily due to greater solubility at low temperatures and wind-wave induced mixing effects (Table 42). During the summer studies, maximum dissolved oxygen concentrations generally occurred on flood tides and were fairly consistent at all stations. However, at Stations 5 and 6 (marsh and mudflat dominated) during the August 25 study, and at Stations 3 - 6 on August 27, there was a pronounced decrease in dissolved oxygen concentration. These depressed levels were sampled in the early morning and near low water, a period of known diurnal oxygen stress in salt marsh systems (Nixon and Oviatt 1972; Johnson and Welsh 1985). On August 24, 1987 we observed some dead decapod crustaceans along the shore of Salt Pond which was possibly the result of oxygen stress. In the Town Cove tidal kettle pond, residence time of bottom waters in summer could be one-week during which time anoxic conditions could develop (Teal 1983).

Data Appendix D-1 contains the hourly measurements of relative tide height, tide direction, salinity, temperature and dissolved oxygen.

SUSPENDED SESTON CONCENTRATIONS

During the August sampling period there was an increase in total and inorganic suspended seston concentration from the inlet to the more typical estuarine habitat-dominated Nauset Bay station for both mean ebb and mean flood tide data (Figs. 39, 40; hourly measurements are in Data Appendix D-2). This trend also existed in February, but was not as dramatic. These results are consistent with findings of Aubrey and Speer (1985), stating that the flood asymmetry of the Nauset system should result in a net up-estuary transport of suspended sediment. Shallowness of the upper reaches of the system (i.e., Nauset Bay and observed shoaling of the Town Cove entrance channel) confirm the infilling of the estuary. Higher suspended seston concentrations within marsh-mudflat dominated habitats may also be a reflection of bioturbation (Frey and Basan 1978). No habitat trends for organic suspended seston were noted during either season (Fig. 41).

NITROGEN, PHOSPHORUS AND CARBON CONCENTRATIONS

The dominant form of dissolved inorganic nitrogen in Nauset Marsh during summer and to a lesser degree in winter was ammonia. This is consistent with results from Town Cove (Teal 1983), as well as from studies of other New England salt marsh systems (Valiela et al. 1978; Welsh 1980; Daley and Mathieson 1981). With respect to habitat relationships (Fig. 42; hourly measurements in Data Appendix D-3), ebb tide ammonia concentrations in August were consistently highest in the mudflat-dominated habitat (Station 6, Nauset Bay) as opposed to other parts of the system. Further, the mean ebb concentration was significantly greater than the

Table 42. General characteristics during the two tidal cycles sampled in August, 1987 and one tidal cycle in February 1988.

STATION	TIDAL RANGE (m) ¹			SALINITY (ppt)						TEMP (°C)						DISSOLVED OXYGEN (mg/L)					
	8/25	8/27	2/28	8/25		8/27		2/28		8/25		8/27		2/28		8/25		8/27		2/28	
				max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min
1. Inlet	n.d. ²	1.38	1.35	32	31	32	31	30	27	19	17	18	17	2.0	1.5	9.3	6.9	8.4	6.7	10.9	8.8
2. Nauset Harbor	1.12	1.14	1.23	32	31	32	30	31	28	19	18	19	18	2.0	2.0	9.6	6.6	8.3	6.6	11.3	10.0
3. Mouth of Town Cove	1.00	1.10	-	32	29	31	28	-	-	22	19	20	18	-	-	9.1	6.6	7.5	4.0	-	-
4. Hemenway Channel	0.96	1.13	1.24	32	30	31	29	32	26	22	17	19	19	6.0	2.5	9.1	6.6	7.0	4.1	11.2	9.6
5. North Channel	0.91	1.04	-	34	30	32	30	-	-	20	16	17	17	-	-	8.6	5.3	8.2	5.6	-	-
6. Nauset Bay	0.85	0.95	1.06	30	27	29	27	29	25	23	16	18	18	6.3	3.4	8.5	3.5	8.1	4.8	11.5	10.7

¹Tidal range is based on hourly readings from temporary tide staffs. May not reflect the true range as measurements were only hourly.

²n.d. - no data.

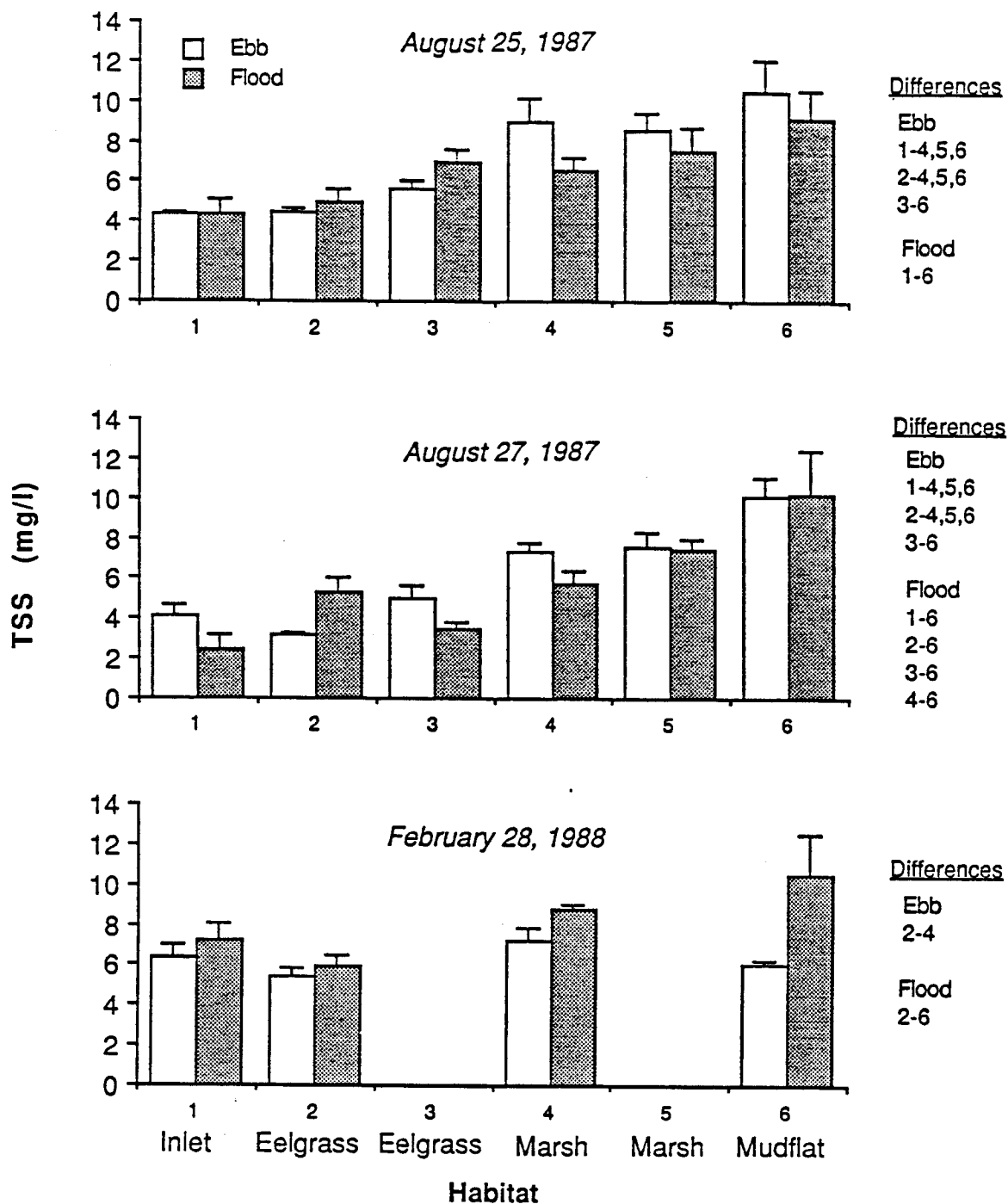


Figure 39. Mean ebb tide and mean flood tide concentrations (± 1 standard error) of total suspended seston (TSS) for the three study dates and six sample stations.

GENERALIZED CAPTION for Figures 39 - 43: ANOVAs were performed to determine significant differences ($p < 0.05$) in ebb means by station and flood means by station. Results of the Tukey-Kramer multiple comparison procedure are indicated (e.g., ebb mean from station 1 is different from ebb means of stations 4, 5 and 6). Asterisk (*) indicates that corresponding ebb and flood means from a station are significantly different (t-test, $p < 0.05$).

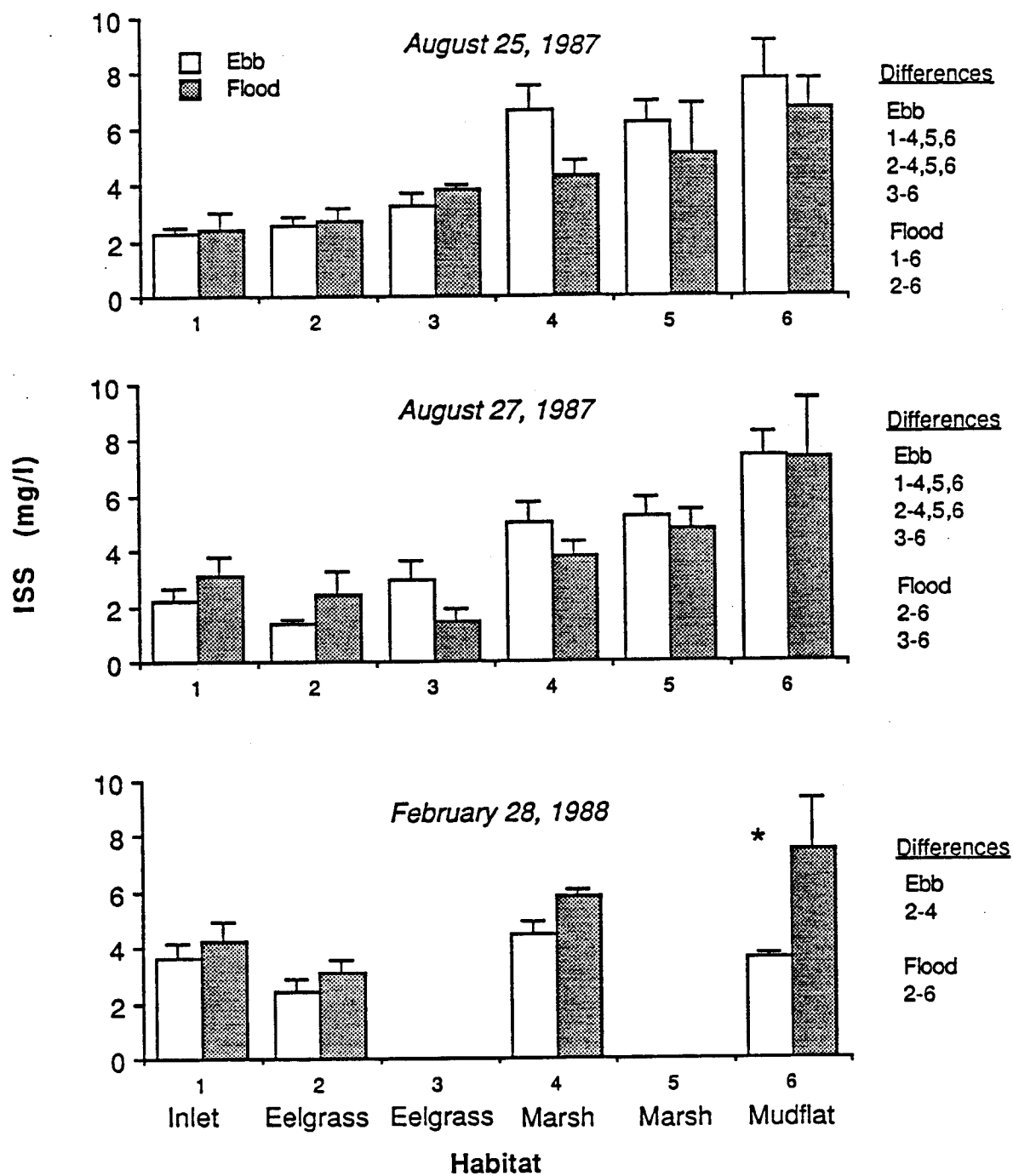


Figure 40. Mean ebb tide and mean flood tide concentrations (± 1 standard error) of inorganic suspended seston (ISS). See Fig. 39 for additional explanation.

