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Woods Hole Oceanographic Institution

New England Salt Pond Data Book

by

Anne E. Giblin

June 1990

Technical Report

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CRC-90-2
Coastal Research Center

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ABSTRACT

This volume contains information on New England salt ponds and lagoons. The first part contains abstracts of a symposium on salt ponds and lagoons held in conjunction with the New England Estuarine Research Society (NEERS) on April 21, 1988. These should provide both scientists and managers with an overview of recent research on salt ponds. the second part contains, maps, morphometric data, and references for individual salt ponds in Connecticut, Rhode Island, and Massachusetts. The third section is a comprehensive bibliography of papers and reports on salt ponds, including information on ponds located outside of New England. A listing of references organized according to topic areas is also provided.

PREFACE

On April 21, 1988 a Special Symposium on Salt Ponds and Lagoons was held in conjunction with the 1988 Spring meeting of the New England Estuarine Research Society (NEERS). The day long symposium was co-sponsored by the Ecosystems Center of the Marine Biological Laboratory and the Waquoit Bay National Estuarine Research Reserve. Participants in the symposium were asked to submit an abstract of their presentation and copies of relevant research papers.

The "New England Salt Pond Data Book" is an out growth of that symposium. The first section contains the abstracts which summarize the participants' recent research on salt ponds. These should provide both scientists and policy makers with an overview of some of the environmental problems salt ponds are experiencing. The second part contains maps, morphometric data, and references for individual salt ponds in New England. In many cases the maps are not current. Maps are provided to help design sampling programs, current charts should be consulted for navigation. Finally, the third section is a comprehensive bibliography of papers and reports on salt ponds and lagoons. Many of these papers are on file at the Waquoit Bay National Estuarine Research Reserve. The Reserve is currently undergoing renovations which will be completed by October 1990. Individuals wishing to use the library there should contact the Waquoit Bay Reserve Manager after September 30, 1990 (508-457-0495).

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EXTENDED ABSTRACTS AND PROGRAM

1988 SPECIAL SYMPOSIUM ON COASTAL PONDS AND LAGOONS

HELD APRIL 19, 1988 AS PART OF THE SPRING MEETING OF
THE NEW ENGLAND ESTUARINE RESEARCH SOCIETY

SPONSORED BY

THE ECOSYSTEM CENTER
MARINE BIOLOGICAL LABORATORY
WOODS HOLE, MASS

AND

THE WAQUOIT BAY NATIONAL ESTUARINE RESEARCH RESERVE
WAQUOIT, MASS

SPECIAL SYMPOSIUM ON COASTAL PONDS & LAGOONS

21 APRIL, 1988

WOODS HOLE, MASSACHUSETTS

HOSTED BY

THE ECOSYSTEMS CENTER
MARINE BIOLOGICAL LABORATORY
WOODS HOLE, MASSACHUSETTS

AND

WAQUOIT BAY NATIONAL ESTUARINE RESEARCH RESERVE

PROGRAM

Morning session chaired by Anne Giblin, The Ecosystems Center

0850	Welcome: John Hobbie, Director, The Ecosystems Center
0900	Lee, V., Coastal Resources Center, GSO, University of Rhode Island, Narragansett, RI. EUTROPHICATION, SCIENTIFIC RESEARCH AND MANAGEMENT INITIATIVES FOR RHODE ISLAND COASTAL LAGOONS.
0940	Caraco, N. F., Institute of Ecosystem Studies, Millbrook, NY. RELATIONSHIP BETWEEN PRODUCTION AND NUTRIENT LOADING IN A BRACKISH COASTAL POND, SIDERS POND, FALMOUTH, MASSACHUSETTS.
1000	Break
1020	Valiela, I. and J. Costa, Boston University Marine Program, Marine Biological Laboratory, Woods Hole, MA. N AND P INPUTS INTO BUTTERMILK BAY AND ITS WATERSHED.
1040	Gaines, A. G. Jr., Marine Policy Center, Woods Hole Oceanographic Institution, Woods Hole, MA. PERSPECTIVES ON SCIENCE AND MANAGEMENT IN SOUTHERN NEW ENGLAND ESTUARIES.
1100	Kerfoot, W. B., K-V Associates, Inc., Falmouth, MA. FIVE YEARS UNDER SAIL - EXPERIENCES WITH THE NUTRIENT BYLAWS.
1125	Buckland, K. J., Planning Board, Town of Falmouth, MA. SCIENTIFIC CERTAINTY VS. REGULATORY NEEDS: THE CASE OF NUTRIENT STANDARDS FOR COASTAL PONDS.
1145	Discussion
1200	Lunch

Afternoon session chaired by Ed Rastetter, The Ecosystems Center

1320	Spaulding, M. L., Ocean Engineering, University of Rhode Island, Kingston, RI 02881. TIDAL EXCHANGE BETWEEN BLOCK ISLAND SOUND AND NINIGRET POND.
1400	Fitzgerald, D. M., Department of Geology, Boston University, Boston, MA. FORMATION AND FATE OF COASTAL BAYS AND TIDAL INLETS IN NEW ENGLAND.
1420	Anderson, D. M., and B. A. Keafer, Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA. DINOFLAGELLATE SPECIES SUCCESSION IN A COASTAL POND: MECHANISMS AND DYNAMICS.
1500	Break
1520	Hickey, M., Division of Marine Fisheries, Sandwich, MA. COLIFORMS.
1540	Teal, J. M. and B. L. Howes, Woods Hole Oceanographic Institution, Woods Hole, MA. NITROGEN BUDGET OF A CRANBERRY BOG.
1600	Short, F. T., E. C. Brainard and J. Wolf, Jackson Estuarine Laboratory, University of New Hampshire, Durham, NH. EAST COAST EELGRASS POPULATIONS: LATITUDINAL TRENDS AND HEALTH ASSESSMENT.
1620	Costa, J. E., Boston University Marine Program, Marine Biological Laboratory, Woods Hole, MA. RECENT AND HISTORICAL CHANGES IN ABUNDANCE OF EELGRASS (*Zostera marina* L.) IN WAQUOIT BAY, MA.
1640	Deegan, L. A., S. Saucerman and D. Basler, Department of Forestry and Wildlife Management, University of Massachusetts, Amherst, MA. CHANGES IN THE WAQUOIT BAY FISH COMMUNITY OVER A TWENTY YEAR PERIOD.
1700	Adjourn

EUTROPHICATION, SCIENTIFIC RESEARCH AND MANAGEMENT INITIATIVES FOR RHODE ISLAND COASTAL LAGOONS.

V. Lee

Coastal Resources Center

GSO, University of Rhode Island

Narragansett, Rhode Island

Coastal lagoons, locally known as salt ponds, are an important feature along Rhode Island's ocean shore. They are highly productive systems supporting commercial and recreational fin and shellfisheries as well as intense recreational use. Their shoreline is the drawing card for an unprecedented rate of residential and commercial development within their watersheds. The water quality impacts of this development have been documented by a multidisciplinary University of Rhode Island research program and more recently by a volunteer citizen monitoring project. The results of the research have been incorporated into state and local government regulations designed to curtail excessive nutrient and bacteria loadings.

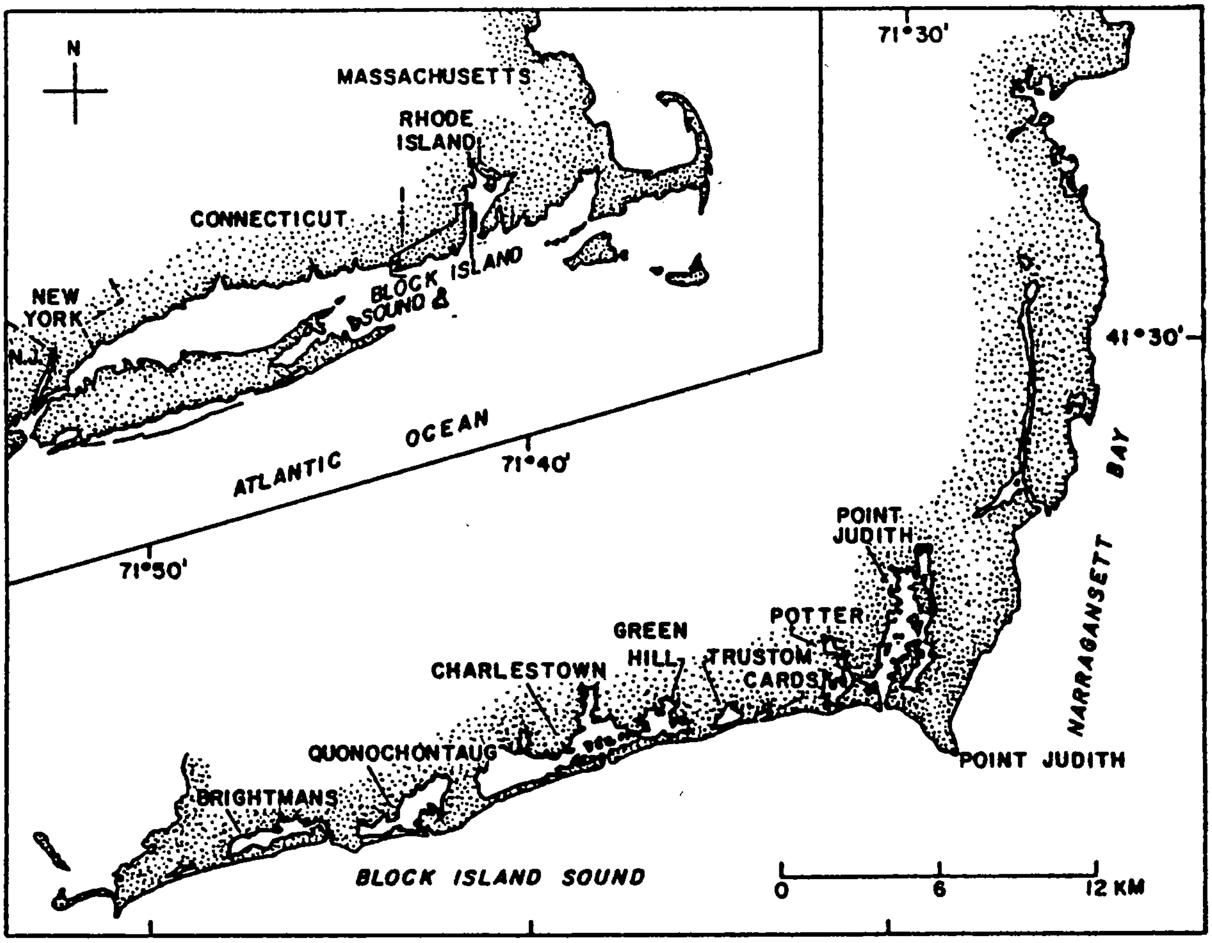
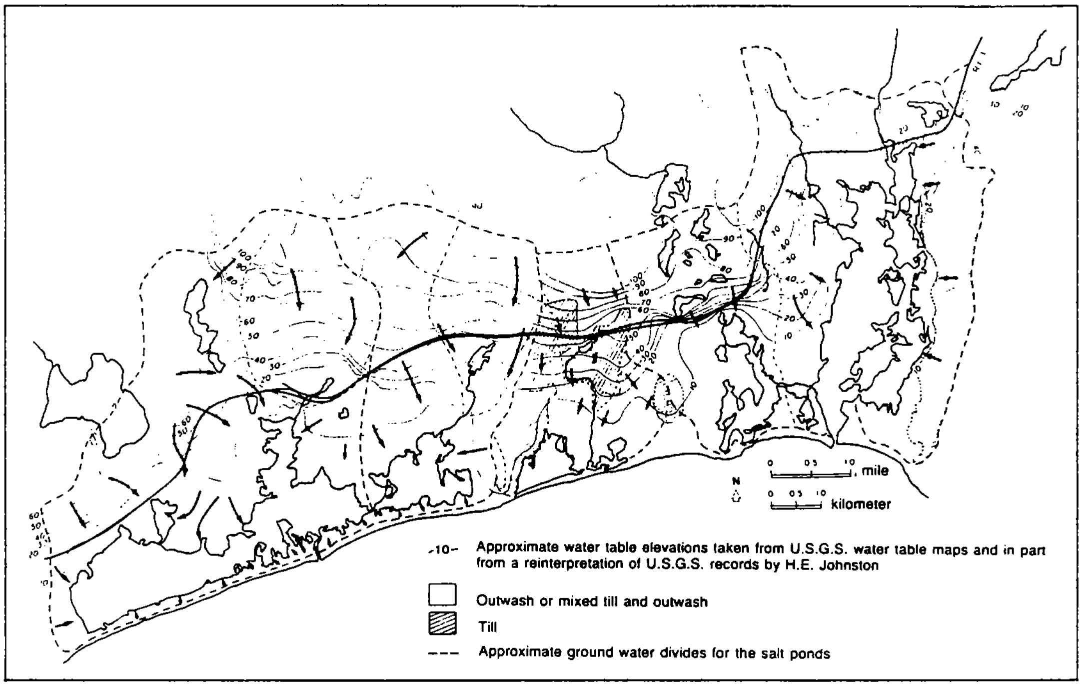
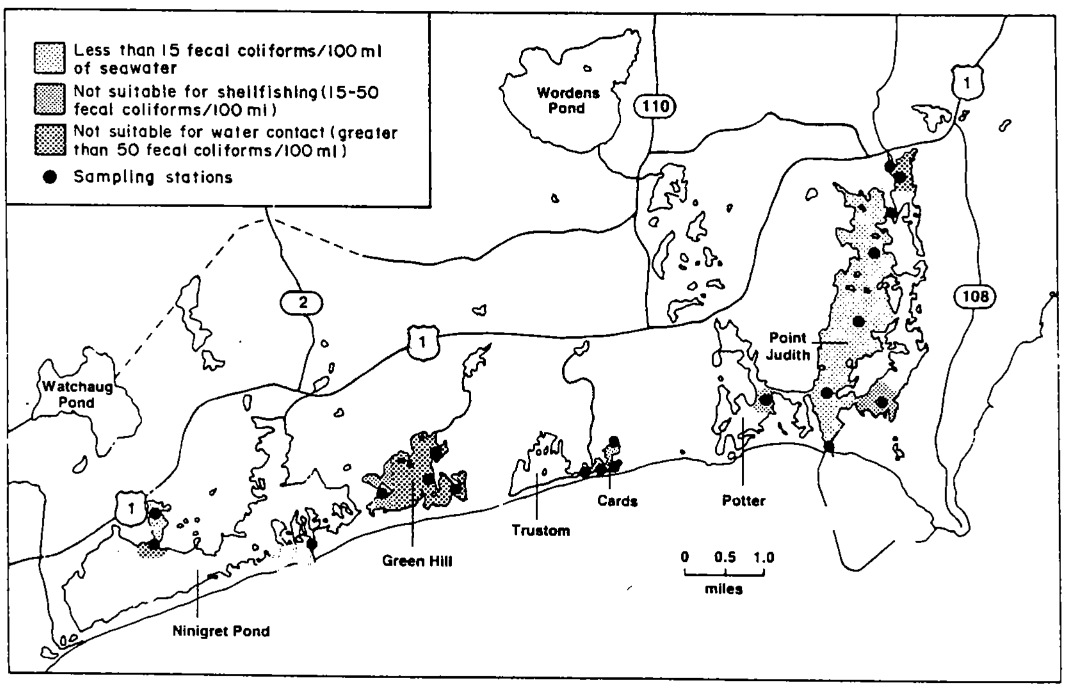


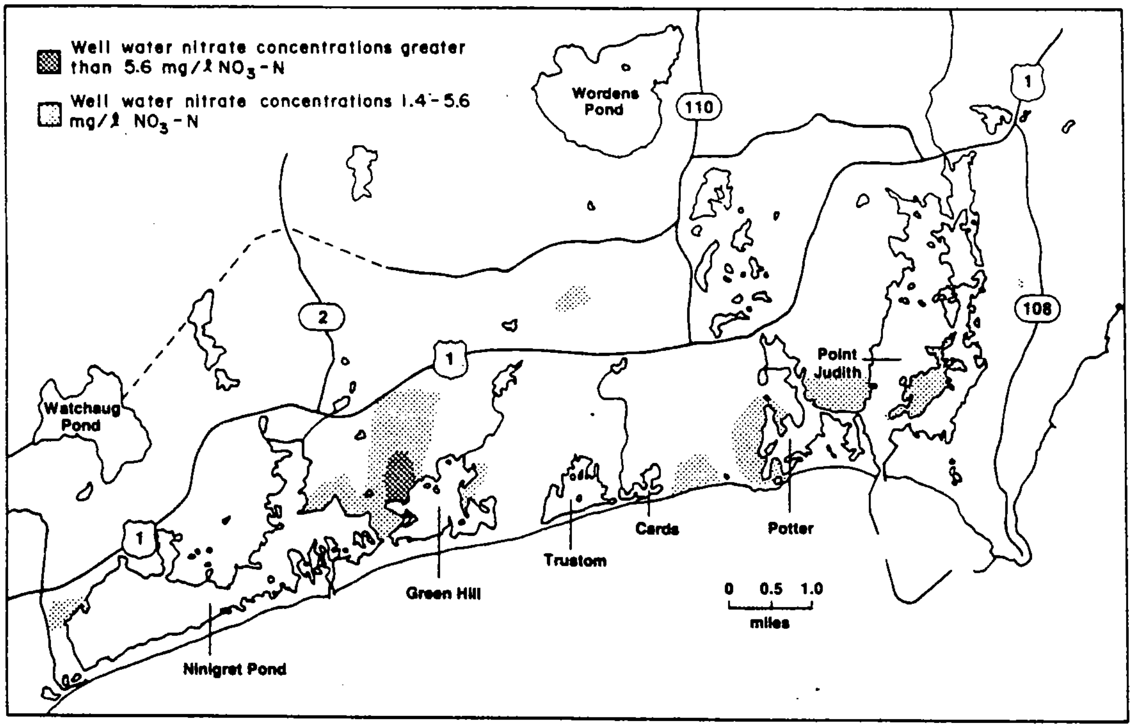
Figure 1. Rhode Island's South Shore salt ponds. The study area includes the ponds from Point Judith west to Charlestown Pond.



Watershed boundaries for the salt pond region. The arrows indicate approximate direction of groundwater flow. Data compiled from U.S.G.S. records by John Grace, 1981.



Median fecal coliform bacteria concentrations in the salt ponds 1980-1981, June through October. Adapted from Nixon et al., 1982.



Distribution of elevated nitrate concentrations in the groundwater of the salt pond region. Concentrations are in milligrams of nitrate nitrogen per liter (ppm) and are mapped from data taken seasonally of groundwater from over 200 residential wells in the region. From Nixon et al., 1982.

Preliminary Estimates of Inorganic Nitrogen Inputs to the Salt Ponds (lbs. N/yr.) (from field measurements by Nixon et al. 1982)

Source	Ninigret Pond	Green Hill Pond	Trustom Pond	Cards Pond	Potter Pond	Pt. Judith Pond
Groundwater	66,920	37,080	9,260	13,910	24.317	59,830
Precipitation on ponds surface	7,400	1,860	680	180	1,420	6,790
Storm runoff	500	230	70	150	140	810
Streams	2,800	2,460	0	570	0	[illegible],000
Block Island Sound	6,000	3,000	0	0	in prep.	in prep.
TOTAL	83,620	42,540	10,010	14,820	25,880	83,440

RELATIONSHIP BETWEEN PRODUCTION AND NUTRIENT LOADING IN A BRACKISH COASTAL POND, SIDERS POND, FALMOUTH MASSACUHUSETTS.

Nina Caraco, Institute of Ecosystem Studies, Millbrook, N.Y.

Coastal ponds are standing bodies of water located close enough to the sea to receive influxes of salt water. On Cape Cod over one hundred coastal ponds mediate the exchange of nutrients between fresh water and the sea and are an important part of the coastal landscape. Numerous dwellings are built on the periphery of coastal ponds and, because human activity in watersheds increase nutrient inputs to the waters they adjoin, this developement is likely responsible for eutrophication of these systems.

The exact relationship between nutrient inputs and eutrophication of brackish coastal ponds is of yet poorly defined. Presently there are relatively few studies on the relationship between nutrient loading and productivity in brackish coastal ponds and, thus, no predictive models of nutrient loading vs. production. If such predictive models were available, they would be extremely useful in the managment of these systems (and in planning development in the region). In this study an attempt is made to determine if empirical models of P loading vs. trophic state developed for fresh waters can be applied directly to brackish coastal ponds. We use trophic data from one brackish coastal pond, Siders Pond, Mass., and compare these measured values with those predicted from models developed in fresh-water lakes.

Trophic State of Siders Pond - Siders Pond is located in the town of Falmouth, Massachussetts. I studied this pond from 1980 to 1983 in order to access the trophic state of this system. Water clarity, phytoplankton chlorophyll and phosphorus concentrations were measured throughout this period (Fig. 1). Further, measurements of phytoplankton production were made during a one year period (1982-83). Finally, benthic metabolism, an additional indicator of lake trophy was estimated as the build up of dissolved inorganic carbon (DIC) in bottom waters. Results from all this data indicate that Siders Pond is eutrophic (Fig. 2) mean surface water chlorophyll concentrations were 15 ug/l, total P concentations averaged 1.2 uM, light extinction coefficient (k) was 2 m^{-1}, dayly production was 860 mg C m^{-2} d^{-1}, and benthic metabolism was 193 mg C m^{-2} d^{-1} (or converting to oxygen, RQ=1, 500 mg O_2 m^{-2} d^{-1}). Thus, Siders Pond trophic status was similar to Lake Erie in 1965-1970.

Nutrient loading to Siders Pond - Siders Pond has a dense population of people in the watershed and this likely leads to high nutrient inputs to the pond. In order to quantify nutrient loading from the watershed I used land-use data and retention coefficients in the watershed of 95% and 50% for P and N, respectively. Other inputs were based on water fluxes and concentrations. Results indicated that P entered Siders Pond primarilly through ground water that was nutrient rich due to sewage inputs (Table 1). I estimate that the total N loading to the lake was 50 g m^{-2} y^{-1}; P loading was roughly 1.3 g m^{-2} y^{-1}.

Relationship Between P loading and Trophic State - There are several empirical models which relate phosphorus loading to trophic state of fresh water lakes. Because this quantitative relationship is known managers can assess the likely impact more watershed developement will have on a lake. Such relationships are unavailable for brackish coastal ponds, therefore, I attempted to see if fresh-water derived models could be applied directly to brackish ponds. Table 2. gives the various trophic state indicators predicted (as functions of P loading) and actual measured values. Results from this comparison demonstrate that trophic state of Siders Pond, at ca 3.5 ppt, can be predicted relatively accurately. Although more comparisons need to be made, this agreement suggests that freshwater derived models, which have been invaluable in managment, may be able to be directly used, or modified slightly, for use in the management of brackish ponds.

Table 1. Annual phosphorus and nitrogen inputs to Siders Pond.

	P	N
	(kg y^{-1}	)
GROUNDWATER	200	6600
PRECIPITATION	5	100
SEA WATER	5	200
RUNOFF	3	12
WATER FOWL	7	50

Table 2. Indices of pond trophic status which were measured and predicted from external P loading to Siders Pond. O2 delpletion is the rate of hypolimnetic oxygen consumption in g m^{-2} d^{-1}, chlorophyll is the average eplimnetic chlorphyll concentration in mg m^{-3}, secchi depth is in m, and production is total water column production in g C m^{-2} y^{-1}.

PARAMATER	MEASURED	PREDICTED	REFERENCE
O_2 depletion	0.55	0.40	Jones and Lee 1982
Summer Secchi	0.8	2.5	Jones and Lee 1982
Chlorphyll	16	19	Vollenweider 1976
Production	315	300	Imboden and Gachter 1975

Fig. 1 Variation in surface water chemistry of Siders Pond from 1980 to 1983. Upper Panel: Total dissolved P, Middle Panel: Chlorphyll concentration, and Lower Panel: Light extinction (1.7/secchi depth).

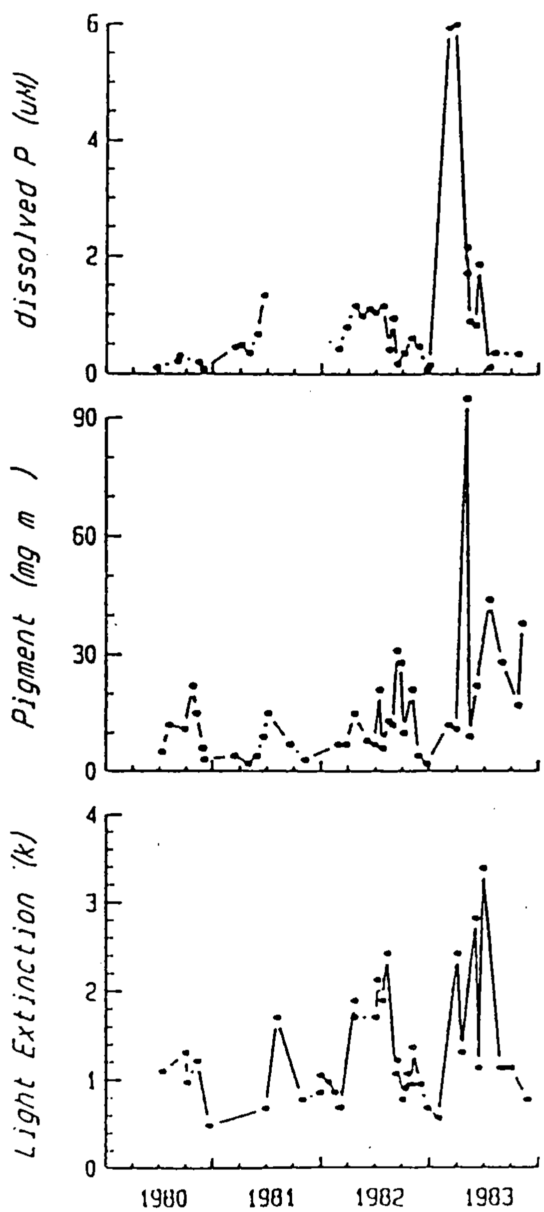
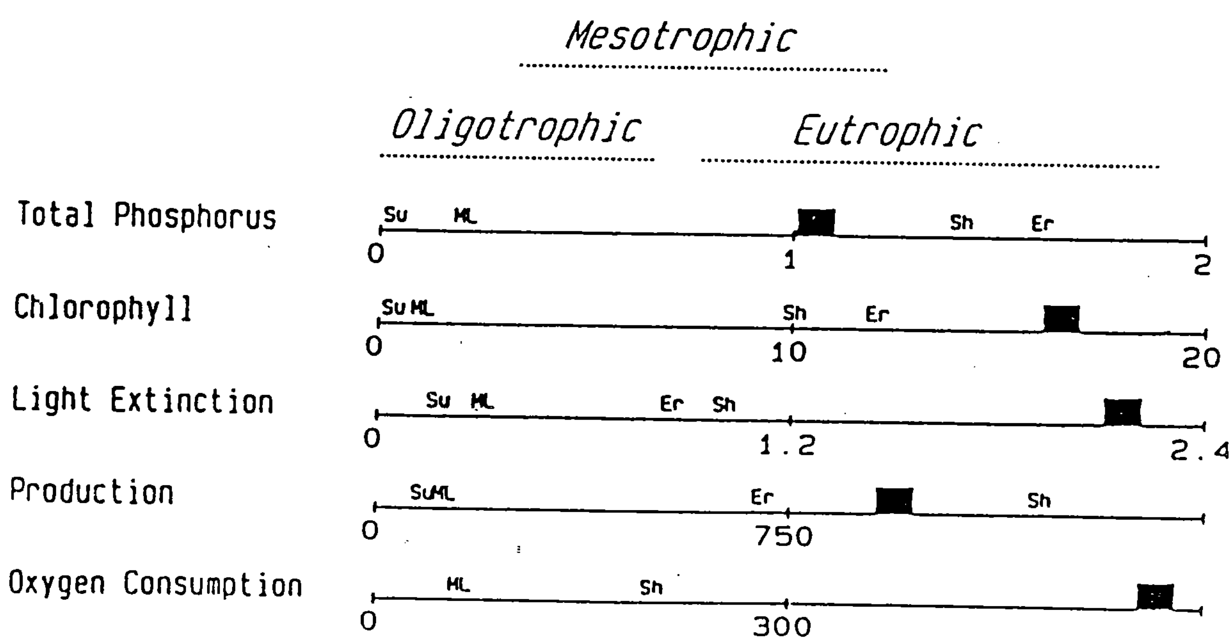


Fig 2. Trophic state of Siders Pond compared to several other lakes and accepted standards (from Wetzel 1975). Siders Pond is indicated by the dark blocks. Data for other lakes shown are from: Mirror Lake (ML); Cole 1982 and Likens 1985;, Shagawa Lake (Sh); Larsen and Malueg 1976, and Lakes Superior and Erie (Su and Er); Schelske 1974.



N AND P INPUTS INTO BUTTERMILK BAY AND ITS WATERSHED

I. Valiela and J. Costa

Boston University Marine Program

Marine Biological Laboratory

Woods Hole, Massachusetts

To evaluate the relative importance of various sources we estimated inputs of nutrients into the watershed and into the Bay itself. Septic systems contributed about half the nitrogen and phosphorus entering the watershed, with precipitation and fertilizer use adding the remainder. Groundwater transported over 85% of the nitrogen and 75% of the phosphorus entering the Bay. Uptake by forests, soils, denitrification, and adsorption intercept two-thirds of the nitrogen, and nine-tenths of the phosphorus that entered the watershed; most nutrients entering the watershed thus failed to reach the Bay. Nitrogen reaching the Bay most likely originates from subsoil injections into groundwater by septic tanks, plus some leaching of domestic fertilizers. Buttermilk Bay water contains relatively low nutrients, probably because of uptake by macrophytes and relatively rapid tidal flushing. Nutrients entering the watershed have a N/P of 6, but passage through the watershed raises N/P to 23, probably because of adsorption of PO_4 in transit. Urbanization of watersheds further increases loadings to nearshore environments, and shifts nutrient loadings delivered to coastal waters to relatively higher N/P, potentially stimulating growth of nitrogen-limited primary producers.

Inputs of nitrogen and phosphorus into the watershed of Buttermilk Bay. N/P expressed by atoms.

