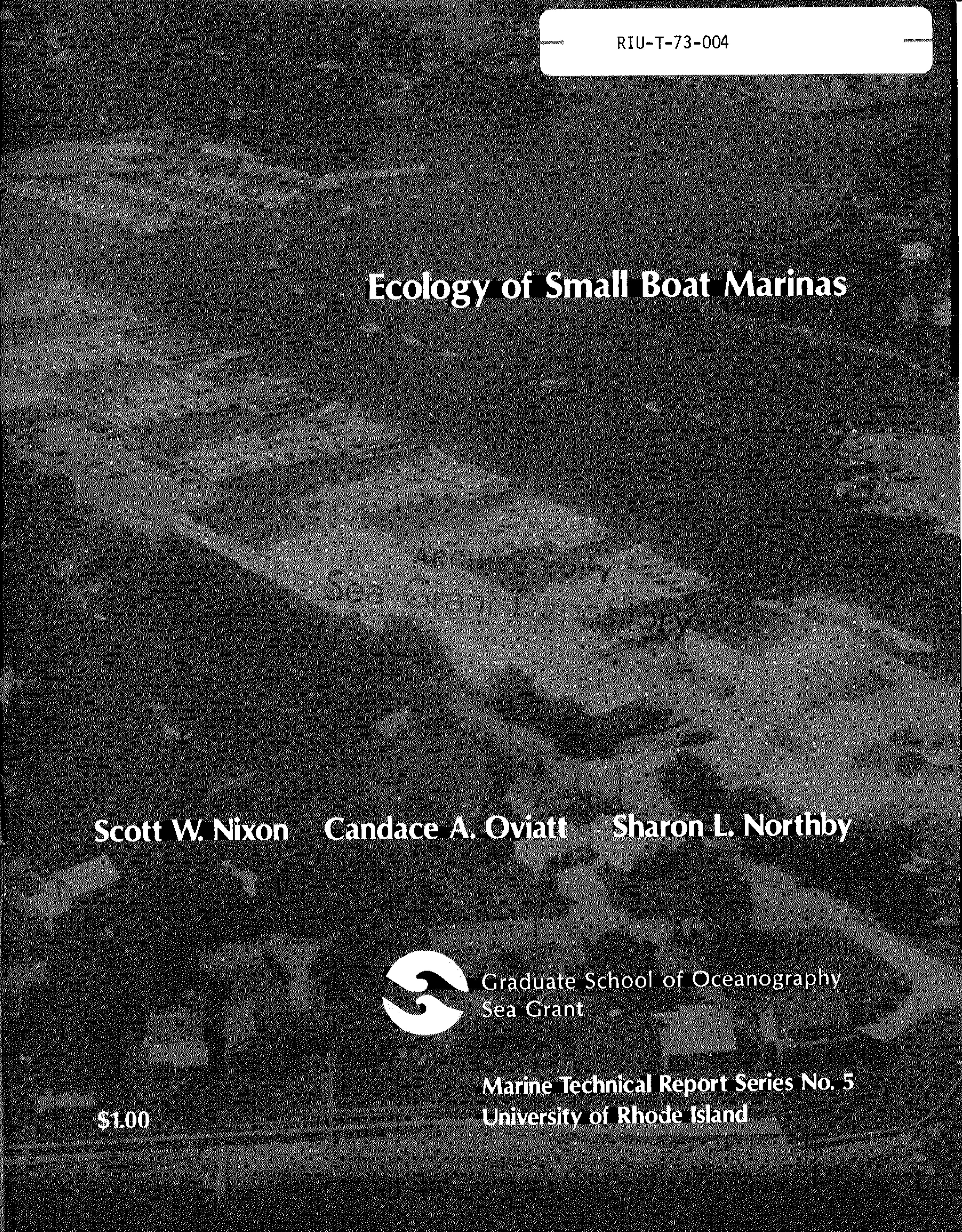

Ecology of Small Boat Marinas

Scott W. Nixon   Candace A. Oviatt   Sharon L. Northby

Graduate School of Oceanography
Sea Grant

Marine Technical Report Series No. 5
University of Rhode Island

$1.00

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Acknowledgements

This research was supported by the Office of Sea Grant Programs, NOAA, U. S. Department of Commerce, and carried out in cooperation with the University of Rhode Island Marine Advisory Service (MAS) and the Rhode Island Marine Trades Association. We are grateful to the Rhode Island Department of Natural Resources Marine Fisheries Section in Wickford and the National Marine Water Quality Laboratory, Environmental Protection Agency, in West Kingston for providing equipment and field support. The owners and managers of the following marinas cooperated in the study: Quigley's, Wickford Cove, Wickford Shipyard, Norton's, Apponaug Cove, Port Edgewood, Ida Lewis and Goat Island. Much of the extensive field and laboratory work could not have been completed without the help of Ann Gall, William Macy, Fred Short, Steve Hobbs, Jim O'Reilly, Joyce Hempstead, Pandora Ray, Pam Brown and Nigel Blakely. Neil W. Ross of the MAS and Charles Dickerson, president of the Rhode Island Marine Trades Association, were instrumental in developing the project and serving as liaison with the individual marina owners. Henry Stebbins ran the heavy metal analysis, using atomic absorption equipment provided by Robert Duce and Gerald Hoffman at the University's Graduate School of Oceanography. Pure cultures of Narragansett Bay phytoplankton were provided by Paul Hargraves from the University's marine phytoplankton culture collection.

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Abstract

In Wickford Harbor, Rhode Island, a yacht marina area and a salt marsh cove were considered as ecological systems and compared to evaluate biological populations and magnitudes of production and respiration. Volume and flushing characteristics of both areas were similar. Analyses were made in each cove on marsh grass production, suspended particulate matter, phytoplankton, nutrients, bacteria, dissolved organics, copper levels, fish and sediments. Biomass and metabolism measurements were made on the fouling communities present on floats and pilings in the marinas. Preliminary bioassays were performed with concentrations of outboard motor exhaust water on several species of estuarine organisms. Some additional comparative measurements were taken inside and outside other marinas located in Narragansett Bay.

No major differences were found in marsh grass production, concentrations of suspended particulate matter, nutrients, bacteria, dissolved organics, infauna, or sediment metabolism. Copper levels, while lower than toxic concentrations reported in the literature, were higher in the marina cove, ranging from 0.009 $\mu g/g$ in the water to 160 $\mu g/g$ in the fouling community. Fish species reached the same levels of diversity in both the marina and the marsh cove, but abundance was greater in the marsh cove due to the presence of dense juvenile menhaden schools.

The fouling communities of the marinas, which appeared to be a food source for juvenile mummichogs (*Fundulus heteroclitus*), exerted a significant oxygen demand on the marina cove. Diurnal curves of dissolved oxygen showed lower concentrations at the end of the night in marina areas than in adjacent waters. For this reason, and because preliminary bioassays indicated some toxicity due to exhaust waters, it is suggested that marina sites be well flushed with oxygenated tidal waters. The luxurious fouling growths which developed in the marina cove may serve as additional food sources to complement the detritus input from the salt marsh.

In most respects the marina cove and the marsh cove appeared to be not only similar, but also compatible ecological systems.

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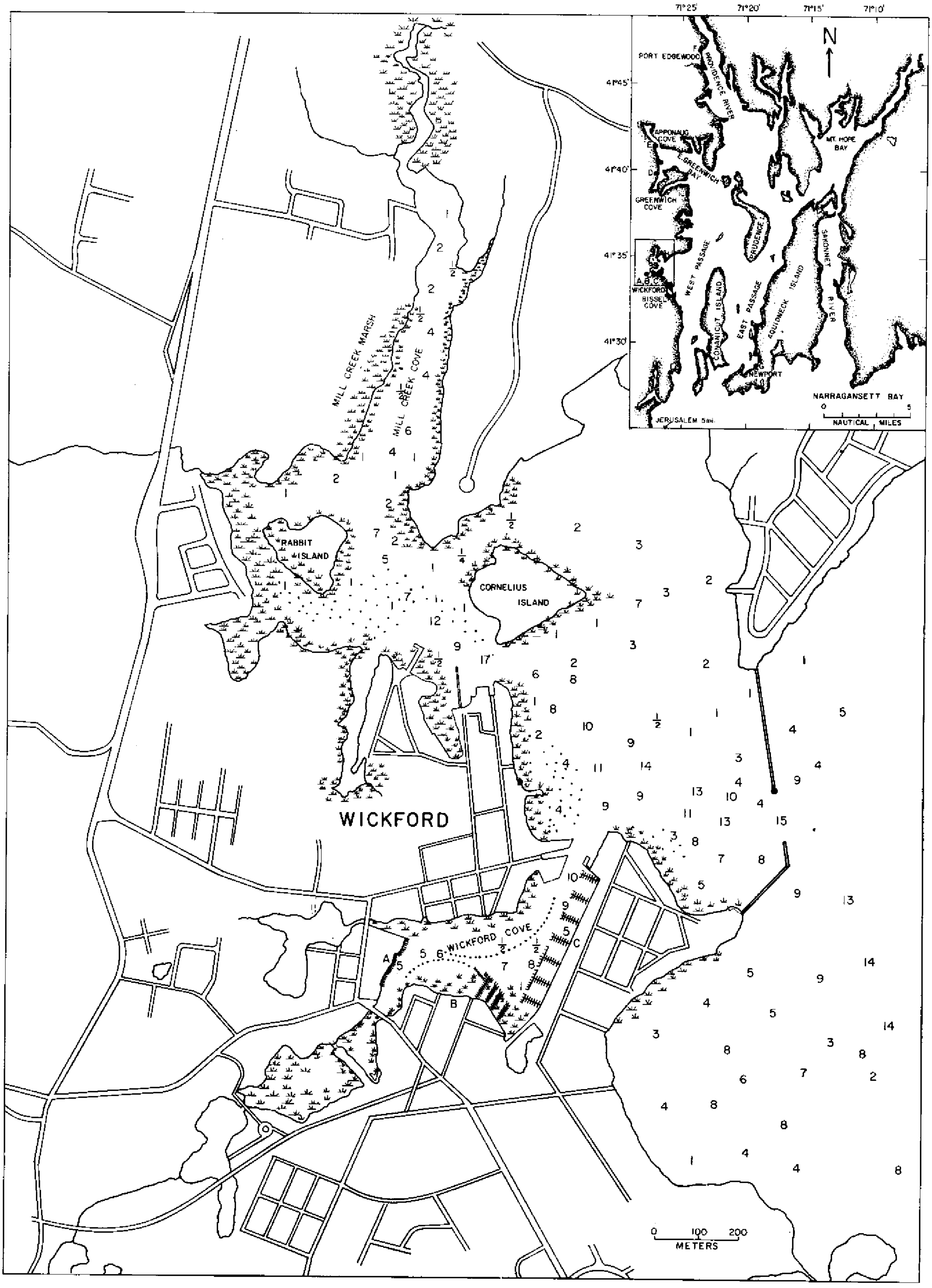

71°25'
71°20'
71°15'
71°10'
41°45'
41°40'
41°35'
41°30'
N
PORT EDGEWOOD
PROVIDENCE RIVER
APPONAUG COVE
E
D
GREENWICH BAY
GREENWICH COVE
MT. HOPE BAY
PRUDENCE
WEST PASSAGE
EAST PASSAGE
SAKONNET RIVER
AQUIDNECK ISLAND
CONANICUT ISLAND
A,B,C
WICKFORD
BISSEL COVE
NEWPORT
JERUSALEM 5mi.
NARRAGANSETT BAY
0
5
NAUTICAL MILES
MILL CREEK MARSH
MILL CREEK COVE
RABBIT ISLAND
CORNELIUS ISLAND
WICKFORD
WICKFORD COVE
A
B
C
0
100
200
METERS

Introduction

The coastal zone provides a source of continuing controversy between the increasing numbers of those who wish to develop and expand man's housing, recreation, and other activities there, and those who wish to preserve nature's long-standing patterns. Part of the controversy involves the conflicting demands of marina owners and users, and salt marsh conservationists. And, in part, this conflict arises because both marinas and marshes require similar conditions for development, including protection from strong waves and currents.