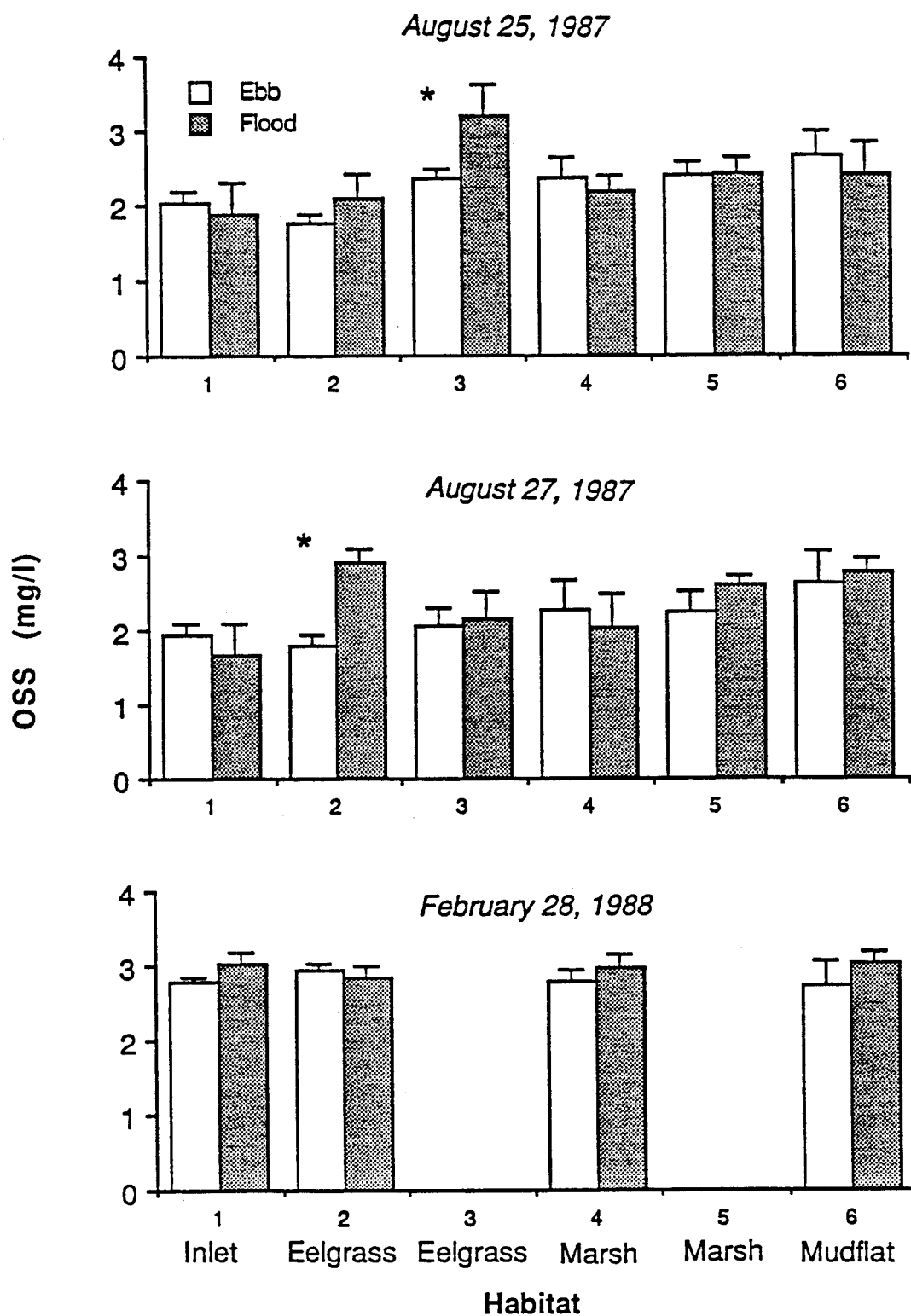


Figure 41. Mean ebb tide and mean flood tide concentrations (± 1 standard error) of organic suspended seston (OSS). See Fig. 39 for additional explanation.

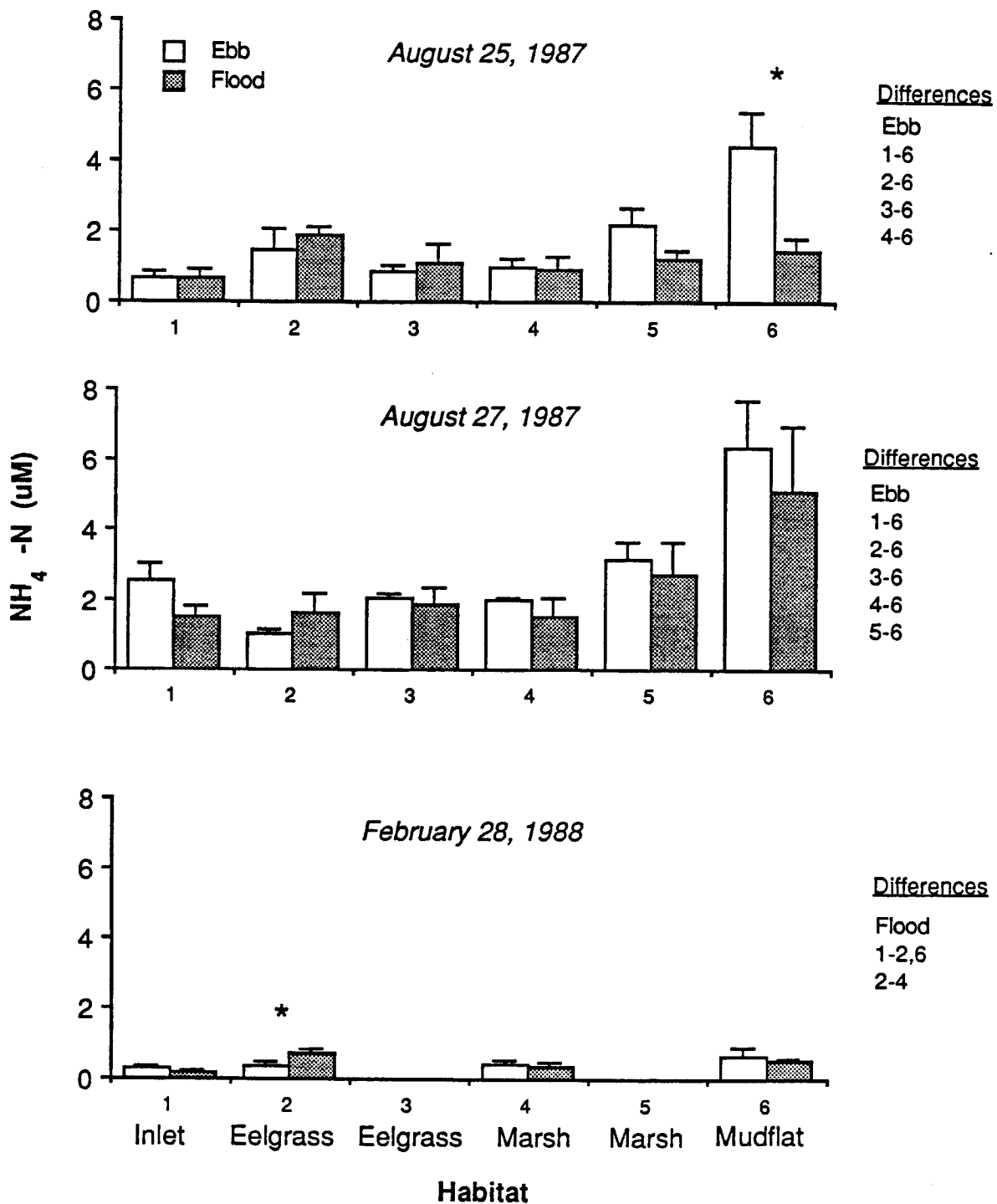


Figure 42. Mean ebb tide and mean flood tide concentrations (± 1 standard error) of ammonia ($\text{NH}_4\text{-N}$). See Fig. 39 for additional explanation.

flood at this station. This enrichment of mudflat ebb tide waters may be attributed to a combination of several factors including; diffusion or regeneration of ammonia from the sediments to the water column, runoff, seepage, and leaching from the marsh surface and vegetation, and remineralization from decomposition of organics (Valiela et al. 1978; Woodwell et al. 1979; Valiela 1983; Whiting et al. 1987).

Nitrate-nitrite concentration showed a similar trend with respect to habitat, at least for the August 27 study (Fig. 43). As suggested for the North Inlet (SC) system, nitrification of ammonia-rich waters could be a source of the elevated nitrate-nitrite concentrations (Whiting et al. 1987).

No consistent concentration-habitat relationships are noted for the other water quality constituents studied (Data Appendix D-4). However, based on the results from suspended seston and inorganic nitrogen species, it becomes evident that the habitats within a total salt marsh-estuarine system function differently with respect to biogeochemical cycling.

MATERIAL FLUXES

The net exchange and direction of flux for each measured constituent and for each sample station (i.e., habitat) were determined by multiplying each hourly material concentration by the corresponding instantaneous water volume estimate (as derived from the numerical model; see Research Appendix D). Integrating these instantaneous material fluxes over the complete tidal cycles yielded estimates for flood tide and ebb tide transport. It must be noted that the objective of these flux calculations was to evaluate relative differences among habitats with respect to the direction (flood vs. ebb) of net exchange. No attempts are made to project monthly or annual fluxes, as the literature confirms considerable short-term cycle-to-cycle variability in both volume and material concentration estimates (Kjerfve and Proehl 1979; Roman 1984; Wolaver et al. 1984; Whiting et al. 1985). Considerable variability in mean flood and mean ebb concentration of the water quality parameters measured was noted between the replicate sample dates in August (Table 43).