	Nitrogen inputs		Phosphorus inputs		
	mol × 10^3 yr^{-1}	% of total	mol × 10^3 yr^{-1}	% of total	N/P
Precipitation onto watershed	1169	33.9	149	23.1	7.7
Septic systems	1466	42.6	247	38.3	5.9
Domestic use of fertilizers	579	16.8	41	6.3	14.2
Agricultural use of fertilizers	231	6.7	209	32.3	1.1
Totals	3445		645		5.3

Table . Measured annual nitrogen and phosphorus inputs into Buttermilk Bay. Values are the product of the average concentration of N and P (Table 1), and annual flows of water from each source, calculated as described in text.

	N inputs		P inputs		
Sources	mol × 10^3 yr^{-1}	% of total	mol × 10^3 yr^{-1}	% of total	N/P
Streams	112	9.6	5.6	11.0	20.0
Groundwater	1000	85.4	38.3	75.3	26.1
Surface runoff	2.2	0.2	0.1	0.2	22.5
Precipitation	54.4	4.6	6.9	13.5	7.9
Waterfowl	2.6	0.2	—		—
Total	1171		50.9		23.0

Inputs and outputs of nitrogen and phosphorus into and out of the watershed of Buttermilk Bay.

	N (mol × 10^3 yr^{-1})	P (mol × 10^3 yr^{-1})	N/P
Inputs into watershed[a]	3445	645	5.3
Outputs from watershed into Buttermilk Bay[b]	1112 (267–1896)	43.9 (11.5–73.9)	25
% Intercepted in watershed	68 (45–92)	93 (89–98)	

[a] This is the total of inputs from precipitation, septic systems, and fertilizer use from Table 4.
[b] This is the sum of inputs to Buttermilk Bay via groundwater and streams from Table 5. Numbers in parentheses are the absolute range of loading based on the lowest and highest estimates of groundwater flow from Moog (1987).

Mean concentrations of nutrients in source waters for Buttermilk Bay used in nutrient budget calculations. N/P expressed by atoms.

	Mean concentration (μM)				
Source	NH_4	NO_3	DIN	PO_4	N/P
Streams[a]	8.6	5.5	14.0	0.7	20
Groundwater[b]	16.2	70	86	3.3	26
Surface runoff[c]	6	21	27	1.2	23
Precipitation[d]	8.7	13.7	22.4	2.9	7.9

[a] Mean annual concentrations from Red Brook.
[b] Data shown in Figure 8.
[c] Data from samples taken in 5 sites around Buttermilk Bay, 18 Aug 86 (average: 6.0 ± 1.1 μM NH_4, 20.6 ± 13.4 μM NO_3, 1.2 ± 0.5 μM PO_4).
[d] Data from Valiela and others (1978), weighted mean concentration of precipitation during a year and a half of collections.

Value Judgement and Science in Coastal Management:
The Case of Anoxia

Arthur G. Gaines, Jr.
Marine Policy Center
Woods Hole Oceanographic Institution

While scientists and other academicians legitimately argue that sound coastal management practices must be based on rigorous scientific and technical information, the importance and role of more or less arbitrary judgements also needs to be recognized. Value judgements are often not overtly identified in setting management goals and sometimes are expressly concealed. For example, a management goal is sometimes to return an impacted water body to an earlier condition, under the unexpressed assumption that the earlier condition was "better". Commonly it is assumed that maintenance of high biological diversity is desirable, although there is no "scientific proof" that this is true. Other examples of value judgements in management are that eutrophication (nutrient enrichment or enhanced productivity) or anoxia (depleted oxygen) or high organic sediments are undesirable. While these are legitimate value judgements and can be the basis of management goals, they are not scientific facts.

One reason for the blurring of value judgement and scientific fact is that scientists sometimes testify on environmental issues without specifically making the distinction themselves. Another is that in the process of setting environmental priorities, agencies such as the U.S. EPA often lump perceived problems of bureaucrats and activists with more technically based issues, such as involving public health.

In this short paper I would like to make the point that anoxia in coastal ponds is improperly perceived by coastal managers, who generally identify the condition as undesirable or even indicative of severe pollution or environmental degradation. While this can be true in some instances, the generalization could lead to expensive and unnecessary mitigation measures in others.

Over the past several years, studies in southern New England have identified several coastal ponds with seasonally reduced oxygen or intermittent or permanent anoxia, typically in their bottom waters (Figs. 1, 2). As research continues it is likely that others will be identified. Generally speaking, these brackish ponds are deeper than 15 feet (5m) and have a sill separating them from the coast, restricting circulation. Under these circumstances oxygen can be completely depleted and hydrogen sulfide can accumulate to very high levels. For example in the Narrow River in Rhode Island (adjacent to Narragansett Bay) hydrogen sulfide accumulates to one of the highest concentrations reported for an arm of the sea. Because these basins are effectively stratified, even local people who frequently use the ponds are often unaware of the anoxia, and during infrequent periods when deep waters are overturned the smell of sulfide can cause considerable public alarm. Sider's Pond in Falmouth, Massachusetts, is probably a similar example.

A study of the sediments in the basins of the Narrow River suggests that bottom waters have been anoxic for over a thousand years—long before significant human impacts could have been present. Judging from changes in the sulfur content of the sediment (Fig 3), we surmise that initiation of anoxia coincided with marine flooding of a fresh water lake formerly occupying this coastal landform. Given the abundant sulfur in seawater, the organic productivity under natural conditions was sufficient to sustain permanent anoxia.

For many years the Narrow River has sustained local fisheries (crabs, shellfish, bass, perch) including one of the major alewife runs in southern Rhode Island. While there has been considerable fluctuation in these fisheries (and in the number of people pursuing them) there is no evidence that anoxia has been detrimental to these uses. The River also sustains many recreational uses, although contamination by fecal bacteria (but not anoxia) has been a problem in recent times.

It is my contention, therefore, that anoxia in certain conditions constitutes a natural feature which managers need not regard as a problem. This is not to say, however, that anoxia cannot be considered a problem or indicative of one. The 1984 anoxic event in Green Pond, Falmouth, Massachusetts, occurred in shallow water and was associated with a massive fish kill (although it is not known which came first).

A related matter is the accumulation of organic sediments in coastal ponds. This material has a consistency sometimes described as "black mayonnaise" and typically smells of hydrogen sulfide. Commonly, high organic sediment is believed to suggest pollution and several coastal communities have proposed removal of these sediments or their burial under clean sand. As indicated in the Narrow River sediment study, this kind of sediment has been deposited naturally in both fresh and brackish basins since glacial ablation over 10,000 years ago.

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Orr, W.L. and A.G. Gaines, 1973. Observations on Rate of Sulfate Reduction and Organic Matter Oxidation in the Bottom Waters of an Estuarine Basin: The Upper Basin of the Pettaquamscutt River (Rhode Island). p. 791-812 In Advances in Organic Geochemistry, Proceedings of the 6th International Congress on Organic Geochemistry, September 18-21, Rueil-Malmaison, France.

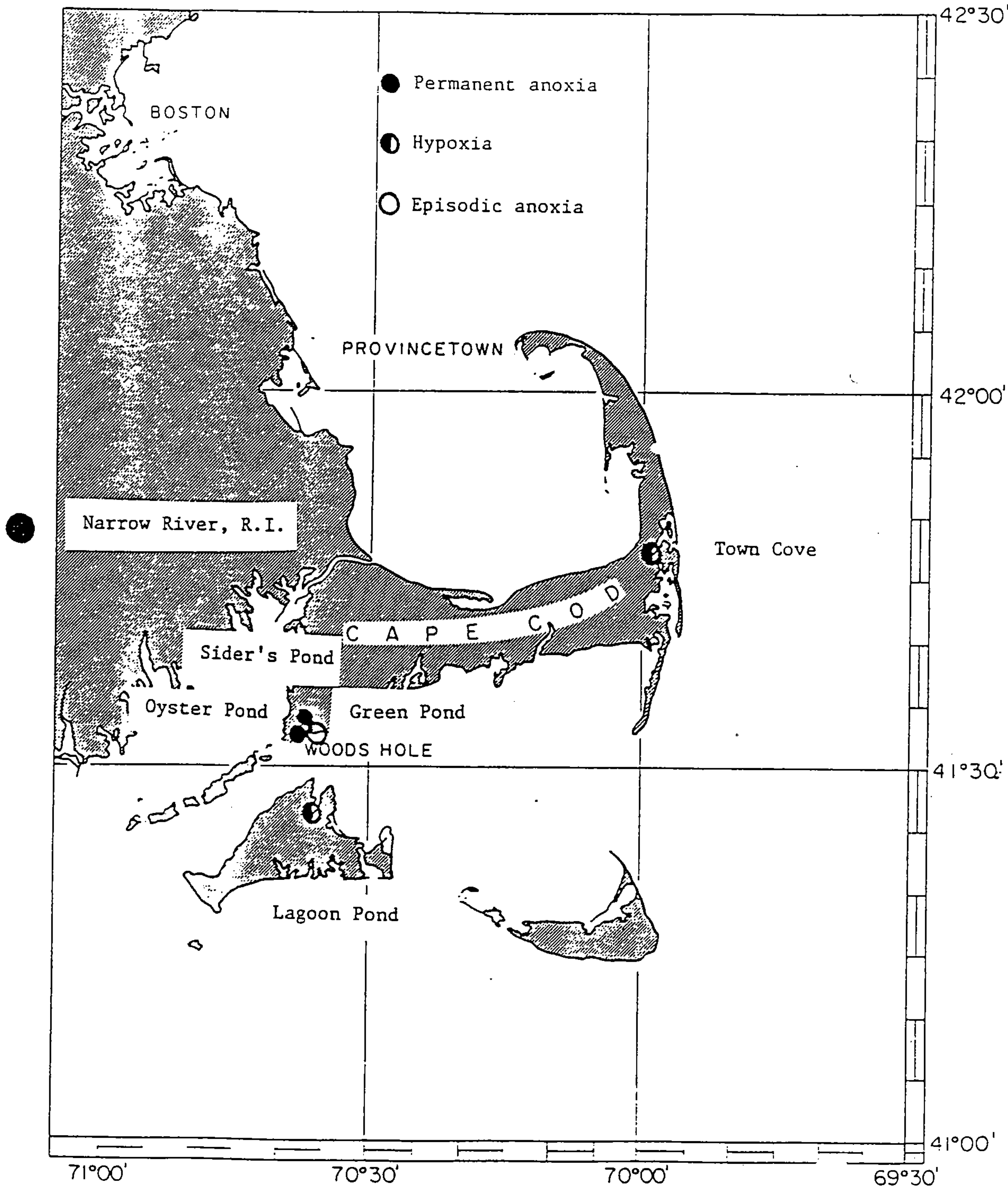


Figure 1. Location of coastal ponds in southern New England containing hypoxic or anoxic bottom waters.

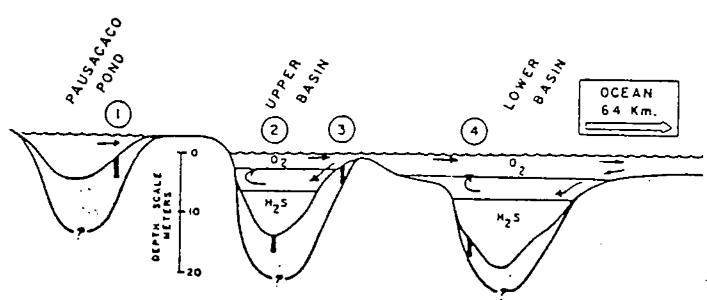


Figure 2. Profile of the Narrow River, Rhode island, showing anoxic bottom waters occupying the estuarine basins (from Orr and Gaines, 1973).

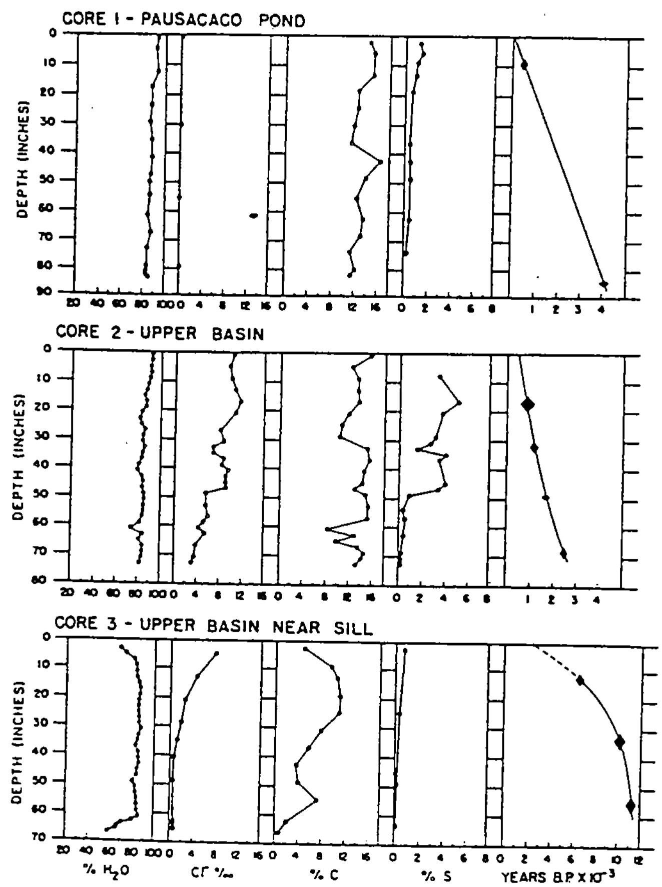


Figure 3. Sediment composition and age in cores from the Narrow River, Rhode Island (from Orr and Gaines, 1973).

ABSTRACT

Five years under sail - experiences with the nutrient bylaws

William B. Kerfoot
K-V Associates, Inc.

In 1982, the Planning Office of the Town of Falmouth commissioned K-V Associates to prepare a cumulative impact procedure for assessing development in vital resource areas. The regions were defined as recharge zones for municipal supply wells, freshwater kettle ponds and salt ponds. The approach involved defining the carrying capacity for the receiving waters based upon best available scientific information and then computing backwards to the nonpoint source contribution from each land surface area to be developed.

Originally, the salt water standards were based upon fresh water guidelines projected from the Dillon-Vollenweider Lake approaches. The past few years have strengthened the basis for the marine water proposed critical level. Fish kill events in Bournes Pond and Green Pond have established the undesirability of exceeding the total mean total nitrogen level of .750 mg/l (ppm). A simple model was also developed to allow evaluation of denitrification from fringe marsh regions of salt ponds.

New challenges appear to lie in dealing with salt pond regions where saturation development will exceed the carrying capacity of the water body. Choices of remedial action are presented and discussed. Should action standards be critical limits or be changed to recreational limits to avoid "designing for failure"?

SCIENTIFIC CERTAINTY VS REGULATORY NEEDS: THE CASE OF NUTRIENT STANDARDS FOR COASTAL PONDS

K. J. Buckland

Planning Board, Town of Falmouth

Falmouth, Massachusetts

Falmouth adopted regulations in 1984 called the Nutrient Loading Bylaw. These regulations require a determination of the levels of both the project site and total recharge area loading of phosphorous and nitrogen compounds into the ground water and/or receiving open water body. The results of these assessments have been used to restrict or negotiate changes in development projects, and as a broader planning tool for managing inland and coastal ponds. However, the nitrogen standards for coastal ponds, listed as a maximum 0.75 mg/l N, has remained controversial. The attempts to resolve differences between scientific certainty and regulatory needs are discussed.

COPY OF ARTICLE 46 AND THE VOTE TAKEN
ON SAME AT THE ANNUAL TOWN MEETING HELD
IN FALMOUTH, MASSACHUSETTS ON APRIL 4, 5, 6, 7, 1988

ART. 46 To see if the Town will vote to amend the Zoning Bylaws and ADOPT a NEW Section 4700 COASTAL POND OVERLAY DISTRICT to read as follows:
SECTION 4700 COASTAL POND OVERLAY:
SECTION 4710 PURPOSE: The purpose of this bylaw is to preserve water quality in Falmouth's coastal ponds and harbors in accordance with adopted plans for both development and preservation, while recognizing that the public sector has an equal role with private sectors in meeting the established goals for swimmable, fishable, and usable water of the highest possible esthetic and natural quality.
SECTION 4720 APPLICABILITY: This bylaw shall apply to all developments listed here:
1. Sub-divisions of greater than five (5) lots.
2. Commercial development requiring Site Plan Review Special Permit.
3. Special permit uses filed in accordance with Section 7300 of these bylaws within 2000' of those other water bodies listed in Section 4740 that do not have defined recharge areas if those developments fall within the recharge areas for coastal ponds as shown on the Official Zoning Map.
SECTION 4730 PROCEDURE:
1. All such development proposals listed in Section 4720 must file an Analysis of Development Impact as specified by section 5342, a. sb. and c. with the application made to the reviewing board.
2. The reviewing board shall make findings regarding the Analysis and may withhold approval if the proposal does not comply with the standards of this bylaw, or, the reviewing board may apply restrictions for mitigation in accordance with.
SECTION 4740 RESTRICTIONS:
Development anywhere within the defined recharge areas shall be restricted in accordance with the following goals and standards;
1. HIGH QUALITY AREAS: Areas designated as High Quality Areas shall be provided the highest level of protection. These estuarine areas support high quality shellfish and finfish habitat, valuable recreational areas including swimming areas, and areas of high scenic and esthetic quality. Those development proposals not meeting the standards for these areas must be permanently restricted as necessary to reduce nutrient loading including such actions as:
a. reduction in number of units, bedrooms, rooms or leasable square footage of a building.
b. improvements to area road drainage, pond circulation and other physical conditions within and around the affected water body. High Quality Area Standard: 0.32 mg/l total Nitrogen within the affected water areas as an average over a year.

HIGH QUALITY AREAS:

Megansett Harbor	Wild Harbor	Rands Canal
Seapit River	Waquoit Bay	Israel's Cove
Perch Pond		

Herring River from Buzzards Bay to Wing Pond
West Falmouth Harbor to Chappaquoit Road
Snug Harbor inland to Nashawena Road
Waterways within the Great Sippewissett Marsh
Waterways within the Little Sippewissett Marsh
Outer Quissett Harbor from entrance inland 1400'
Great Harbor west from Gosnold Road
Great Pond inland from Vineyard Sound to Bourne Street
Bournes Pond from Vineyard Sound to Gayle Avenue
West Branch Eel Pond to Fisher Road
East Branch Eel Pond to Seapit River
Green Pond from Vineyard Sound to Green Harbor Road

STABILIZATION AREAS:

Areas designated as stabilization areas shall allow higher nitrogen loading than High Quality Areas if those loadings when combined with public and private capital improvements in a comprehensive program including: dredging, channel openings, drainage improvements, animal control, upgrading septic systems as necessary, etc. would eventually improve water quality in those areas to a point higher than the established standard. Development proposals exceeding the limit for these areas may be temporarily restricted until such improvements are made. Stabilization Area Standard: 0.5 mg/l total Nitrogen.

STABILIZATION AREAS:

Wild Harbor River	Oyster Pond	Salt Pond
Little Pond	Hamblins Pond	

Green Pond above the Menauhant Bridge
Moonakis River south of Route 28
Eel Pond, east branch between Seapit River and Atwater Drive

3. Intensive Water Activity Areas. Areas designated as Intensive Water Activity Areas are set aside for the most intensive land uses and active water uses where esthetic quality is the principal water quality concern. Water quality standards shall be the least stringent in these areas to accommodate planned growth and development. Intensive Water Activity Areas Standard: 0.75 mg/l total Nitrogen.

INTENSIVE WATER ACTIVITY AREAS:

Great Harbor east of Gosnold Road	Little Harbor, Woods Hole
Eel Pond, Woods Hole	Falmouth Harbor
Inner Quissett Harbor	Fiddlers Cove

Childs River south of Route 28 to Atwater Drive
Green Pond between the south end of Green Harbor Road and Menauhant Road.

Or do or take any other action in this matter. On request of the Planning Board.

AMENDED: That the Town vote to adopt a new section 4700, Coastal Pond Overlay District as follows:

SECTION 4700 COASTAL POND OVERLAY DISTRICT:

SECTION 4710, PURPOSE: The purpose of this bylaw is to preserve water quality in Falmouth's coastal ponds and harbors in accordance with adopted plans for both development and preservation, while recognizing that the public sector has an equal role with private sectors in meeting the established goals for swimmable, fishable and usable water of the highest possible esthetic and natural quality.

SECTION 4720, APPLICABILITY: This bylaw shall apply to all developments listed here:

1. Subdivisions greater than five (5) lots.

2. Commercial development requiring Site Plan Review Special Permit.

3. Special Permit uses filed in accordance with Section 7300 of these bylaws within two thousand (2,000') feet of those other bodies listed in Section 4740 that do not have defined recharge areas if those developments fall within the recharge areas for coastal ponds as shown on the Official Zoning Map.

SECTION 4730, PROCEDURES:

1. All such development proposals listed in Section 4720 must file an Analysis of Development Impact as specified by Section 5342, a., b., c., and d. Sub-sections 1, 2 and 3 with the application made to the reviewing board.

2. The reviewing board shall make all findings regarding the Analysis and may withhold approval if the proposal does not comply with the standards of this bylaw. However, the reviewing board shall not withhold approval of an application for a special permit if the applicant provides measures for the reduction of the nutrient loading rate, on a pounds per acre basis, to a rate below that which would produce critical eutrophic levels in the receiving water body. It shall be the responsibility of the applicant to demonstrate to the Special Permit Granting Authority that the proposed mitigating measures will work as designed, and the Special Permit Granting Authority may require the applicant to demonstrate on an annual basis that said mitigating measures are operating satisfactorily.

SECTION 4740, RESTRICTIONS:

Development anywhere within the defined recharge areas shall be restricted in accordance with the following goals and standards:

1. HIGH QUALITY AREAS: Areas designated as High Quality Areas shall be provided the highest level of protection. These estuarine areas support high quality shellfish and areas of high scenic and esthetic quality. Those development proposals not meeting the standards for these areas must be permanently restricted as necessary to reduce nutrient loading including such actions as:

a. reductions in number of units, bedrooms, rooms or leasable square footage of a building;

b. improvements to area road drainage, pond circulation and other physical conditions within and around the affected water body.

HIGH QUALITY AREA

Megansett Harbor	Rands Canal	Israels Cove
Wild Harbor	Seapit River	Waquoit Bay

Herring River from Buzzards Bay to Wing Pond
West Falmouth Harbor to Chappaquoit Road
Snug Harbor inland to Nashawena Road
Waterways within the Great Sippewissett Marsh
Waterways within the Little Sippewissett Marsh
Outer Quissett Harbor from entrance inland 1400'
Great Harbor west from Gosnold Road
Great Pond inland from Vineyard Sound to Bourne Street
Bournes Pond from Vineyard Sound to Gayle Avenue
West Branch Eel Pond to Fisher Road

East Branch Eel Pond to Seapit River
Green Pond from Vineyard Sound to Green Harbor Road
2. STABILIZATION AREAS: Areas designated as stabilization areas shall allow higher nitrogen loading than High Quality Areas if those loadings, when combined with public and private capital improvements in a comprehensive program, include: dredging, channel openings, drainage improvements, animal control, upgrading septic systems as necessary, etc. would eventually improve water quality in those areas to a point higher than the established standard. Development proposals exceeding the limit for these areas may be temporarily restricted until such
improvements are made.

STABILIZATION AREAS

Wild Harbor River	Oyster Pond	Salt Pond
Little Pond	Hamblins Pond	Perch Pond

Green Pond above the Menauhant bridge
Moonakis River south of Route 28
Bourne Pond north of Gayle Avenue to Route 28
Eel Pond east branch between Seapit River and Atwater Drive
3. INTENSIVE WATER ACTIVITY AREAS: Areas designated as Intensive Water Activity Areas are set aside for the most intensive land uses and active water uses where esthetic quality is the principal water quality concern. Water quality standards shall be the least stringent in these areas to accommodate planned growth and development.

INTENSIVE WATER ACTIVITY AREAS

Great Harbor east of Gosnold Road	Little Harbor, Woods Hole
Eel Pond, Woods Hole	Falmouth Harbor
Inner Quissett Harbor	Fiddlers Cove

Childs River south of Route 28 to Atwater Drive
Green Pond between the south end of Green Harbor Road and Menauhant Road.
4. STANDARDS: Critical Eutrophic Levels for each of the areas shall be as follows:
a. High Quality Areas - 0.32 mg/l total nitrogen;
b. Stabilization Areas - 0.52 mg/l total nitrogen;
c. Intensive Water Activity Areas - 0.75 mg/l total nitrogen.
These shall be considered as averages over a year.
SECTION 4750, EXEMPTIONS: The Special Permit Granting Authority may exempt an application from the requirements of Section 4700 provided that applicant can demonstrate that:
a. Nutrients from the development will not in fact be recharged to the designated water body or public water supply well; or,
b. that the development will not result in any increase in loading of the relevant nutrient.
SECTION 4760: The requirements of this section shall supersede the standards of Section 5342.d.)4.) for salt water.

VOTED: That the Town vote Article 46 as amended.

Passed Monday, April 4, 1988, a unanimous vote, a quorum being present.

A TRUE COPY ATTEST

Carol Martin
Town Clerk of
Falmouth, Massachusetts

QUESTIONNAIRE
CUMULATIVE IMPACT APPRAISAL
FALMOUTH PLANNING BOARD

1. Does the proposed development lie within a

   a. Recharge area of a municipal well?
      (If yes, go to 2)

   b. Recharge area of a coastal pond?
      (If yes, go to 3)

   c. Recharge area of a freshwater kettle hole pond?
      (If yes, go to 4)

2. If the development lies within a recharge area of a municipal well, does the projected nitrogen loading exceed 17.4 lbs N/year per acre?

   a. (# dwelling units) ___ x 24 lbs N/yr = ___ lbs N/yr

   b. (road runoff/miles roadway) ___ x 2 x .19 lbs N/curb mile/day x 365 = ___lbs/yr

   c. (precipitation area in acres) ___ x 1.2 lbs N/acre/yr = ___ lbs/yr

      Total above for total loading = ___ lbs N/yr

   d. (total loading/area [acres] of development) = ___ lbs/yr per acre

      If 2d is greater than 17.4 lbs N/yr per acre), an impact report should be prepared.

3A. If the development lies within a recharge area of a coastal pond, does the projected nitrogen loading exceed the critical loading rate of the receiving water?

   a. Mean depth of coastal pond (in meters) = ___

   b. Flushing rate per year = 365 days/time for complete flushing (days) = ___

   c. Surface area of pond in acres = ___

   d. Surface area of recharge zone in acres = ___

   e. Critical loading rate = $.750 \times (3A.a) \times (3A.b + .54) \times \frac{(3A.c)}{(3A.d)} \times 8.9 =$ ___

   f. Compute total development loading per acre as in 2d.

      If 3A.f is greater than critical loading rate (3A.e), an environmental impact report should be prepared.

3B. For cumulative impact based upon potential lot development:

Existing	(# units) ___ x 24 lbs =	___ lbs N/yr
	Roadway =	___ lbs N/yr
Potential	(# units) ___ x 24 lbs =	___ lbs N/yr
	Roadway =	___ lbs N/yr
Background	1.2 lbs N per acre in recharge area x (# acres in recharge area) ___ = ___ lbs N/yr	

Total above = ___ lbs N/yr in recharge area or ___ lbs N/yr per acre in recharge area

For required N loading in remaining potential developable land:

$$\frac{[\text{lbs N per acre (developed) x acres developed}] \text{ x } [\text{Y lbs N per acre (undeveloped) x acres undeveloped}]}{\text{acres developed + acres undeveloped}} =$$

critical loading per acre for recharge area (3A.e)

Y = ___ lbs N per acre permissible in undeveloped land

The cumulative development loading (would, would not) fall within the desirable loading of ___ lbs N per acre calculated for the undeveloped land to be within critical loading parameters.

4. If the development lies within a recharge area of a freshwater kettle pond, does the projected phosphorus loading exceed the critical loading rate of the receiving water?

   a. Mean depth of kettle pond (in meters) = ___ meters

   b. Flushing rate per year = ___

   c. Surface area of pond in acres = ___ acres

   d. Surface area of immediate watershed area (acres) = ___

   e. Compute critical loading rate:
   L_c = (flushing rate, 4.b) x (mean depth, 4.a) x (.020) x
   $5 \times \frac{(4.c)}{(4.d)} \times 8.9$ = ___ lbs P/acre per year

   f. Compute development loading rate:

   Septic Systems:
   # of units with systems within 300' of shoreline x .75 lbs P/yr = ___ lbs P

   Road Runoff:
   Length roadway (miles) x 2 x .15 lbs P/day x 365 = ___ lbs P/yr

   Watershed Nonpoint Runoff:
   A (see table below) x 5.4 x .28 x (4.d) = ___

   Precipitation:
   Area of development (acres) x .32 lbs P/yr per acre = ___ lbs P/yr

   Total above for total P loading: ___lbs P/yr

   g. $\frac{\text{total loading}}{\text{area of development (acres)}}$ = lbs P/yr per acre

   If 4.g is greater than 4.e, an impact report should be prepared.