Coastal ecologists have made a great effort over the years to study marshes and document their importance in estuarine ecology (Chapman 1960, Teal 1962, Odum and de la Cruz 1967, Udell et al 1969, Williams and Murdoch 1969, Pomeroy et al 1972, Nixon and Oviatt in press, a). In contrast, little is known about the environmental impact or ecology of marinas as alternative systems. A recent descriptive study of a large marina in southern California by Bowerman and Chen (1971) emphasized the chemical impact of storm drainage into the area, rather than general ecology. A few studies have attempted to show the effects of outboard motor exhaust on freshwater lakes and fish. These include work by Lagler et al (1950), the Environmental Protection Agency (1971), Kuzminski and Jackivicz (1972) and the well known Lake X project by Environmental Engineering, Inc. (1970). Studies of trash and sewage pollution by boats have also been carried out by Clarke (1968), Furfari and Verber for the United States Public Health Service (1969), Griscom (1972) and others.

While there have been few, if any, attempts to look at the marina as an ecological system, Isard et al (1972) made a recent analysis of the economic effects of coastal marina developments. They considered some environmental factors and evaluated the ecological "trade-off" of marina construction for the one-year market value of the clams, mussels, worms, and fish that the marsh system would have produced. They did not consider that the exploited marsh was not a managed mariculture system, that the marina might be evaluated as an environment in its own right, or that the ecological "trade-offs" between marshes and marinas might not all be negative. The "ecologic cost" which Isard suggested as a concept for widespread use in many resource development projects would place the value of *Spartina alterniflora* marsh at less than $25 per acre. In contrast, the value increases dramatically to $12,000 per acre if Odum's (1971) energy analysis, which is based on a ratio of average national dollars to kilocalories of 1:10,000, is applied to marsh production. But both ecosystem evaluations fail to include the time dimension. For example, any type of cash crop production might be permanently removed by development, making the value range from $25 to $12,000 per acre *per year*, depending on one's point of view. Thus, neither of these methods of accounting seems satisfactory, one, perhaps, resulting in figures too low and the other, too high. A more realistic approach may be to evaluate the replacement costs for goods and services provided by a system to the biosphere as well as to man. As a first step in this direction for the marina system, we have made some basic ecological measurements of its production, respiration, diversity, and major populations for comparison with those of estuarine salt marshes and other natural communities.

Fig. 1. Wickford Harbor showing the two major study areas, Wickford Cove in the south, and Mill Creek salt marsh cove in the north. Depths are in feet at mean low water (MLW). Narragansett Bay, Rhode Island, is shown in the insert, which includes additional study sites.

Study Areas

Wickford Harbor, off the West Passage of Narragansett Bay, Rhode Island, is one of the finest and most popular small boat harbors in New England (*Narragansett Times* 1972). It also provides a morphology and development pattern that is almost ideal for a study of the ecology and ecological impact of coastal marinas. Two similar coves open into the harbor. The first, Wickford Cove, contains three marinas and numerous moorings, while the second, Mill Creek, is bordered by a fringing *Spartina alterniflora* marsh with no boats, docks, or moorings (Fig. 1). It is thus possible to make comparative measurements in each cove.

The marina area contained 300-400 boats throughout the summer, including 13.9 percent sail, 40.3 percent outboards and 45.8 percent inboards during a survey in June. The relatively large proportion of boats with inboard power reflects the size distribution in the marinas, where the following distribution of boats by length was found:

less than 15 feet	1.0%
16-20 feet	32.4%
21-30 feet	31.4%
31-40 feet	26.2%
41-50 feet	5.0%
over 50 feet	4.0%

The great numbers of larger boats in these marinas is in contrast to the general distribution of registered pleasure craft in 1970 in the state, where 92 percent were less than 27 feet and almost 80 percent were powered by sail and /or outboard motors (Rorholm and Feld 1971). It is, however, representative of the general size distribution of boats in full-time commercial marinas, since 85 percent of boats were in the 16-40-foot class statewide, and 90 percent were in this category in Wickford.

Dredging of a five-to-seven-foot channel in Wickford Cove had produced deeper water and a somewhat greater volume of it in the marina area; otherwise, the hydrographic conditions in each cove were similar.

	Wickford Cove	**Mill Creek**
Area	73×10^3 m^2 (18 acres)	72×10^3 m^2 (18 acres)
Marsh area		
in marinas	2.4×10^3 m^2 (0.6 acres)	112.5×10^3 m^2 (27.8 acres)
above marinas	42.9×10^3 m^2 (10.6 acres)	
Mean depth (MLW)	1.1 m (3.7 ft)	0.8 m (2.6 ft)
Channel depth (MLW)	2 m (6.6 ft)	....
Volume (MLW)	83×10^3 m^3 (21.9×10^6 gal)	56.8×10^3 m^3 (15.0×10^6 gal)
Tidal prism	10×10^4 m^3 (26.4×10^6 gal)	9.8×10^4 m^3 (25.8×10^6 gal)

Hypsographic curves for the two coves are shown in Figure 2. If complete mixing of the tidal water is assumed, both areas were flushed more than 50 percent on each tidal cycle.

Additional marina and marsh areas were also sampled occasionally to provide comparative data. The locations of these areas are also shown (see insert, Fig. 1); they include East Greenwich Bay, Providence River, Newport Harbor, Jerusalem and Bissel Cove.

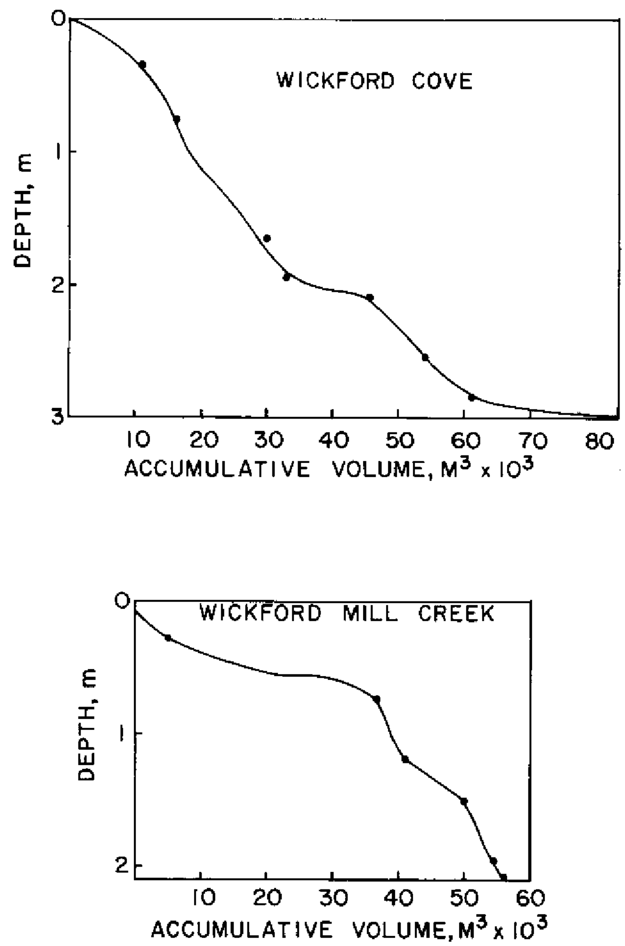

Fig. 2. Hypsographic curves for Wickford Cove and Mill Creek Cove.

Methods, Results and Discussion

Marsh Grass Production

The height and weight of the tall form of *Spartina alterniflora* were measured on grass growing around the marinas and in the Mill Creek marsh. Ten samples were taken at the end of the growing season in each area by random toss of a ¼ m^2 quadrat. All of the grass within the quadrat was clipped at ground level, dried at 105-110C, and weighed. Twenty blades from each sample were selected at random for measurement of length prior to drying.

Results The standing crop of tall *Spartina alterniflora* growing in patches around the Wickford marinas averaged 857 g dry weight/m^2, while the Mill Creek marsh values averaged 1146 g/m^2 (Table 1). This difference was not statistically significant at the 95 percent confidence level, although a mean difference in height of the grass in the two areas of 8 cm was significant (Table 1, Fig. 3). This small difference was not visually apparent in the field. Both the height and weight data for Wickford coves were similar to other marshes in this area of the Bay (Nixon and Oviatt in press, b).

Table 1. Height and standing crop of the tall form of *Spartina alterniflora* growing around the Wickford Cove marinas and in the Mill Creek salt marsh.

Sample	Height, cm*		Standing Crop, g/m²	
	Marinas	*Marsh*	*Marinas*	*Marsh*
1	116 ± 21	111 ± 9	648	687
2	109 ± 20	129 ± 21	650	587
3	120 ± 31	123 ± 11	928	1327
4	144 ± 16	116 ± 19	1138	557
5	119 ± 21	101 ± 19	931	826
6	129 ± 14	157 ± 9	989	1681
7	131 ± 23	164 ± 15	1173	1717
8	113 ± 10	145 ± 11	536	1375
9	119 ± 16	129 ± 17	911	1001
10	154 ± 15	155 ± 24	672	1702
$\bar{X}$	125 ± 23	133 ± 26	857 ± 219	1146 ± 471

* *Mean ± 1 standard deviation, N = 20.*

Suspended Particulate Matter

The concentration of suspended particulate matter on ebb tides was measured at the mouth of each cove on seven days during the summer. Water samples were taken hourly, filtered through pre-weighed Reeve Angel No. 934 AH glass fiber filters and dried at 105-110C before re-weighing. Comparative data were also taken from three other marinas on upstream transects through each area.