Corresponding to the three study dates, the numerical model predicted instantaneous volume flux at one-twelfth hour intervals for cross-sections at the six sample locations (Research Appendix D). The asymmetrical shape of the volume curve over a complete tidal cycle and the previously discussed time-asymmetry between flood and ebb duration are clearly evident for a representative cycle (Fig. 44). Integrating the area under these curves yields estimates of flood tide and ebb tide volume flux. The model predicts an excellent agreement, and thus, a net water balance (Table 44). It is noted that a significant percentage of the system's mean tidal prism (approximately $5600 \times 10^3 \text{ m}^3$) flows through the southern portion of the system (Stations 1, 2, 3).

Flood and ebb transports of the measured constituents by sample date and by sample cross-section or habitat are presented in Data Appendix D-5. Some of the more salient exchange-habitat relationships are discussed here.

As noted from Fig. 45, there was a net import (i.e., flood greater than ebb) of total suspended sediment at the southern stations (1 - 3) in August and at all the sampled stations in February. This is consistent with the previously mentioned

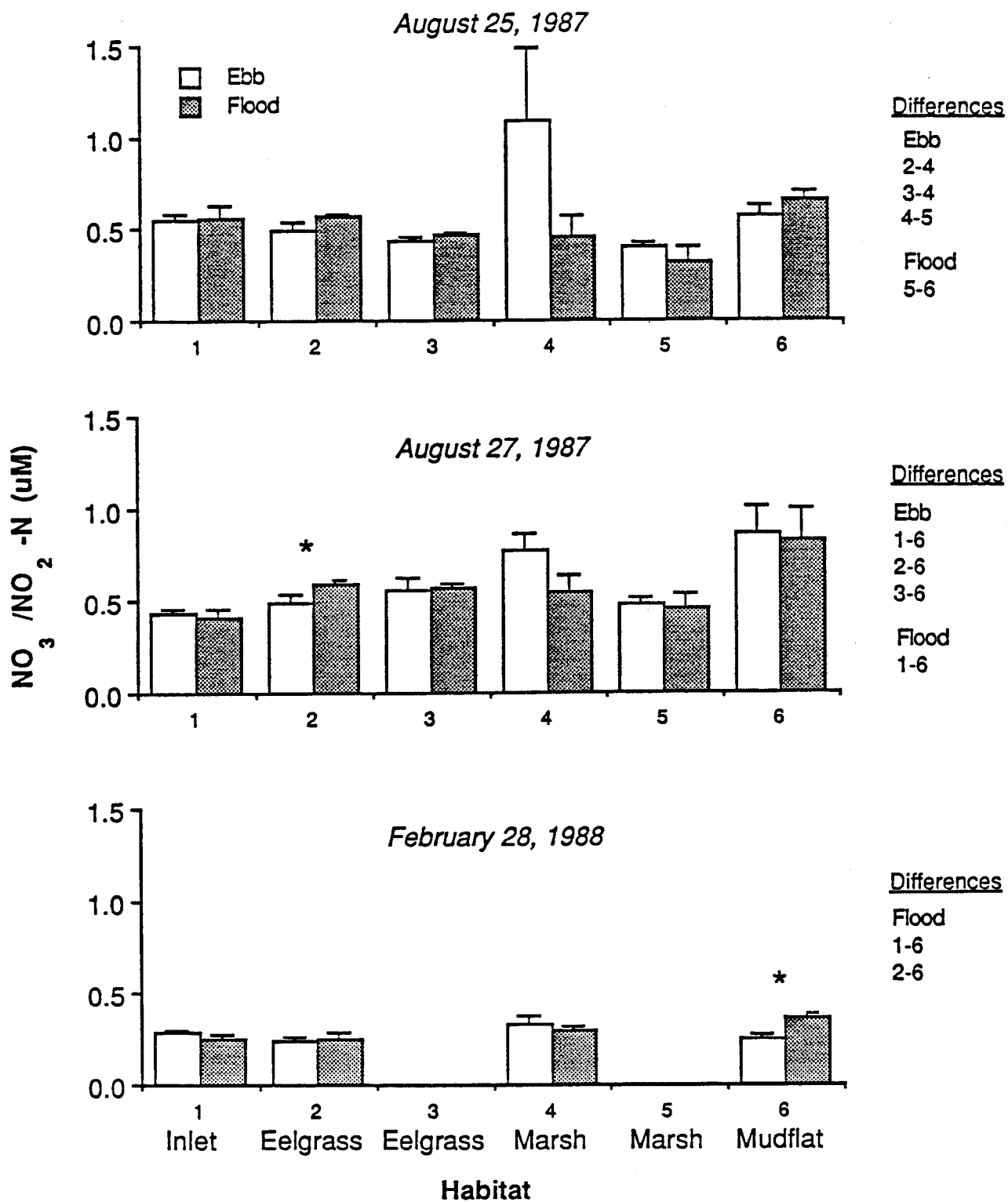


Figure 43. Mean ebb tide and mean flood tide concentrations (± 1 standard error) of nitrate-nitrite ($\text{NO}_3\text{-NO}_2$). See Fig. 39 for additional explanation.

Table 43. Results of ANOVA ($p < 0.05$) to evaluate variability in mean tide stage concentrations between the August 25 and 27 sampling dates. For each sample station and for each tidal stage (Flood, Ebb) separate ANOVAs were performed to compare the two sample dates.

Station	Water Quality Parameter															
	TSS		ISS		OSS		NH ₄ -N		NO ₃ -N		TDN		DON		PO ₄ -P	
	E	F	E	F	E	F	E	F	E	F	E	F	E	F	E	F
1							*		*				*		*	*
2	*	¹		*							*					*
3		*		*			*		*		*		*	*		*
4							*				*		*			
5											*				*	*
6													*			

¹Example: Asterisk indicates that a comparison of the August 25 and 27 mean ebb tide concentrations of total suspended seston at Station 2 revealed a significant difference.

August 27, 1987

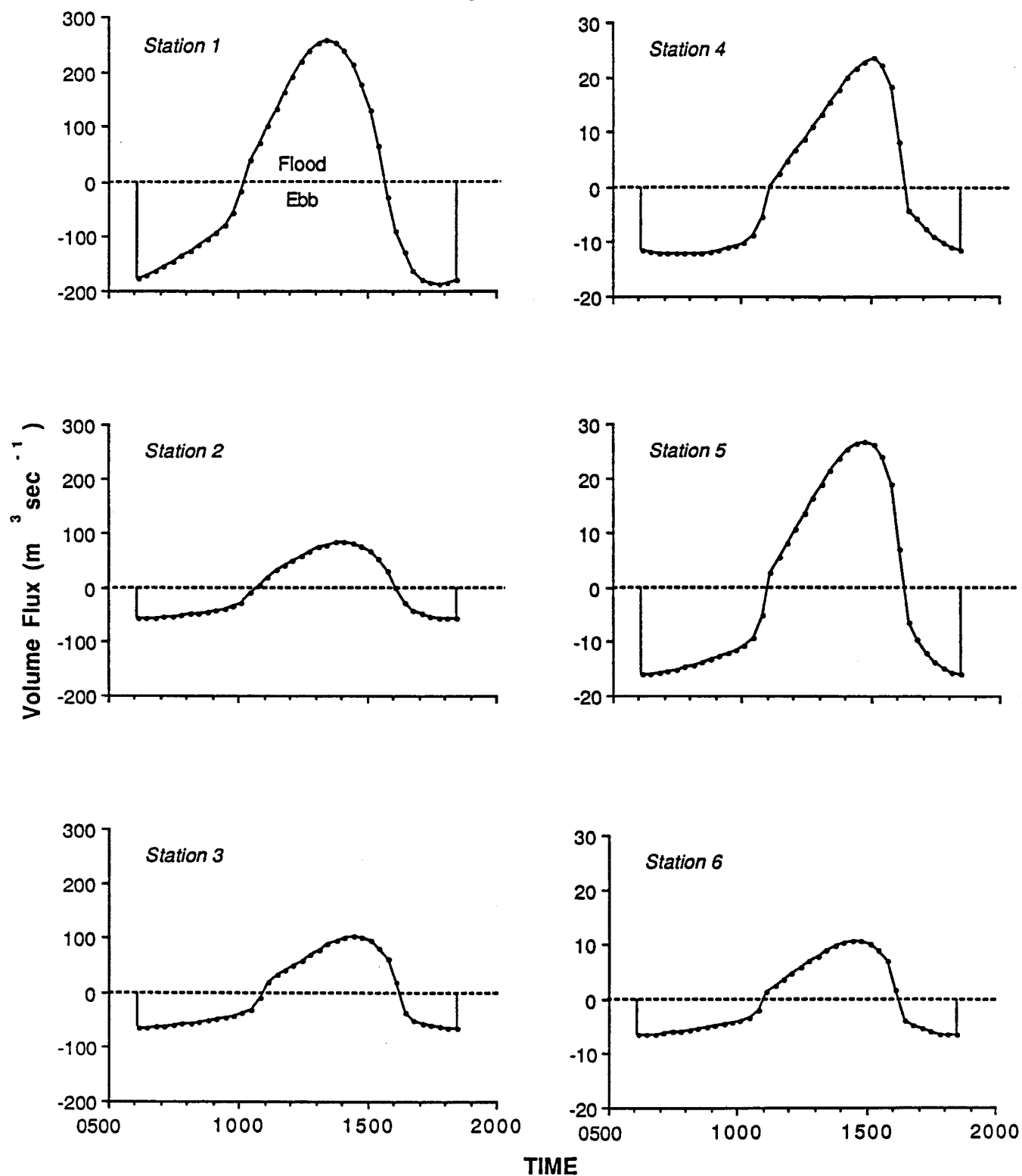


Figure 44. Instantaneous volume flux at each station on the August 27, 1987 sample date. Data are predicted values from the Nauset numerical model (Research Appendix D). Note change in scale from stations 1 - 3 to 4 - 6.

Table 44. Flood and ebb tide volume flux for the three study dates. Estimates are predicted from the Nauset numerical model (Research Appendix D).