Table of R Values for Watershed

% Agricultural + Urban Land Use (A)	Mean Total Phosphorus Concentration in Runoff Water (A Value)
5	.016
10	.018
15	.020
20	.022
30	.028
40	.033
50	.043
60	.053

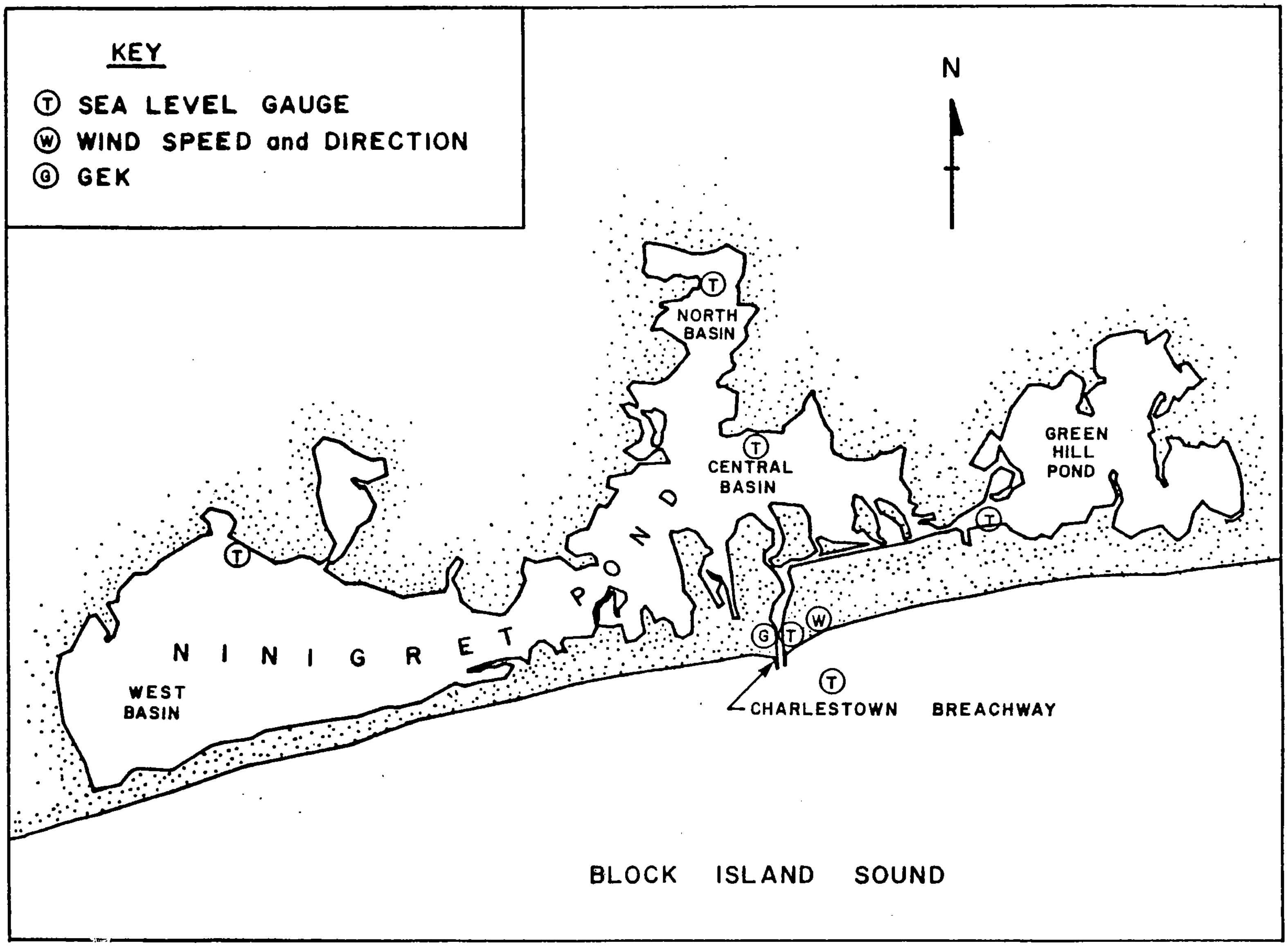
TIDAL EXCHANGE BETWEEN BLOCK ISLAND SOUND AND NINIGRET POND

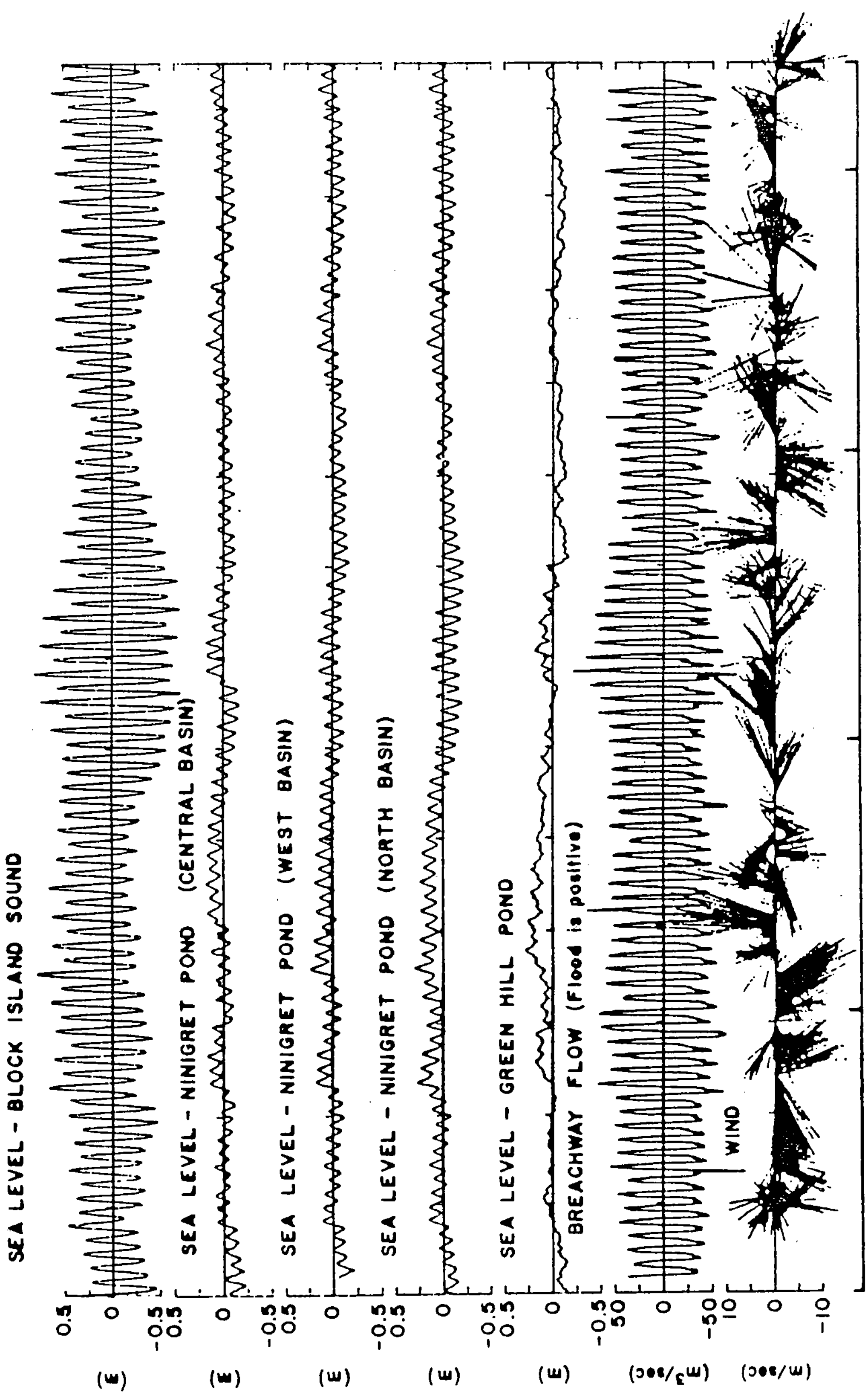
M. L. Spaulding

Ocean Engineering, University of Rhode Island

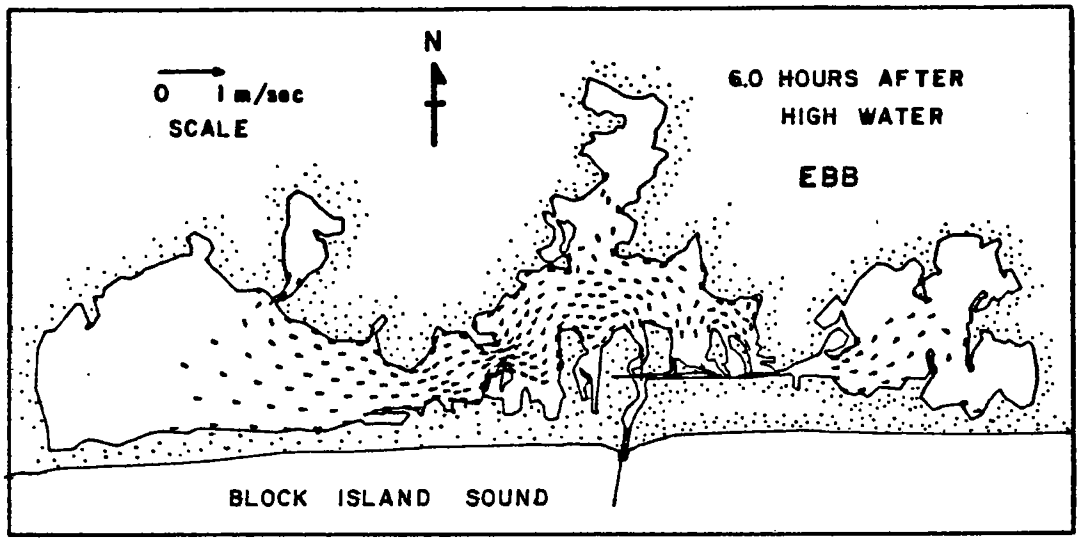
Kingston, Rhode Island

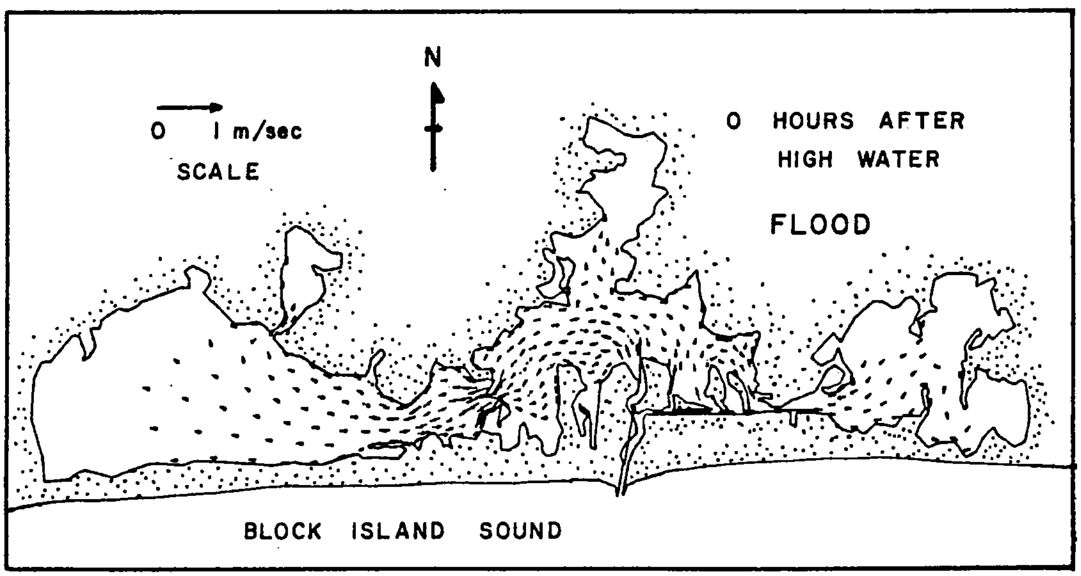
A field program was performed to determine the exchange of water between Ninigret Pond and Block Island Sound (BIS) at tidal and subtidal frequencies. Times series on sea level variations in BIS and Ninigret Pond, spatially integrated velocities across the breachway connecting the two (obtained by a GEK) and wind speed and direction were collected from April 21 - June 3, 1980. A hybrid hydrodynamic model incorporating a simplified one-dimensional approximation for the breachway channel systems and a two-dimensional approximation for the breachway channel systems and triangular grids for the pond proper was used to model the pond's response to ocean forcing. Model predictions were in good agreement with the field data. Both show a factor of 5.5 reduction in the semi diurnal tidal amplitude, and a high water shift of 2.5 hrs., relative to BIS.


KEY
T SEA LEVEL GAUGE
W WIND SPEED and DIRECTION
G GEK
N
NORTH BASIN
CENTRAL BASIN
GREEN HILL POND
WEST BASIN
NINIGRET POND
CHARLESTOWN BREACHWAY
BLOCK ISLAND SOUND

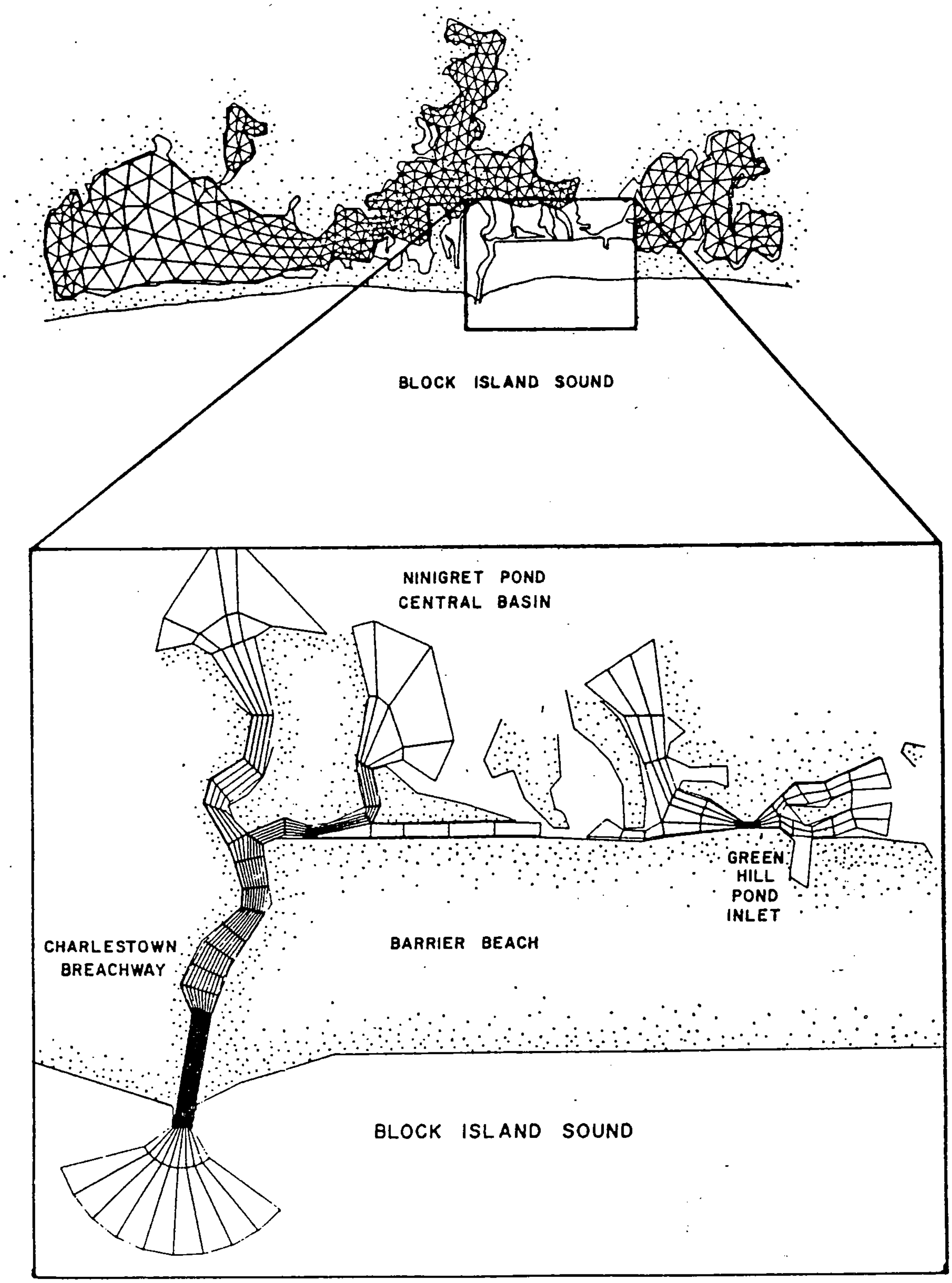


SEA LEVEL - BLOCK ISLAND SOUND
SEA LEVEL - NINIGRET POND (CENTRAL BASIN)
SEA LEVEL - NINIGRET POND (WEST BASIN)
SEA LEVEL - NINIGRET POND (NORTH BASIN)
SEA LEVEL - GREEN HILL POND
BREACHWAY FLOW (Flood is positive)
WIND
(m)
(m³/sec)
(m/sec)
0.5
0
-0.5
50
-50
10
-10
0
10
20
30
40
TIME (DAYS)

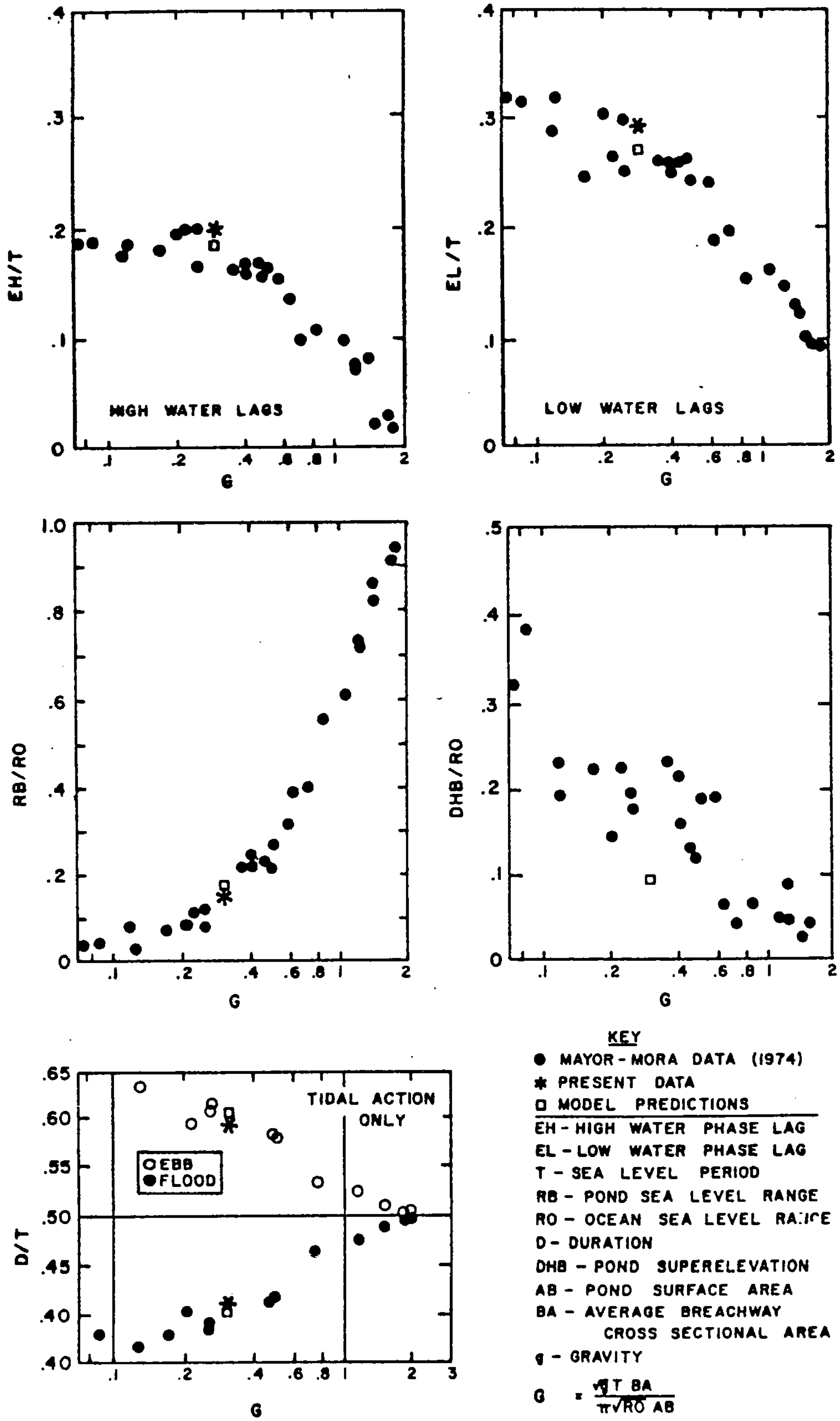

N
0 1 m/sec
SCALE
6.0 HOURS AFTER
HIGH WATER
EBB
BLOCK ISLAND SOUND


N
0 1 m/sec
SCALE
0 HOURS AFTER
HIGH WATER
FLOOD
BLOCK ISLAND SOUND

TRIANGULAR FINITE ELEMENT GRID



INLET HYDRAULICS MODEL NET


HIGH WATER LAGS
EH/T
G
LOW WATER LAGS
EL/T
G
RB/RO
G
DHB/RO
G
TIDAL ACTION ONLY
EBB
FLOOD
D/T
G
KEY
● MAYOR-MORA DATA (1974)
* PRESENT DATA
□ MODEL PREDICTIONS
EH - HIGH WATER PHASE LAG
EL - LOW WATER PHASE LAG
T - SEA LEVEL PERIOD
RB - POND SEA LEVEL RANGE
RO - OCEAN SEA LEVEL RANGE
D - DURATION
DHB - POND SUPERELEVATION
AB - POND SURFACE AREA
BA - AVERAGE BREACHWAY CROSS SECTIONAL AREA
g - GRAVITY
$G = \frac{\sqrt{g}\,T\,BA}{\pi\sqrt{RO}\,AB}$

THE DEVELOPMENT OF COASTAL BAYS AND TIDAL INLETS

Duncan M. FitzGerald
Geology Department
Boston University
Boston, MA

ABSTRACT: Many of New England's bays and coastal ponds owe their origin to glacial processes. This is particularly true on the southward-facing coasts of Cape Cod, Buzzards Bay, Martha's Vineyard, Nantucket, and Rhode Island. Excavation by glacial ice and meltwater streams was responsible for the formation of valleys and ridges in the coastal region. Glaciers also delivered vast quantities of sediment to the coast, Cape Cod being a remarkable example. As the glaciers retreated and meltwater was added to the oceans, the valleys were innundated by the rising seas and glacial deposits were redistributed by wave and tidal processes. Some of these sediments formed barrier spits which built across embayments and straightened the shoreline. The inlets that formed as a result of this process were kept open by currents produced by the rise and fall of the tides.

After their initial development, the coastal bay-barrier - tidal inlet systems were altered by a variety of processes. Continued sea level rise during the past 5000 years (2-3 meters, 6-10 feet) has caused the encroachment of the tides further onto the land. This process by itself would, through time, serve to increase the size of the bays and the volume of water entering and leaving the tidal inlets. However, during the same period, the bays have been filled through a number of different mechanisms, including; 1) landward migration of coastal barriers by overwash processes, 2) currents, 3) fine-grained sedimentation in the intertidal zone, 4) aeolian (wind-blown) sediment transport across the barrier, and 5) the addition of sediment from the surrounding upland region. The net result of these processes has been that most of the coastal bays have decreased in size through time, and some have been cut off from the sea. The closure of tidal inlets occurs when bays reach a critical size, such that, the tidal currents can no longer scour the sand that is dumped into the inlet channel by wave action. At this stage the ponds change to a brackish water environment and the existing plant and animal communities are replaced by less salt tolerant flora and fauna.

The factors that control tidal inlet size include the area of the bay, tidal range, and wave action along the inlet shoreline. Generally, as

tidal range and area of the bay decrease, inlet cross-sectional area also decreases. Shorelines that experience moderate to high wave energy (wave height greater than 1.5m, 5ft) usually have smaller equilibrium cross-sectional areas. The southeastern Massachusetts, Rhode Island, and Nantucket Sound shorelines are characterized by small tidal ranges (less than 1.2m, 4ft), with mostly small coastal bay areas and low wave energy. This physical setting explains the relatively small size of the tidal inlets in this region and why, in many instances, dredging programs and engineering coastal structures are required to keep them open.

INTRODUCTION

Coastal bays come in a variety of sizes and shapes along the New England shoreline (Figure 1). Some are as large as Boston Harbor and Plymouth Bay while others are much smaller such as the Westport River Estuary on the Buzzards Bay coast, or even smaller, Allens Pond in South Dartmouth, Massachusetts. Although these coastal features have varying dimensions and physical settings with different tidal ranges and wave energies, they all have associated with them the same basic components (Figure 2). These components include:

1) an irregular shaped bay with sand shoals and a peripheral marsh,
2) a fronting sandy spit system that protects the bay from open-ocean wave activity, and
3) a tidal inlet that allows the exchange of water between the bay and ocean during the rise and fall of the tides.

Coastal bays are important for both economic and aesthetic reasons. They provide harbors for fishing and pleasure craft, breeding and nursing grounds for many coastal species, and the permanent home of many commercial fish and shellfish. They become much less useful economically when they are closed off from the ocean. The purpose of this paper is to discuss: 1) how bays developed geologically, 2) what factors control tidal inlet hydraulics, 3) how the bays are being modified and finally 4) what the future history of the bays will be.

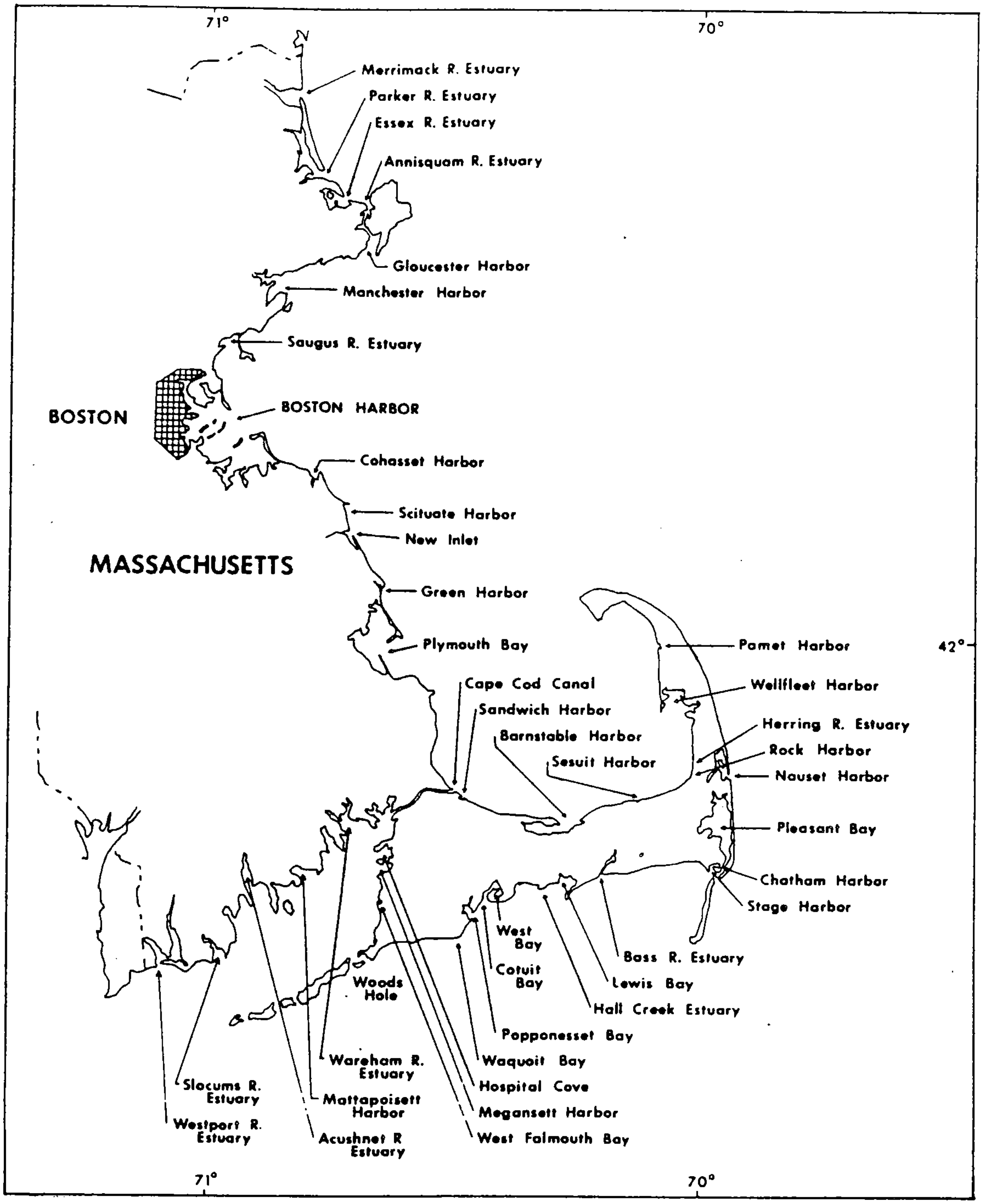


Figure 1. Some of the coastal bays in Massachusetts.

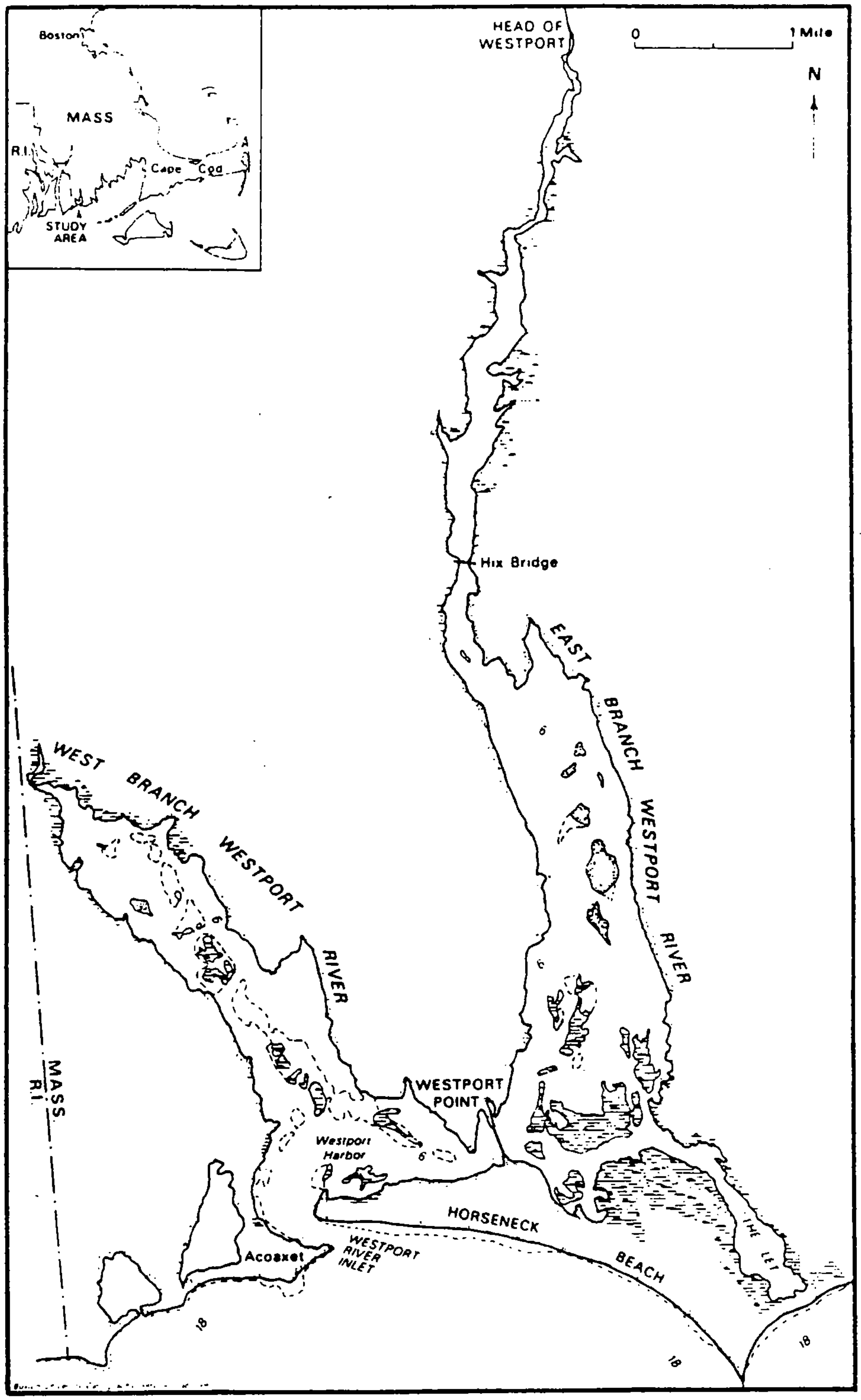


Figure 2. Coastal bays have a variety of sizes and shapes. In spite of differing dimensions, they all, like the Westport River, contain open-water areas, bordering marshes, a barrier beach system, and a tidal inlet.