Results The concentration of suspended particulate matter on ebb tides from both areas was remarkably uniform throughout the summer, averaging about 20 mg/liter for both the marinas and the marsh in Wickford (Table 2). No statistically significant difference was found between the two areas. The results of transect measurements on three other marinas are shown in Figure 4. No consistent effect of the marinas on the concentration of particulates is apparent, since the levels decrease in one location, increase in another, and remain the same at a third. While there are many possible sources for this material, including marsh grass detritus, fragments of fouling communities, plankton, land run-off, and resuspended sedimentary material, the particulate matter in total may serve as a valuable food source for estuarine organisms. Although there is little, if any, difference in gross abundance of suspended particulate matter between the marina and marsh area, differences in chemical composition or nutritional value may exist.

Table 2. Concentration of suspended particulate matter on ebb tides from Wickford Cove marinas and Mill Creek salt marsh.

Date	Number of Samples	Concentration, mg/l*	
		Marinas	*Marsh*
6-13-72	6	22.5 ± 2.6	20.4 ± 6.1
6-29-72	6	22.7 ± 5.6	21.7 ± 2.7
7-13-72	6	20.9 ± 7.8	18.3 ± 6.9
7-17-72	4	19.6 ± 5.7	15.5 ± 4.6
7-27-72	5	15.6 ± 3.7	18.5 ± 9.5
8-11-72	6	22.9 ± 4.7	21.1 ± 2.8
9- 7-72	7	22.0 ± 6.2	22.3 ± 4.1
	$\bar{X}$	21.1 ± 5.5	19.9 ± 5.6

* *Mean ± 1 standard deviation.*

Phytoplankton Abundance and Plankton Metabolism

The relative abundance of phytoplankton in water ebbing from the coves was estimated by measurements of the plant pigment, chlorophyll *a* (Strickland and Parsons 1968). Water samples were taken hourly at the mouth of each cove during the ebb tide on three days, filtered through 0.8 micron membrane filters, and the filters extracted with acetone.

Photosynthesis by the phytoplankton and respiration by the phytoplankton and zooplankton were measured by the light-and-dark-bottle method. Oxygen concentrations were determined by Winkler titration (Strickland and Parsons 1968). Samples were taken in triplicate at three or more stations (head, middle, mouth) in each cove on six days during the summer. Incubations were made for four hours during the mid-day at 0.5 m depth.

Results Concentrations of chlorophyll *a* appeared higher in water ebbing from the marsh cove on each of the three days measured, with a mean value for the Mill Creek marsh of 21.5 μg/l compared with 11.8 μg/l in Wickford Cove (Table 3). The differences observed in July were significant at the 95 percent level of confidence, while for those in August the comparable level of confidence was 90 percent. If the chlorophyll content of phytoplankton is taken as 1 percent of their dry weight (Parsons et al 1961), then the levels of particulate matter found in both areas may consist of from 2.5 percent to 25 percent phytoplankton by weight, with the rest coming from zooplankton, detritus, and other sources.

The higher chlorophyll levels in the marsh water did not result in greater production. With the exception of a single day when there was a phytoplankton bloom in the marsh cove, gross production values in marina water averaged 0.21 mg O_2/l/hr while the values in the marsh average 0.08 mg O_2/l/hr (Table 4). Respiration values for the plankton community in both areas were similar, averaging 0.08 and 0.06 mg O_2/l/hr in the marina and

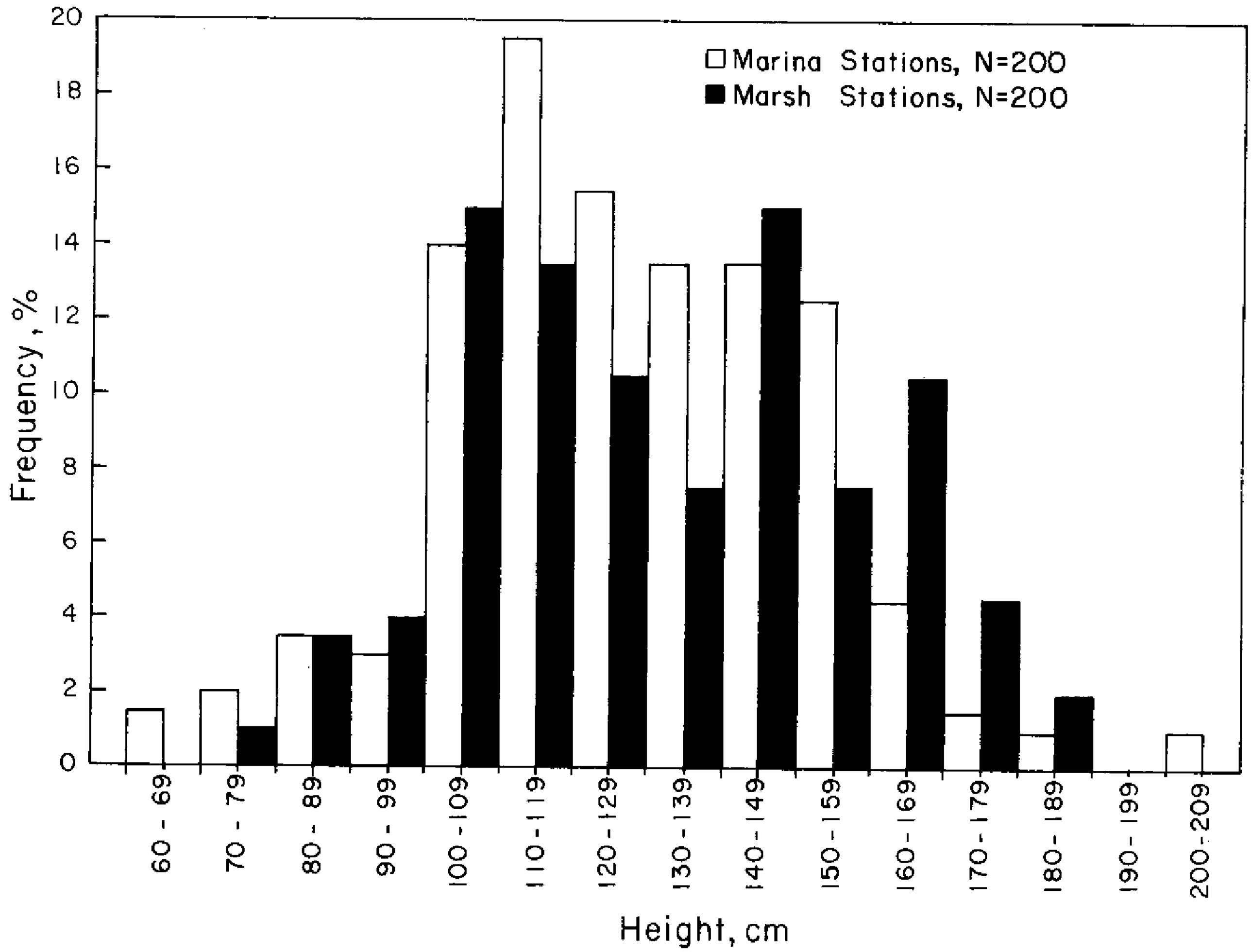

Fig. 3. Height class frequency for tall *Spartina alterniflora* at the end of the growing season near Wickford Cove marinas and in the Mill Creek marsh.

Table 3. Concentrations of chlorophyll *a* in water ebbing from the Wickford Cove marinas and the Mill Creek salt marsh.

Date	Tide	Chl *a*, μg/l	
		Marina	*Marsh*
6-29-72	high slack + 1 hr	19	33
	+ 5 hr	8	29
7-27-72	high slack + 1 hr	14	27
	+ 2 hr	22	—
	+ 3 hr	24	48
	+ 4 hr	5	25
	+ 5 hr	15	39
8-11-72	high slack	8	8
	+ 1 hr	7	8
	+ 2 hr	6	11
	+ 3 hr	7	12
	+ 4 hr	9	11
	+ 5 hr	9	7

marsh, respectively. While the plankton species composition may have differed in the two locations, the marinas did not appear to have any inhibitory effect on overall plankton photosynthesis or respiration.

Nutrient Concentrations

Concentrations of ammonia and phosphate were measured three times in transects down each cove using the methods of Solarzano (1969) and Strickland and Parsons (1968). A series of measurements of ammonia, nitrite, and nitrate was taken hourly during one ebb tide at the mouth of each cove. The concentrations of nitrite and nitrate were measured with a Technicon Autoanalyzer.

Results The few nutrient samples analyzed did not indicate that either area showed abnormally high levels of phosphate or ammonia. The most complete series of nitrogen measurements, taken in June when almost all of the boats were in the water, showed higher levels of ammonia, nitrite, and nitrate in the marsh cove (Table 5). There did not

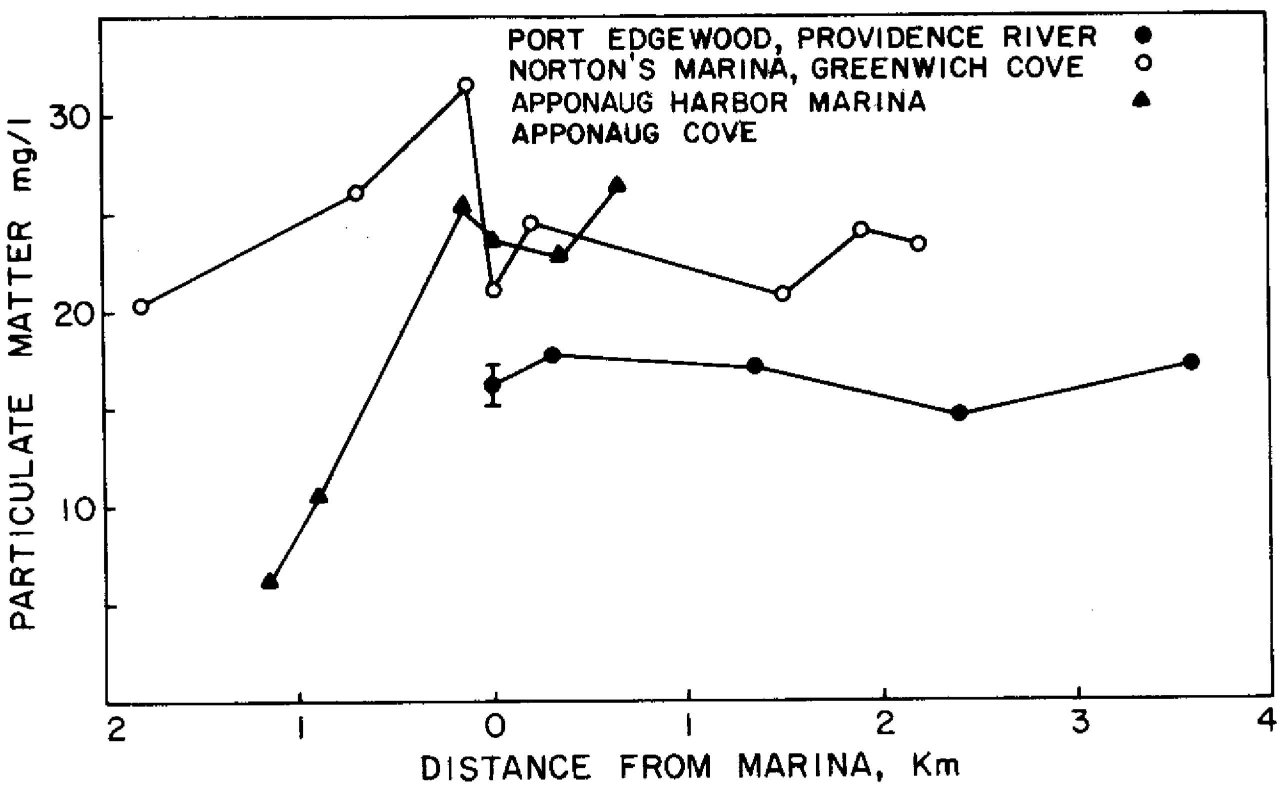

Fig. 4. Suspended particulate matter on upstream-downstream transects through marinas.