STATION	TIDE STAGE	Volume ($m^3 \times 10^3$)		
		8/25/87	8/27/87	2/28/88
1	F	3108	3238	3312
	E	3169	3258	3414
2	F	1033	1065	1076
	E	1077	1115	1171
3	F	1246	1298	
	E	1257	1310	
4	F	246	257	261
	E	245	256	270
5	F	311	326	
	E	311	324	
6	F	125	131	134
	E	127	133	138

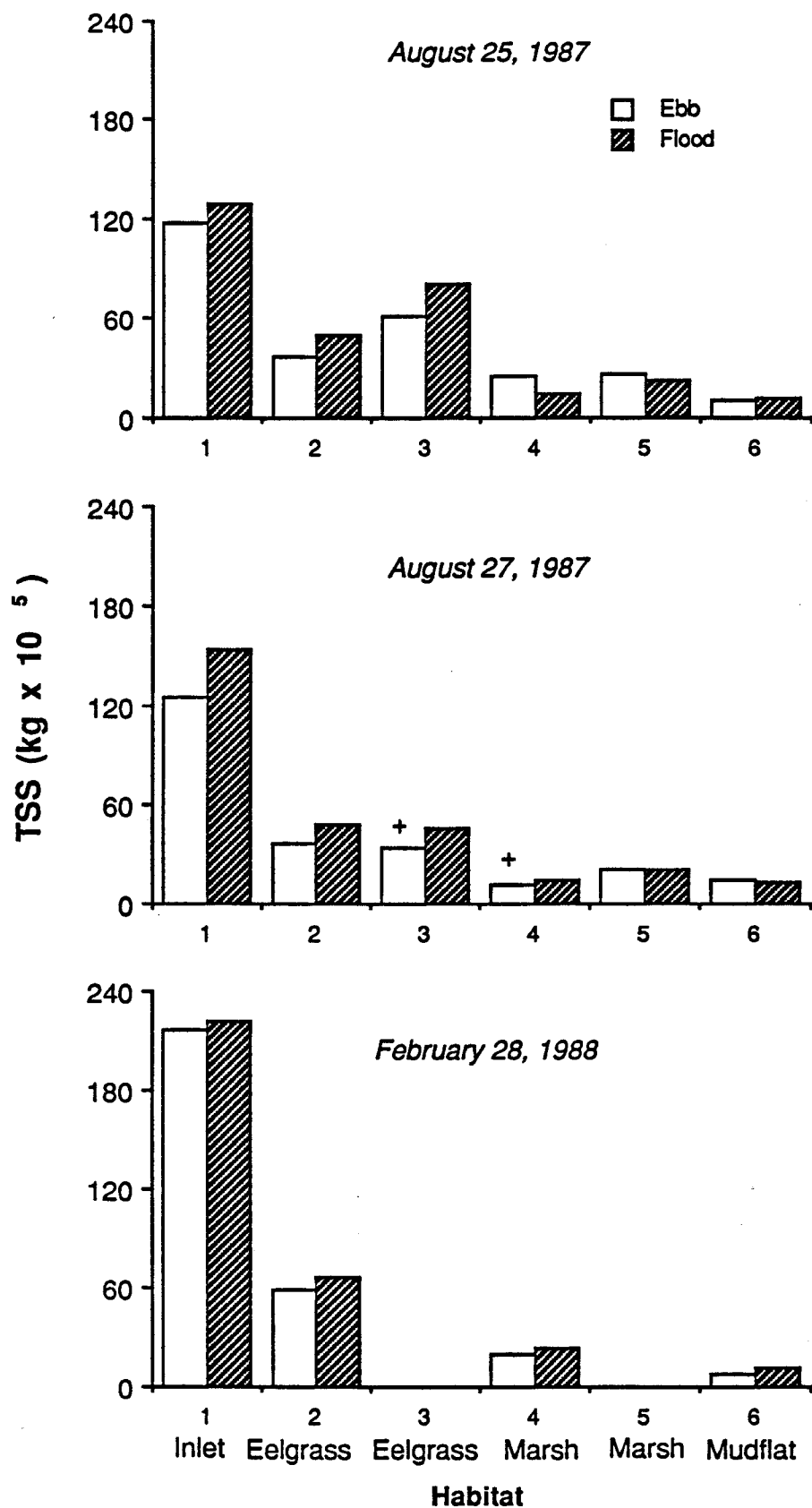


Figure 45. Total ebb tide and flood tide transport of total suspended seston. A plus (+) sign above a tide bar indicates that, due to missing data, transport mean is an underestimate.

trend toward infilling of the Nauset system (Aubrey and Speer 1985). The observed balance or occasional net export from the marsh and mudflat-dominated stations (4 - 6) in August could be related to bioturbation effects of short-term wind-wave resuspension. Although over the long-term, mudflats and salt marshes are considered to be depositional habitats, they often undergo significant periods of erosion (Anderson et al. 1981).

For ammonia flux, the habitat differences are interesting, yet not consistent between the two August study dates. On August 25, the southern stations (Inlet and eelgrass-dominated) showed a net import of ammonia, while the marsh and mudflat stations were net exporters (also Aug. 27, Fig. 46). Other marsh-dominated systems in New England (Valiela et al. 1978; Woodwell et al. 1979), and in the southeast (Whiting et al. 1987) report ammonia export in late summer. Ammonia import or conservation within the eelgrass-dominated portion of the system may indicate uptake of ammonia by eelgrass (Thursby and Harlin 1982) and phytoplankton. However, on August 27 this pattern was different, as the Inlet station showed a net export and the eelgrass stations a balance. Continuous monitoring must be considered to effectively account for day-to-day variability.

For nitrate-nitrite there was a slight trend toward import in August (both studies) at the southern stations and an export in the marsh-mudflat dominated portions of the system (Fig. 47). Again, for the marsh-dominated stations, this summer trend of nitrate-nitrite export is consistent with the literature (Valiela et al. 1978; Woodwell et al. 1979; Welsh 1980). In February there appeared to be a net balance, except at the Inlet station (export).

It is noted that both Nixon et al. (1976) and Welsh (1980), studying New England salt marsh-mudflat-embayment systems, found that dissolved inorganic nitrogen (ammonia and nitrate-nitrite) was conserved and/or tightly coupled within the mudflat-embayment habitat rather than being exported to overlying waters and adjacent habitats. This mechanism does not appear to function at Nauset Bay, a similar type of marsh-mudflat system, perhaps due to lower biomass of macro-algae. Welsh (1980) suggests that nutrient removal by dense mats of the macroalga (*Ulva lactuca*) may account for the conservation phenomenon in summer.

CONCLUSIONS

The water quality data presented in this section and Data Appendix D will provide an excellent baseline for system-wide, long-term monitoring efforts. Further, by employing a habitat approach we have demonstrated that habitats within salt marsh-estuarine systems function differently with respect to nutrient processing. A nutrient flux study conducted only at the mouth of a system with diverse habitats may yield misleading interpretations concerning the magnitude and direction of exchanges with coastal/nearshore waters. To evaluate the key biological and geochemical processes controlling salt marsh-estuarine nutrient dynamics, it is suggested that study designs include a habitat approach.

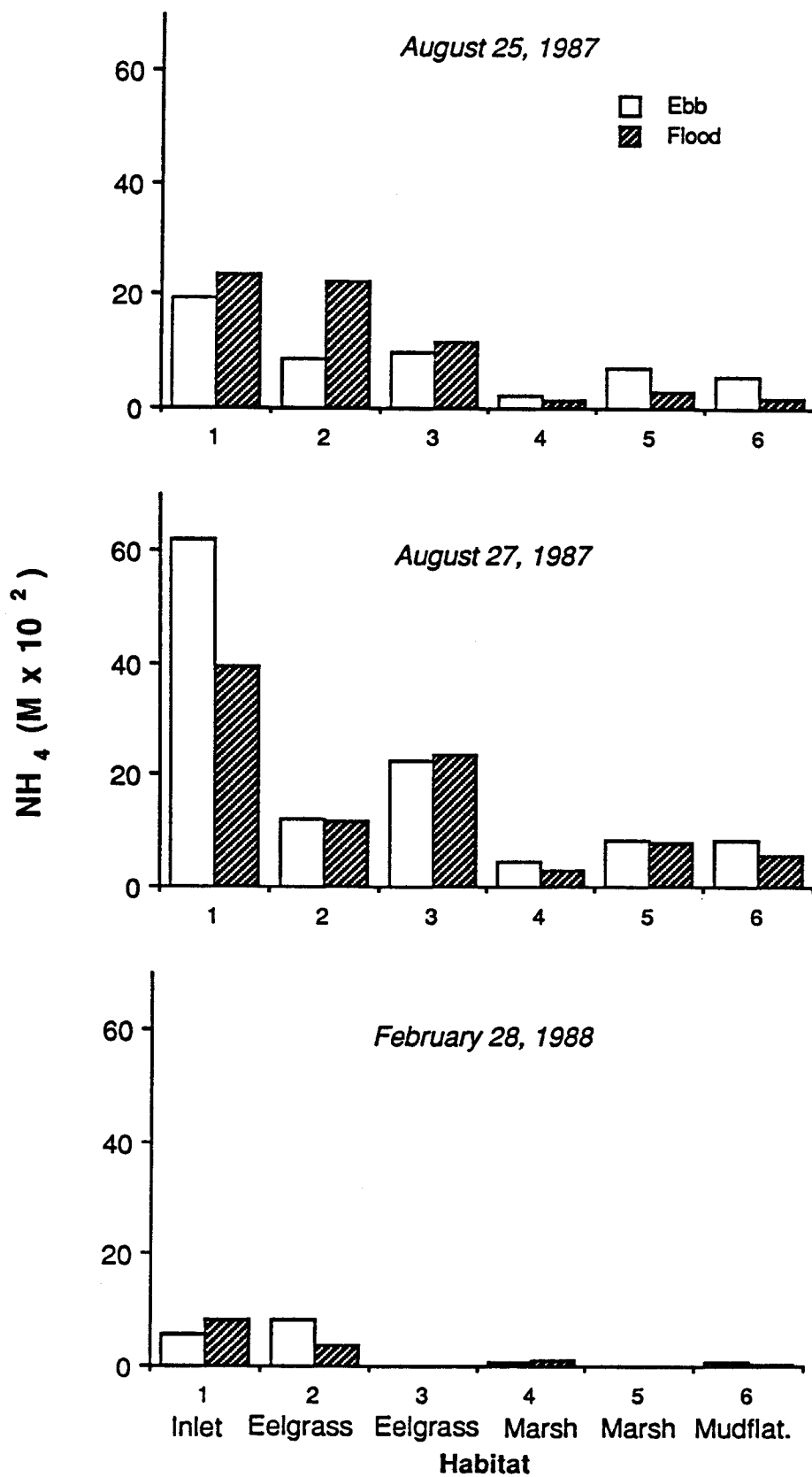


Figure 46. Total ebb tide and flood tide transport of ammonia.