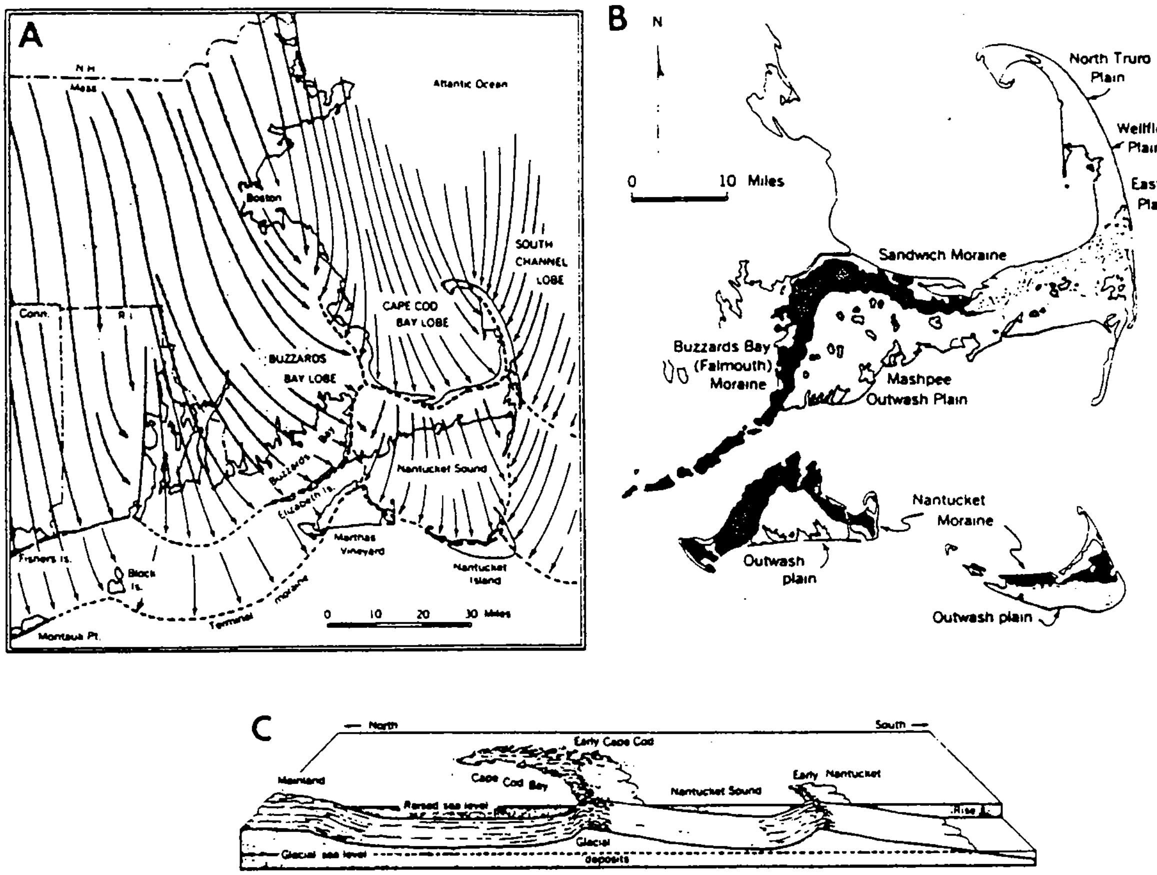


Figure 3. Formation and glacial geology of Cape Cod and the surrounding region.

A. Ice flow directions. Dashed lines indicate ice front still stand positions.

B. Glacial deposits of Cape Cod.

C. Cross-section of Cape Cod depicting glacial deposition and relative sea level positions. (from Strahler, 1966.)

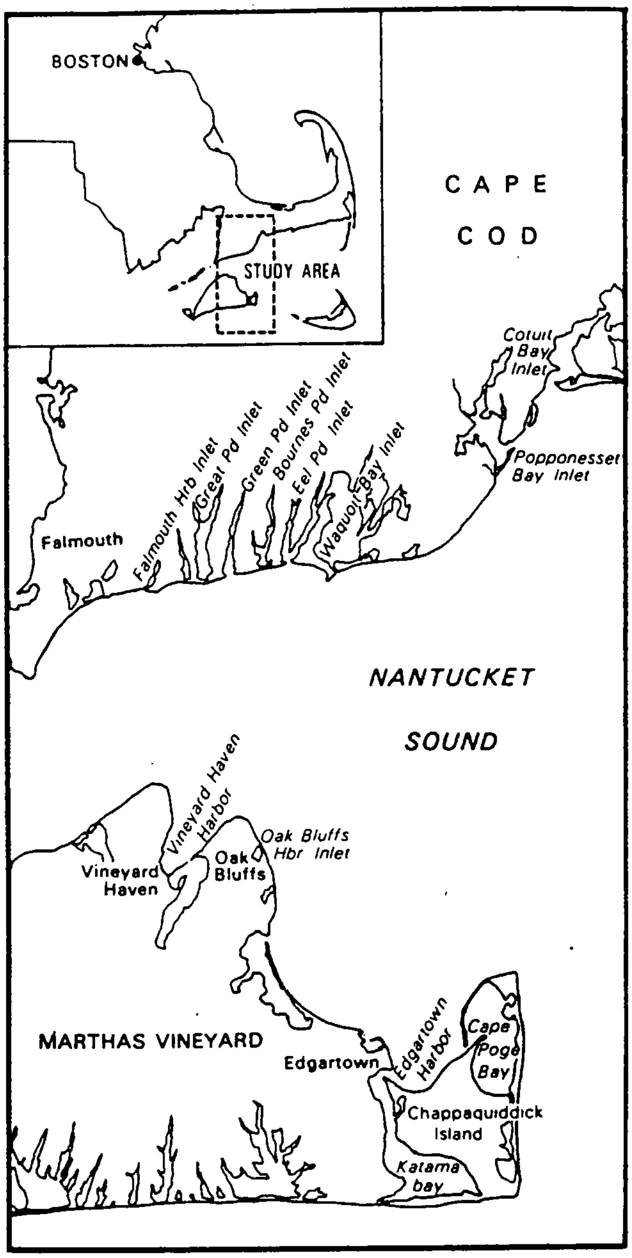


Figure 4. Drowned river valleys formed by glacial meltwater streams incising outwash plain deposits.

DINOFLAGELLATE SPECIES SUCCESSION IN A COASTAL POND:
MECHANISMS AND DYNAMICS

Donald M. Anderson
Bruce A. Keafer

Biology Department
Woods Hole Oceanographic Institution

Coastal ponds on Cape Cod are highly productive embayments, many of which are dominated by dinoflagellates throughout the year. The numerous dinoflagellate species can bloom in a bewildering pattern throughout the year that on first glance appears to be a random succession of species (Figures 1 and 2). However, if the dominant species are grouped together on the basis of their survival strategies and the characteristics of the species within each group compared, the species succession becomes understandable and possibly even predictable.

This study focussed on Perch Pond, Falmouth MA., a salt pond with an average depth of 1.5 m and average salinity near 25 ppt. We initially separated the dinoflagellates into three groups: a)species that form resting cysts during some part of their life history (meroplanktonic); b)strictly planktonic, endemic species that are able to tolerate the large seasonal temperature changes; and c)species that are less tolerant and that thus must rely on advection to re-introduce them into the pond each year.

We examined the cyst-forming species in great detail, focussing on Gonyaulax tamarensis, Scrippsiella trochoidea, Gonyaulax verior, Gyrodinium uncatenum, Gonyaulax polyedra, and Gonyaulax rugosum. Several important characteristics of the cyst germination process for each of these species were determined and then compared in the context of the natural environmental changes in the salt pond. For example, the length of time a newly-formed cyst must remain dormant before it is capable of germination varies between three weeks for S. trochoidea and 2-6 months for G. tamarensis. This means that new cysts formed during a bloom of G. tamarensis in the spring will not be able to re-seed the water column until the fall, consistent with the observed pattern of two temporally separated blooms for that species (Figure 1). The other extreme, S. trochoidea cysts can germinate a few weeks after formation, allowing that species to cycle rapidly between the benthos and the plankton, again consistent with the numerous blooms of that species throughout the year (Figure 1).

An equally-important parameter controlling the succession of cyst-forming species is the temperature "window" for germination. We determined the upper and lower temperatures at which germination of each species would occur, and found low temperature species that could germinate between 4 and 10°C (e.g. G. verior, Figure 3) several that required warm temperatures above 18°C (Gonyaulax polyedra, Figure 4), and several species that were intermediate. We thus had a clear indication of the manner in which cold and warm water species would bloom in a temporal sequence determined by the characteristics of their cysts.

An interesting trend that was found for all cyst forming species tested was that germination occurred at temperatures well below those that were optimal for cell division (as determined in the laboratory). For example, G. tamarensis will germinate in the early spring as the waters warm above 4°C, but cell division is not possible for Perch Pond strains of this species until the water is 6°C, and optimal growth occurs at 12°C. Newly-germinated cells are thus in the water and ready to take advantage of the warming trend as it occurs each spring.

In contrast to the cyst-forming species which seem to have established themselves in distinct temporal niches tied to the seasonal temperature cycle, there are species like Heterocapsa triquetra and Dinophysis acuminata which are present in the pond throughout the year, sometimes dominating the phytoplankton when temperatures are very cold as well as later in the year when the water is warm (Figure 2). When the growth rate of these species is measured at different temperatures in the laboratory, it is clear that they are eurythermal - tolerating a wide range of temperatures. In the case of H. triquetra, cell division is relatively rapid between 2 and 27°C, and the cells easily survive 0°C. Clearly, species like these do not need a cyst stage to survive through the winter.

The final survival or growth strategy is exemplified by Prorocentrum micans, which does not tolerate cold temperatures and does not have a cyst, but does bloom periodically in Perch Pond. Since there are long intervals when this species is not seen in the pond even when a lot of water is examined, it clearly must be introduced by tidal advection, blooming in the pond only when it has been introduced in sufficient quantity from nearshore waters to take advantage of favorable growth conditions.

With the type of information described above, we can look back at the complex pattern of dinoflagellate blooms in Perch Pond (Figures 1 and 2) and recognize that long maturation times for cyst formers result in spring and fall blooms separated by a summer when those species are not in the plankton (e.g. G. tamarensis, G. verior), that as the waters warm, species will germinate in a pre-determined succession depending on the lower limit of their temperature threshold, that some non cyst-forming species are present throughout the year because of their temperature tolerance, and that other opportunistic species only bloom when they are introduced to the pond as an allochthonous population from coastal waters. Although the magnitude of all of these blooms is dependent on environmental and nutritional factors that can vary considerably year-to-year, the temporal succession of the dinoflagellate species does follow an understandable and even predictable pattern.

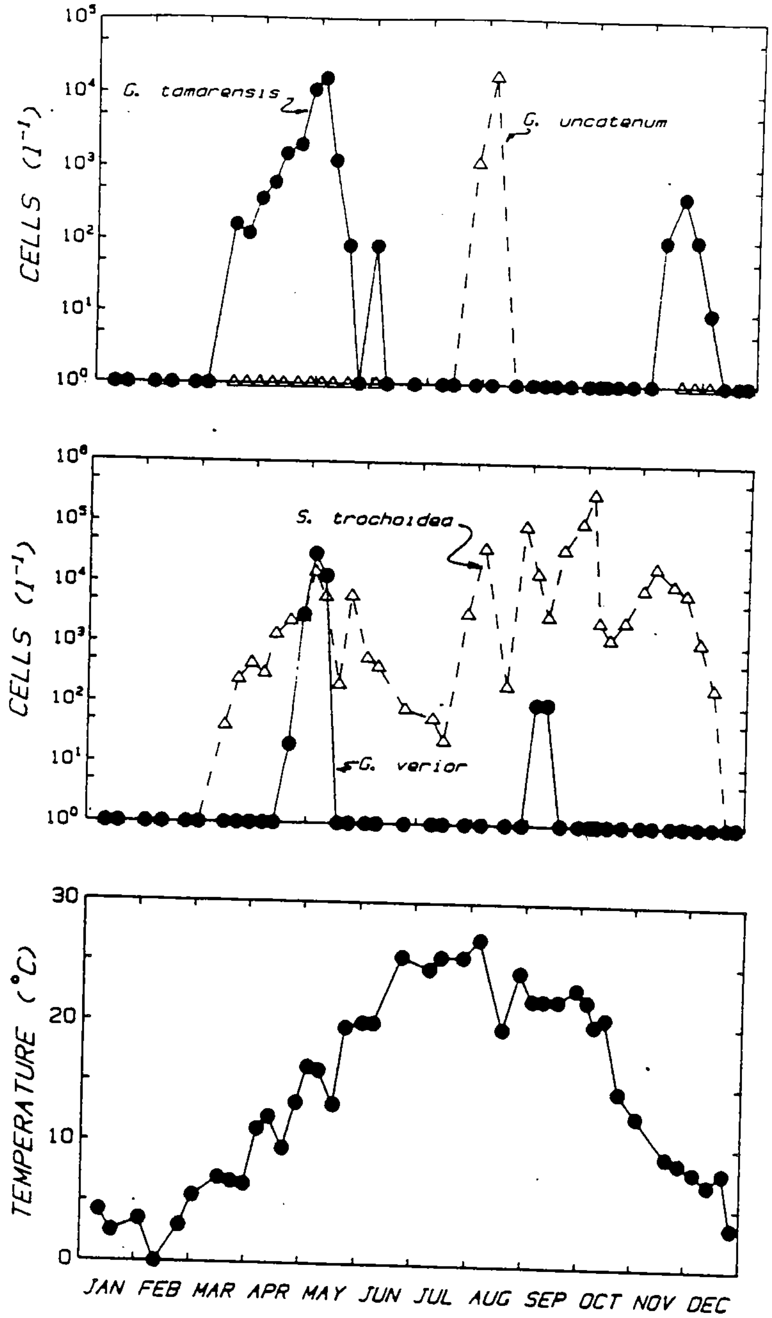


Figure 1. Blooms of cyst-forming dinoflagellates in Perch Pond. Some, like G. tamarensis have a long maturation period after cyst formation and thus are forced to bloom at two discrete times of the year. Other species, like S. trochoidea, mature quickly and thus can alternate between the plankton and the benthos numerous times each year, consistent with the frequent blooms of this species.

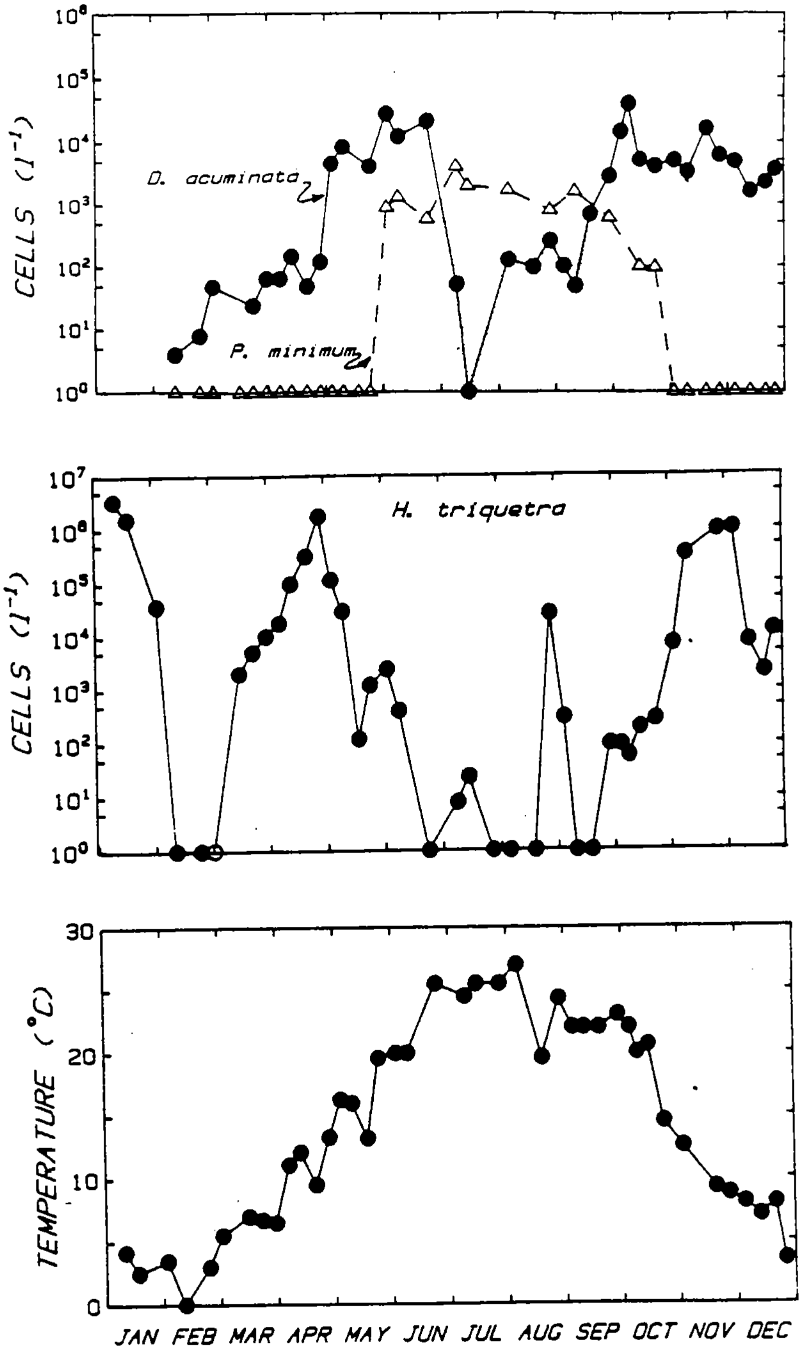


Figure 2. Blooms of non-cyst forming dinoflagellates in Perch Pond. In this figure, eurythermal species such as D. acuminata and H. triquetra are present throughout the year, clearly surviving without the need for a cyst stage. Prorocentrum minimum is present only during the warm summer months, relying on advection for its introduction to the Pond.

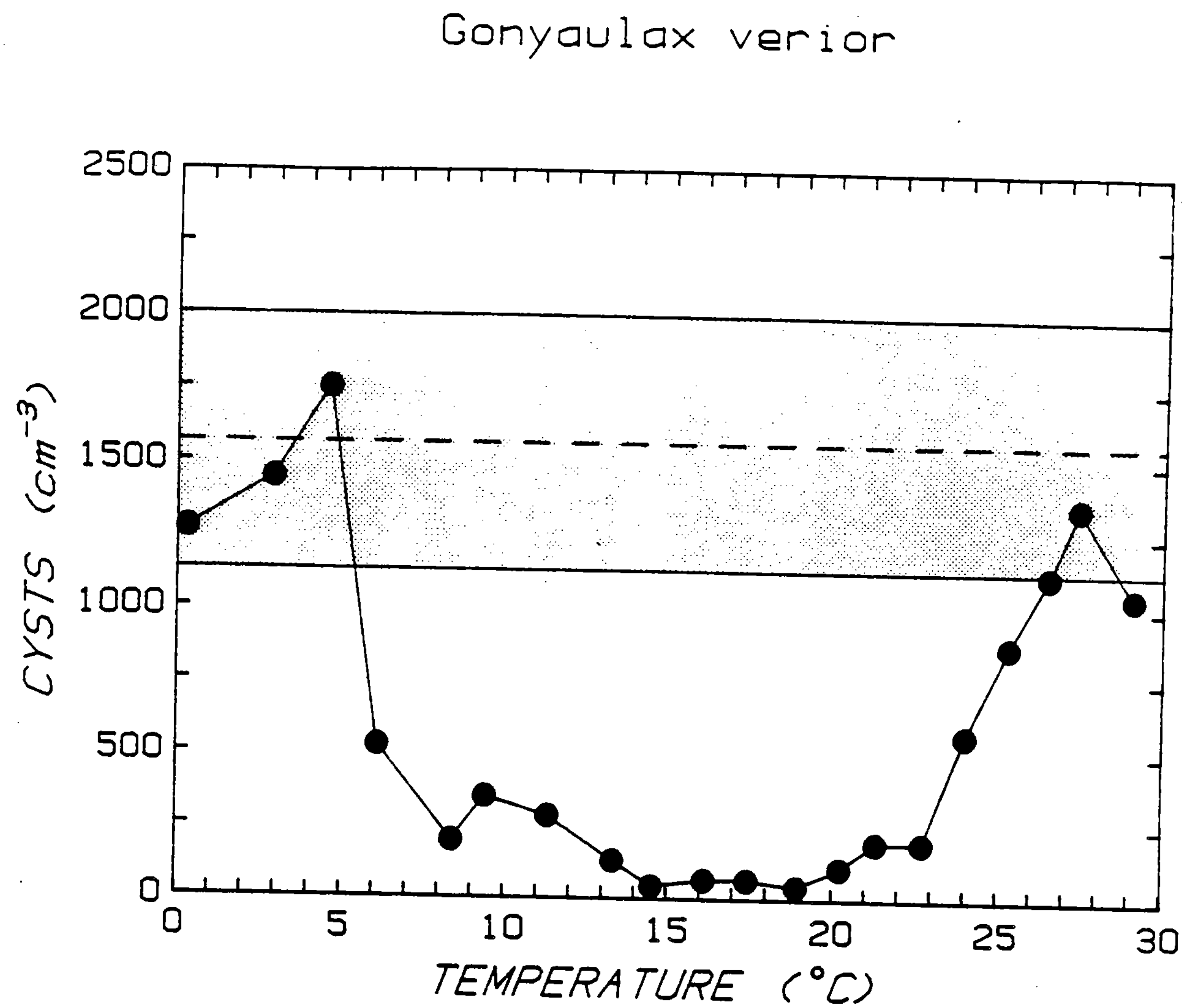


Figure 3. Temperature "window " for germination of Gonyaulax verior cysts. The shaded area represents the initial concentration of cysts in a sediment sample that was then incubated at each of the indicated temperatures. Counts after 6 weeks show the temperature that permitted germination - between 5 and 24°C for this species.

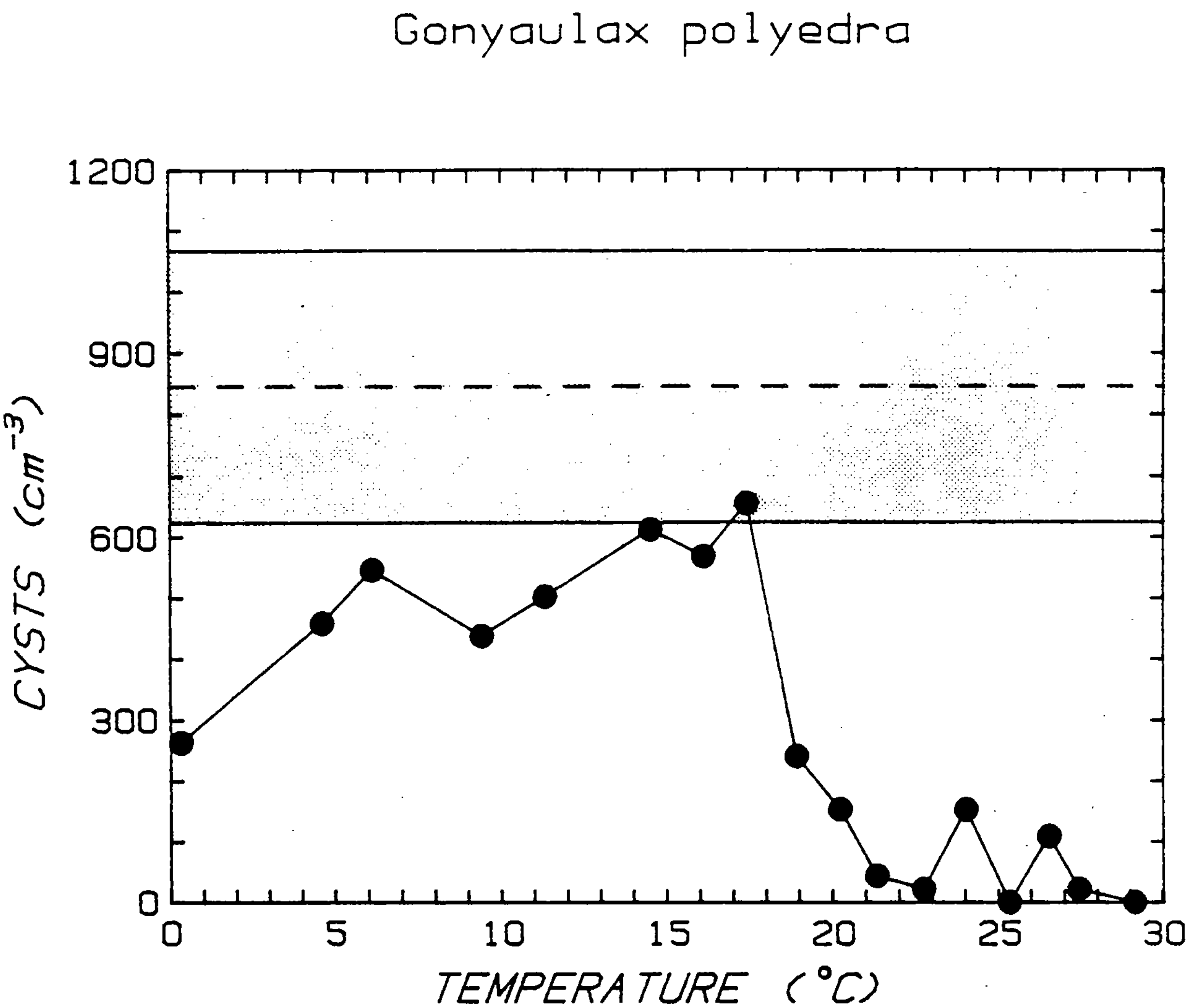


Figure 4. Temperature window for Gonyaulax poledra cyst germination. This is a warm-water species, with germination only possible above 17°C. The shaded area represents the initial cyst concentration. Note that the deviation from the initial counts at low temperatures is due to mortality, not germination.

NITROGEN BUDGET OF A CRANBERRY BOG

J. M. Teal and B. L. Howes
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Cranberry bogs are the most extensive type of agriculture in southeastern Massachusetts. Bogs are usually associated with streams which flow directly into coastal ponds and embayments. Bogs are fertilized throughout the growing season and are occasionally flooded and drain into these streams. Portions of the bogs function as permanent freshwater wetlands and can be responsible for significant amounts of nitrogen retention release. So cranberry bogs have the potential to be either a source or a sink for nutrient runoff and may contribute to or aid in the control of coastal eutrophication. We have continuously measured inputs and outputs of water and nutrients from one bog system throughout one year. We have measurements of nitrogen exchanges between the water and sediments of the bog creeks and vegetated surface. We also have measurements of dissolved nitrogen concentrations in porewater. With these data and data on plants, fertilization, and harvest we have constructed an annual nitrogen balance for a cranberry bog system.

EAST COAST EELGRASS POPULATIONS: LATITUDINAL TRENDS AND HEALTH ASSESSMENT

F. T. Short, E. C. Brainard and J. Wolf
Jackson Estuarine Laboratory
University of New Hampshire
Durham, New Hampshire

We designed an experimental program to examine eelgrass populations latitudinally in National Estuarine Research Reserve sites from New Hampshire to North Carolina, hypothesizing that eelgrass growth, abundance, and plant morphometrics show latitudinal variations distinct from the health of plant populations related to coastal pollution and wasting disease. Sites were selected at each of four Research Reserves for similar environmental characteristics of light, mean depth, temperature, current velocities and sediment type, while factors of salinity and tidal variation differed between sites. Eelgrass samples collected in July at all sites showed strong trends with latitude. Eelgrass leaf abundance and shoot size were greatest in the north and showed a consistent decrease, the minimum occurring in North Carolina. Eelgrass health did not show latitudinal trends. Rather, pollution levels and the extent of wasting disease at each Research Reserve site combined to determine plant health. Waquoit Bay eelgrass showed evidence of light stress, the apparent result of nutrient pollution. All sites showed evidence of the expanding eelgrass wasting disease, with the greatest impact in Great Bay, New Hampshire.

The eelgrass research, funded by NOAA, was conducted at Rachel Carson/Beaufort, North Carolina, Narragansett Bay and Waquoit Bay National Estuarine Research Reserve sites and in eelgrass mesocosms at the Jackson Estuarine Laboratory, UNH. Parallel work in Great Bay, New Hampshire was conducted simultaneously under separate funding from the New Hampshire Fish and Game Department and the New Hampshire Waterfowl Association.