Table 4. Plankton metabolism in the Wickford Cove marinas and the Mill Creek salt marsh.

Date		Gross Production* mg O_2/l/hr		Respiration* mg O_2/l/hr		Net Production mg O_2/l/hr	
		Marinas	*Marsh*	*Marinas*	*Marsh*	*Marinas*	*Marsh*
5-8-72		0.24 ± 0.01	0.04 ± 0.04	0.07 ± 0.04	0.04 ± 0.03	0.17	0.00
5-11-72		0.30 ± 0.13	0.11 ± 0.05	0.11 ± 0.08	0.07 ± 0.05	0.19	0.03
6-27-72		0.16 ± 0.09	0.06 ± 0.06	0.08 ± 0.09	0.04 ± 0.04	0.08	0.02
7-25-72		0.27 ± 0.05	0.12 ± 0.14	0.09 ± 0.02	0.08 ± 0.04	0.18	0.04
8-24-72		0.29 ± 0.04	1.03 ± 0.41	0.13 ± 0.05	0.12 ± 0.02	0.16	0.91
10-12-72		0.06 ± 0.02	0.07 ± 0.00	0.04 ± 0.04	0.05 ± 0.04	0.02	0.02
	$\bar{X}$†	0.22	0.23	0.09	0.07	0.13	0.17
	$\bar{X}$‡	0.21	0.08	0.08	0.06	0.13	0.02

* *Mean ± 1 standard deviation from triplicate samples of three or more stations; † mean for all samples; ‡ mean with 8-24-72 deleted.*

appear to be any indication that the boats in Wickford Cove were a major source of nutrient enrichment.

Table 5. Nutrient levels in the Wickford Cove marinas and the Mill Creek salt marsh.

Transect Measurements, μ moles/l

Date	*Nutrient*	*Marina*			*Marsh*		
		head	*mid-dle*	*mouth*	*head*	*mid-dle*	*mouth*
5-10-72	ammonia	4.31	4.39	4.34	2.95	2.95	0.03
5-17-72	phosphate	0.99	1.24	0.99	0.99	0.81	0.81
7-27-72	ammonia	ND	ND	ND	ND	4.54	ND

Ebb Tide Measurements Near Mouth 6-13-72, μ moles/l

Tide	*Marina*			*Marsh*		
	ammonia	*nitrite*	*nitrate*	*ammonia*	*nitrite*	*nitrate*
high slack	1.18	ND	0.03	0.86	ND	0.28
ebbing 1	1.88	ND	0.04	2.35	ND	0.98
ebbing 2	2.59	ND	0.04	3.35	0.09	2.89
ebbing 3	2.91	ND	0.05	5.74	0.20	10.01
low slack	2.53	ND	0.04	3.76	0.12	5.72

Bacteria

On three days water samples were collected with sterile bottles in the Wickford marina and salt marsh coves. Additional samples were taken on transects through other marinas, and also at the mouth of the coves in Wickford Harbor on three ebb tides. Sampling days were included at the beginning and end of the week to get "before-and-after" estimates of total and fecal coliform bacteria across the weekend period of heavy boat use. Samples were analyzed by sanitary engineers in the University's Department of Environmental Engineering.

Results No clear pattern is evident in the bacteriological analysis of water samples for coliform and fecal coliform bacteria carried out by the engineers. In almost all cases, counts in both areas are high, often exceeding the 70/100 ml limit used by the U.S. Public Health Service in closing areas to the taking of shellfish (Table 6). Additional samples were taken on transects through marinas at Apponaug in East Greenwich Bay and at the Ida Lewis and Goat Island Marinas in Newport Harbor. Again, the background levels of coliform resulting from land-based sewage input were so high that no impact of the marinas could be detected. As Furfari and Verber (1969) point out in a detailed bacteriological study of the effect of boats on water quality in Potter Cove, Narragansett Bay, the traditional counts of coliform bacteria are probably not useful in detecting pollution from boats. Since the input from boats is in the form of fresh fecal material rather than sewage, the associated coliform number is low with respect to standards based on city sewage. The counts of fecal coliform are much more indicative of fresh pollution.

Table 6. Bacteriological analysis of water from the Wickford Cove marinas and the Mill Creek salt marsh.

Date	Tide	N	Bacteria—MNP/100 ml			
			Marina		*Marsh*	
			Total Coliform	*Fecal Coliform*	*Total Coliform*	*Fecal Coliform*
5-10-72 (W)	ebb	3	70	6	33	5
7-13-72 (Th)	ebb	2	1100		59	
7-17-72 (M)	ebb	3	53		110	
7-27-72 (Th)	ebb	3	52	15	1609	815
9-4-72 (M)	ebb	6	6.6	3		

Dissolved Organics

Water samples from both coves as well as from other areas in Wickford Harbor were collected on a Monday morning in July for analysis by absorption spectrophotometry. It was hoped that collection at this time would reflect heavy weekend use of boats and motors. Levy (1971) has suggested that ultraviolet absorption characteristics may be useful in identifying machine hydrocarbons. Samples were filtered through 0.8-micron membrane filters and their absorption measured from 220 to 350 nm in a Cary 15 recording spectrophotometer. Quartz cuvettes were used with a NaCl distilled water solution as reference.

Results Ultraviolet absorption spectra of water samples from the Wickford Cove marinas, Mill Creek salt marsh, and the Wickford Harbor breakwater are shown in Figure 5. All of the curves appear very similar except for differences in the concentration of absorbing compounds. The spectra do not resemble those shown by Levy (1971) which indicated oil pollution in the marine waters of eastern Canada. A closer similarity is found to the absorption pattern reported by Sieburth and Jensen (1968) for a freshwater bog, except that the peaks here are broader and more distinct, and shifted about 50 nm further into the ultraviolet. It appears that much of the dissolved organic matter in both coves is similar, and consists of breakdown products from decaying marsh grass, *Spartina* (Sieburth, personal communication). The lower concentration of these materials in the marina cove reflects the smaller amount of marsh grass in the area and perhaps greater dilution by Bay water. It was not possible to identify any oil or gasoline "fingerprint" in spectra from the marinas.

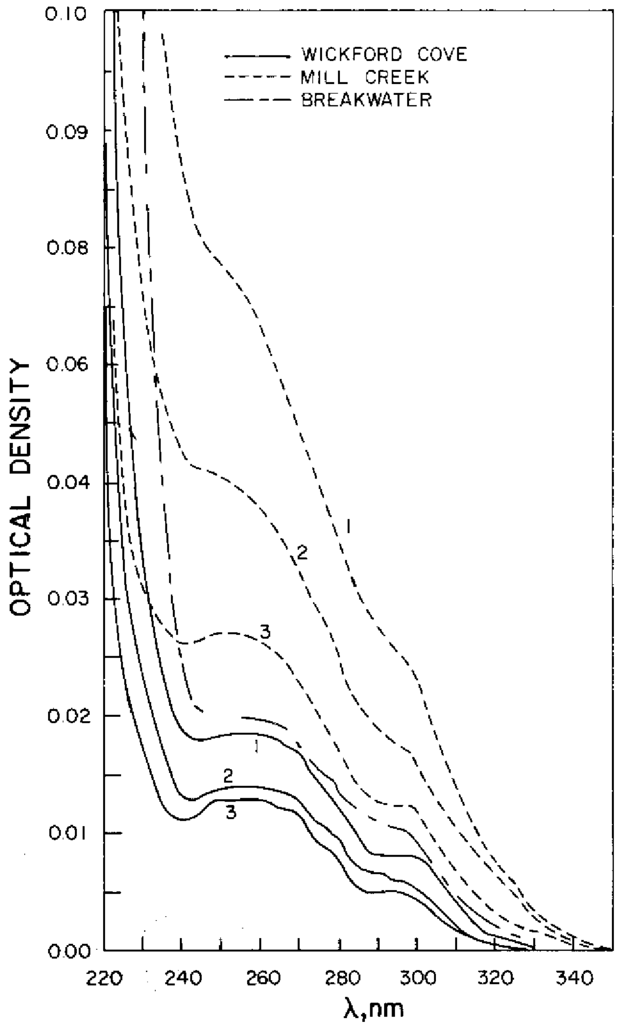

Fig. 5. Ultraviolet absorption spectra for filtered water samples from Wickford Harbor. The numbers 1, 2, 3 represent stations at the head, middle, and mouth of each cove.

Copper Levels

Samples of characteristic marsh and marina organisms, as well as sediments and water, were analyzed for copper content. Except for water samples, the materials were dried at 60C and ground to a powder before wet-ashing with concentrated HNO_3. Water samples were prepared according to Environmental Protection Agency directions (1971). Concentrations of copper were determined with a Perkin-Elmer 303 atomic absorption unit, using an external copper standard.

Results The concentrations of copper in common organisms, water, and sediments from the two Wickford coves are summarized in Table 7. In three cases—a green alga, *Ulva lactuca* or sea lettuce; the fouling communities that developed on suspended plastic plates, and the sediments—there was a significantly higher concentration of copper in the marina area. High levels of copper were also found in the established fouling community growing on floats in the marinas. Since copper is the most common heavy metal in the antifouling paint used on boats, it is not surprising that high concentrations appear in these stationary parts of the marina community. The copper in the fouling community does not appear to move through the food chain into the fish or shrimp, but only adult animals were measured. Other evidence, discussed in the section on fish, indicates that juvenile common mummichog may use the fouling organisms for food. They should be carefully checked in future work, as well as the sport fish that prey on them.

Table 7. Concentrations of copper in organisms, water and sediments from the Wickford Cove marinas and the Mill Creek salt marsh.