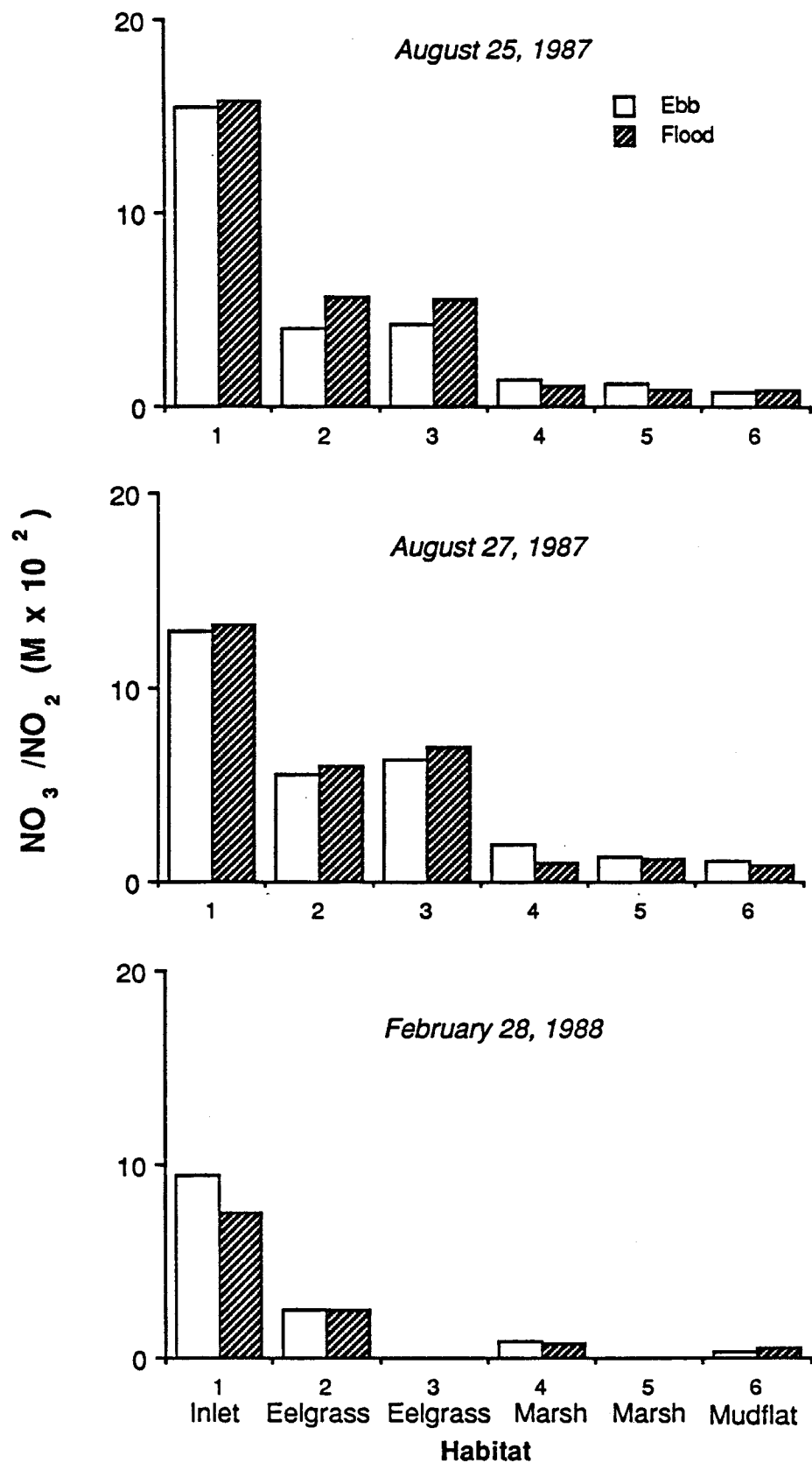


Figure 47. Total ebb tide and flood tide transport of nitrate-nitrite.

LONG-TERM ENVIRONMENTAL MONITORING PROGRAM

MONITORING OBJECTIVES

External development has been identified as a major problem or threat confronting Seashore Parks (Roman et al. 1987), as well as all Parks of the National Park Service system (Stottlemeyer 1987). Nauset Marsh is particularly vulnerable because the southern and western portions of the system are surrounded by residential development. In a study of nitrogen inputs, Teal (1983) estimated that 10 - 20% of total nitrogen loading into Town Cove could be derived from the Orleans town center. As development increases the cumulative effects of non-point source inputs of nitrogen, other nutrients and toxics (i.e., metals, oils) could become acute. Further, oil inputs from tanker accidents, recreational vessels and bilge discharges pose a threat, as the Nauset Marsh system has been designated as a highly vulnerable area (Cape Cod Planning and Economic Development Commission 1981).

A long-term monitoring program at Nauset Marsh must be implemented immediately so that changes to the system caused by human-induced factors or natural processes (e.g., inlet dynamics) can be detected and appropriate resource management decisions made. The results of our intensive 3 year study, presented in this Final Report, represent a quantitative baseline characterization -- first phase to long-term monitoring. This detailed data base, coupled with our interpretations of the functional ecology of major habitats, will provide the foundation for effective management and protection of Nauset's estuarine resources. Further, based on our detailed efforts, a comprehensive and systematic program of environmental monitoring can be designed.

The proposed Nauset Marsh monitoring program employs a simple and cost-effective approach, thereby enhancing the chances for a successful effort. For the program to be effective at detecting subtle changes in the environmental and ecological status of the system, data must be collected consistently, analyzed quantitatively, and most important, the program must continue for the long-term.

PROGRAM COMPONENTS

PHYSICAL PARAMETERS

Long-term water temperature and salinity measurements can provide an excellent baseline record. Changes in the oceanic influence on the estuary, groundwater seepage and surface runoff inputs, and inlet dynamics can be detected, at least in part, from these physical measurements. In addition knowledge of physical changes can help in interpreting the causes of long-term ecological change.

It is recommended that temperature and salinity be recorded at 7 - 10 day intervals at several locations throughout the system. To maintain consistency, measurements should be from the shore or a dock, taken at daylight hours and near high slack water. Temperature should be measured by a stick thermometer

and salinity by a refractometer or salinometer. If instrumentation for salinity, is not available, then just temperature should be measured. Date, time, tide stage (flood, ebb, slack), temperature ($^{\circ}\text{C}$) and salinity (ppt) should be recorded. A minimum of two locations is recommended; Nauset Bay (perhaps in front of NPS housing), and Town Cove (Town Dock at Goose Hummock).

WATER QUALITY

Human-induced nutrient enrichment represents a potential threat to Nauset Marsh, and thus, long-term water quality monitoring is a necessity. However, design of a water quality monitoring program that is effective and that fits within our goal of developing a simple and cost-effective program is difficult. Given the day-to-day and seasonal variability in nutrient concentrations and fluxes observed in this study, observed in Town Cove by Teal (1983), and in other marsh-estuarine systems (Wolaver et al. 1984; Kjerfve and McKeller 1980), and the site-to-site variability noted in Nauset Marsh, it is imperative that a water quality monitoring program consider both temporal and spatial variability. Ideally, sampling should account for tidal, daily, seasonal and habitat induced variability and include the entire suite of dissolved and particulate forms of nitrogen and phosphorus, as well as some toxic substances (i.e., metals, hydrocarbons). The water quality monitoring program recommended herein is only one part of a comprehensive environmental program, and thus, cannot employ the perfect design. However, it is expected that the program will provide an effective data set for detecting long-term trends in the water quality status of Nauset Marsh.

A minimum of two sites should be monitored. Town Cove (Goose Hummock dock) is representative of the developed portion of the system where future growth is occurring. Further, baseline water quality data exist (Teal 1983). Hemenway Landing (Eastham) is a sample site influenced by less developed land use and different habitats (marsh, mudflat, tidal channels). If time and cost availability allow, then Nauset Harbor (Town Landing at Snow Shore Rd.) and Nauset Bay should also be included to enhance coverage of the system.

Water collections should be made at the same time (e.g., 10:00 am) on consecutive days. Sampling for approximately 15 consecutive days would encompass a complete tidal cycle (e.g., if sampling started at high water, high water would again be sampled about 15 days later). This schedule includes both tidal and daily variability. Seasonal variability is accounted for by including numerous 15-day sampling periods over a year. A variation of this sampling design has been used at the North Inlet (SC) estuary (Wolaver et al. 1984).

It is recommended that a minimum of two 15-day studies be conducted per year (August, April) at the two sites. August represents the peak period of both human activity and estuarine biological productivity, while April is selected because it corresponds to the general period of peak precipitation and presumably non-point source inputs to the system. Obviously, additional study periods can be included to enhance seasonal accountability.

Water should be collected from mid-depth. Results from our August (1987) study suggest a relatively well-mixed water column. At Town Cove, collections should be made from the dock. A small boat should be used to provide access to the channel at Hemenway Landing, and the other optional sites. Simultaneous with

the collections, water temperature, salinity, tide height (from a permanently fixed tide staff), and tide direction should be recorded.

Water quality parameters to measure should include, at a minimum, nitrate-nitrite, ammonia, and ortho-phosphate. Further, chlorophyll *a* should be monitored as a gross indicator of eutrophication trends in the system. Standard laboratory methods should be employed (Parsons et al. 1984).

In terms of data analysis, it is recommended that for each 15-day sample period and for each water quality parameter, a mean flood tide, mean ebb tide, and combined mean concentration be calculated. As the long-term data set builds, ANOVAs, coupled with a multiple comparison procedure, can be used to evaluate year-to-year trends for each seasonal period sampled (i.e., August data should be analyzed separately from April data).

VEGETATION

The vegetation monitoring program includes three parts: 1) eelgrass wasting disease index, 2) eelgrass epiphyte biomass, and 3) remote sensing of *S. alterniflora* peak biomass.

Eelgrass Wasting Disease

In the 1930's, an eelgrass pathology, commonly known as "wasting disease", reached epidemic proportions and nearly eliminated eelgrass from the North Atlantic. While anecdotal accounts (pers. comm.) indicate that Nauset Marsh eelgrass meadows were devastated at that time, as demonstrated in this study, they have since made an excellent recovery. Recent studies of eelgrass populations in New England and elsewhere, however, are reporting symptoms similar to those produced by the 1930's wasting disease (Short et al. 1986, 1987, 1988) and there is growing concern that a second epidemic may be developing.

The present infection is caused by a pathogenic strain of *Labyrinthula* (a slime mold) which attacks eelgrass causing tissue necrosis and local population decline (Short et al. 1987). Along the east coast of the United States, infected populations have recently been discovered from Maine to North Carolina and the disease is considered responsible for the loss of eelgrass beds in three New England states. While no significant eelgrass decline in Nauset Marsh was documented during the course of this study, populations sampled in Town Cove, Nauset Harbor and Mill Pond demonstrated low to moderate levels of *Labyrinthula* infection. It has been suggested that the growth of epiphytic algae on eelgrass, a common phenomenon in some Nauset meadows, may provide more favorable conditions for the wasting disease organism (Frederick T. Short, University of New Hampshire, pers. comm.) and research is currently underway to test this hypothesis. Eutrophication of the ambient environment, one potential result of increased human impact on the Nauset system, can greatly enhance epiphyte production (see following section, "Eelgrass Epiphyte Biomass", for discussion) and may, in turn, increase the impact of *Labyrinthula*'s presence.

The loss of eelgrass in Nauset Marsh would have profound effects on the ecosystem. Documented consequences to estuarine environments due to the 1930's wasting disease epidemic include; 1) reduction in commercial fisheries (Thayer et

al. 1975), b) loss of migratory waterfowl (Addy and Aykward 1944), and 3) erosion of soft sediments near shore (Rasmussen 1973). As demonstrated in this Final Report, Nauset eelgrass is heavily utilized by a variety of faunal species with ecological (e.g., sticklebacks), recreational (e.g., Canada Goose), and economical (e.g., juvenile white hake) importance. Further, its high productivity significantly contributes to the detrital food web and its broad coverage within the system is important to the present stability of nearshore sediments. The future of eelgrass in Nauset Marsh is threatened not only by wasting disease alone, but also by the primary (physical disturbance and increased turbidity) and secondary (enhancement of epiphyte production) effects of increasing human impact, as well as by the predicted southerly shift in inlet location. Although there is no known prevention for wasting disease, the acceleration of its destructive potential by human influence may be ameliorated, and mitigation (i.e., eelgrass transplants) may be conducted following the decline of the disease. A critical component of sound resource management will be to identify the probable cause(s) of eelgrass loss should it occur. It is recommended, therefore, that regular sampling and assessment of the severity of wasting disease infection in Nauset Marsh eelgrass populations be included as part of the long-term monitoring program.