Map 1. Composite map showing the Great Bay, New Hampshire and the National Estuarine Research Reserve sites: Rachel Carson/Beaufort, North Carolina; Narragansett Bay, Rhode Island; and Waquoit Bay, Massachusetts.

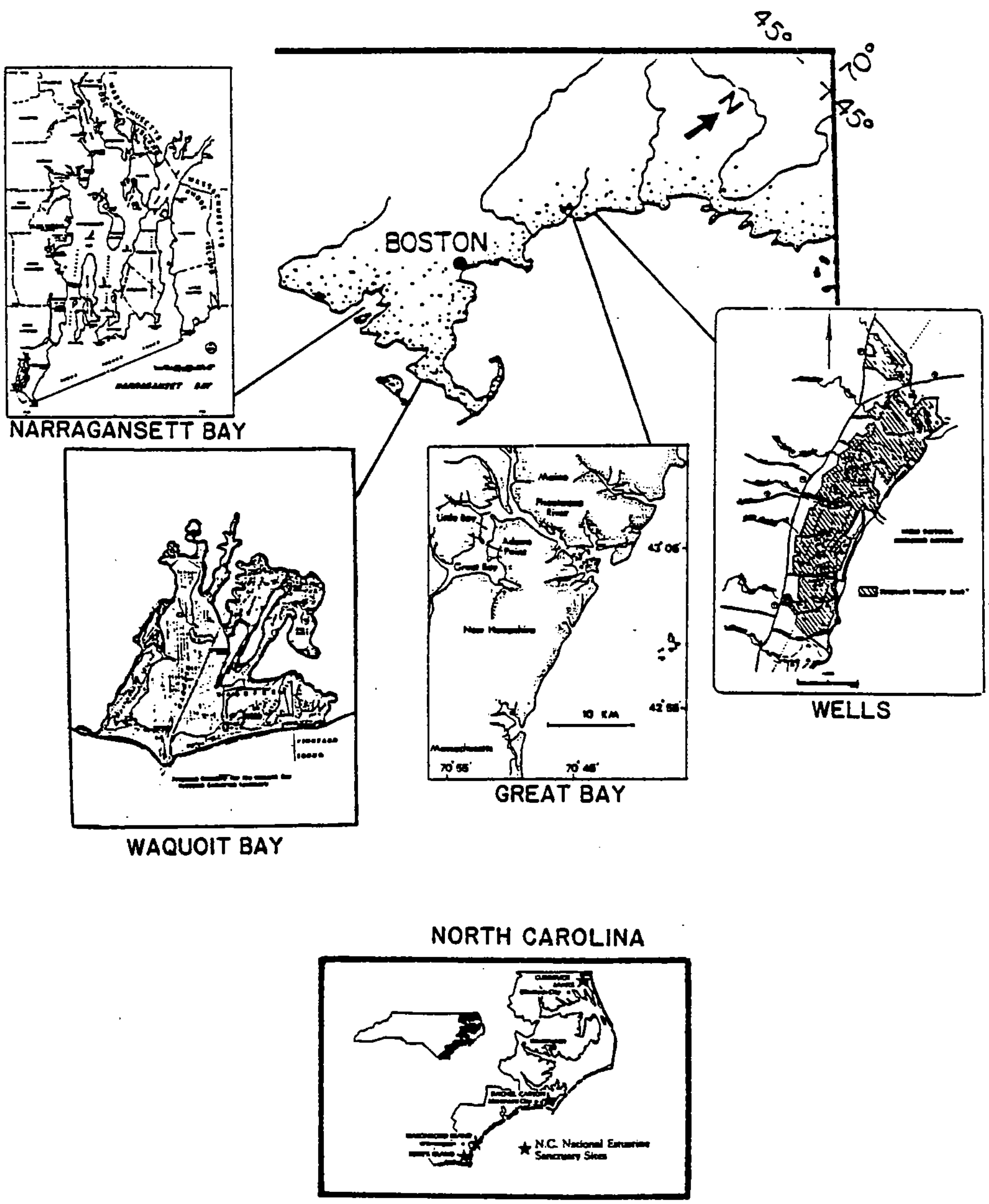


Figure 2. Eelgrass leaf biomass samples were taken at four locations along the east coast of the U. S. in July 1987, at Great Bay, New Hampshire and in the National Estuarine Research Reserves at Waquoit Bay, Massachusetts, Narragansett Bay, Rhode Island, and Beaufort, North Carolina. Eelgrass leaf biomass was measured on triplicate 1/16 m^2 quadrants collected at each site. Eelgrass biomass is plotted as the mean for each site and ± 1 standard deviation. The sites are indicated as: GB (Great Bay), WB (Waquoit Bay), NB (Narragansett Bay), and NC (North Carolina). These data show a notable decrease in leaf biomass from north to south.

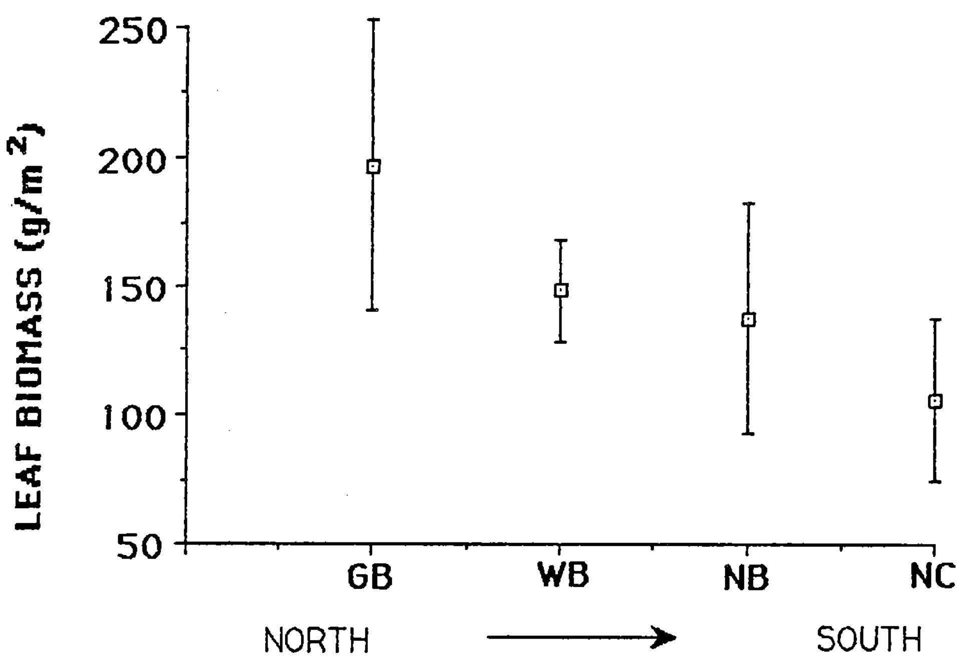


Figure 3. Eelgrass leaf size: leaf length and leaf width. Eelgrass samples were taken from Great Bay, New Hampshire and the National Estuarine Research Reserve sites at Waquoit Bay, Massachusetts, Narragansett Bay, Rhode Island, and Beaufort, North Carolina. At each site, eelgrass plants were collected from 1/16 m^2 quadrants with 3 replicates taken at each location. Length of the longest leaf per shoot and its leaf width were measured for ten plants per sample. The sites are indicated as: GB (Great Bay), WB (Waquoit Bay), NB (Narragansett Bay), and NC (North Carolina).

From the most northern location (GB) to the southernmost (NC), a decrease was observed in the mean leaf length, but there was no obvious relationship for leaf width. Analysis of these data suggest that the change in leaf biomass from north to south may result from a limitation in plant size.

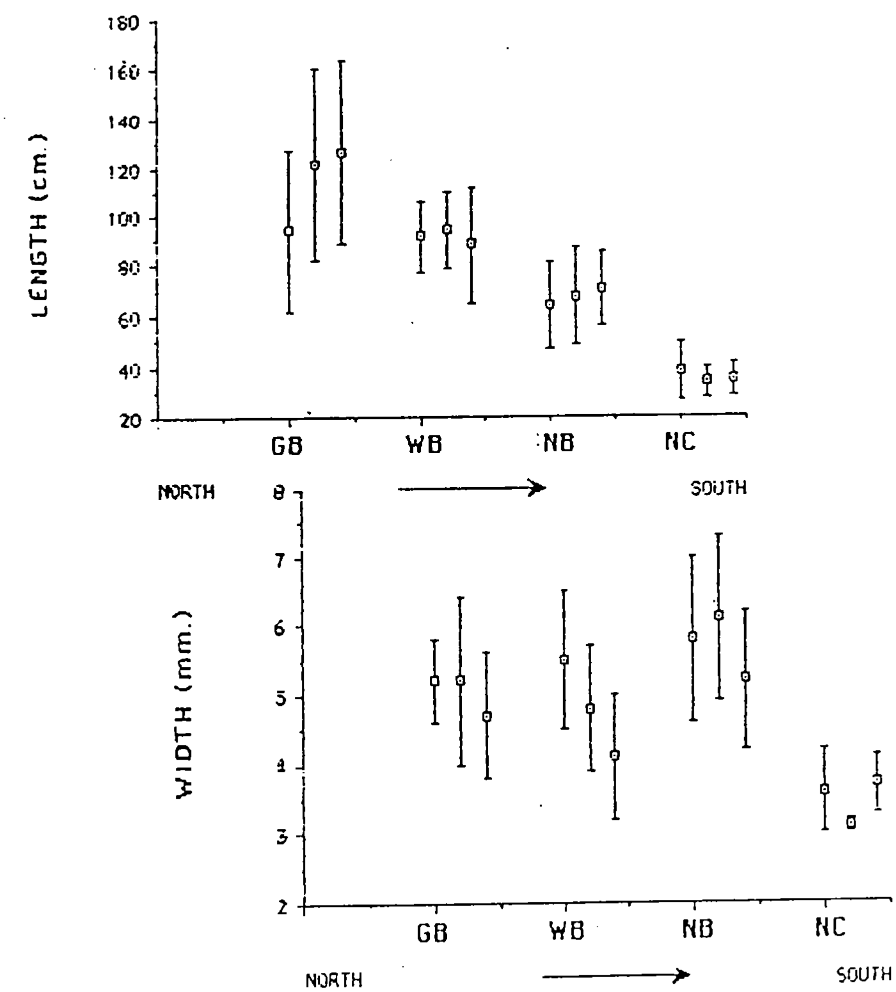
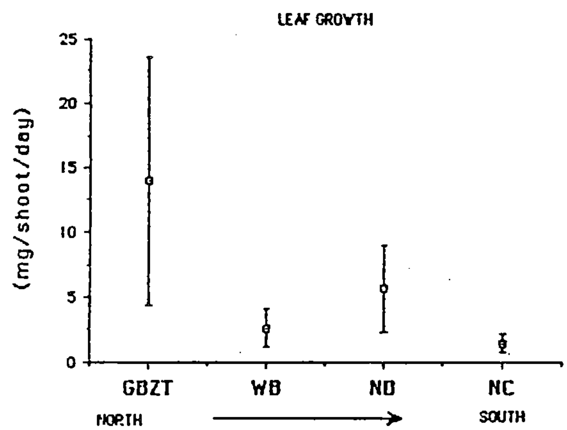
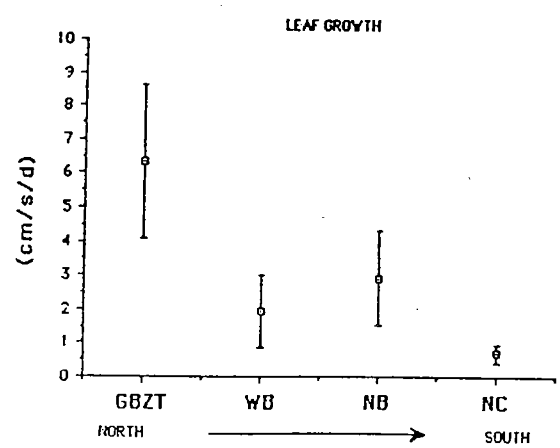


Figure 4. Eelgrass leaf growth: milligrams per shoot per day and centimeters per shoot per day. Twenty to thirty eelgrass shoots were marked for growth at Great Bay, New Hampshire, and at each National Estuarine Research Reserve site, Waquoit Bay, Massachusetts, Narragansett Bay, Rhode Island, and Beaufort, North Carolina.

The plants were marked <u>in situ</u> by means of a 21 gauge needle inserted through the leaf bundle at a location just below the end of the leaf sheath. After 10 - 14 days, the marked plants were collected and measured. Leaf growth was determined by measuring the distance between the pin hole in the sheath and the hole in each individual leaf.

Measurements were made for each leaf of each shoot. New growth was recorded in terms of both weight and length. The means for all shoots from a location are shown.





RECENT AND HISTORICAL CHANGES IN ABUNDANCE OF EELGRASS (ZOSTERA MARINA L.) IN WAQUOIT BAY, MA.

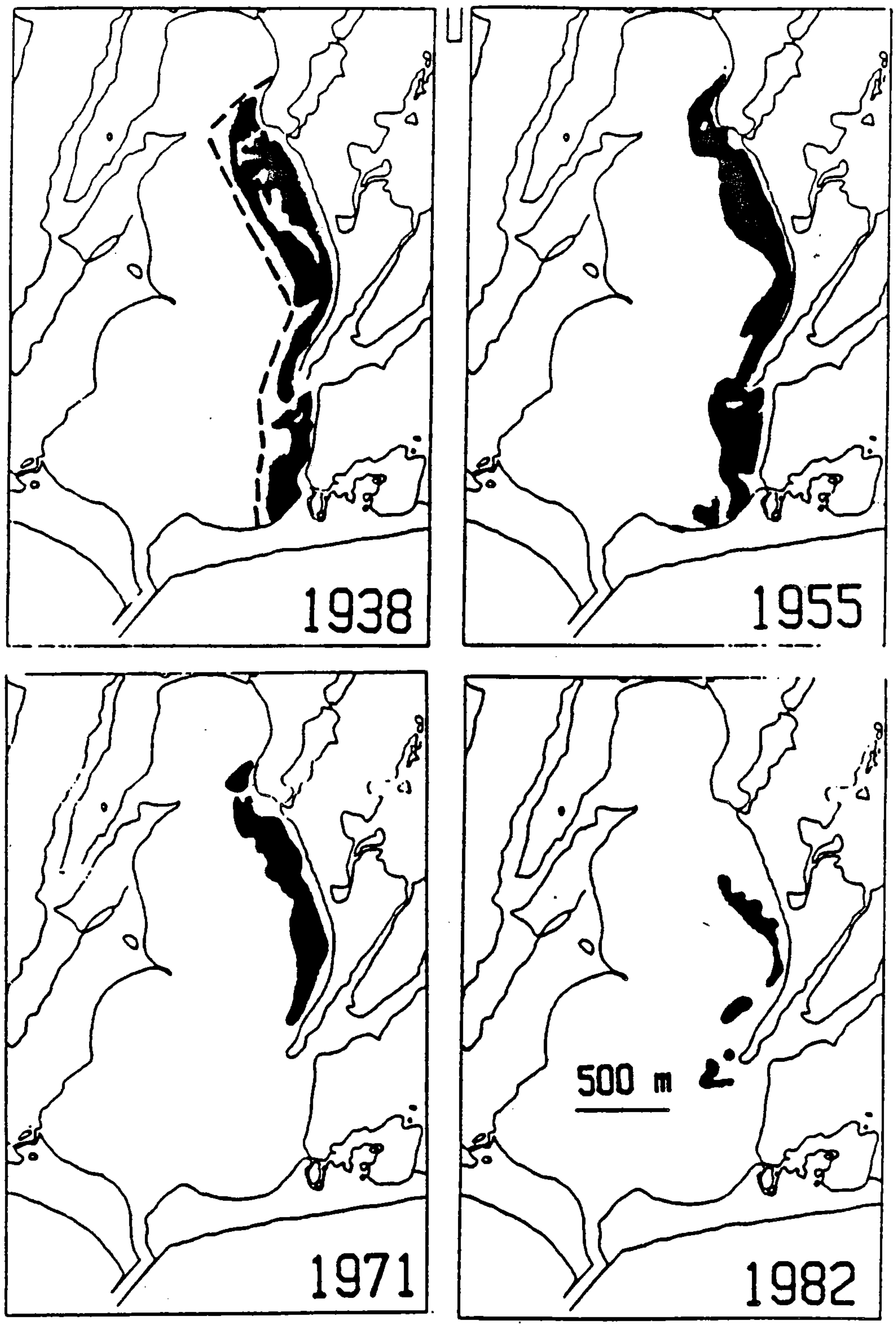
J. Costa

Boston University Marine Program

Marine Biological Laboratory

Woods Hole, Massachusetts

Changes in eelgrass (Zostera marina L.) abundance in Waquoit Bay, a lagoon on Cape Cod, were documented with aerial photographs, sediment cores, and first-hand accounts. Because eelgrass seed deposition reflects local abundance, seeds in sediment cores were used to document historical changes in eelgrass cover. Four cores were dated using the 1931-32 wasting disease seed decline and other biogenic markers. Seed profiles in near-surface sediments coincide with changing eelgrass cover in the photographic record. Carbon stable isotope ratios ($\delta^{13}C$) in core sediments are also generally consistent with historical changes. Eelgrass declined in Waquoit Bay during 3 periods in this century: during the wasting disease, ca. 1904, and during 1965-75. The 1904 decline coincides with a report of an earlier outbreak of disease. The most recent decline (>80% loss) coincides with human disturbance and nutrient loading. Today dense layers of benthic drift algae cover most substrate where eelgrass once grew. The primary mechanism of this decline appears to be decreased light availability to eelgrass because of increased water turbidity and increased algal epiphytes from added nutrients.



Distribution of eelgrass beds within Waquoit Bay from 1934 to 1984, mapped from aerial photographs. Only the area to the east of the dotted line was mapped.

CHANGES IN THE WAQUOIT BAY FISH COMMUNITY OVER A TWENTY YEAR PERIOD.

L. A. Deegan, S. Saucerman and D. Basler
Department of Forestry and Wildlife Management
University of Massachusetts, Amherst, Massachusetts

We have examined changes in the fish structure of Waquoit Bay over the last twenty years by comparing new data to a 1966 survey. Although we have not yet finished a full years sampling we have observed some striking changes in fish abundances. Only 5 species increased in abundance; all the rest decreased. The most dramatic change is a 6000% increase in rainwater killifish. This increase may be due to its preference for filamentous algae as spawning and feeding areas. Large areas of Waquoit are now covered in filamentous algae presumably as a result of nutrient loading. Of the fish that decreased in abundance, fish with an estuarine dependent life-history declined the most. We believe this is because of the decline in eelgrass habitat. We suggest that eutrophication has caused changes in the quality of the estuary as a nursery and feeding area.

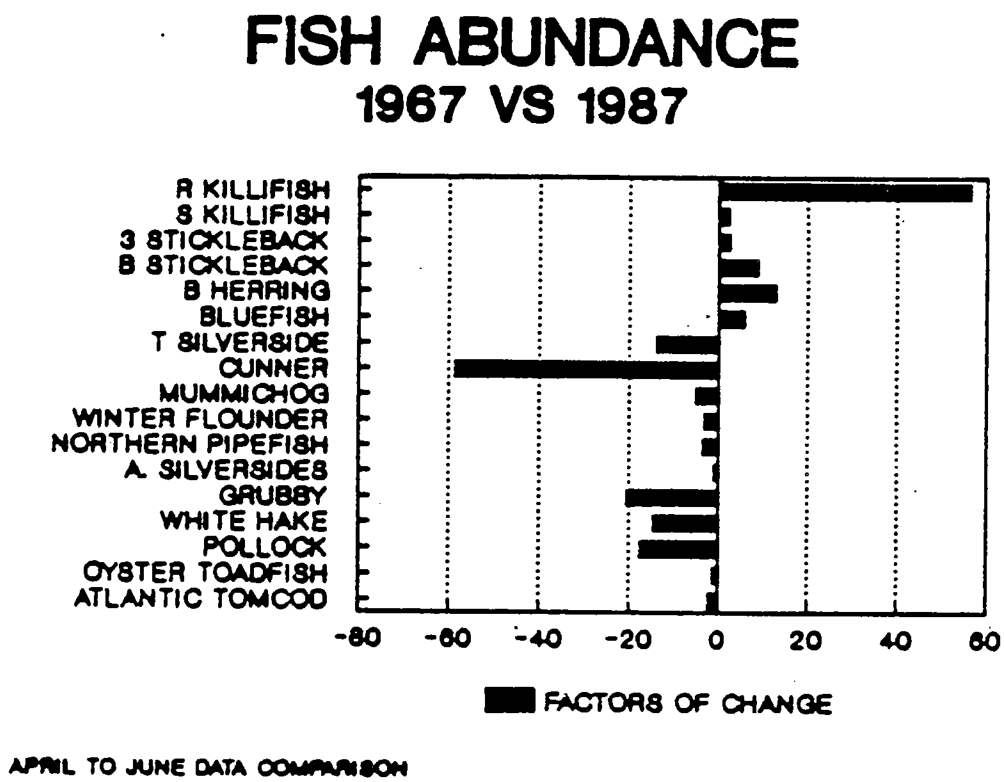


Figure 1. Twenty year change in fish abundance in Waquoit Bay, Ma. Graph is the ratio of the 1966 abundance to the 1987 abundance based on total number of fish caught in sienes and trawls for the April-June period. A 10 factor of change is a 100% change in abundance.

MAPS AND BIBLIOGRAPHIES OF SPECIFIC SALT PONDS AND LAGOONS

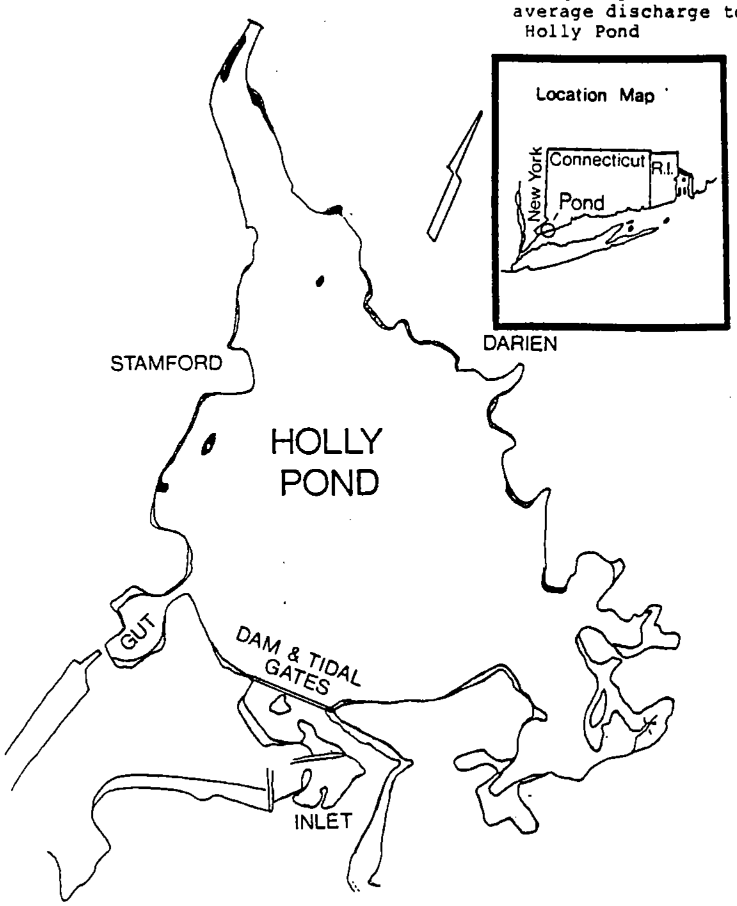
HOLLY POND, STAMFORD AND DARIEN, CONNECTICUT

REFERENCES

Buckland, K.J., (1985) Analzes project designed to improve water quality.Includes references to other studies done by Town, USGS, and Consulting firms.

Morphometric Data (from Buckland 1985)

Noroton River	
-watershed area	12 sq.mi.: 19.3 sq. km.
-discharge	
100-year storm	5300 cfs
10-year storm	1900 cfs
mean annual flow	18 cfs
average discharge	2.5 mill. gal/day surface
	6.0 mgd groundwater
	8.5 mgd total
Holly Pond	
-volume	390 mill. cubic feet
-area	183 acres @ MHW
-avg. depth	7 feet/ 2 meters
Long Island Sound	
mean tidal range	7.2'/2.2m
spring range	8.3'/2.5m
frequency	12.4 hours between highs
average discharge to Holly Pond	164 mgd/ 504 acre-feet



PETAQUAMSCUTT RIVER, NARRAGANSETT, RHODE ISLAND

Morphometric Data (Orr & Gaines 1973)

River Length: 9.7 km Drainage Area: 35 km^2

	Upper Basin	Lower Basin
Surface Area:	289,000 m^2	720,000 m^2
Max Depth:	13.5 m	19.5 m

REFERENCES

Gaines, A.G., 1975 - Dissertation on Geomorphology, Hydrography & Geochemistry of Petaquamscutt.

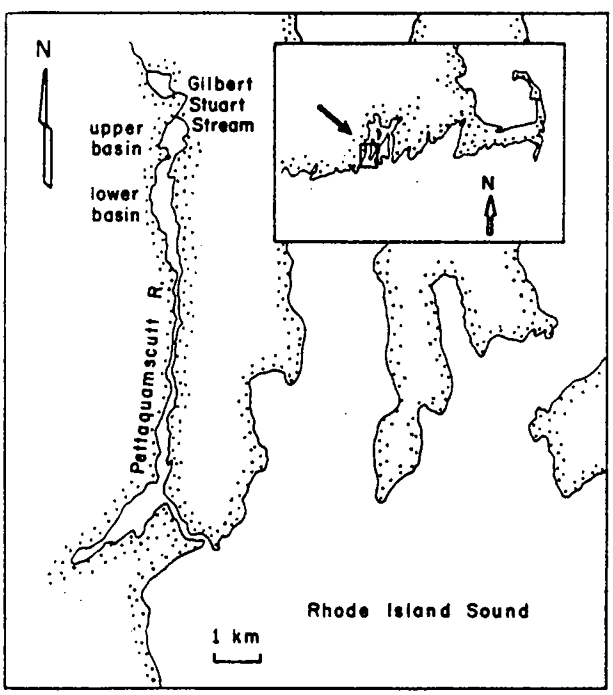
Gaines A.G. & M. Pilson 1972 - contains measurements of water column chemistry (oxygen, alkalinity, sulfide, nutrients, chlorinity, DIC, and pH) from 1969.

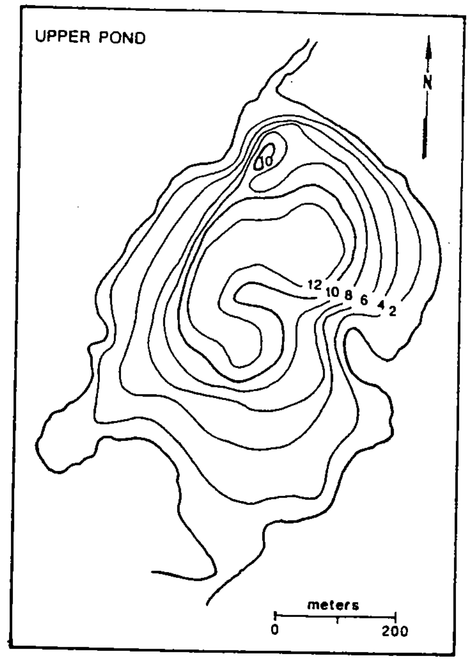
Horton, D. 1958 - MS thesis on distribution of fish in upper areas

Jefferies, H.P. 1960 - occurence of elvers (eels) in a number of estuaries

Mills, G.L. et al. 1989 - measurements of dissolved orgaic copper. Includes water chemistry data (temperature, salinity, oxygen, DOM, sulfide, Cu) from from 1983.

Orr, W.L. & A.G. Gaines 1988 - calculations on rates of sulfate reduction and organic matter oxidation in the upper basin. Contains water chemistry information from 1971 and sulfur data from sediments. Sedimentation rates were measured using ^{14}C.





OTHER RHODE ISLAND COASTAL PONDS

PT. JUDITH, POTTER, CARD, TRUSTON, GREEN HILL, NINIGRET (CHARLESTOWN), QUONOCHONTAUG, WIHNAPAUG

Note - many studies involved several of these ponds so they are presented together.

Morphometric Data -

Table 1. Characteristics of Rhode Island Salt Ponds

	Ninigrit	Green Hill	Potter	Point Judith
Salt Pond				
Area ($x10^6$ m^2)	6.45	1.55	1.35	7.85
Average depth (m)	1.2	0.8	1.8	1.8
Mean annual salinity ($^o/oo$)	28	23	27	30
Fresh water inflow ($x10^6$ m^3 y^{-1})	15	6.8	5	25.3
Tidal range (cm)	13.7	3.7	20	44.5
Inlet dimensions (m)	34 x 2	7 x 1	22 x 2	80 x 4.6
Watershed				
Area ($x10^6$ m^2)	28.48	16.23	9.91	21.62*
Developed (%)	18	28	22	35
Undeveloped (%)	75	66	67	58
Agriculture (%)	3	5	10	3
Public Parks (%)	4	1	1	4

* Excluding the Saugatuck River Watershed

REFERENCES

Asare, S.O. & M.M. Harlin, 1983 - N fluctuation in 5 species of macrophytes.

Boothroyd, J.C. et al. 1985 - physical data on ponds, coastal geomorphology, sedimentation, and wave height information.

Conover, R.J. 1961 - A study of Charlestown and Green Hill Ponds 1955-1957 including watercolumn nutrients, chlorophyll, oxygen, temperature and zooplankton.

Crawford, R.E. winter flounder and eel in the ponds. Stock assessment, spawning, and larval information.

Crawford, R.E. 1983 finfish and shell fish information including species lists. Larval distribution data, importance of hydrodynamics.

Crawford, R.E. & C.G. Cary 1985 - looked at the influence of hydrodynamics on retention of larval flounder.

Grove, C.A. 1982 - Information on winter flounder inc. hydrodynamic model to estimate larval loss.