Sample	N	Copper, μg/g*		
		Marina		*Marsh*
Common mummichog (f)	5,5	12 ± 0.6		13 ± 3.3
Common mummichog (m)	5,5	11 ± 2.1		8.8 ± 1.4
Silversides *(M. menidia)*	5,5	3.1 ± 0.2	†	4.9 ± 0.7
Grass shrimp *(P. pugio)*	5,5	150 ± 27		134 ± 12
Algae *(Ulva lactuca)*	5,5	27 ± 0.5	†	18 ± 1.0
Fouling community on plastic plates	4,7	76.3 ± 15.7	†	20 ± 8.8
Fouling community on docks	2,0	160		
Marsh grass detritus *(Spartina)*	0,1			17
Quahog *(M. mercenaria)*	1,1	16		18
Bottom worms	1,1	31		32
Sediment	5,5	39 ± 5.7	†	12 ± 3.2
Water (ebb tide)	5,5	0.009 ± 0.003		0.012 ± 0.002

* *Mean ± 1 standard deviation;* † *significant difference at the 95% confidence level.*

The concentration of copper in the water in both coves, about 10 μg/l, was higher than that in seawater (3-5 μg/l, Mandelli 1969). This may be more a reflection of generally higher concentrations of copper in Narragansett Bay resulting from jewelry and other metal industry effluents than it is of any local influence from boats. The concentration in the marina water was well below the levels that have been found to inhibit growth of estuarine phytoplankton. Erickson et al (1970) report an 80 percent inhibition of growth in *Olisthodiscus luteus,* an abundant component of the summer plankton, at 50 μg copper/l, and a 36 percent inhibition in *Skeletonema costatum,* a characteristic Bay phytoplankter, at 100 μg/l. Another study by Mandelli (1969) has shown copper inhibition at concentrations ranging from 30-500 μg/l, with an inhibition of cell division in *Skeletonema* at 50 μg/l. In general, flagellates appear more sensitive than diatoms. Mandelli also points out that the effective concentrations of copper in coastal waters may be much higher than culture experiments indicate due to the presence of chelators, such as carboxylic acids, amino acids, etc., that can inactivate copper ions. In a study of the impact of large inputs of copper on the ecology of a Texas lagoon, Marin et al (1961) found no lasting effect of concentrations from about 6-25 μg/l on phytoplankton, zooplankton, barnacles or snails.

Fish Abundance and Diversity

The species composition, relative abundance, and size of fish in marina and marsh areas were followed throughout the summer. Three to five small baited traps (7 mm mesh) were left overnight and collected once or twice each week from the two Wickford coves. Additional samples were taken occasionally from traps placed in four other marinas and adjacent marsh areas around the Bay. Monthly 17 m seine hauls (7 mm mesh) were also made in 90-degree arcs from shore at six stations in the Wickford coves and inside and outside of the other marinas. In early summer and fall, 67 m (15 mm mesh) seine hauls were made in a similar manner at three stations in the marina and marsh cove. In all cases, the fish were identified and the number of species and individuals counted. The standard lengths of the abundant common mummichog *(Fundulus heteroclitus)* were measured from the traps and the 17 m seine hauls.

A preliminary estimate of sports fishing activity in the two Wickford coves was begun by interviewing fishermen on three days at the end of summer.

Results The numbers of small animals and total number of species captured in weekly trap measurements were highly variable, but throughout the summer showed no apparent difference between the marina or marsh areas (Fig. 6). The total number of animals, including small fish, snails, crabs and shrimp, increased in late summer. The same seasonal pattern in species abundance has been shown in detail for a nearby marsh area (Nixon and Oviatt, in press, a). If only fish are considered in the trap counts, the resulting seasonal pattern and the similarity between the two areas remain unchanged (Fig. 7). However, an analysis of the diversity of fish in the trap data by month using Sanders' (1968) rarefaction method showed a greater diversity of small fish in the marsh during June. This trend narrowed in July and may have reversed in August when juvenile fish moved into the marinas (Fig. 8). Interpretation of the August data is complicated by the crossing of the species number curves for the two areas.

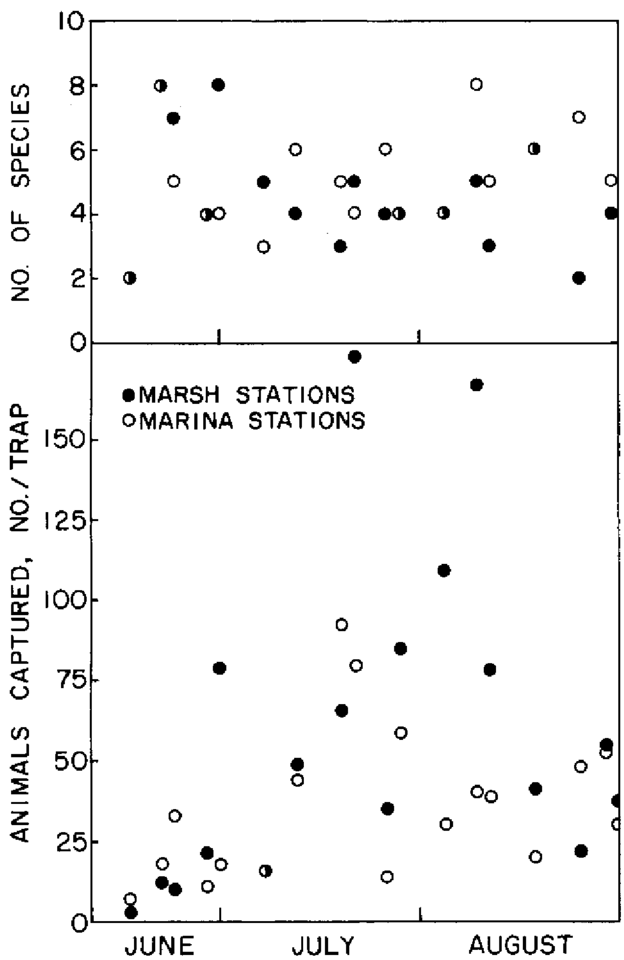

Fig. 6. Number of species and total number of animals captured in two-day trap sets.

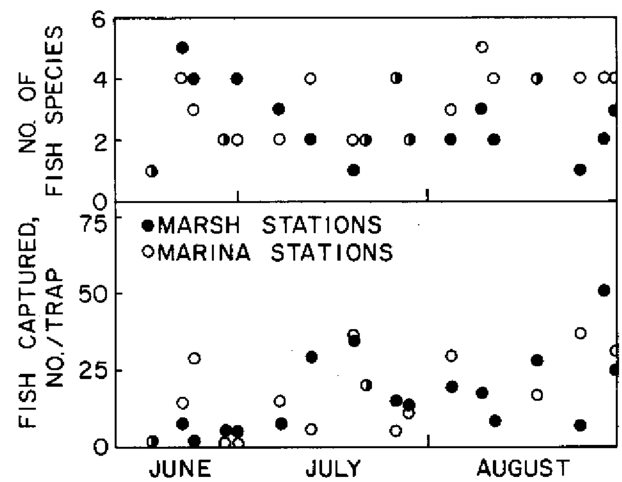

Fig. 7. Number of fish species and total number of fish captured in two-day trap sets.

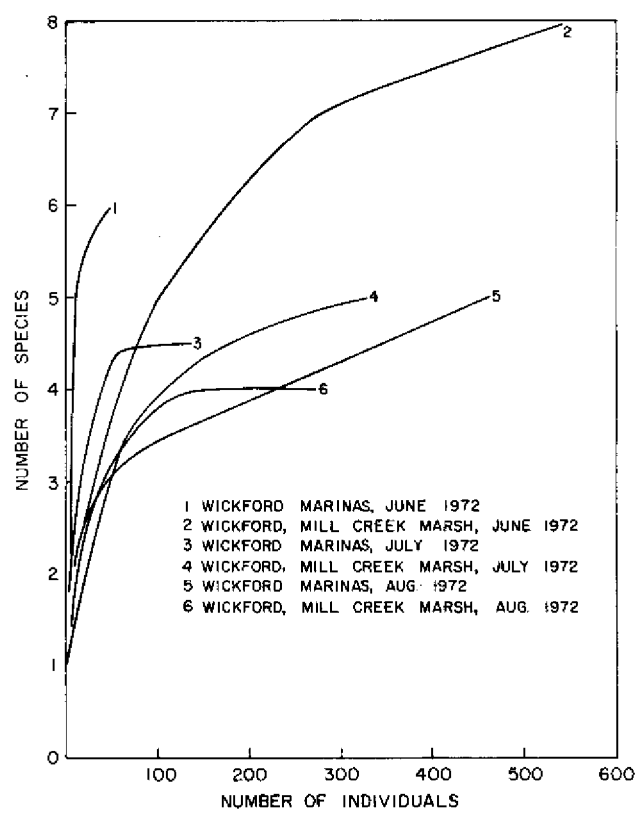

Fig. 8. Diversity of fish in trap captures, using Sanders' (1968) rarefaction plot.

The results of 17 m seine hauls, which captured larger animals, showed a greater number of fish and a higher diversity in the Mill Creek marsh than in the Wickford Cove marinas (Fig. 9). Results from other areas, however, show that this pattern does not always hold. The diversity of fish in the Apponaug Cove marina appeared higher than in two of the marshes, while diversity for the Bissel Cove marsh was similar to that found in the polluted Providence River. While a wide variety of environmental factors and stresses influence the diversity of species in an area, it does appear from the Wickford data that under comparable conditions, the diversity may be lower in marinas than in salt marsh areas. An analysis of data from the larger 67 m seine hauls shows a similar pattern of slightly higher diversity in the Wickford marsh (Fig. 10). The much greater number of animals caught in the marsh reflects large schools of juvenile menhaden that were often captured in marsh samples. Only a few strays of these fish were ever found in the marina area. Since menhaden are very sensitive to a variety of environmental factors, more work is needed to see if the menhaden really do avoid marina areas and serve as a warning of declining water quality. The seine data from Rabbit Island, near the marsh cove, show that fish populations in the area do not appear to have changed much in three years.