The recommended sampling sites are in Town Cove and Mill Pond where eelgrass meadows are easily accessible by wading from shore. During the growing season these meadows support light to moderate epiphyte loads and, as the surrounding areas are under active development, they are likely to reflect any human influence on the progress of the disease. Nauset Harbor (Town Landing at Snow Shore Rd.) should be considered as an optional sampling site because the epiphyte load of the meadows there is much reduced.

At each site an established meadow should be chosen to serve for the duration of the monitoring program. During the growing season, between May 15 and September 15, eelgrass samples should be collected and analyzed at two week intervals. For the remainder of the year, monthly collections are sufficient. By wading through the meadow, ten shoots should be randomly chosen, clipped at the sediment level and stored in a "ziplock" plastic bag containing as little water as possible. In the laboratory, infection of the leaves should be evaluated based on a "wasting disease index" (F. T. Short, pers. comm.).

Eelgrass Epiphyte Biomass

During the growing season, the accumulation of epiphytic algae on aboveground eelgrass is characteristic of some meadows in the Nauset Marsh system. However, eutrophication of the ambient environment due to human introduction of organic pollutants can stimulate excessive epiphyte production. Numerous seagrass studies have shown that under such conditions, leaf turnover and chemical inhibition are not sufficient to defend against the rapid accumulation of epiphytes and that, by attenuating light, among other effects, the epiphytic community can cause mortality of the hosts (van Montfrans et al. 1984-review; Short and Short 1984; Cambridge et al. 1986; Silberstein et al. 1986). Because of increasing human influence, Nauset eelgrass is particularly vulnerable to this kind of disturbance and its decline may have profound consequences to the secondary productivity and bathymetry of the system. As part of a long-term monitoring program, it is recommended that regular determination of eelgrass epiphyte biomass be conducted.

The suggested sampling sites are in Town Cove, Mill Pond and Nauset Harbor where eelgrass meadows are easily sampled by wading from shore. In the field, a plastic 5 gallon bucket with the bottom removed may be used as a quadrat. The bucket should be pushed into the sediment at a randomly chosen location within the meadow and all eelgrass within its circumference should be gently pulled from the substrate and placed in a plastic bag. Care should be taken that epiphytic material is not lost in the process and belowground material should be clipped off at the base of the sheath prior to bagging. It is recommended that a minimum of five quadrat samples be collected at each site. (Ideally, a preliminary study should be conducted to determine the minimum number of quadrats needed to obtain an acceptable level of variability.)

In the laboratory, eelgrass leaves and sheaths may be gently scraped of epiphyte material using the side of a glass microscope slide. Epiphyte material should be rinsed with tapwater through a fine-meshed sieve (e.g., 75 micron) and eelgrass should also be well-rinsed. All visible animals should be removed from the samples and epiphyte and eelgrass should then be dried at 60°C to a constant weight, and weighed on an analytical balance.

For each field site, these procedures should be conducted at least three times during the growing season: once in mid-May, once in mid-July and once in mid-September. These samples will provide mean epiphyte and eelgrass biomass estimates which may be examined separately for seasonal and year-to-year changes. For statistical analysis, because epiphyte biomass is largely dependant on the quantity of eelgrass substrate, data should be reduced by obtaining the ratio of epiphyte biomass/eelgrass biomass for each quadrat. This will also help to minimize the influence of meadow variability. These ratios may then be analyzed for significant difference between and among years by site and corresponding sampling times using ANOVA [E.g.; for Mill Pond, the data sets for May 1990, May 1991 and May 1992 (each containing five biomass ratios) are examined in a single ANOVA].

Spartina Remote Sensing

Year-to-year changes in S. alterniflora biomass occur in salt marshes and remote sensing techniques, both ground- and satellite-based, are useful tools to monitor these changes (Hardisky et al. 1984, 1986). As previously described in this Final Report, short form S. alterniflora biomass was estimated at Nauset Marsh using a hand-held radiometer. It is recommended that this ground-based technique be continued as a labor- and cost-effective means of monitoring long-term changes. In the future it may be appropriate to establish Nauset Marsh as a monitoring site using spectral information from a satellite platform. The LANDSAT Thematic Mapper (30 m resolution), utilizing the same spectral bands as the hand-held radiometer, is proving to be a successful tool for long-term biomass monitoring in wetlands (Gross et al. 1987).

The objective of a S. alterniflora biomass monitoring program would be to estimate seasonal live biomass and evaluate long-term trends in the status of the system's dominant macrophyte primary producer. Observed changes may be a reflection of natural (i.e., inlet dynamics, hydrodynamic changes) and/or human-induced (i.e., nutrient inputs, oil spills) factors.

As noted in the earlier section of this Final Report on remote sensing of S.

alterniflora, there was considerable variability in the data. This technique is promising and should be pursued at Nauset Marsh, yet, additional research must be conducted before an effective monitoring program can be implemented. Data collection to calibrate and verify spectral radiance models for Nauset Marsh should be pursued.

FISHES AND DECAPOD CRUSTACEANS

Over the past three years, this study has provided an extensive data base on the abundance and species composition of fishes and macroinvertebrates utilizing the Nauset Marsh system. Many of these species, including winter flounder and American lobster, are economically important and the condition of their populations reflect the system's overall environmental quality. The ideal monitoring program would include an intensive fish and macroinvertebrate inventory conducted at 3 - 5 year intervals. As done in this study, the study design should include seasonal sampling, numerous habitats and many gear types. Such an intensive program is clearly not within the scope of the proposed Nauset Marsh monitoring program. Thus, we recommend an abbreviated program that may be capable of detecting at least gross changes in the system's faunal assemblage.

Consistent with the habitat approach to the study of Nauset Marsh, it is proposed that four habitats be sampled; eelgrass--Station 7, mud flat--Station 2, sand bottom--Station 1, and deep water--Station 5 (see Fig. 8 for station locations). At a minimum, annual collections should be in September and June, corresponding to the periods of peak abundances and recruitment, respectively. As employed in the inventory phase, collections should be made using a small otter trawl (4.9 m with 0.6 cm cod-end mesh). Based on species accumulation curves, four 2-minute tows at each station are an appropriate sampling effort. The collections of each tow should be kept separate, sorted live, and discarded back into the system. If time and personnel resources permit, the trawl sampling should be augmented by seine gear at selected stations. All fish and decapod crustaceans should be identified and counted by species. Additionally, select species, which are economically significant and/or important ecological indicators, should be used to provide long-term length frequency information. The fish species are; pollock, white hake, winter flounder, three-spined stickleback, four-spined stickleback, and grubby. Decapod crustaceans include, green crab and American lobster. If represented by 25 or fewer individuals in a given tow, all specimens of these select species should be measured for total length or carapace length or width, as appropriate. For very abundant species, 25 randomly chosen individuals should be measured and the remainder counted.

Data analyses should include the use of similarity indices and statistical tests to compare species abundance and composition between habitats, seasons, and years. Length frequency data should be analyzed to yield information on growth and life history stage of the eight select species.

HABITAT BOUNDARIES

Nauset Marsh is composed of a diverse assemblage of habitats. The areal extent and boundaries of these habitats will likely change in response to both human and naturally induced variability throughout the system. For example, it

has been previously stated in this report that the extensive eelgrass areas in the vicinity of Nauset Harbor will be reduced or lost with a change in inlet location to the south. The eelgrass habitat will most likely be replaced by subtidal-intertidal sand bottom habitat (i.e., flood tidal delta). Other habitats, such as algal-dominated intertidal mudflats, may change in areal extent in response to changes in the system's water quality and/or circulation patterns. Quantitatively documenting habitat changes will prove to be an important component of the Nauset Marsh monitoring program.

Fig. 3 of this report shows the approximate habitat boundaries of the Nauset Marsh system based on October 1982 aerial photographs and 1986 ground-truthing. To document changes in habitat boundaries and areal extent, it is recommended that the Nauset Marsh habitat map be revised at about 3 year intervals. Vertical aerial photographs of relatively large scale (less than 1:9,000) should be obtained. The flight should be scheduled in summer, at low tide, and filters should be used to enhance the detection of submerged aquatic vegetation. Ground-truthing may be done from the ground and through observations from a low altitude overflight.

HARD CLAM GROWTH RATES

It is proposed that the growth rate of hard clams be monitored annually to serve as an indicator of ecosystem change (i.e., natural or human-induced). Any significant shifts in growth rate from the baseline provided in this Final Report (see section on Habitat Specific Studies) may suggest that environmental changes are occurring and further investigation is warranted.

Annually (July), 30 clams should be randomly collected from the Nauset Harbor eelgrass meadow (Town Landing at Snow Shore Rd.) and 30 from an adjacent unvegetated sand bottom. The clams should be immediately frozen until shell growth analysis is performed (see earlier section for methods). It is suggested that NPS personnel collect the clams and then ship them (frozen) to a laboratory that is equipped for analysis and interpretation of shell growth.

MIGRATORY SHOREBIRDS

The intertidal habitats of Nauset Marsh represent one of several rich and consistent sources of energy along the flight path of a large and diverse contingent of shorebirds during their migrations between Arctic breeding grounds and southern U.S. and South American wintering areas. For this reason, shorebird feeding at Nauset may be of hemisphere-wide importance to populations of Semipalmated Sandpipers, Short-billed Dowitchers, Black-bellied Plovers, Dunlin, and perhaps several other less common species. The importance of physically preserving these habitats and protecting these transient populations from anthropic disturbances is appreciated. Periodic and quantitative data on habitat utilization by migratory bird populations can signal more general changes in habitat quality (Goss-Custard 1977; Schneider and Harrington 1979).

Shorebird foraging abundance should therefore be monitored annually and at peak migratory periods: during late July to early August for Semipalmated Sandpipers, Short-billed Dowitchers, and Yellowlegs, late August to early September for Black-bellied Plovers, and mid-October for Dunlin. Count frequency is difficult to determine without data on annual variability, but observed

phenology suggests that biweekly counts (one low tide per two-week period) from late July through mid-October should be adequate to estimate peak abundance. Nevertheless, intensive shorebird movement from 20 July to 15 August should be followed on a weekly basis. Counts should be standardized by concentrating on the same study site, Nauset Bay, used in this baseline inventory and by counting foraging birds consistently at low ebb tide. At least two counts, i.e., spaced one hour apart, would improve reliability. Actual inventory locations (and data interpretation) may have to be adjusted over time to account for natural geomorphic changes affecting the configuration and temporal availability of appropriate habitat.

Roosting shorebird counts, begun in 1988 by NPS resource management staff (K. Jones, pers. comm.), provide another useful index of shorebird use and should be continued in conjunction and concurrent with the ongoing protection of beach-nesting birds. Unlike foraging abundance, high-tide roost counts are probably less dependent upon the current configuration of nearby feeding habitats. It should be noted that roost sites can move from year-to-year.