Harlin, M.M. & B. Thorne-Miller, 1981 - experiments on the effects of nutrient enrichment on seagrass and macroalgae.

Harlin, M.M. & B. Thorne-Miller, 1982 - experiments and observations on seagrass in Ninigret pond.

Isaji, T. et al. 1985 - hyrodynamic information on tidal exchange.

Jefferies, H.P. 1960 - winter occurence of elvers (eels) in ponds.

Lee, V. unpublished. Management questions

Lee, V. 1960 - discussion of management issues, sedimentation, eutrophication, nutrients, fisheries, land use.

Lee, V. & S. Olsen, unpublished - issues concerning barrier island management.

Lee, V. et al. 1985 - managment issues pertaining to tidal inlet modification.

Nixon, S. et al. 1982 - includes morphometric data, nutrient data, coliform data, run off and loading calculations and management recommendations.

Nixon, S.W. & V. Lee, 1981 - nutrient budget and calculations of nutrient exchange between the ponds and offshore waters.

Nowicki, B.L. & S.W. Nixon, 1985 - benthic remineralization of N & P in Potter's Pond.

Nowicki, B.L. & S.W. Nixon, 1985 - benthic community metabolism in Potter's Pond.

Olsen, S. unpublished - includes information on nutrient inputs, housing density in watershed, fishing information.

Olsen, S. 1985 - science and policy issues in managing ponds

Olsen, S. & V. Lee, 1982 - effects of inlet modification.

Olsen, S. & V. Lee, 1985 - salt pond area management plan - very comprehensive and contains many references.

Smith, T.P & K.E. McConnell, 1979 - economic of recreational finfishing in ponds.

Spaulding, M.L. & C.H. Beauchamp, 1983 - modelling tidal circulation.

Thorne-Miller, B. & M.M. Harlin, 1984 - 1984 production of seagrass and other macroalgae.

Thorne-Miller et al. 1983 - distribution and biomass of seagrass and macroalgae in five ponds.

Wang, H-P, 1975 - a hydrodynamic model of Ninigret Pond.

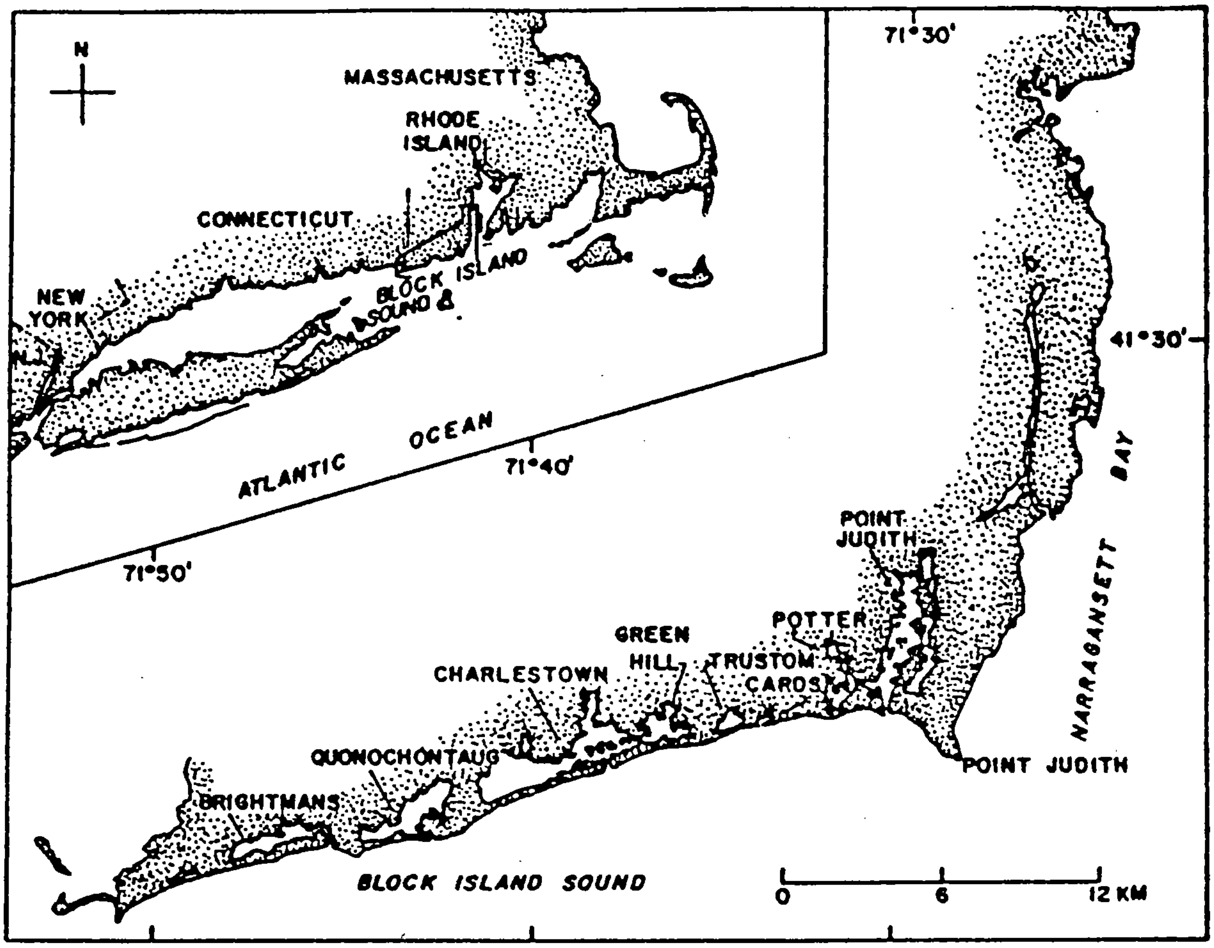


Figure 1. Rhode Island's South Shore salt ponds. The study area includes the ponds from Point Judith west to Charlestown Pond.

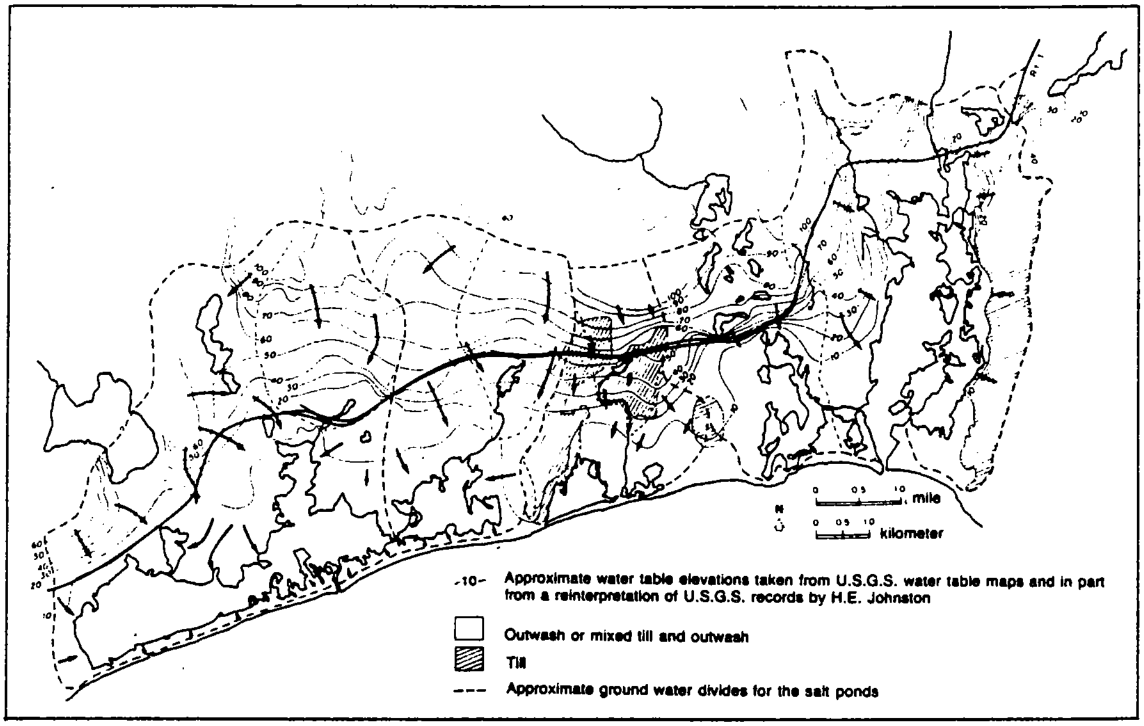


Figure 2. Watershed boundaries for the salt pond region. The arrows indicate approximate direction of groundwater flow. Data compiled from U.S.G.S. records by John Grace, 1981.

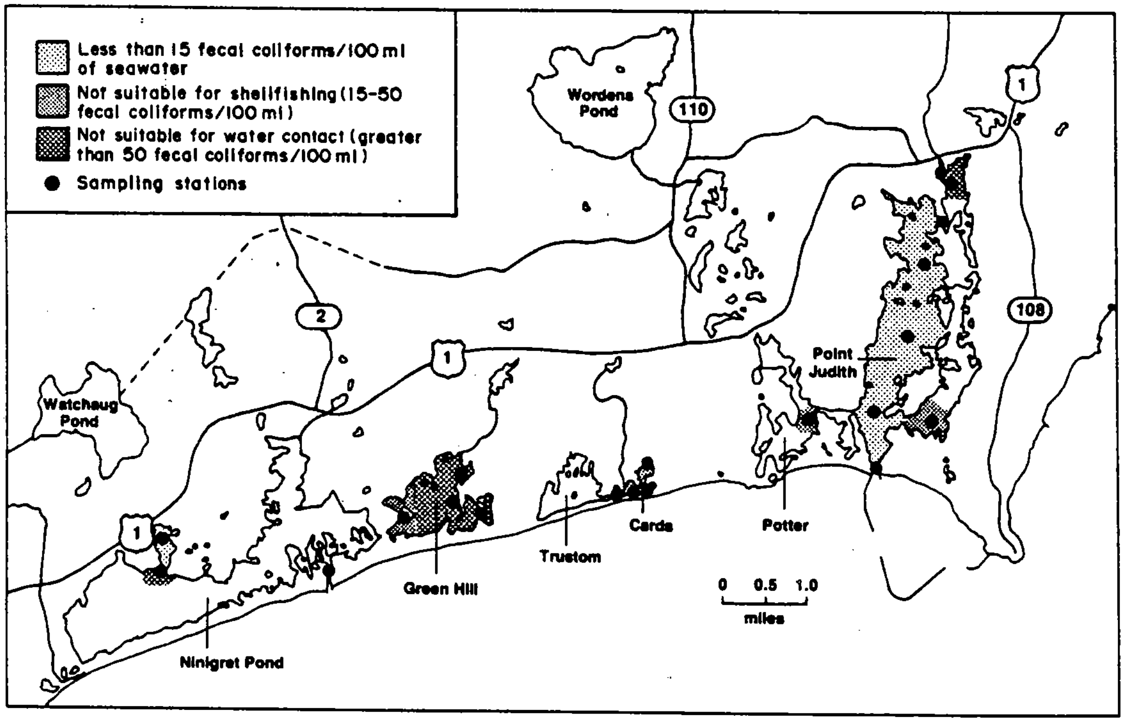


Figure 3 Median fecal coliform bacteria concentrations in the salt ponds 1980-1981, June through October. Adapted from Nixon et al., 1982.

BUTTERMILK BAY, BOURNE AND WAREHAM, MASS

Morphometric Data (Valiela & Costa, 1988)

Mean Depth: 1m
Tidal Range: 1m
Watershed Area: 46.2 km^2
Area of Bay: 2.1×10^6 m^2

Other Data

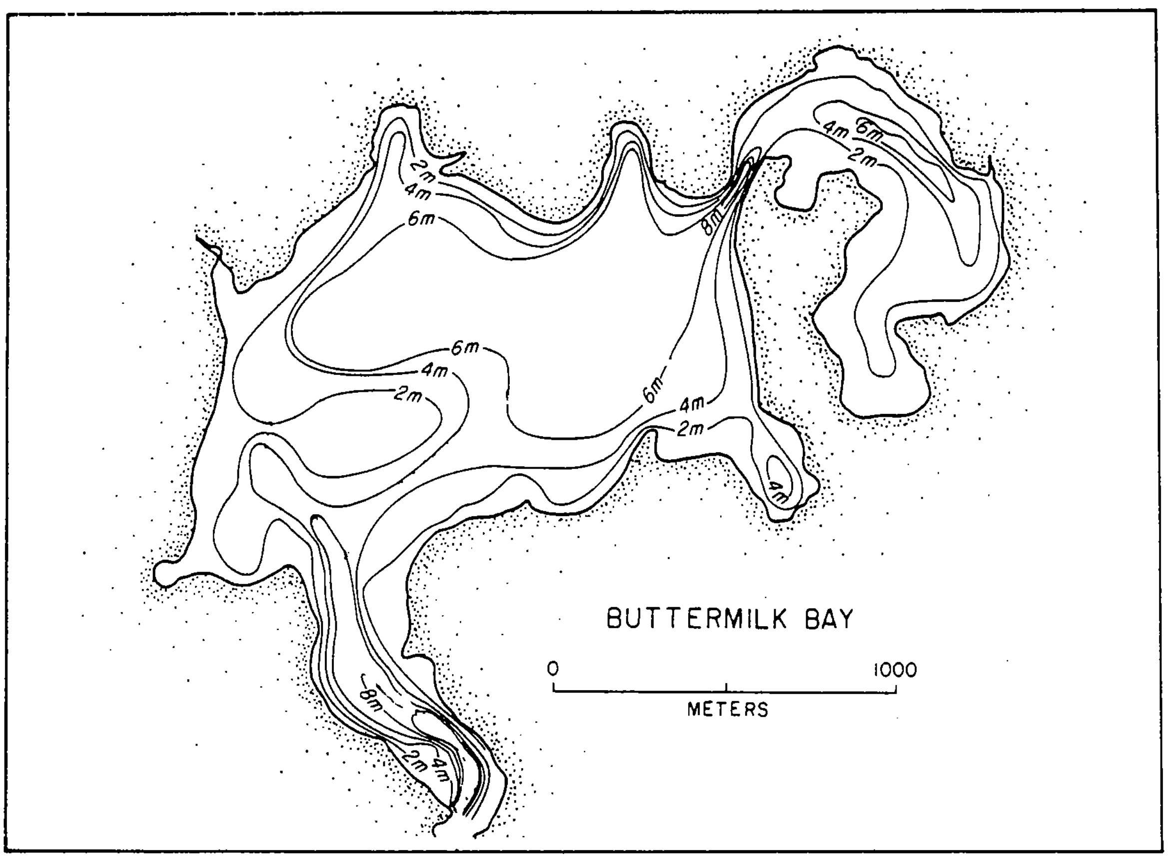
Avg. Salinity Central Portion: 29.6 o/oo
Water Residence Time: 1-5 d

REFERENCES

Costa, J. 1988 - Eel grass, euthrophication

Valiela, I & J. Costa, 1988 - N and P budgets, euthrophication, nutrient loading, groundwater, septic tanks, nutrient budgets

Walsh, G.E. 1965a - Part of a survey of carbohydrates in salt ponds and other water bodies.



WESTPORT RIVER, WESTPORT, MASS

Morphometric Data: (Fiske et al. 1968)

The following data summarizes the more pertinent morphometric measurements made of the east and west branches of the Westport River:

WEST BRANCH OF RIVER

Maximum Length:
The length of the straight line which connects the two extremities of the study area:
3.62 statute miles (3.15 nautical miles)

Maximum Width:
The length of a straight line, drawn approximately at right angles to the maximum length line and which does not cross any land except islands:
1.32 statute miles (1.15 nautical miles)

Mean Width:
The total surface area of the study area divided by the maximum length:
Mean high water—0.53 statute miles (0.46 nautical miles)
Mean low water—0.48 statute miles (0.42 nautical miles)

Total Surface Area:
The total surface area of the study area:
Mean high water—1,237.91 acres (1.93 sq. miles)
Mean low water—1,097.60 acres (1.71 sq. miles)

Salt Marsh Area:
Acreage of salt marsh which drains into the Westport River study area:
228.00 acres (0.36 sq. miles)

Shoreline Length:
The length of shoreline enclosing the study area:
Mean high water—15.08 statute miles (13.11 nautical miles)
Mean low water—13.71 statute miles (11.92 nautical miles)

Maximum Depth:
The maximum depth known:
Mean high water—28.90 feet
Mean low water—26.00 feet

Mean Depth:
The volume of the study area divided by its surface area:
Mean high water—7.00 feet
Mean low water—4.10 feet

Volume:
The total volume of water contained within the study area:
Mean high water—283,758,000.00 cu. feet
Mean low water—133,608,000.00 cu. feet

EAST BRANCH OF RIVER

Maximum Length:
7.89 statute miles (6.86 nautical miles)

Maximum Width:
1.00 statute miles (0.87 nautical miles)

Mean Width:
Mean high water—0.39 statute miles (0.34 nautical miles)
Mean low water—0.38 statute miles (0.33 nautical miles)

Total Surface Area:
Mean high water—1,986.66 acres (3.10 sq. miles)
Mean low water—1,909.49 acres (2.98 sq. miles)

Salt Marsh Area:
775.00 acres (1.21 sq. miles)

Shoreline Length:
Mean high water—36.23 statute miles (31.60 nautical miles)
Mean low water—32.94 statute miles (28.73 nautical miles)

Maximum Depth:
Mean high water—22.00 feet
Mean low water—19.00 feet

Mean Depth:
Mean high water—6.10 feet
Mean low water—3.10 feet

Volume:
Mean high water—357,568,000.00 cu. feet
Mean low water—128,414,000.00 cu. feet

REFERENCES

Fiske et al. 1968 - A study of the marine resources including data on physical and chemical characteristics, finfish and shellfish resources and information on tidal marshes.

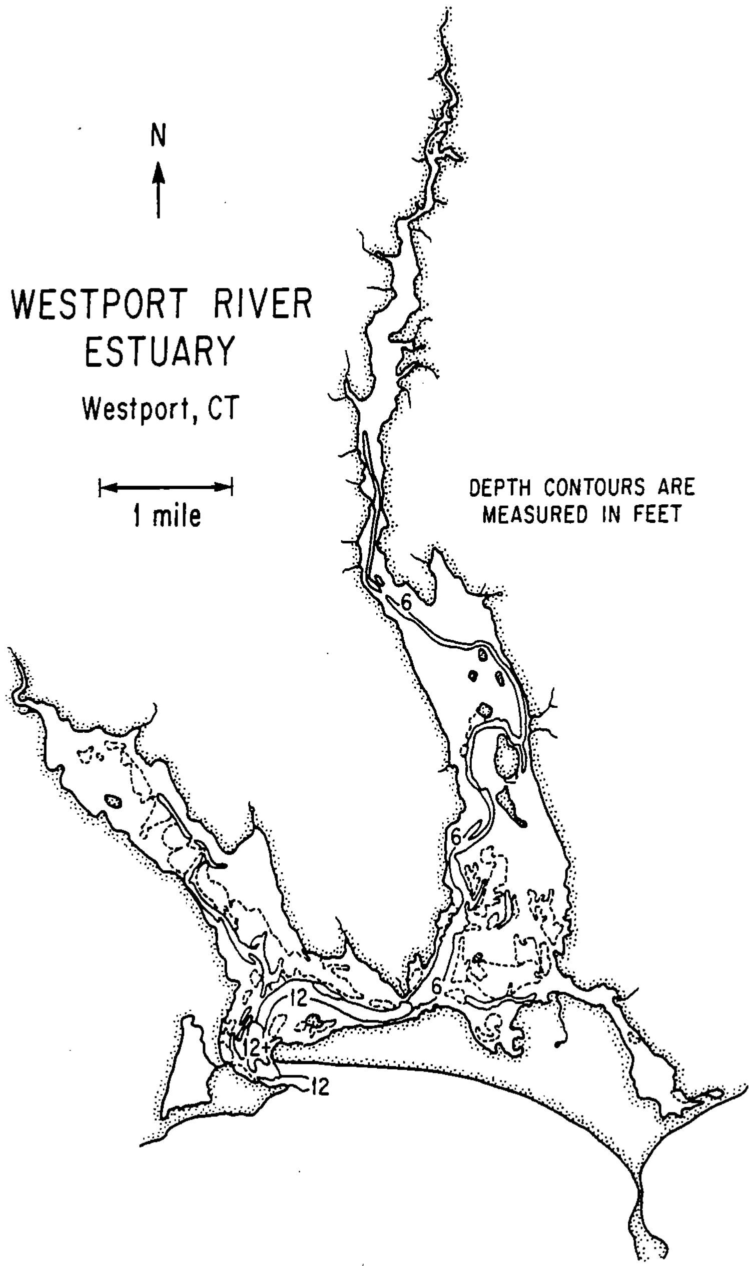
FitzGerald, D.M. 1985 - an overview on the development of bays and tidal inlets which contains morphometric and tidal information on the Westport River.

FitzGerald et al. 1987 - a hydrogeologic comparson of several inlets along the Massachussetts coast.

GHR Engineering Associates, Inc. 1987 - a survey of coliforms in the east branch of the Westport River.

Kelly, E.F. et al. 1986 - a study to determine the causes, types and locations of pollutants.

Pivetz, B.E. et al. 1986 - a study of bacteria and suspended sediment.



PLEASANT BAY - NAUSET SPIT, CHATHAM, MASS

Morphometic Data: (Fiske et al. 1967)

Maximum length:
9.8 statute miles (8.6 nautical miles)

Maximum effective length:
6.6 statute miles (5.7 nautical miles)

Maximum width:
3.4 statute miles (3.0 nautical miles)

Maximum effective width:
4.0 statute miles (3.5 nautical miles)

Mean width:
Mean high water 1.2 statute miles (1.0 nautical miles)
Mean low water 0.8 statute miles (0.7 nautical miles)

Total surface area:
Mean high water 7,285 acres (11.4 sq. miles)
Mean low water 5,393 acres (8.4 sq. miles)

Salt marsh area:
1,203 acres (1.9 sq. miles)

Shoreline length:
Mean high water 55.1 statute miles (48.2 nautical miles)
Mean low water 11.6 statute miles (10.1 nautical miles)

Maximum depth:
Mean high water 25.2 feet
Mean low water 22.0 feet

Volume:
Low tide — 1,346,491,872 cu. ft.
High tide — 2,208,815,036 cu. ft.

REFERENCES

Buckley, G.D. 1974 - An abstract on the ecological aspests of some molluscan speicies.

Fiske et al. 1967 - A study of the marine resources including data on physical and chemical characteristics, finfish and shellfish resources and information on tidal marshes.

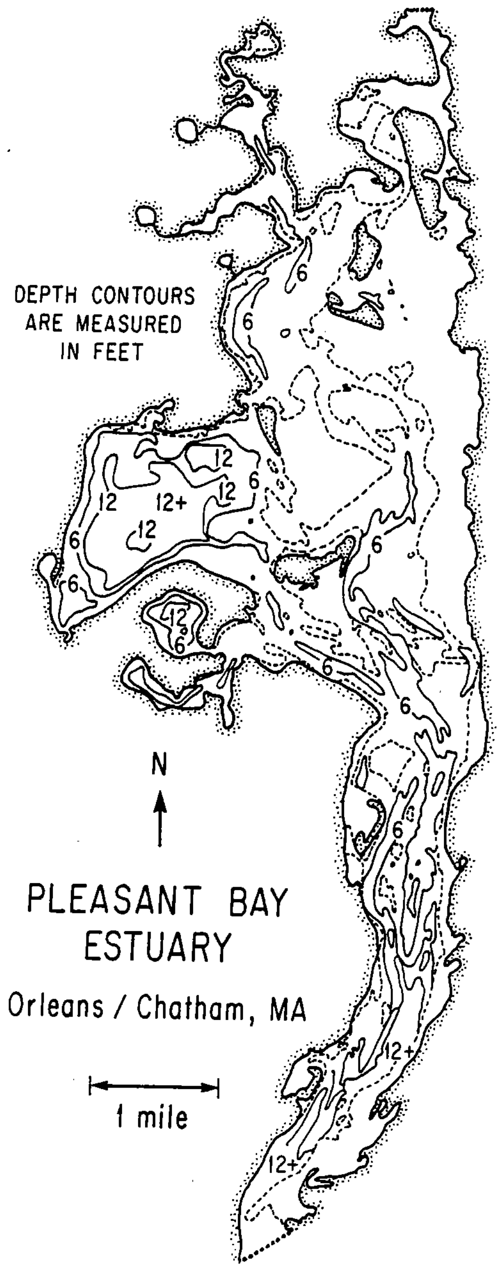
Friedrichs, C.T. & D.G. Aubrey 1988 - includes tidal analysis for Chatham harbor in comparison with many other inlets.

Giese, G.S. 1988 - an analysis of the historical changes in the barrier beach since 1700.

Giese, G.S. et al. 1989 - Information on the development, characteristics and effects of the new inlet.

LeClair, L.D. et al. 1978 - an abstract on the seismic reflection profiles, sediments and topography of Chatham Harbor.

Morse, M.P. et al. 1981 - an abstract on the size distribution and growth lines of the scallop (A. irradians) population in the Bay in the winter of 1979.



SWAN POND, DENNIS, MA

Morphometric Data (Aubrey Consulting, Inc.)

Area Pond: 3.11×10^5 m^2
Length Pond: 1200
Width Pond: 925m

Area Pond and River: $3.39 \times 10^5 m^2$
Length Pond and River: 4400m

REFERENCES

Aubrey Consulting, Inc. 1988 - report describes how shoaling has reduced circulation and flushing leading to reduced salinities and decreased water quality.

Aubrey, D.G. 1985 - analyzed winds, tide and waves to determine what factors were causing shoaling at the inlet.

Beasant, J.J. & P.A. Kuczma 1972 - a salinity study.

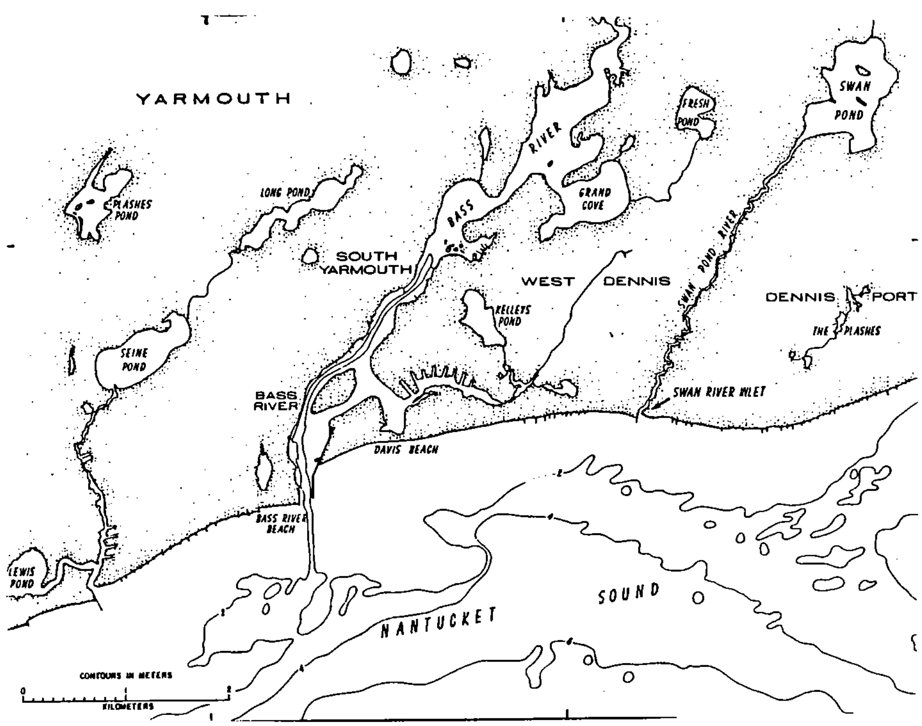
Bloomhardt, M. 1980 - a survey of Swan River.

Eldredge, J.K. 1978 - a report to the Town on data taken during the summer of 1978.

Friedrichs, C.T. & D.G. Aubrey 1988 - a synthesis paper which contains data from 26 inlets including Swan River.

Hickey, J. 1974 - a salinity survey.

Nickerson, S. & M. Borowski 1977 - a survey of river and pond.



SALT POND, EASTHAM, MASS

Morphometric Data (from Anderson & Stolzenbach 1985)

Area: 82,200 m^2
Max depth (low tide) 7 m
Volume (low tide) 278,000 m^3
Avg. Depth (low tide) 3.4 m

Other Data

Avg. salinity: 31 o/oo

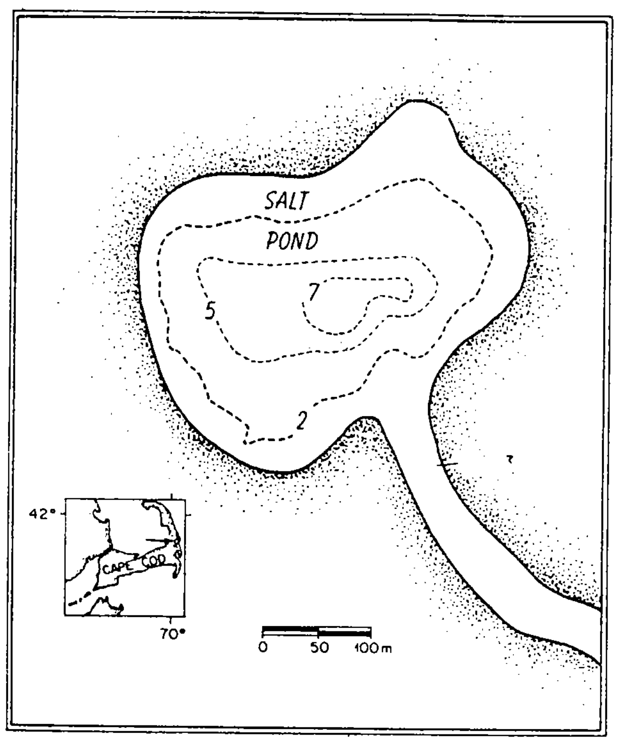
REFERENCES

Anderson, D. et al. 1983 - Population dynamics of Gonyaulax tamerinsis (red tide organism). Includes seasonal data (Mar - June 1980 and 81) on phytoplankton cell counts, water temp, nitrate, ammonium, phosphate, silica, polychaete larvae, copepods, and particulate carbon as dinoflagellates or diatoms.