An interesting pattern was also apparent in the size-frequency distribution for the most abundant fish, the common mummichog, *Fundulus heteroclitus.* While trap data for June and July showed almost identical normal distributions for the size classes of fish in the Wickford marinas and marsh,

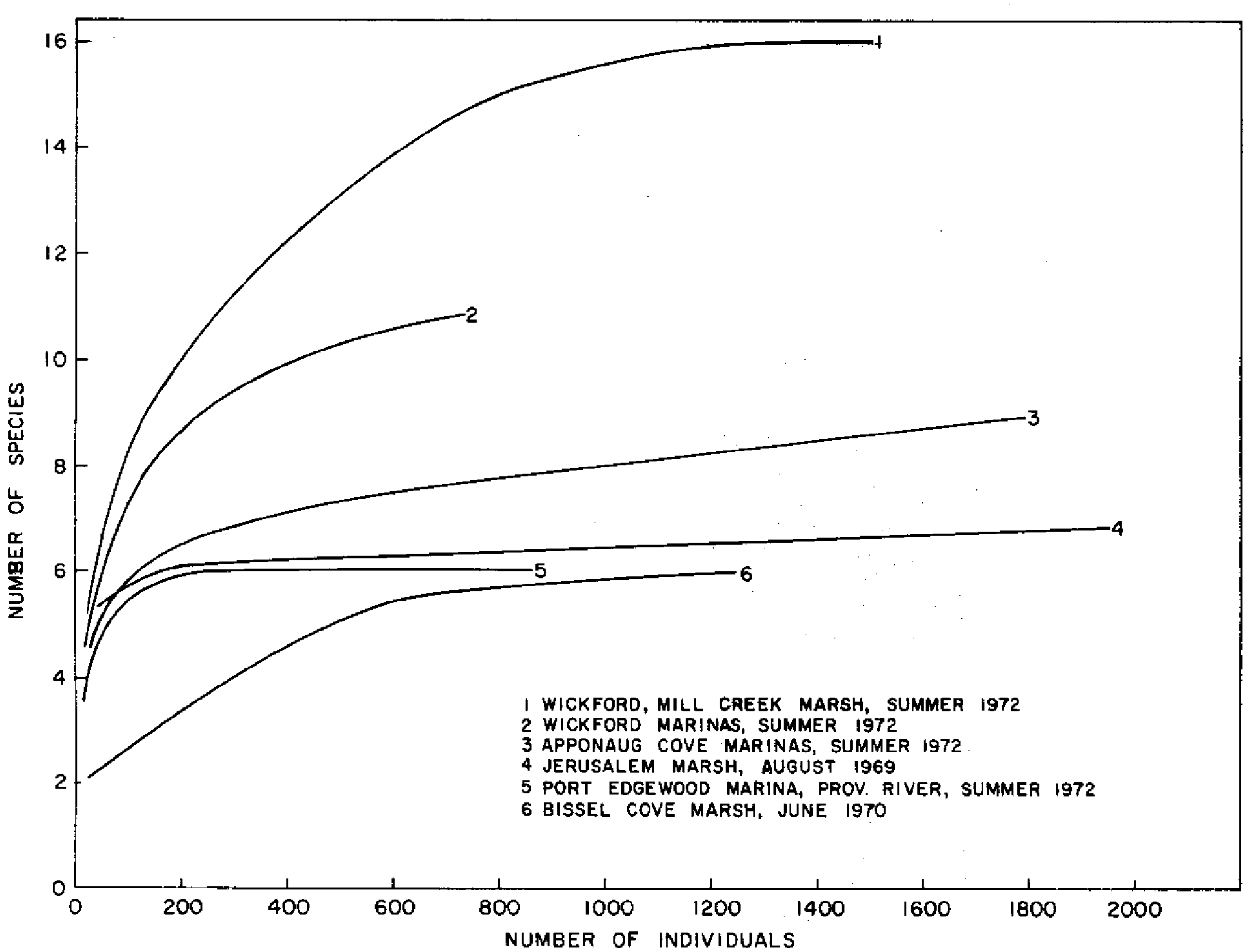

Fig. 9. Diversity of fish in 17 m seine captures, using Sanders' (1968) rarefaction plot.

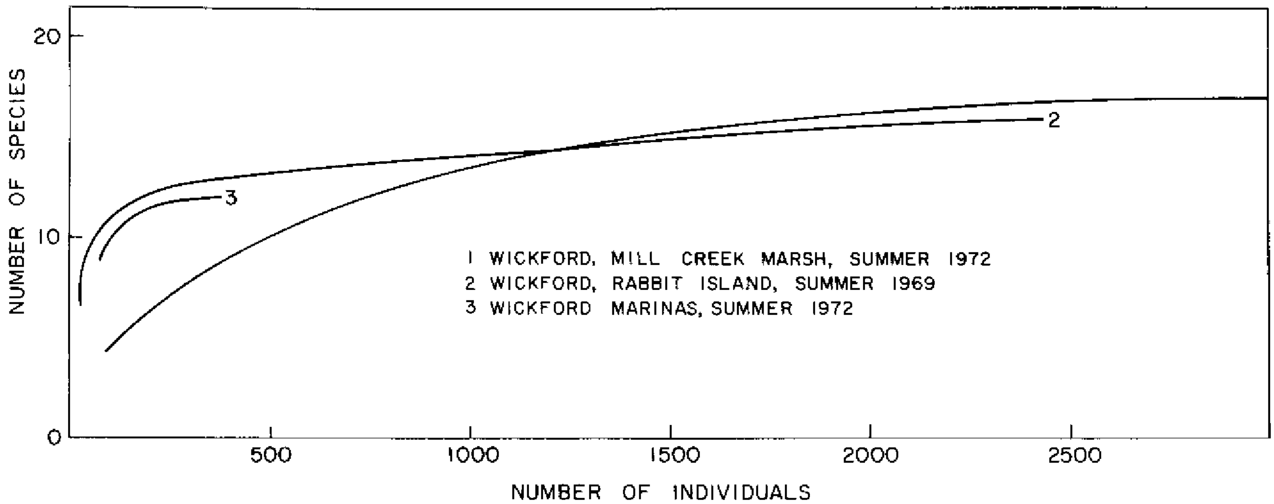

Fig. 10. Diversity of fish in 67 m seine captures, using Sanders' (1968) rarefaction plot.

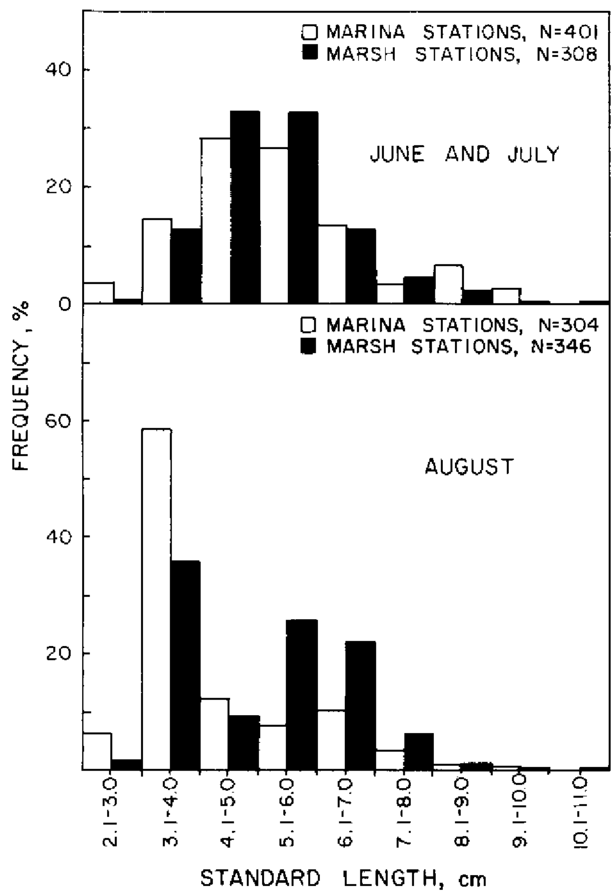

Fig. 11. Size-frequency distribution for common mummichog, *Fundulus heteroclitus*, in Wickford trap captures.

the data from August, when "young-of-the-year" fish become large enough to catch, showed a relatively greater number of small fish in the marinas (Fig. 11). The same trend was also found in the 17 m seine data from Wickford (Fig. 12) and in a series of seine hauls in a transect through the Apponaug Cove marinas in late summer (Fig. 13). It appeared that the hardy juvenile common mummichogs may feed on the abundant fouling organisms

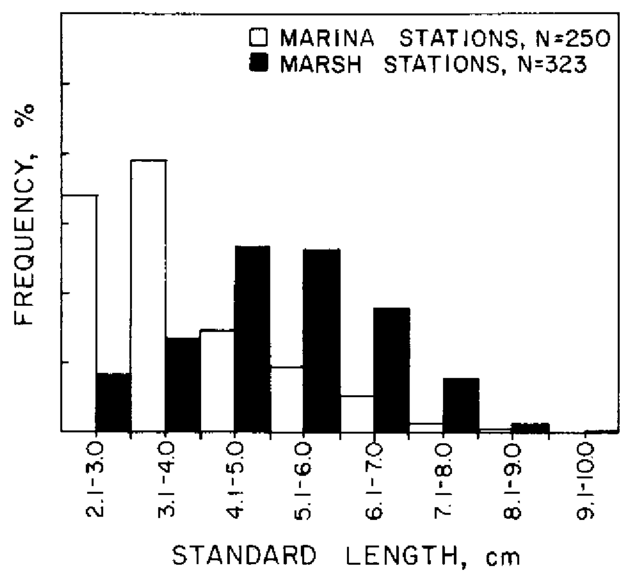

Fig. 12. Size-frequency distribution for common mummichog, *Fundulus heteroclitus*, in 17 m seine captures in Wickford.

found in the marinas. Their presence also appeared to be effective in drawing larger predatory sport fish, such as bluefish, into the marinas. A preliminary survey of sport fish caught in the marina and marsh areas was made on two weekdays and one weekend in late summer. In ten hours of fishing in each area, the catch/unit effort was 5.5 fish/hr in the marina and 1.5 fish/hr in the marsh.

Fouling Communities

The biomass of fouling communities, including associations of barnacles, mussels, tunicates, sponges, amphipods, algae, and bacterial slimes, was measured at the beginning and end of the summer on floats and pilings in the Wickford marinas and in three other marinas around the Bay. At each location, five quadrats of 625 cm^2 were scraped by scuba divers from the undersides of randomly selected marina floats. The collected material was dried at 105-110C, weighed, and ashed for three hours in a muffle furnace at 525-550C to determine its organic content. Long thin areas measuring 10 cm by 62.5 cm were also scraped from the intertidal and upper subtidal sections of five pilings in each marina.

Field measurements of the respiration rate of fouling communities in the three Wickford marinas were made on 14 occasions by fastening a plastic dome to the underside of floats and monitoring the concentrations of dissolved oxygen under the dome with a Winkler calibrated Yellow Springs (Y.S.I.) oxygen meter and self-stirring probe. Readings were taken every ten minutes for one to two hours. Laboratory measurements were also made on fouling community respiration at temperatures from 5-20C. Duplicate samples of the communities were taken from Wickford marinas by removing slices of plastic foam from floats and placing them in 4-liter aquariums containing filtered Bay water. Plastic film was placed on the water surface to prevent diffusion. Measurements were run in a controlled environment chamber in the dark, using a Winkler calibrated Y.S.I. oxygen meter.

Estimates of the rate of settlement and growth of fouling communities in the two Wickford coves were made using replicate sets of 900 cm^2 plastic plates that were suspended in each area during mid-June. A plate was removed from each area each month through October, and the species composition, dry weight and organic content were determined.

Results Almost any free surface placed in coastal water will quickly develop an association of plants, animals and bacteria living on it. While the bottoms of boats are painted with copper or other poisons to inhibit this growth, the undersurface of floats and the wooden pilings used in dock construction are usually not painted and often develop a luxurious growth of fouling communities that increases each summer and dies back during the winter.