The American Black Duck, Cape Cod's predominant wintering waterfowl, is more conspicuous and more easily counted in all Nauset habitats than small, cryptic shorebirds. Because their numbers appear stable throughout the winter, few observations are necessary if timed to avoid hunter and other human disturbances. An appropriate and potentially productive monitoring strategy may be to census the entire marsh population on three occasions annually: at October arrival, in mid-winter (January) and in late March. Such a program could document winter losses, in addition to providing a higher-resolution annual census.

NPS resource management staff should coordinate all data gathering and data management relative to the monitoring of Nauset Marsh-dependent birds. In addition to NPS staff, actual data gathering could be shared with local groups, e.g., the Cape Cod Bird Club and Massachusetts Audubon's Wellfleet Bay Sanctuary, provided that volunteers (or contracted observers) adhere to standard methods and study areas.

PROGRAM IMPLEMENTATION

The proposed Nauset Marsh monitoring program is designed to be relatively simple. However, only with a close cooperative effort among NPS, town and university sectors can the program be effectively implemented. The data will be collected, analyzed and interpreted by numerous groups and individuals. Therefore, it is imperative that a team or committee be established to coordinate and synthesize the results of the monitoring effort. It is recommended that a Nauset Marsh Monitoring Committee be chaired by the Park Resource Management Specialist. Other key members or affiliations of the committee should include; Town of Eastham Natural Resources Dept., Town of Orleans Shellfish Dept., Park biologist, Commonwealth of Massachusetts Division of Marine Fisheries and/or Coastal Zone Management Office, and a representative from the Rutgers CRU Nauset research team. On an annual basis the Committee should prepare a written summary of the data and interpretations of long-term trends. Comments on the report should be solicited from all participating monitoring personnel, from members of the Rutgers CRU Nauset research team (i.e., principal and associate

investigators), and from other researchers, naturalists and interest groups familiar with the system.

With respect to actual implementation, it is suggested that the program be developed in a stepwise manner (Table 45). During the initial phase (PHASE ONE), it is recommended that the physical parameter (temperature and salinity) measurements, eelgrass wasting disease assessment, shorebird monitoring, fish/decapod inventory and habitat boundary documentation be implemented. These aspects of the program will be relatively inexpensive to initiate and will serve to establish a working network of NPS, town, university and volunteer personnel. As long-term resources are allocated to the monitoring program, the other components (PHASE TWO) should be incorporated toward development of a comprehensive monitoring program.

Table 45. Summary of the proposed Nauset Marsh long-term monitoring program. Two phases of program implementation are suggested.

Program Component	Sample Site	Sample Periodicity
<u>PHASE ONE</u>		
Physical Parameters (temp & salinity)	Nauset Bay Town Cove Salt Pond (optional) Nauset Harbor (optional)	7-10 day intervals (continuous) ¹
Eelgrass Wasting Disease Index	Town Cove Mill Pond Nauset Harbor (optional)	May-Sept (biweekly), monthly thereafter (continuous)
Shorebirds	system-wide	July-Oct (intense), less frequent there- after (continuous)
Fishes and Decapods	Nauset Harbor Town Cove Nauset Bay North Channel	June & Sept (annual)
Habitat Boundaries	system-wide	Summer (3 yr intervals)
<u>PHASE TWO</u>		
Hard Clam Growth	Nauset Harbor	July (annual)
Epiphyte Biomass	Town Cove Mill Pond Nauset Harbor (optional)	May, July, Sept (annual)
Water Quality	Town Cove Hemenway Landing Nauset Harbor (optional) Nauset Bay (optional)	August & April (annual)
<u>Spartina</u> Biomass	Hemenway-Fort Hill	July-August (annual)

¹"Continuous" denotes ongoing monitoring at the indicated frequency.
"Annual" denotes event sampling during the indicated time or period.

LITERATURE CITED

- Able, K.W., K.L. Heck, Jr., M.P. Fahay, and C.T. Roman. 1988. Use of salt-marsh peat reefs by small juvenile lobsters on Cape Cod, Massachusetts. Estuaries 11:83-86.
- Addy, C.E., and D.A. Aylward. 1944. Status of eelgrass in Massachusetts during 1943. J. Wildl. Manage. 8:269-275.
- Ambrose, W.G., Jr. 1986. Estimate of removal rate of Nereis virens (Polychaeta: Nereidae) from an intertidal mudflat by gulls (Larus spp.). Mar. Biol. 90:243-247.
- Anderson, F.E., L. Black, L.W. Watling, W. Mook, and L.M. Mayer. 1981. A temporal and spatial study of mudflat erosion and deposition. J. Sediment. Petrol. 51:0729-0736.
- Aubrey, D.G., and P.E. Speer. 1984. Updrift migration of tidal inlets. J. Geol. 92:531-545.
- Aubrey, D.G., and P.E. Speer. 1985. A study of non-linear tidal propagation in shallow inlet/estuarine systems. Part I: observations. Est. Coast. Shelf Sci. 21:185-207.
- Bartlett, D.S., M.A. Hardisky, R.W. Johnson, M.F. Gross, V. Klemas, and J.M. Hartman. 1988. Continental scale variability in vegetation reflectance and its relationship to canopy morphology. Int'l. J. Rem. Sens. 9:1223-1241.
- Bildstein, K.L., R.L. Christy, and P. DeCoursey. 1982. Energy flow through a South Carolina salt-marsh shorebird community. Wader Study Group 34:35-37.
- Cambridge, M.L., A.W. Chiiffings, C. Britian, L. Moore, and A.J. McComb. 1986. The loss of seagrass in Cockburn Sound, Western Australia II: Possible causes of seagrass decline. Aquat. Bot. 24:269-285.
- Cambridge, M.L., and A.J. McComb. 1984. The loss of seagrass in Cockburn Sound, Western Australia. I: The time course and magnitude of seagrass decline in relation to industrial development. Aquat. Bot. 20:229-243.
- Cape Cod Planning and Economic Development Commission. 1981. Cape Cod Coastal Oil Spill Response Plan. Barnstable, MA.
- Clark, G.R., II. 1980. Study of molluscan shell structure and growth lines using thin sections, p. 603-606. In D.C. Rhoads and R.A. Lutz (eds.), Skeletal Growth of Aquatic Organisms. Plenum, New York.
- Conover, D.O., and S.A. Murawski. 1982. Offshore winter migration of the Atlantic silverside, Menidia menidia. Fish. Bull. 80:145-150.
- Daly, M.A., and A.C. Mathieson. 1981. Nutrient fluxes within a small north temperate salt marsh. Mar. Biol. 61:337-344.

- Degobbis, D. 1973. On the storage of seawater samples for ammonia determination. Limnol. Oceanogr. 18:146-150.
- D'Elia, C.F., P.A. Steudler, and N. Corwin. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnol. Oceanogr. 22:760-764.
- DeVlas, J. 1985. Secondary production by siphon regeneration in a tidal flat population of Macoma balthica. Netherlands J. Sea Res. 19(2):147-164.
- Duffy, D.C., N. Atkins, and D.C. Schneider. 1981. Do shorebirds compete on their wintering grounds? Auk 98:215-229.
- Evans, P.R. 1976. Energy balance and optimal foraging strategies in shorebirds: Some implications for their distributions and movements in the non-breeding season. Ardea 64:117.
- Evans, P.R. 1979. Adaptations shown by foraging shorebirds to cyclic variations in the activity and availability of their intertidal invertebrate prey. p. 357-366. In E. Naylor and R.G. Hartnoll (eds.), Cyclic phenomena in marine plants and animals. Pergamon Press, Oxford.
- Evans, P.R., D.M. Herdson, P.J. Knights, and M.W. Pienkowski. 1979. Short-term effects of reclamation of part of Seal Sands, Teesmouth, on wintering waders and shelduck. I. Shorebird diets, invertebrate densities, and the impact of predation on the invertebrates. Oecologia 41:183-206.
- Fiske, J.D., C.E. Watson, and P.G. Coates. 1967. A study of the marine resources of Pleasant Bay. Div. Mar. Resources, Commonwealth of Massachusetts, Monograph Series No. 5. 56 p.
- Frey, R.W., and P.B. Basan. 1978. Coastal salt marshes, p. 101-159. In R.A. Davies (ed.), Coastal Sedimentary Environments. Springer-Verlag, New York.
- Fritz, L.W. and D.S. Haven. 1983. Hard clam, Mercenaria mercenaria: Shell growth patterns in Chesapeake Bay. Fish. Bull. 81(4):697-708.
- Goss-Custard, J.D. 1969. The winter feeding ecology of the Redshank, Tringa totanus. Ibis 3:338-356.
- Goss-Custard, J.D., D.G. Kay, and R.M. Blindell. 1977. The density of migratory and overwintering redshank, Tringa totanus (L.) and curlew, Numenius arquata (L.), in relation to the density of their prey in south-east England. Est. Coast. Shelf. Sci. 5:497-510.
- Grandy, J.W., IV. 1972. Winter ecology of maritime black ducks (Anas rubripens) in Massachusetts: With special reference to Nauset Marsh, Orleans and Eastham. Ph.D. Thesis. Univ. Massachusetts. 93 p.
- Gross, M.F., M.A. Hardisky, V. Klemas, and P.L. Wolf. 1987. Quantification of biomass of the marsh grass, Spartina alterniflora Loisel, using Landsat thematic mapper imagery. Photogram. Eng. Rem. Sens. 53:1577-1583.

- Gross, M.F., M.A. Hardisky, V. Klemas, and P.L. Wolf. (in prep.) Interannual variability in standing crop biomass of the marsh grass, Spartina alterniflora.
- Hardisky, M.A., R.M. Smart, and V. Klemas. 1983. Seasonal spectral characteristics and aboveground biomass of the tidal marsh plant, Spartina alterniflora. Photogram. Eng. Rem. Sens. 49:85-92.
- Hardisky, M.A., F.C. Daiber, C.T. Roman, and V. Klemas. 1984. Remote sensing of biomass and annual net aerial primary productivity of a salt marsh. Rem. Sens. Environ. 16:91-106.
- Hardisky, M.A., M.F. Gross and V. Klemas. 1986. Remote sensing of coastal wetlands. BioScience 36:453-460.
- Heck, K.L., and T.A. Thoman. 1981. Experiments on predator-prey interactions in vegetated aquatic habitats. J. Exp. Mar. Biol. Ecol. 53:126-134.
- Heck, K.L., and K.A. Wilson. 1987. Predation rates on decapod crustaceans in latitudinally separated seagrass communities: A study of spatial and temporal variation using tethering techniques. J. Exp. Mar. Biol. Ecol. 107:87-100.
- Johnson, D.A., and B.L. Welsh. 1985. Detrimental effects of Ulva lactuca (L.) exudates and low oxygen on estuarine crab larvae. J. Exp. Mar. Biol. Ecol. 86:73-83.
- Kennish, M.J., R.A. Lutz, and D.C. Rhoads. 1980. Preparation of acetate peels and fractured sections for observation of growth patterns within the bivalve shell, p. 597-602. In D.C. Rhoads and R.A. Lutz (eds.), Skeletal Growth of Aquatic Organisms. Plenum, New York.
- Kersiwill, C.J. 1949. Effects of water circulation on the growth of quahaugs and oysters. J. Fish. Res. Bd. Can. 7:545-551.
- Kjerfve, B., and H.N. McKellar, Jr. 1980. Time series measurements of estuarine material fluxes, p. 341-357. In V.S. Kennedy (ed.), Estuarine Perspectives. Academic Press, New York.
- Kjerfve, B., and J.A. Proehl. 1979. Velocity variability in a cross-section of a well-mixed estuary. J. Mar. Res. 37:409-418.
- Leatherman, S.P., and R.E. Zaremba. 1986. Dynamics of a northern barrier beach: Nauset spit, Cape Cod, Massachusetts. Geol. Soc. Am. Bull. 97:116-124.
- Leber, K.M. 1985. The influence of predatory decapods, refuge and microhabitat selection on seagrass communities. Ecol. 66:1951-1964.
- Main, K.L. 1985. The influence of prey identity and size on selection of prey by two marine fishes. J. Exp. Mar. Biol. 98:145-152.