Anderson, D. & K. Stolzenbach 1985 - Includes physical data on pond as well as vertical profiles of salinity irradience, temp, nutrients and cysts of G. tamarensis and H. triqueta.

Anderson, D. & D. Wall 1978 - Distribution of red tide cysts in 13 embayments.

Watras, C.J. et al. 1982 - regulation of G. tamarensis growth. Inc. salinity, temp and population density from Mar-June 1980.



Map of Salt Pond, Eastham, Massachusetts (USA)
Contours are in m at slack low tide

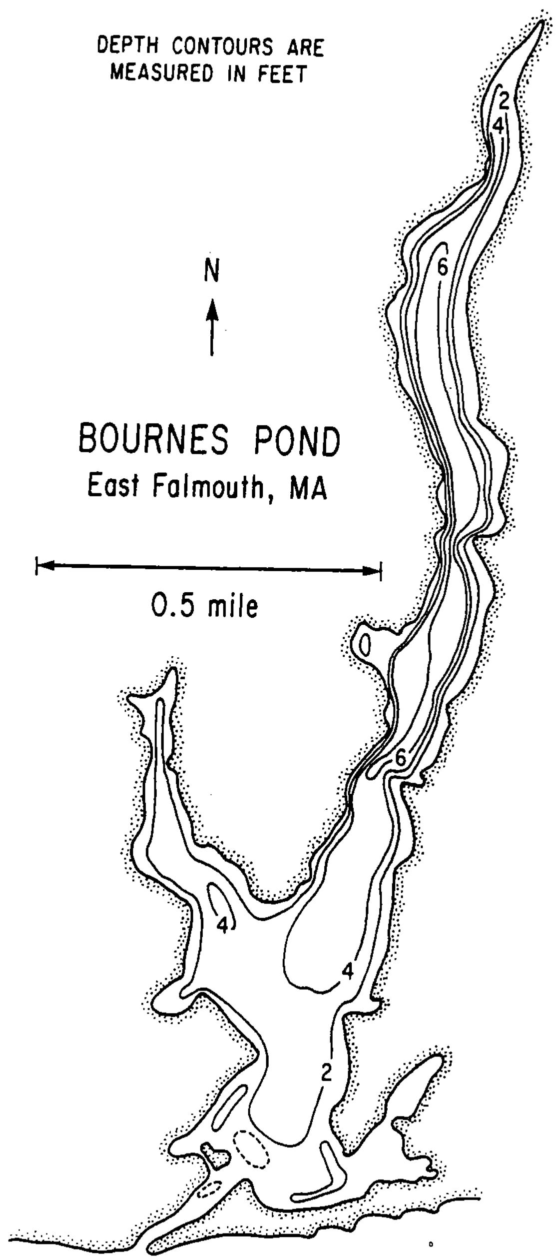
BOURNES POND, FALMOUTH, MASS

Morphometric Data: (Moody 1988)

Max. depth: 2.4m
Area: 0.61 km^2

REFERENCES

Moody, J.A. 1988 - a study of tidal distortion in comparison to a number of other inlets in the area. Includes a comparision of before and after the inlet was modified.



GREAT POND, FALMOUTH, MASS

Morphometric Data: (Conover 1956)

Length: 3,300 m
Max Depth: 7-8 feet
Max Width: (approx) 300 m

REFERENCES (Note Perch Pond is listed separately)

Anderson, D. & F.M. Morel, 1979 - information on Gonyaulax cysts, cells in water column, as well as water column data.

Barlow, J.P., 1952 - Thesis on maintenance and dispersal of endemic zooplankton species in pond.

Barlow, J.P., 1955 - information on zooplankton biomass, distribution, production, and tidal exchange.

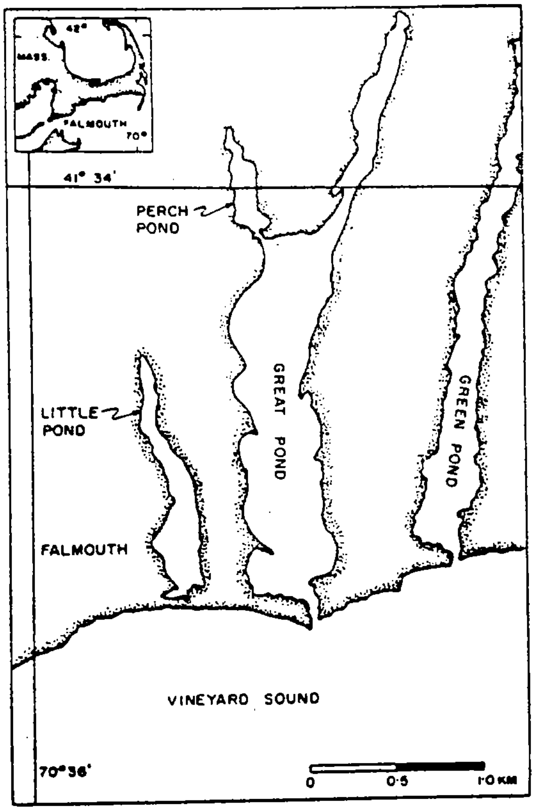
Barlow, J.P. 1956- effect of wind on the salinity distribution

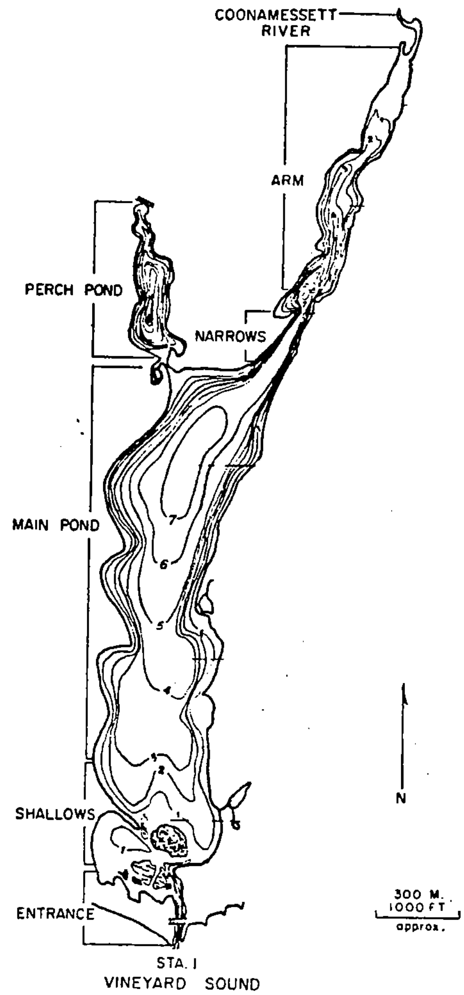
Conover, J.T., 1958 - Extensive data set on benthic macrophytes and water chemistry taken from 1952-4.

Hulbert, E.M., 1956a - seasonal cycle, cell counts, and species composition of phytoplankton.

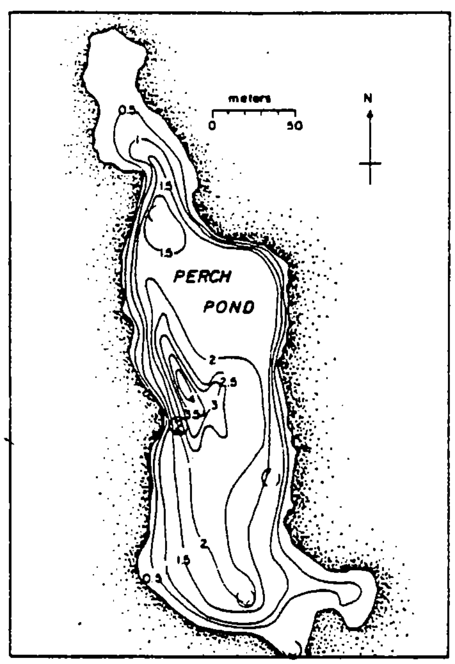
Hulbert, E.M., 1956b - seasonal cycle of primary production, total and inorganic P, cell counts.

Hulbert, E.M., 1957 - Taxonomy of unarmored Dinophycae





Bathymetric chart of Great Pond; depth in feet.



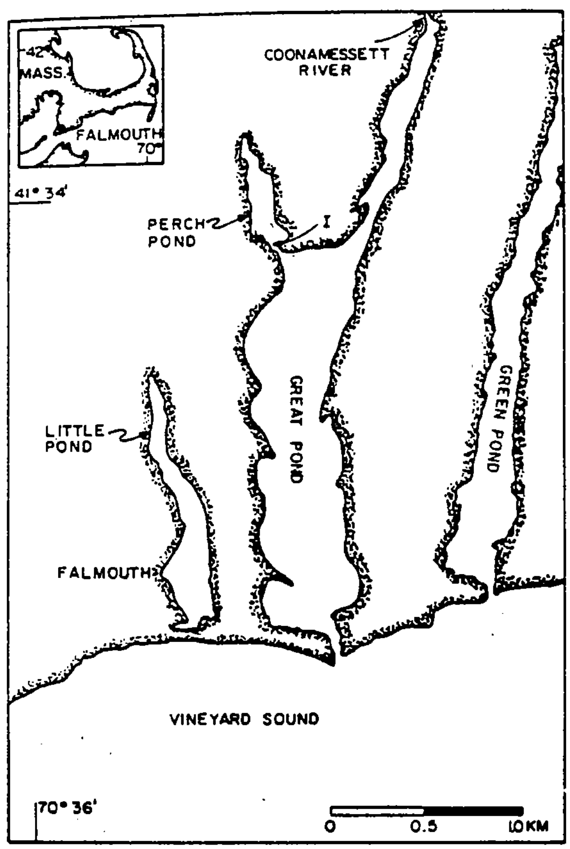
GREEN POND, FALMOUTH, MASS

Morphometric data (Gaines 1986)

Area: 0.63 km^2
Shoreline length: 9.3 Km

REFERENCES

Gaines, A.G. 1986 - Study on nitrogen loading, watershed data in comparison to Lagoon Pond and Town Cove.



OYSTER POND, FALMOUTH, MASS

Morphometric Data (Emery, 1969)

Length: 1050 m — Max. Width 400 m

Surface Area 0.25 km^2 (62 acres) — Mean Depth 3m

Volume 750,000 Cu. m

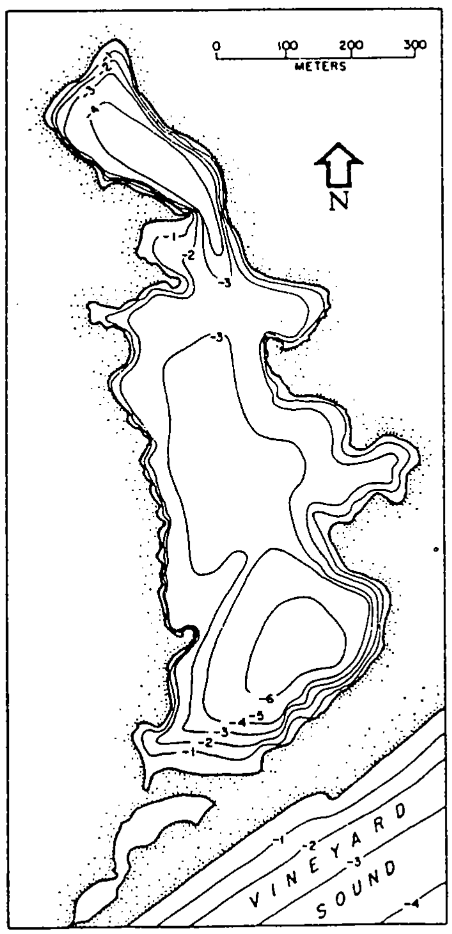
REFERENCES

Caraco, N. et al. 1987 - N vs. P limitation compared to other local ponds.

Emery, K.O., 1972 - Book on Oyster Pond, includes geology, topography, sediment and water column chemistry, and information on animals, plants, and primary production.

Walsh, G.E. 1965a - carbohydrate levels in water compared to other coastal ponds and fresh water bodies.

Walsh, G.E. 1965b - Diurnal fluctuation of carbohydrates in Oyster Pond. Contains information on primary production.



Bathymetric contours in meters

PERCH POND, FALMOUTH, MASS

Morphometric Data (from Anderson & Stolzenbach 1985)

Area: 66,400 m^2
Volume (low tide) 98,500 m^3
Avg. Depth (low tide) 1.48 m

Other Data

Avg. Salinity: 26 o/oo

REFERENCES

Anderson,D. & D. Wall 1978 - Distribution of red tide cysts in 13 embayments.

Anderson, D.M. & F.M.Morell, 1979 - On seeding of red tide blooms by germination of benthic G. tamarensis cysts. Also includes seasonal (mar-may 1977) data on water temp, # of cells, salinity, and rainfall, nutrient data, and iron. Time series of encystment Mar-Nov.

Anderson, D.M. et al. 1983 - Population dynamics of Gonyaulax tamerinsis (red tide organism). Includes seasonal data (Mar - June 1980 and 81) on phytoplankton cell counts, water temp, nitrate, ammonium, phosphate, silica, polychaete larvae, copepods, and particulate carbon as dinoflagellates or diatoms.

Garcon, V.C. et al. 1986 - measured flushing in Perch Pond

Stoecker, D.K. et al. 1984 - Distribution of planktonic ciliates, dinoflagellates well as vertical profiles of light, temp, at several times during the year.

Turner, J.T. & D.M. Anderson, 1983 zooplankton grazing during dinoflagelates bloom. Information of abundances of dinoflagelates, tintinnids, copepods and polycheate larvae.

Watras, C.J. et al. 1982 - regulation of G. tamarensis growth. Inc. salinity, temp and population density from Mar-June 1980.

Map shown with Great Pond

SALT POND, FALMOUTH, MASS

Morphometric Data (Kim & Emery 1971)	Other Data
Maximum Depth - 5.5 m	Salinity 25-31 o/oo
Area - 28.5 hectares	

REFERENCES

Caraco, N. et al. 1987 - tested N vs. P limitation of phytoplankton

Hulbert, E.M. 1963 - phytoplankton species composition compared to offshore areas.

Hulbert, E.M. 1965 - identification of flagellates, with a comparison to other salt ponds.

Kim, C.M. & K.O. Emery 1971 - information on topography, sediments, and water column oxygen, temperature and salinity

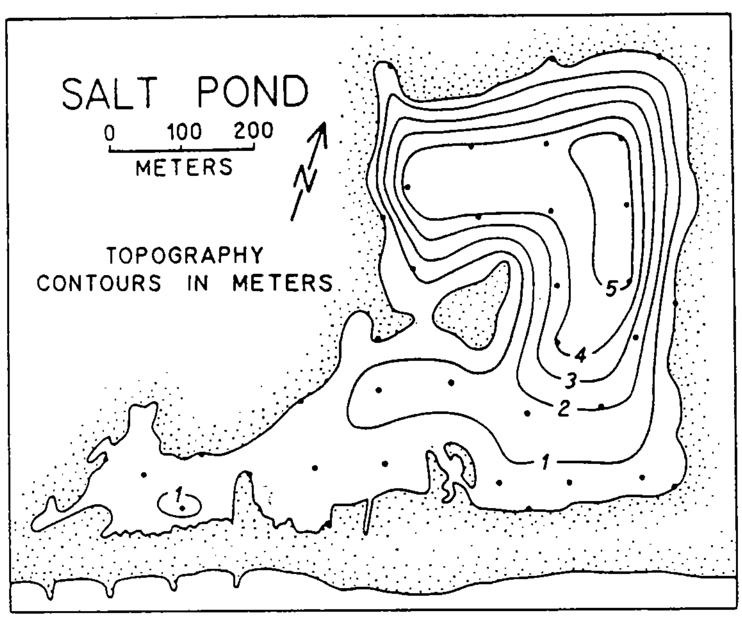
Lohrenz, S.E. 1985 - information on light profiles, water chemistry, and primary production.

Mitchell, J. 1988 - water column information

Wakeham S.G. et al. 1984 - Seasonal cycle of DMS fro June 1982 - July 1983. Also water column chemistry, oxygen, pigment, and sulfide profiles from several dates.

Wakeham, S.G. et al. 1987 - Profiles of oxygen, DMS carbon, pigments, DMS and methane from several dates in the summer of 1985.

Walsh, G.E, 1965a - carbohydrate and salinity data, some sediment data.



SIDERS POND, FALMOUTH, MASS

Morphometric Data (Caraco, 1986)

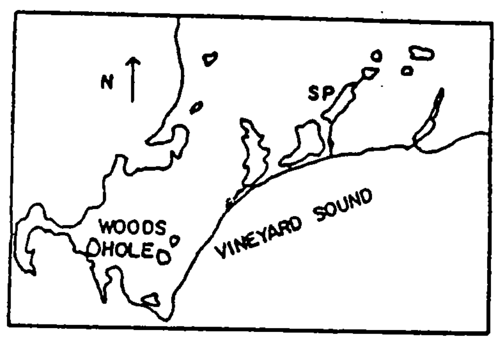
Pond Area: 134,000 m^2 Max Depth: 15m
Watershed area: 2,400,000 m^2

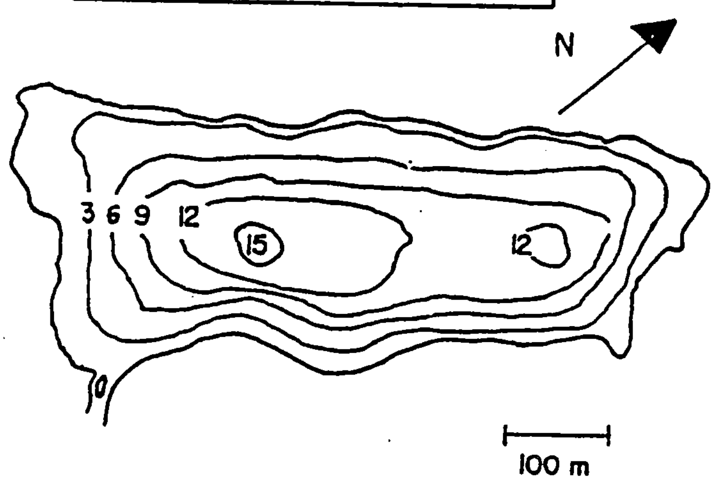
REFERENCES

Caraco, N.M. 1986 - Thesis on pond. Includes information on water chemistry, primary production and nutrient loading.

Caraco, N.M., et al. 1987 - Compares N vs. P limitation to several other ponds. (See also Caraco 1988 for reply to comments on this article)

Caraco, N.M. and I. Valiela (unpublished) a manuscript on the N and P budget of the pond.





WAQUOIT BAY - EEL POND, FALMOUTH, MASS

Morphometric Data - (adapted from Curley et al. 1971)

Sub-system	Max length (km)	Max width (km)	Max depth (m)	Mean depth (m)	water area (ha)	marsh area (ha)	upland area (ha)
Waquoit Bay	4.18	1.77	2.74	0.82	3.75	2.7	-
Quashnet R.	1.77	0.16	2.32	unk	19	2.7	-
Hamlin Pond/ Little R.	2.74	0.64	1.52	0.61	64	28	-
Jehu Pond/ Great R.	3.7	0.48	2.32	unk	78	43	-
Eel River/ Childs R.	3.41	0.23	-	-	100	-	-
Sage Lot P.	0.43	0.64	unk	unk	20	-	-
Flat Pond	0.22	0.76	unk	unk	16	-	-
Caleb Pond	0.19	0.18	unk	unk	2.6	-	-
Bog Pond	0.13	0.13	unk	unk	1.2	-	-
Bourne Pond	0.29	0.29	unk	unk	4.8	-	-
Washburn Island		-	-	-	-	14.8	135.2
South Cape Beach		-	-	-	-	40.2	141.6
Swift Estate	-	-	-	-	-	0.9	9.1

REFERENCES

Anderson, D.M. & D. Wall, 1978 - Sampled 13 estuaries around Cape Cod for (Gonyaulax) dinoflagellate cysts. Reports geographical information but no other water or sediment column data.

Aubrey D.G. & A.G. Gaines 1982 - contains information on the with of the Waquoit barrier beach 1938-1980.

Costa, J.E., 1988 - Reports on changes of abundance of Eel grass in Waquoit Bay. Thesis includes eel grass information on Buzzards Bay area.

Curley, J.R. et. al. 1971 - Monograph on fisheries resources of Waquoit Bay-Eel pond estuary. Also contains morphometric data, and salinity information.

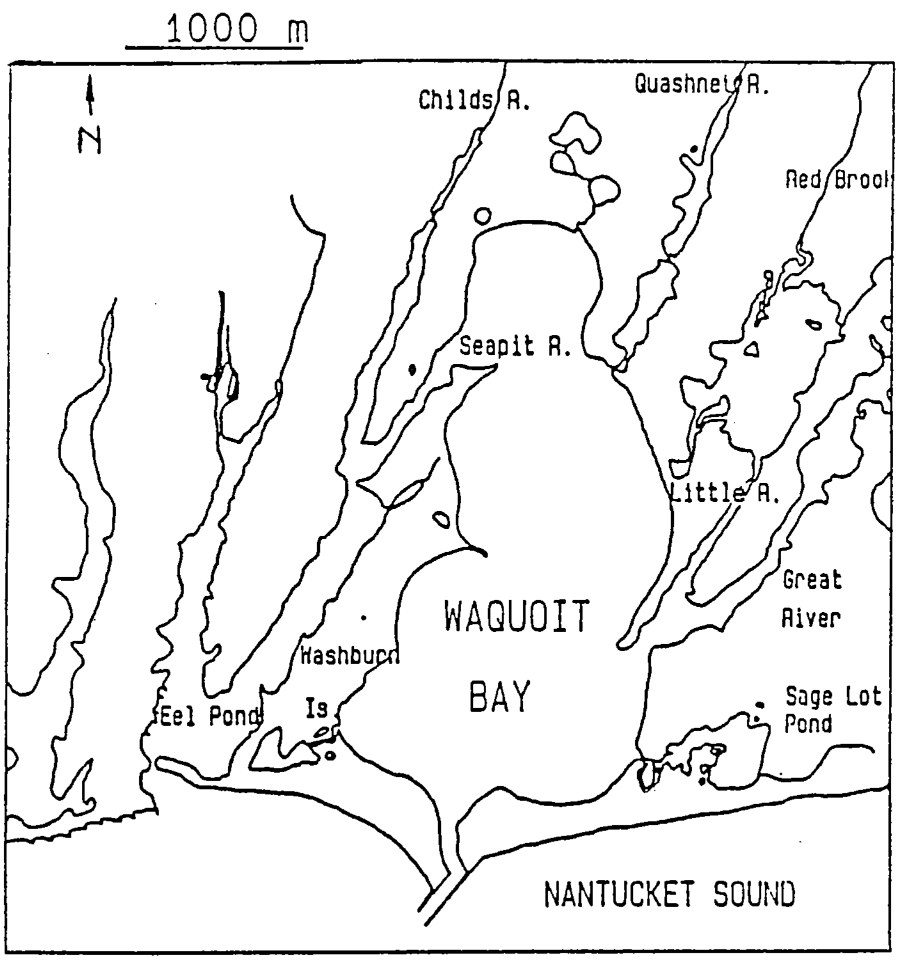
Howe, A.B. et al. 1976 - Information on Flounder population in Waquoit Bay taken from 1969-1971. Includes length frequency, mortality, and recruitment estimates.

Orson, R.A. 1988 - a historical look at wetland development

Taylor, R. & J. Capuzzo, 1983 - Information on scallop reproduction and seasonal cycles in Waquoit Bay. Includes temp., salinity, and DO information from 1979.

Walsh, G.E., 1965a - Data on carbohydrate concentration, salinity, pH, Eh and bottom sediments from a number or areas inc. Waquoit Bay.

Williams, G.C., 1960 - Examined fish dispersal in the period from 1956-1958.



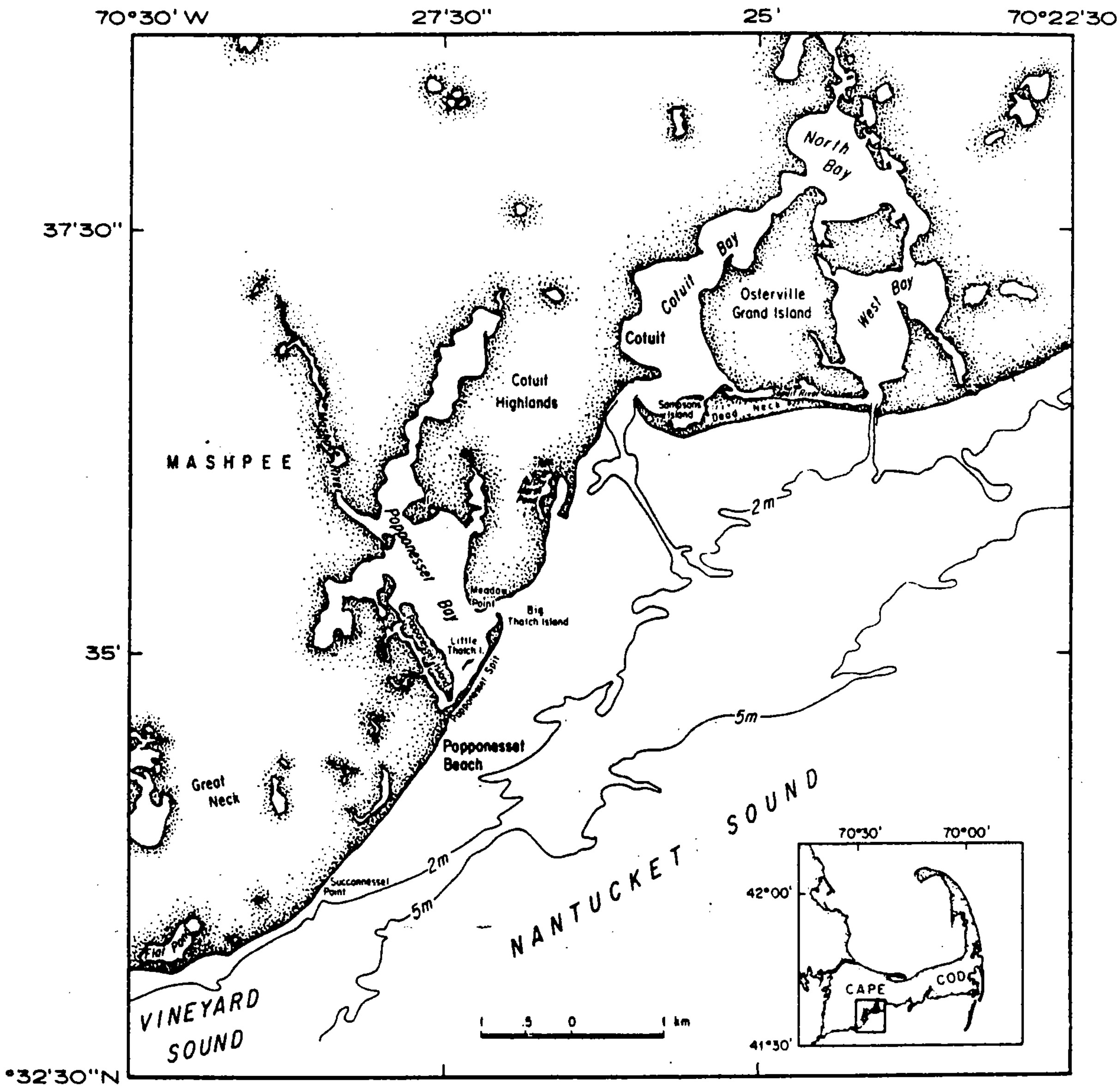
POPPONESSET BAY, MASHPEE, MASS

REFERENCES

Anderson, D.M. and D. Wall, 1978 distribution of red tide cysts

Aubrey, D.G. & A. G. Gaines, 1982 - formation and degradation of spit, historical maps on changes in spit

Walsh, G.E. 1965a - Data on carbohydrate conc. in waters, salinity, pH, Eh and bottom sediments



LITTLE NAMSKAKET CREEK, ORLEANS, MASS

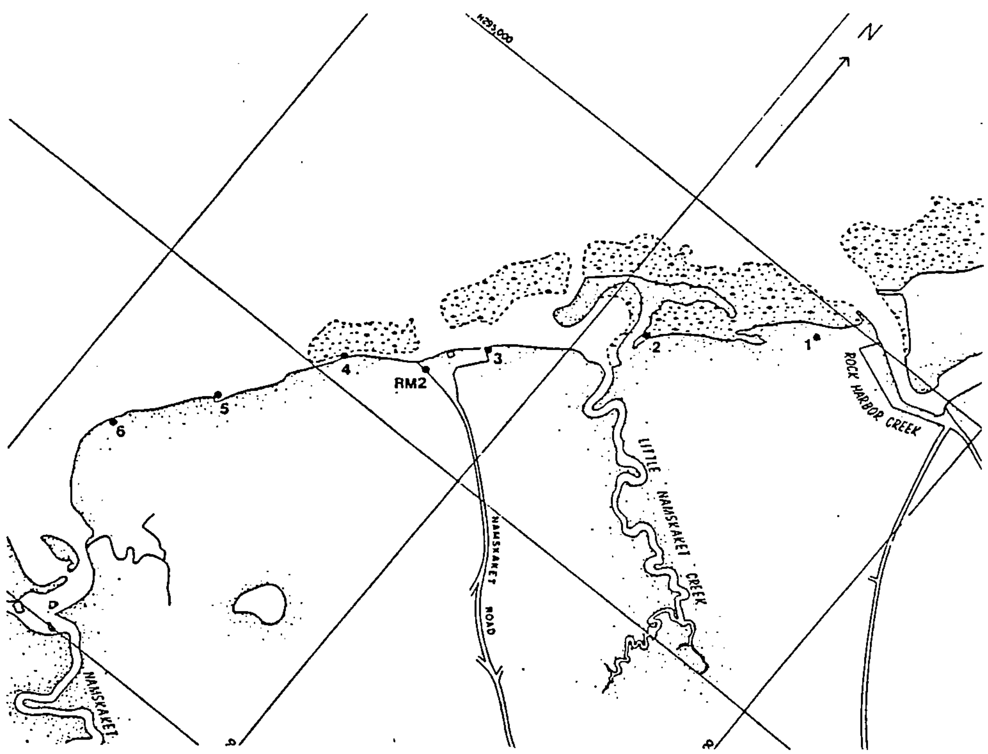
Morphometric Data: (Aubrey Consulting, Inc.)