The species comprising this growth differed slightly from marina to marina and at different times during the summer. In general, the communities were characterized by the following:

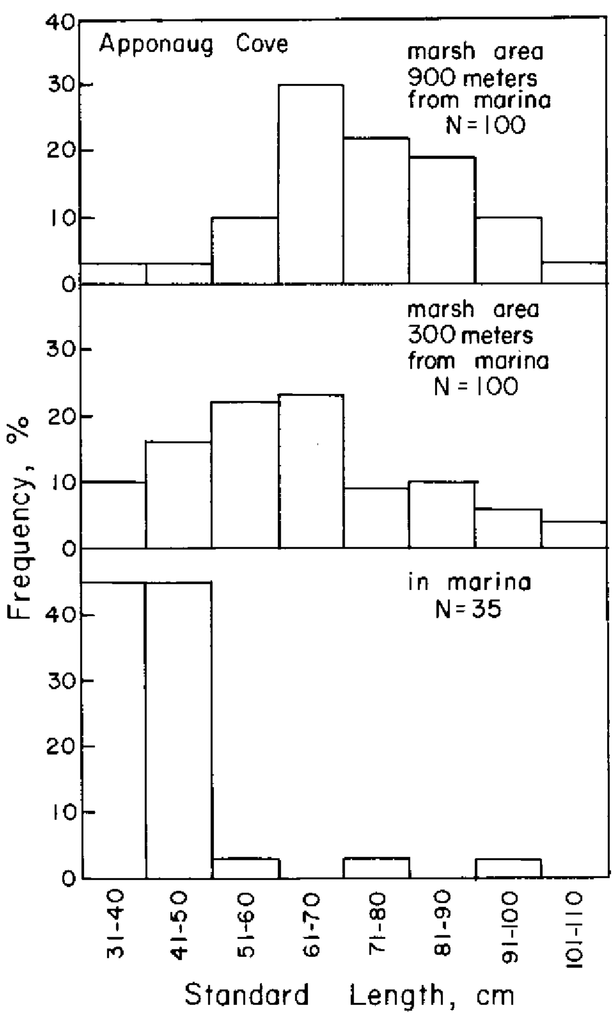

Fig. 13. Size-frequency distribution for common mummichog, *Fundulus heteroclitus,* in 17 m seine captures in Apponaug Cove.

Solitary ascidian, *Molgula manhattensis*
Compound ascidian, *Botryllus schlosseri*
Barnacle, *Balanus balanoides*
Amphipod, *Corophium* sp.
Hydroids, *Obelia* and *Campanularia*
Polychaetes
Gastropods
Nudibranchs
Anthozoa, *Metridum senile* and *Haliplanella luciae*
Mussel, *Mytilus edulis*
Ectoproct, *Bugula* sp.
Mud crabs, *Neopenope texana*
Encrusting sponges
Scale worms
Algae, *Enteromorpha* sp., *Polysiphonia* sp., *Fucus* sp.

Just as decaying grass may serve as an input of detritus in marsh coves, the fragments of organic matter continually broken off the fouling community may be an important detritus input in marinas. This input may be especially large in the fall, when the fouling communities are dying back and the greatest numbers of fish, particularly juveniles, are in the area. The intact communities may be an important food source for fish during the summer (Sutherland 1972).

The biomass of fouling organisms on floats and pilings in a number of marinas is summarized in Tables 8 and 9. The low value for the Providence River marina probably results from occasional low oxygen stress in the river near high sewage inputs from the city. Except for Newport, the subtidal section of pilings had a substantially larger biomass than the more stressed intertidal regions. While the maximum biomass of the fouling communities reached 5000 g/m^2, almost five times the standing crop of marsh grass, the organic content of the fouling communities averaged only 31 percent of its dry weight. The comparable value for *Spartina* is 89 percent (Udell et al 1969). Thus, a fouling community must develop about 3000 g/m^2 to equal the organic content of a 1000 g/m^2 marsh. This material, however, is all available for consumption by fish, shrimp, etc., while only some 45 percent of the marsh production ever enters the water (Teal 1962). In terms of food production available to the aquatic community, only about 1500 g/m^2 of fouling must be developed to equal the input from a square meter of marsh. Even though the growth of the fouling organisms represents largely secondary production, while the growth of marsh grasses results from photosynthetic primary production, much of the food value of grass detritus appears to result from the secondary development of bacteria and fungi on the grass particles (Odum and de la Cruz 1967).

The growth of fouling communities on exposed plastic plates was greatest in the marsh area, with the fastest rate of increase in early August (Fig. 14). Maximum biomass on the marsh plates was over seven times that in the marina with the difference due to increased barnacle growth in the marsh. Since the levels of suspended particulate matter were equal in the two areas (Table 2), and phytoplankton production was higher in the marina (Table 4), the decreased growth on the ma-

Table 8. Biomass of fouling communities on floats* in some Narragansett Bay marinas.

Marina	Date	Biomass, g/m^2†
A (Wickford)	6-15-72	1202 ± 426
C (Wickford)	6-19-72	1136 ± 567
D (E. Greenwich)	6-19-72	772 ± 171
E (Apponaug)	6-19-72	2599 ± 1045
F (Providence)	7-14-72	124 ± 80
A (Wickford)	9- 5-72	2283 ± 976
C (Wickford)	8-28-72	877 ± 492
E (Apponaug)	8-30-72	5299 ± 1114

* *Samples taken from synthetic foam floats that had been in the water continuously for at least one year. In marina D, the floats had been removed briefly for repair two months prior to sampling.*

† *Dry weight, mean of 5 samples ± 1 standard deviation.*

Table 9. Biomass of fouling communities on pilings in some Narragansett Bay marinas.

Marina	Date	Biomass, g/m^2*	
		Intertidal	*Subtidal*
A (Wickford)	6-23-72	390 ± 390	880 ± 253
B (Wickford)	7- 7-72	221 ± 90	387 ± 253
D (E. Greenwich)	6-22-72	162 ± 233	298 ± 167
E (Apponaug)	7-10-72	658 ± 383	1426 ± 295
G (Newport)	7-11-72	2755 ± 915	825 ± 544
C (Wickford)	8-29-72	381 ± 166	925 ± 748
E (Apponaug)	8-31-72	3214 ± 4395	5435 ± 3113

* *Dry weight, mean of 5 samples ± 1 standard deviation.*

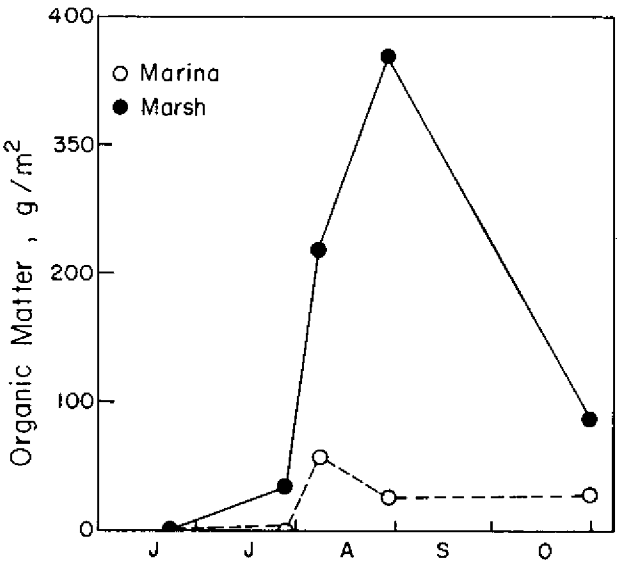

Fig. 14. Biomass of organic matter on replicate plastic plates set in Wickford Cove and Mill Creek salt marsh cove in June. Values have been corrected for ash content.

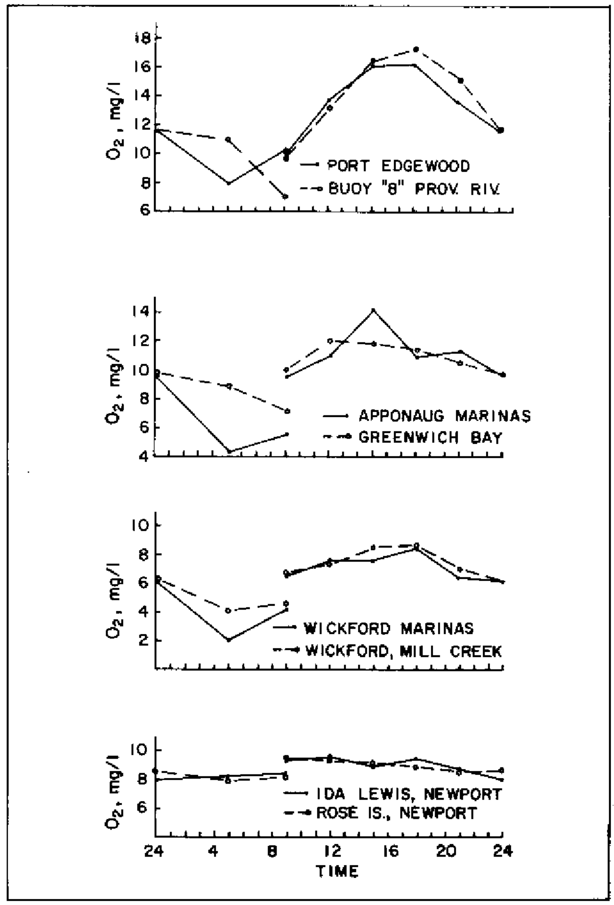

Fig. 15. Diurnal curves of dissolved oxygen in surface water inside and outside of four marinas in early August.

rina plates may have resulted from copper inhibition or from low nighttime oxygen concentrations (Fig. 15). Even though no difference was found in the levels of copper in the water of the two areas, the concentration of copper in the marina fouling community was significantly higher than in the marsh (Table 7).

Field and laboratory measurements of the metabolism of marina fouling communities showed a high rate of respiration and no net photosynthetic production. Field measurements *in situ* showed a range in community respiration from 0.17 to 3.03 g $0_2/m^2/hr$, with a mean of 1.80 g $0_2/m^2/hr$ (Table 10). While not statistically significant, there appeared to be a trend toward lower rates of uptake in moving from the head to the mouth of Wickford Cove. Laboratory measurements showed a dependence of respiratory rate on temperature and dissolved oxygen concentration, which indicates adaptation to low oxygen concentrations. Using multiple regression, an analysis of the data gave the following expression for the relationship:

$$R = 0.096\,T + 0.064\,0_2 - 1.063$$

where R is fouling respiration, mg 0_2/g dry weight/hr
T is water temperature, C
0_2 is dissolved oxygen concentration, mg 0_2/l

The correlation coefficient for the equation is 0.82, with 44 percent of the variance accounted for by temperature and 25 percent by oxygen. At 20C and 100 percent oxygen saturation, the respiration of the fouling community is about 1.34 mg/l/hr, or 75 percent of the maximum reported by Odum and de la Cruz (1967) for *Spartina* detritus in water.