- Main, K.L. 1987. Predator avoidance in seagrass meadows: Prey behavior, microhabitat selection, and cryptic coloration. Ecol. 68:170-180.
- Marsh, C.P. 1986. Rocky intertidal community organization: the impact of avian predators on mussel recruitment. Ecol. 67:771-786.
- Nelson, W.G. 1979. An analysis of structural pattern in an eelgrass (Zostera marina) amphipod community. J. Exp. Mar. Biol. Ecol. 39:231-264.
- Nixon, S.W. 1980. Between coastal marshes and coastal waters - a review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry, p. 437-525. In P. Hamilton and K.B. MacDonald (eds.), Estuarine and Wetland Processes: With emphasis on modelling. Marine Science Vol. II, Plenum Press, New York.
- Nixon, S.W., and C.A. Oviatt. 1972. Preliminary measurements of midsummer metabolism in beds of eelgrass, Zostera marina. Ecol. 53:150-153.
- Nixon, S.W., C.A. Oviatt, J. Garber, and V. Lee. 1976. Diel metabolism and nutrient dynamics in a salt marsh embayment. Ecol. 57:740-750.
- Parsons, T.R., M. Yoshiaki, and C.M. Laui. 1984. A manual of chemical and biological methods for seawater analysis. Pergamon Press, New York. 173 p.
- Peterson, C.H., and M. Quammen. 1982. Siphon nipping: Its importance to small fishes and its impact on growth of the bivalve Protothaca staminea (Conrad). J. Exp. Mar. Biol. Ecol. 63:249-268.
- Peterson, C.H., H.C. Summerson, and P.C. Duncan. 1984. The influence of seagrass cover on population structure and individual growth rate of a suspension-feeding bivalve, Mercenaria mercenaria. J. Mar. Res. 42:123-138.
- Quammen, M.L. 1982. Influence of subtle substrate differences on feeding by shorebirds on intertidal mudflats. Mar. Biol. 71:3339-3343.
- Quammen, M.L. 1984. Predation by shorebirds, fish, and crabs on invertebrates in intertidal mudflats: An experimental test. Ecol. 65:529-537.
- Rasmussen, E. 1977. The wasting disease of eelgrass (Zostera marina) and its effect on environmental factors and fauna, p 1-51. In C.P. McRoy and C. Helfferich (eds.), Seagrass Ecosystems; a scientific perspective. Marcel Dekker, N.Y.
- Recher, H.F. 1966. Some aspects of the ecology of migrant shorebirds. Ecol. 47:393-407.
- Rhoads, D.C., and G. Pannella. 1970. The use of molluscan shell growth patterns in ecology and paleoecology. Lethaia 3:143-161.
- Robertson, A.I. 1979. The relationship between annual production: Biomass ratios and life spans for marine macrobenthos. Oecologia 38:193-202.

- Roman, C.T. 1984. Estimating water volume discharge through salt-marsh tidal channels: An aspect of material change. Estuaries 7:259-264.
- Roman, C.T., and K.W. Able. 1988. Production ecology of eelgrass (*Zostera marina*) in a Cape Cod salt marsh-estuarine system, Massachusetts. Aquat. Bot. 32:353-363.
- Roman, C.T., J.G. Ehrenfeld, and K.F. Nordstrom 1987. The identification of common resource management needs as a basis for barrier island research programs, p. 3306-3313. In O. Magoon et al. (eds.), Coastal Zone '87. American Society of Civil Engineers, NY, NY.
- Rowan, A.T. 1988. Bank erosion, bank stability, and channel migration in salt marsh tidal channels. Masters' Thesis, Rutgers University, New Brunswick, NJ. 167 p.
- Sargent, W. 1985. Shallow waters; a year on Cape Cods' Pleasant Bay. Parnassus Imprints, no place of publishing company indicated. 139 p.
- Schneider, D. 1978. Equalization of prey numbers by migratory shorebirds. Nature 271:353-354.
- Schneider, D.C., and B.A. Harrington. 1979. Habitat studies of migratory shorebirds: A comparison of bird usage to the amount and quality of feeding habitat at two coastal locations in Massachusetts. Manomet Bird Observatory, unpubl. report. 59 p.
- Schneider, D.C., and B.A. Harrington. 1981. Timing of shorebird migration in relation to prey depletion. Auk 98:801-811.
- Schutt, J.B., C.M. Shai, and J.H. Henninger. 1984. Optical coatings formulations containing tetrafluoroethylene. Appl. Opt. 23:1138.
- Short, F.T., B.W. Ibelings, and C. den Hartog. 1988. Comparison of a current eelgrass disease to the wasting disease in the 1930s. Aquat. Bot. 30:295-304.
- Short, F.T., A.C. Mathieson, and J.I. Nelson. 1986. Recurrence of the eelgrass wasting disease at the border of New Hampshire and Maine. Mar. Ecol. Prog. Ser. 29:88-92.
- Short, F.T., L.K. Muehlstein, and D. Porter. 1987. Eelgrass wasting disease: Cause and recurrence of a marine epidemic. Biol. Bull. 173:557-562.
- Short, F.T., and C.A. Short. 1984. The seagrass filter: Purification of estuarine and coastal waters, p. 395-413. In V.S. Kennedy (ed.), The Estuary as a Filter. Academic Press, Inc., New York.
- Silberstein, K., A.W. Chiffings, and A.J. McComb. 1986. The loss of seagrass in Cockburn Sound, Western Australia III. The effect of epiphytes on productivity of *Posidonia australis* Hook F. Aquat. Bot. 24:355-371.

- Solorzano, L. 1969. Determination of ammonia in natural waters by the phenolhypochlorite method. Limnol. Oceanogr. 14:799-801.
- Speer, P.E., and D.G. Aubrey. 1985. A study of non-linear tidal propagation in shallow inlet/estuarine systems Part II: Theory. Est. Coast. Shelf Sci. 21:207-224.
- Stoner, A.W. 1982. The influence of benthic macrophytes on the foraging behavior of pinfish, Lagodon rhomboides (Linnaeus). J. Exp. Mar. Biol. Ecol. 58:271-284.
- Stottlemeyer, R. 1987. External threats to ecosystems of US National Parks. Environ. Management 11:87-89.
- Strickland, J.D.H., and T.R. Parsons. 1972. A practical handbook of seawater analysis. Fisheries Res. Bd. Canada, Ottawa. 310 p.
- Thayer, G.W., D.A. Wolfe, and R.B. Williams. 1975. The impact of man on seagrass systems. Am. Sci. 63:288-296.
- Teal, J.M., editor. 1983. The coastal impacts of ground water discharge: an assessment of anthropogenic nitrogen loading in Town Cove, Orleans, Massachusetts. Prepared by Woods Hole Oceanographic Institution for the Board of Selectmen, Town of Orleans, MA. 162 p. (plus appendices).
- Thursby, G.B., and M.M. Harlin. 1982. Leaf-root interaction in the uptake of ammonia by Zostera marina. Mar. Biol. 72:109-112.
- U.S. Environmental Protection Agency. 1979. Methods for chemical analysis of water and wastes. EPA-600/4-79-020. Office of Research and Development, Cincinnati, OH.
- Valiela, I. 1983. Nitrogen in salt marsh ecosystems, p. 649-678. In E.J. Carpenter and D.G. Capone (eds.), Nitrogen in the marine environment. Academic Press, Inc., New York.
- Valiela, I., J.M. Teal, and W.J. Sass. 1975. Production and dynamics of salt marsh vegetation and the effects of experimental treatment with sewage sludge; biomass, production and species composition. J. Appl. Ecol. 12:978-981.
- Valiela, I., J.M. Teal, S. Volkmann, D. Shafer, and E.J. Carpenter. 1978. Nutrient and particulate fluxes in a salt marsh ecosystem: Tidal exchanges and inputs by precipitation and groundwater. Limnol. Oceanogr. 23:798-812.
- Welsh, B.L. 1980. Comparative nutrient dynamics of a marsh-mudflat ecosystem. Est. Coast. Shelf Sci. 10:143-164.
- Whiting, G.J., H.N. McKellar, Jr., B. Kjerfve, and J.D. Spurrier. 1985. Sampling and computational design of nutrient flux from a southeastern U.S. salt marsh. Est. Coast. Shelf Sci. 21:273-286.

- Whiting, G.J., H.N. McKellar, Jr., B. Kjerfve, and J.D. Spurrier. 1987. Nitrogen exchange between a southeastern U.S.A. salt marsh ecosystem and the coastal ocean. Mar. Biol. 95:173-182.
- Wilson, K.A., K.L. Heck, Jr., and K.W. Able. 1987. Juvenile blue crab Callinectes sapidus, survival: An evaluation of eelgrass, Zostera marina, as a refuge. Fish. Bull. 85(2):53-58.
- Wolaver, T.G., W. Johnson, and M. Marozas. 1984. Nitrogen and phosphorus concentrations within North Inlet, South Carolina - speculation as to sources and sinks. Est. Coast. Shelf Sci. 19:243-255.
- Wolaver, T.G., R.L. Wetzel, J.C. Zieman, and K.L. Webb. 1980. Nutrient interactions between salt marsh, mudflats, and estuarine water, p. 123-133. In V.S. Kennedy (ed.), Estuarine Perspectives. Academic Press, Inc., New York.
- Woodwell, G.M., C.A.S. Hall, D.E. Whitney, and R.A. Houghton. 1979. The Flax Pond ecosystem study: Exchanges of inorganic nitrogen between an estuarine marsh and Long Island Sound. Ecol. 60:695-702.
- Zaremba, R.E., and S.P. Leatherman. 1984. Overwash processes and foredune ecology, Nauset Spit, Massachusetts. Misc. Paper EL-84-8. Environ. Lab, U.S. Army Eng. Waterway Exp. Station, Vicksburg, MS. 232 p.
- Zaremba, R.E., and S.P. Leatherman. 1986. Vegetative physiographic analysis of a U.S. northern barrier system. Environ. Geol. Water. Sci. 8:193-207.