Length: 900m
Width: 25 m

REFERENCES

Aubrey Consulting, Inc. 1989b - summarizes the environmental effects of annual nourishment of Skaket beach on downdrift marshes. Includes an analysis of sediment transport, shoreline changes, flooding potential, and water quality.

Speer, P.E., et al. in press - investigation of hydrodynamics with comparison to other systems.



Upper Little Namskaket Creek

MILL POND, ORLEANS, MASS

Morphometric Data (from Anderson & Stolzenbach 1985)

Area: 160,000 m^2

Other Data

Avg. salinity: 31 o/oo

REFERENCES

Anderson, D.M. et al. 1983 - Population dynamics of Gonyaulax tamerinsis (red tide organism). Includes seasonal data (Mar - June 1980 and 81) on phytoplankton cell counts, water temp, nitrate, ammonium, phosphate, silica, polychaete larvae, copepods, and particulate carbon as dinoflagellates or diatoms.

Anderson, D.M. & D. Wall 1978 - Distribution of red tide cysts in 13 embayments.

Watras, C.J. et al. 1982 - regulation of G. tamarensis growth. Inc. salinity, temp and population density from Mar-June 1980.

TOWN COVE & NAUSET INLET, ORLEANS, MASS

Morphometric data (Teal, 1983) -

Geographic and Hypsometric Statistics for Town Cove, Orleans Quadrangle, Massachusetts.

Depth (m)	Projected Area (m2) a/	Depth Interval	Volume m3	Including Channel
0.0	1.4 X 10^6	0.0-0.5	0.73 X 10^6	0.78 X 10^6
0.5	(1.3) " b/	0.5-1.0	0.49 "	0.54 "
1.0	0.68 "	1.0-1.5	0.32 "	0.38 "
1.5	0.60 "	1.5-2.0	0.29 "	0.34 "
2.0	0.55 "	2.0-2.5	0.27 "	
2.5	0.52 "	2.5-3.0	0.24 "	
3.0	0.45 "	3.0-3.5	0.21 "	
3.5	0.38 "	3.5-4.0	0.17 "	
4.0	0.29 "	4.0-4.5	0.12 "	
4.5	0.18 "	4.5-5.0	0.061 "	
5.0	0.071 "	5.0-5.5	0.019 "	
5.5	0.014 "	5.5-6.0	0.002 "	
6.0	0.0 (assumed)			

Entrance Channel in Town Cove:
Projected Area: 0.114 X 10^6 m^2
Volume: 0.228 X 10^6 m^2 (assume uniform 2 m depth)

Volume of Town Cove: 3.13 X 10^6 m^3.

Average Depth (A/V): 2.2 m.

Projected recharge areas (square meters)

Total Town Cove and the outer Nauset embayment:	27.6 X 10^6
Outer Nauset embayment:	18.1 X 10^6
Terrestrial:	10.3 X 10^6
Estuary (including marsh):	7.9 X 10^6
Town Cove:	9.4 X 10^6
Terrestrial:	7.9 X 10^6
Estuary:	1.4 X 10^6

Perimeter of Town Cove: 6,200 meters

a/ Relative areas determined from bathymetric chart of Aubrey (this report), using USGS (1974) topographic map for the Orleans Quadrangle for surface areas.

b/ Value estimated.

REFERENCES

Anderson, D.M. & D. Wall, 1978 - a report of Gonyaulax tamerensis cysts in sediments, includes data from 13 salt ponds and estuaries.

Aubrey, D.G. & P.E. Speer, 1985 - detailed analysis of non-lineral tidal propagation in the inlet.

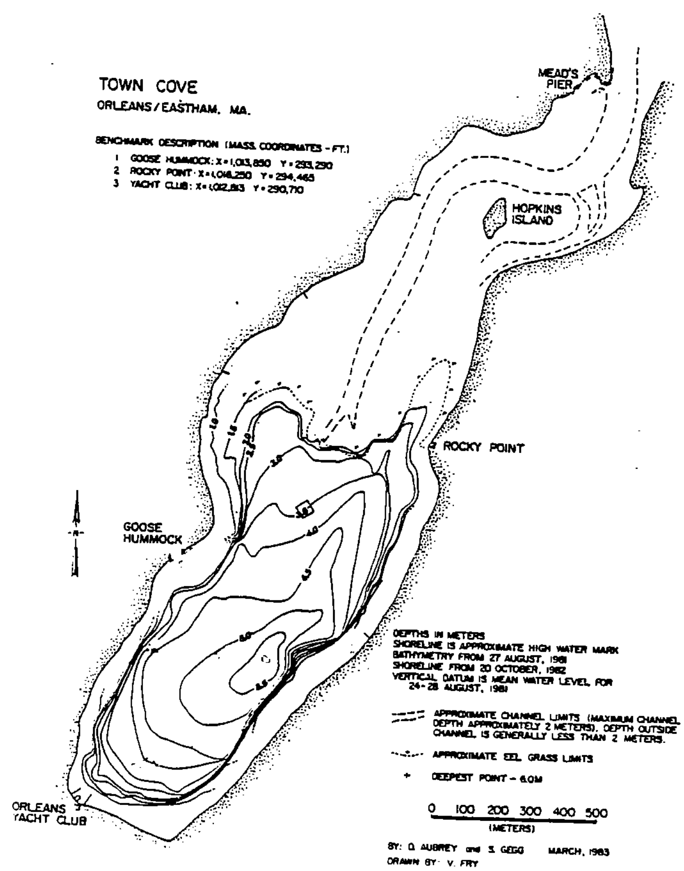
Aubrey, D.G. & P.E. Speer, 1984 - migration of the tidal inlet from the late 1700's to 1980's. Includes information on storms.

Giblin, A.E. & A.G. Gaines, 1990 - a study of the inputs of nitrogen into Town Cove focusing on groundwater inputs.

Moody, J.A., 1988 - an analysis of tidal distortion in the inlet compared to several other inlets on Cape Cod and Martha's Vineyard.

Speer, P.E. 1984 - hydrodynamics of Nauset Inlet

Teal, J.M. 1983 - Nitrogen budget, primary production, water column information, tidal exchange, sediment-water exchange of oxygen and nitrogen, groundwater flow.



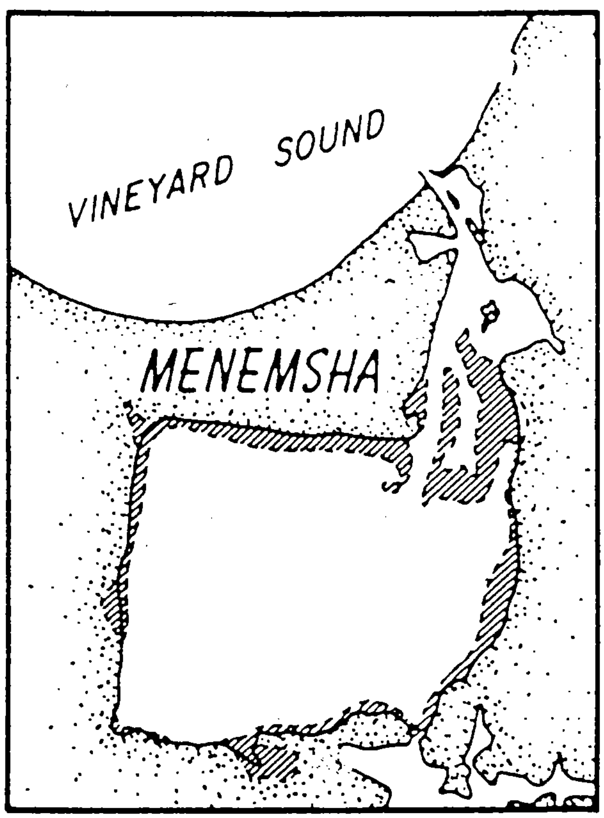
MENEMSHA, CHILMARK, MASS

Morphometric Data: (Moody 1988)

Max Depth: 5.2m
Area: 2.70 km^2

REFERENCES

Moody, J.A. 1988 - An analysis of the tidal characteristics of small inlets with data from five other locations on Cape Cod.



OYSTER POND, EDGARTOWN, MASS

Morphometric Data

Maximum depth: 4m

REFERENCES

Mathiessen, G.C., 1960 Observations on the soft shell clam. Includes temperature and salinity data from 1958

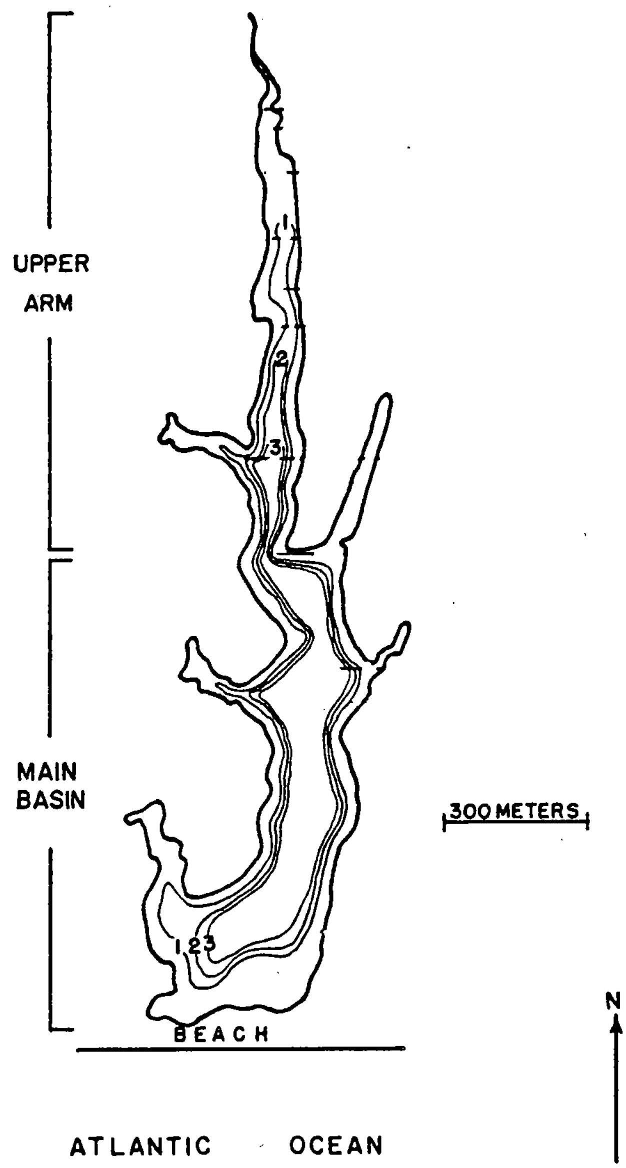
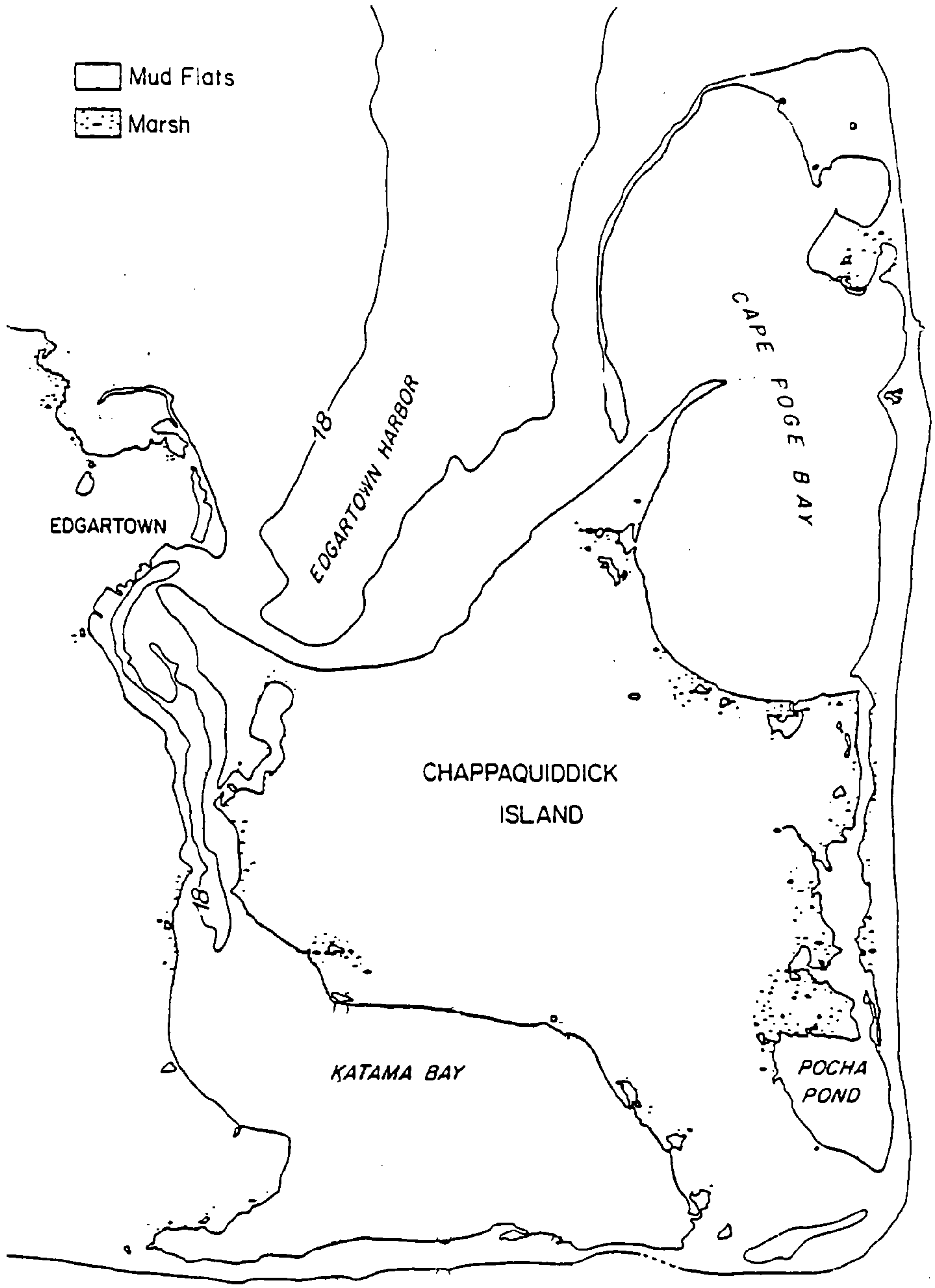


FIG. 1. Chart of Oyster Pond. Depth in meters.

EDGARTOWN HARBOR, CAPE POGE, KATAMA BAY, POCHA POND
EDGARTOWN, MASS

REFERENCES

Gaines, A.G. & A.R. Solow 1989 - a one year study (1989) on the distribution of coliform bacteria in surface water of the Edgartown Harbor complex area. Samples from other areas receiving less human use were also presented.



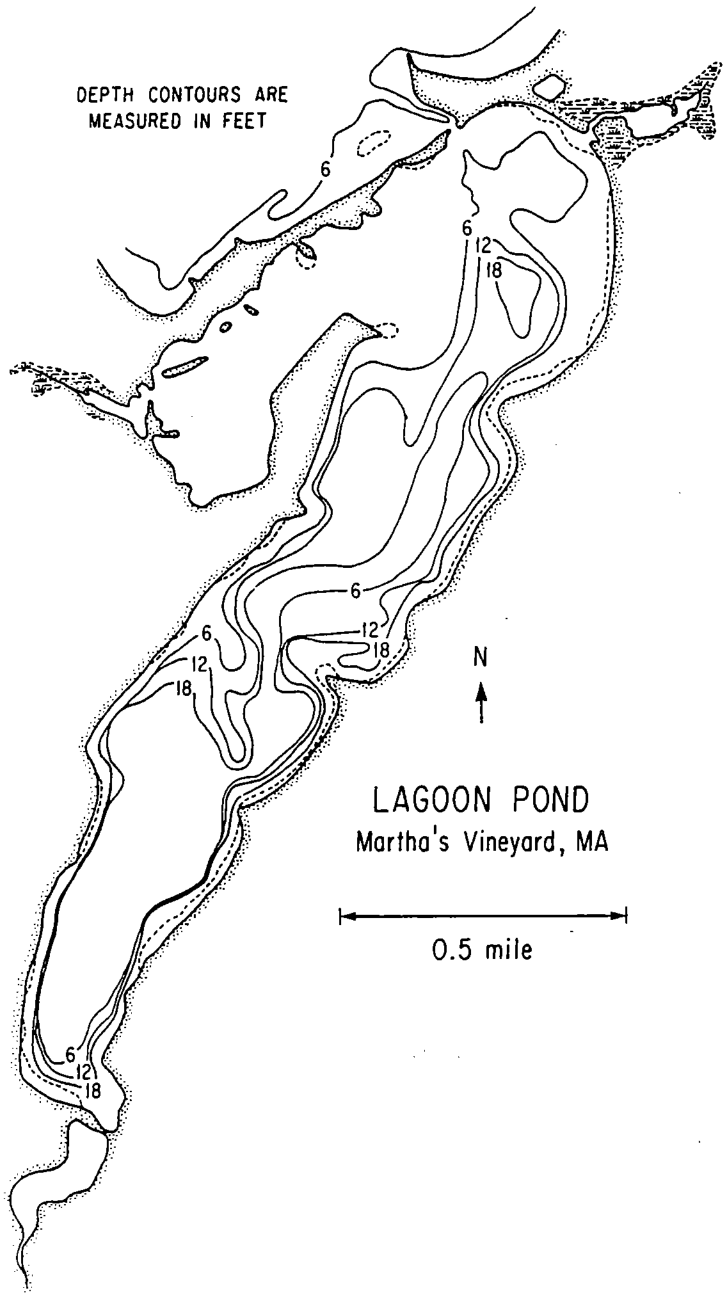
LAGOON POND, OAK BLUFFS, MASS

Morphometric data (Gaines 1986)

Area: 2.18 km^2 Shoreline length: 11.6 Km
Max depth 28 ft.

REFERENCES

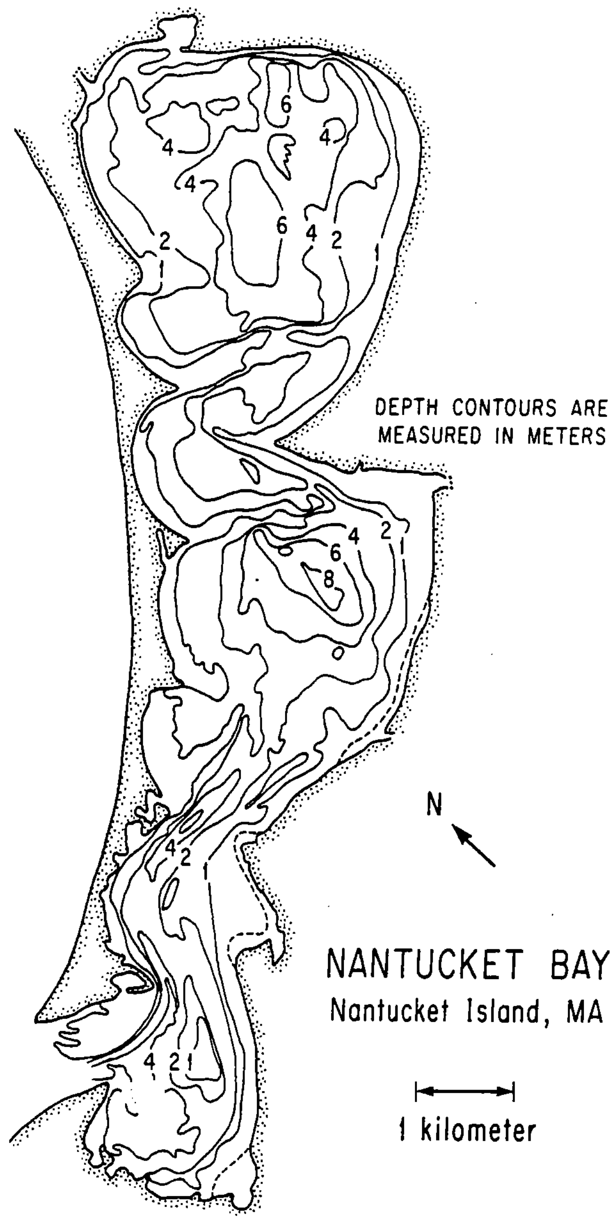
Gaines, A.G. 1986 - Study on nitrogen loading, watershed data



NANTUCKET BAY, NANTUCKET, MASS

REFERENCES

Lidz, L. 1965 - Sediment characteristics, calcium carbonate, foraminifera



SESACHACHA POND, NANTUCKET, MA

Morphometric Data (Aubrey Consulting, Inc.)

Area: $1.01 \times 10^6 m^2$
Max. Depth (1/2 tide level) 5.5m
Max. Width: 1270m
Max. Length: 1430 m

Other data

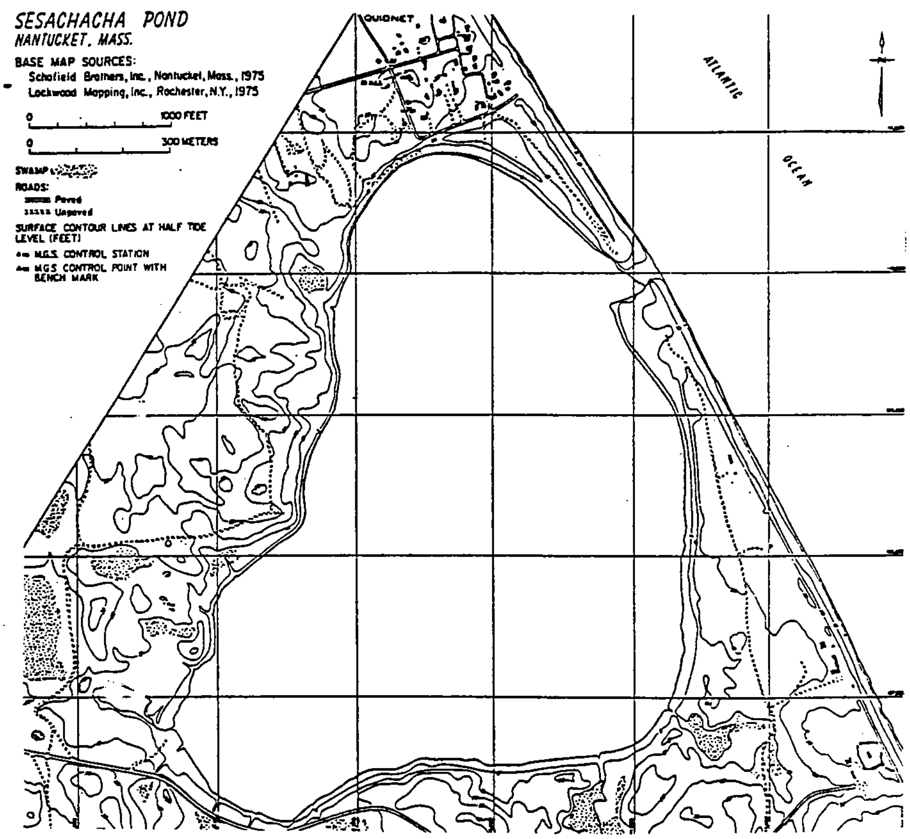
Avg. Salinity 2.4o/oo

REFERENCES

Aubrey Consulting, Inc. 1989a - the biological, physical and chemical parameters of the pond were evaluated to determine management options. Options considered included: <u>status quo</u>, dune restoration, pond opening, and connector regulation.

Kelly, K.M. 1988 - describes the marine resources in the pond and discusses historical shellfish populations.

Perkins Jordan, Inc. 1985 - contains hydrogeologic data and examine the effect that opening the pond would have on the groundwater.



REFERENCES

Anderson, D.M., and D. Wall (1978) Potential Importance of Benthic Cysts of Gonyaulax tamerensis and G. excavata in Initiating Toxic Dinoflagellate Blooms. J. Phycol. 14: 224-234.

Anderson, D.M., and F.M.M. Morel (1979) The Seeding of two Red Tide Blooms by the Germination of Benthic Gonyaulax tamarensis Hypnocysts. Est. Coast. Mar. Sci. 8: 279-293.

Anderson, D.M., and K.D. Stolzenbach (1985) Selective Retention of Two Dinoflagellates in a Well Mixed Estuarine Embayment: the Importance of Diel Vertical Migration and Surface Avoidence. Mar. Ecol. Prog. Series 25: 39-50.

Anderson, D.M., S.W. Chisholm, and C. Watras (1983) Importance of Life Cycle Events in the Population Dynamics of Gonyaulax tamerensis. Mar. Bio. 76: 179-189.

Anderson, G.D., and S.F. Edwards (1986) Protecting Rhode Island's Coastal Salt Ponds: An Economic Assessment of Downzoning. Coastal Zone Management J. 14: 67-91.

Asare, S.O., and M.M. Harlin (1983) Seasonal Fluctuations in Tissue Nitrogen for Five Species of Perennial Macroalgae in Rhode Island Sound. J. Phycology 19: 254-257.

Aubrey, D.G. (1985) Swan Pond River Stabilization Study. A Report Submitted to the Town of Dennis. Suit 2-3, 350 Gifford Street. Falmouth, MA, 02540, 78 pp.

Aubrey, D.G., and A.G. Gaines (1982) Rapid Formation and Degradation of Barrier Spits in Areas with Low Rates of Littoral Drift. Marine Geol. 49: 257-278.

Aubrey, D.G., and P.E. Speer (1982) Recent Evolution of an Active Barrier Beach Complex: Popponesset Beach, Cape Cod, MA. : Woods Hole Oceanographic Inst., p. 77.

Aubrey, D.G., and P.E. Speer (1984a) A Study of Nonlinear Tidal Propoagation in Shallow Inlet/Estuarine Systems. part I: Observations. Est. Coast. Shelf. Sci. 21: 185-205.

Aubrey, D.G. and P.E. Speer (1984b) Updrift Migration of Tidal Inlets. J. Geol. 92: 531-545.

Aubrey, D.G. and C.T. Friedrichs (1988) Seasonal Climatology of Tidal Non-Linearities in a Shallow Estuary. In: D.G. Aubrey & L. Weishar (Eds.) Hydrodynamics and Sediment Dynamics of Tidal Inlets pp. 103-124. Springer Verlag, Lecture Notes on Coastal and Estuarine Studies, Vol. 29.

Aubrey Consulting, Incorporated (1988) Swan River Training Wall and Dredging, Swan Pond, Dennsi, MA. Final Impact Report.

Aubrey Consulting, Incorporated (1989a) Analysis of Pond Management Alternatives, Sesachacha Pond, Nantucket. Draft Environmental Impact Report, 95 pp.

Aubrey Consulting, Incorporated (1989b) Shoreline Processes along Skaket Beach, Orleans, MA. Final Environmental Impact Report.

Barlow, J.P. (1952) Maintence and Dispersal of the Endemic Zooplankton Population in a Tidal Estuary, Great Pond, Massachusetts. PhD thesis: Harvard Universtiy, Cambridge, MA.

Barlow, J.P. (1955) Physical and Biological Processes Determining the Distribution of Zooplankton in a Tidal Estuary. Biol. Bull. 109: 211-225.

Barlow, J.P. (1956) Effects of Wind on Salinity Distribution in an Estuary. J. Mar. Res. 15: 193-202.

Barlow, J.P., C.J. Lorenzen, and R.T. Myren (1963) Euthrophication of a Tidal Estuary. Limnol. Oceanogr. 8: 251-262.

Beasant, J.J. and P.A. Kuczma, (1972) Salinity of Swan Pond River, A Water Quality Factor. Report to the Town of Dennis, Boston College Department of Geology and Geophysics, 61 pp.

Bilven, S., and A.L. Hankin, (Eds.) (1985) Salt Ponds and Tidal Inlets. New Bedford, MA: Llyod Center Publication 2-85, p. 130.

Bloomhardt, M. (1980) A Survey of Swan River. Report to the Town of Dennis.

Boothroyd, J.C., N.E. Friedrich, and S.R. McGinn (1985) Geology of Microtidal Coastal Lagoons: Rhode Island. Mar. Geology 63: 35-76.

Boynton, W.R., W.M. Kemp, and C.W. Keefe (1982) A Comparative Analysis of Nutrients and Other Factors Influencing Estuarine Phytoplankton Production. In V.S. Kennedy (ed): Estuarine Comparisons. New York: Academic Press, pp. 69-90.

Brownlow, A.H.(Ed.). (1979) Cape Cod Environmental Atlas. Boston, MA: Boston University, p. 62.

Buckland, K.J. (1985) Analysis of a Coastal Embayment: Holly Pond, Connecticut. In O.T. Magoon, H. Converse, D. Miner, and D..T. Clark (eds): Coastal Zone '85; Proceedings of the Fourth Symposium on Coastal and Ocean Management. New York: ASCE, pp. 2506-2519.

Buckley, G.D. (1974) Ecological Aspects of some Molluscan Species of Pleasant Bay, Orleans, Massachusetts, USA. Am. Malacol. Union Inc. Bull. 40:13.

Caraco, N.M. (1986) Phosphorous, iron, and carbon cycling in a salt stratified coastal pond. PhD Dissertation. Boston: Boston University, p. 213.

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APPENDIX I

References Organized According to the Following Topic Areas:

Bacteria
Benthos
Coastal Geomorphology
Dinoflagellates - Red Tide
Eutrophication
Finfish & Shellfish
Hydrodynamics
Groundwater
Macroalgae
Management
Nutrients
Phytoplankton
Primary Production
Seagrasses
Sediment Chemistry
Sediment-Water Exchange
Water Chemistry
Zooplankton

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This volume contains information on New England salt ponds and lagoons. The first part contains abstracts of a symposium on salt ponds and lagoons held in conjunction with the New England Estuarine Research Society (NEERS) on April 21, 1988. These should provide both scientists and managers with an overview of recent research on salt ponds. The second part contains, maps, morphometric data, and references for individual salt ponds in Connecticut, Rhode Island, and Massachusetts. The third section is a comprehensive bibliography of papers and reports on salt ponds, including information on ponds located outside of New England. A listing of references organized according to topic areas is also provided.

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