When coupled with the large amount of surface area occupied by fouling communities in marinas, these high respiration rates may have a substantial effect on the oxygen budget of the water. For example, in Wickford Cove the oxygen demand for the 3600 m² of floats was about 146,400 g 0_2/day with an additional demand for the 255 pilings of 9600 g 0_2/day for a total oxygen consumption of about 156,000 g/day. This is equivalent to all of the oxygen contained in over 20 million liters of com-

Table 10. Summer respiration rates of fouling communities in the Wickford Cove marinas.

Date		Respiration, g $O_2/m^2/hr$		
		Marina A	*Marina B*	*Marina C*
6-29-72		1.12		
7-11-72				1.33
7-11-72				1.31
7-18-72			3.03	
7-18-72			2.15	
7-19-72		2.26		
7-19-72		2.24		
7-24-72				0.71
8-16-72			1.52	
8-16-72			1.07	
8-21-72				1.94
8-21-72				1.92
8-22-72		1.89		
8-22-72		2.67		
	$\bar{X}$	2.04 ± 0.58	1.94 ± 0.85	1.44 ± 0.51

pletely saturated Bay water, or 25 percent of the average total volume of the Wickford Cove. The effect of this large oxygen demand was evident in a series of diurnal oxygen curves taken inside and outside of four marinas (Fig. 15). In the Providence River, Apponaug Cove, and Wickford Cove, oxygen levels in the marinas were lower than in adjacent waters. At Newport, where no floats were present, high rates of tidal mixing and diffusion obscured the small effect of piling communities.

Sediments

Three sediment cores were taken to a depth of 10 cm at the head, middle and mouth of each cove. The samples were dried at 105-110C and ashed in a muffel furnace at 525-550C for three hours to determine organic content.

Samples were also taken twice at the head, middle, and mouth of each cove with a Petersen dredge and screened through 3.2 mm mesh. All of the animals retained by the mesh were dried at 105-110C and weighed.

Oxygen uptake by the sediment community in each cove was measured at five locations on transects down the coves. Measurements were made with large, black plastic domes placed over the sediment. Oxygen concentrations were monitored over a two- to three-hour period with a Winkler calibrated Y.S.I. oxygen meter and self-stirring probe.

Results Higher rates of respiration by the sediments may also contribute to the lower diurnal oxygen levels in the Wickford marinas (Table 11, Fig. 15). The mean values for the marina sediments appear almost twice as high as those in the marsh, with the difference statistically significant at the 90 percent confidence level. In both areas, the rates are very close to the 0.07 $g/m^2/hr$ predicted by Hargrave (1969) on the basis of a regression analysis of many sediment respiration rates reported from varying marine and freshwater environments. Oxygen uptake by the sediments, including chemical oxidation as well as the respiration of bacteria and larger infauna, was about 20 times lower than that of the fouling communities.

Table 11. Summer sediment respiration rates in the Wickford Cove marinas and Mill Creek salt marsh.

Respiration, g $O_2/m^2/hr$	
Wickford Cove Marinas	*Mill Creek Salt Marsh*
0.07	0.01
0.12	0.07
0.08	0.03
0.08	0.02
0.09	0.14
$\bar{X}$ 0.09 ± 0.02*	$\bar{X}$ 0.05 ± 0.05*

* *Mean ± 1 standard deviation.*

The biomass of larger infauna was variable in both areas, but in all of the station-to-station comparisons, values in the marina were greater than or equal to those in the marsh (Table 12). While counts of individual species were not made, the superficial number of species in both areas appeared similar. In a more detailed study of shellfish in Wickford Harbor by the Rhode Island Department of Natural Resources, 13 stations were sampled in the marsh cove and 7 in the marina areas (Kovack 1968). Densities of quahogs, *Mercenaria mercenaria,* ranged from 5-18/m^2 in both areas, with the exception of one region of the marina where 10-40 animals/m^2 were found. The distribution of size classes, as a percentage of the stations in which they were found, is shown below:

Size, mm	Marina, %	Marsh, %
48	14	18
48-70	57	64
71-92	57	27
92	43	0

No soft-shelled clams, *Mya arenaria,* were found at the marina stations. They were abundant at only two of the marsh stations where sandy sediments were present instead of silt-clay.

Table 12. Biomass of infauna in the sediments of the Wickford Cove marinas and the Mill Creek salt marsh.

Date	Sample Location	Biomass, g/m²	
		Marinas	*Marsh*
7-7-72	head	10.8	2.9
	middle	12.0	0.4
	mouth	7.9	0.1
8-10-72	head	6.4	0.9
	middle	1.3	1.4
	mouth	263.0	5.8

Organic content of the sediments was high, with a mean of over 8 percent in each area (Table 13). There was no significant difference between the means at the 95 percent confidence level. In both cases, the organic content was highest near the head of the cove where flushing was probably least effective.

Table 13. Organic content of sediment in the Wickford Cove marinas and the Mill Creek salt marsh.

Location	Organic Content, %*	
	Marinas	*Marsh*
head	13.17 ± 2.21	10.37 ± 0.27
middle	6.44 ± 0.95	7.77 ± 0.38
mouth	6.68 ± 0.28	7.91 ± 0.41
$\bar{X}$	8.76 ± 3.52	8.68 ± 1.31

* *Surface to 10 cm, mean ± 1 standard deviation, N = 3.*

Preliminary Bioassays

Since most, if not all, studies of the toxic effects of outboard motor exhaust have been concerned with freshwater organisms (see review by Kuzminshi and Jackivicz 1972) some preliminary studies of acute effects on estuarine species were begun. Exhaust water was prepared by idling a 1970 model 40 h.p. Evinrude motor for one hour in a 180-liter container of Bay water. Various organisms, including the common mummichog, *Fundulus heteroclitus;* the grass shrimp, *Palaemonetes pugio;* mixed zooplankton (mainly *Acartia*); a green isopod, *Idotea baltica,* and two species of phytoplankton (pure cultures of *Skeletonema costatum* and *Olisthodiscus luteus*), were subjected to concentrations of up to 75 percent exhaust water. The number of animals dying within a 24-hour period was recorded for each concentration, while the growth of the phytoplankton in cultures enriched with phosphorus and nitrogen (Guillard and Ryther 1962) was followed for over 20 days using a fluorometric measure of chlorophyll pigments.

Results Only very preliminary indications of the acute effects of outboard motor exhaust water on estuarine organisms were obtained. For example, grass shrimp, *Palaemonetes pugio,* appeared quite resistant and could survive for at least several hours in concentrations of 50 percent exhaust water under aerated conditions. On the other hand, a 50 percent concentration killed mixed zooplankton in two hours. The common mummichog, *Fundulus heteroclitus,* showed 100 percent survival over 24 hours in concentrations at least as high as 10 percent exhaust water. Response of the isopod, *Idotea baltica,* was observed in more detail:

% Exhaust Water	N	Time to 50% Mortality, Hours
75	46	0.5
50	42	1.0
25	35	1.5
15	36	47.0
10	31	(19% at 53 hours)
0	14	(14% at 53 hours)

The diatom *Skeletonema costatum* showed no growth inhibition over a week or longer in concentrations up to 2.5 percent exhaust water in one experiment and 5 percent in another. A single trial with the flagellate *Olisthodiscus luteus* showed no growth inhibition at concentrations up to 5 percent. Above this level, growth was strongly inhibited or did not occur.

While these results are preliminary, they do suggest that there is a definite toxicity associated with outboard motor exhaust water, even using a well "tuned," newer motor with recycling features. However, since the water in the experimental tank had passed through the engine cooling system many times during the hour run, and since the fuel waste of the engine is very much a function of speed, age, and tune, it is not possible to calculate the probable concentrations or toxic effects of exhaust water in the field.

Summary and Conclusions

A small boat marina forms an ecological system similar in many ways to that of a coastal salt marsh cove. However, important differences are apparent.

Both the marina and the marsh cove are estuarine environments with salinity and temperature stresses that result in low diversity and large standing crops of their relatively few species. While the emergent grasses of the marsh show high primary production, both the marsh coves and the marinas are heterotrophic systems, dependent on imports of organic matter. The development of extensive fouling communities in the marina may be analogous to the production of rich grass detritus in the marsh. The input of large pieces of organic matter from the emergent marsh appears to come in midwinter and early spring (Nixon and Oviatt in press, a), while much smaller particulate detritus is added more regularly throughout the year (Shultz and Quinn, in press). The fouling communities with their maximum abundance in late summer, followed by their breakup into the water in fall, may serve as an important food supplement during the time when juvenile fish are abundant and larger numbers of adult fish are present in the marsh cove areas. Thus, in terms of the delivery of food, the marshes and marinas may be compatible systems.

Instead of dumping dredge spoil from marina channels in deep water or on the emergent marsh grasses, it may be possible, with methods described by Woodhouse et al (1972), to use the spoil to increase the area and shoreline of adjacent intertidal marsh. Since the main input of *Spartina* detritus comes from the band of grass along the edge of the marsh, an effort should be made to increase the effective length of shoreline by forming a rounded, dentate coast. It may also be possible to use grass plantings instead of rip-rap or bulkheading to stabilize filled areas.

At least in Wickford Cove, the production and respiration of the plankton community did not reflect any detrimental effects from boat use, nor did the respiration and abundance of sediment organisms. No evidence of environmental deterioration from boat-derived sewage or rubbish was apparent. Levels of copper, however, were higher in marina sediments, attached benthic algae, and fouling communities. Copper enrichment was not found in higher trophic levels.

There was no clear pattern of difference in fish abundance or diversity between marina and marsh areas, although Atlantic menhaden, a sensitive and important commercial species abundant in marsh coves, was seldom found in the marina areas. Preliminary evidence does suggest that sport fish are more abundant in marina areas, perhaps attracted there by large numbers of juvenile bait fish that prefer the marinas.

Since fouling communities appear to be an important food source for fish, especially the juveniles which attract sport fish, painting the undersides of marina floats with antifouling paint should be discouraged. The environmental benefits of this practice may be much greater than the small cost associated with a slightly decreased life span for unprotected floats. It may also be possible to develop antifouling paints which will reduce or eliminate the amount of heavy metals which flake off of boat bottoms. Preliminary development and testing of an antifouling paint based on the antibiotic activity of seaweed has already been described by Sieburth and Conover (1965).

While many features of the marina make it the most acceptable of possible alternatives for marsh development, especially when compared to road construction, housing, dredge spoil disposal, and refuse dumping, certain qualifications must be added. For example, this study did not consider the often important details of species composition in the plankton or the infauna of the marsh and marina areas. The relative abundance and distribution of waterfowl and mammals in the two areas was not studied, and it seems very unlikely that either of these groups would rest in or make extensive use of marinas. Mallard ducks and other rugged species adapted to man may be exceptions. The acute and chronic effects of copper, hydrocarbons, and motor exhaust products on the survival and reproduction of estuarine species remain almost unknown.

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