THE EFFECTS OF FRESHWATER DISCHARGE ON ESTUARINE NURSERY AREAS OF PAMLICO SOUND

by

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ABSTRACT

Four sampling stations were established in tributaries of northern Pamlico Sound in order to evaluate the effects of freshwater runoff from manmade waterways on primary nursery areas. Weather conditions ranged from extremely dry to extremely wet, resulting in various effects on the study area and its production of brown shrimp. During periods of low rainfall, all stations functioned well as primary nursery areas (1977). During extremely wet periods, salinities were depressed resulting in low levels of brown shrimp production at all sampling stations (1978). Salinities remained relatively stable in the unaltered sites during periods of high runoff while rapid pulsating effects were noticed in the altered areas. Overall productivity between altered and unaltered areas indicated that unaltered areas were significantly higher in the production of brown shrimp as well as other commercially important species throughout the study period. Supplemental data indicated drainage has an adverse effect on food organisms utilized by commercial species of finfish.

TABLE OF CONTENTS

INTRODUCTION

Historical Perspective

The changes in the estuarine environment effected by extensive land clearing and drainage on areas adjacent to estuarine waters have long been suspected, but their detriment to fishery resources has not been fully demonstrated. Alteration of the natural drainage patterns in the vast low-lying areas of eastern North Carolina has been attempted since the first settlers arrived around 1700. However, efforts towards agricultural development of these dense swamp areas have largely failed. Large corporate farms have recently come into this area with the machinery and resources necessary to drain, clear, and cultivate large tracts of previously undisturbed land. Extensive land clearing and drainage operations now underway will alter the normal runoff patterns of surface water in this area more drastically than the relatively small operations already completed.

The flat, swampy nature of the Albemarle-Pamlico peninsula, which has caused so many problems for developers, can best be explained by examining the geologic history of the area. The present peninsula (Figure 1) lying between Albemarle Sound and Pamlico River began its formation about 75,000 years ago (Oaks and Coch 1973). The peninsula was formed by the interaction of fluctuations in sea level with the formation of deltas by the Tar and Roanoke Rivers. These deltas were extended eastward during a long period of oscillating sea level that eventually ended about 35,000 years ago. Sea level then receded until about 15,000 years ago when it had reached a point some 400 feet below its present level. The Tar and Roanoke Rivers downcut their channels during this period and formed wide, flat-bottomed valleys (Riggs and O'Connor 1974). The rise in sea level over the past few thousand years has subsequently produced the Albemarle and Pamlico River estuaries in these flooded valleys. The delta formed by these processes is relatively flat with the water table lying close to the surface. The maximum elevation of the area is only 20 ft above sea level, and almost all of the eastern half of the peninsula is less than five ft above sea level (Heath 1975). Poor surface drainage in these low-lying areas provided an environment conducive to the formation of peat, and the organic soils which it produces are highly prized for farming. In order to utilize these soils, however, the water table in the area must be lowered by means of an artificial

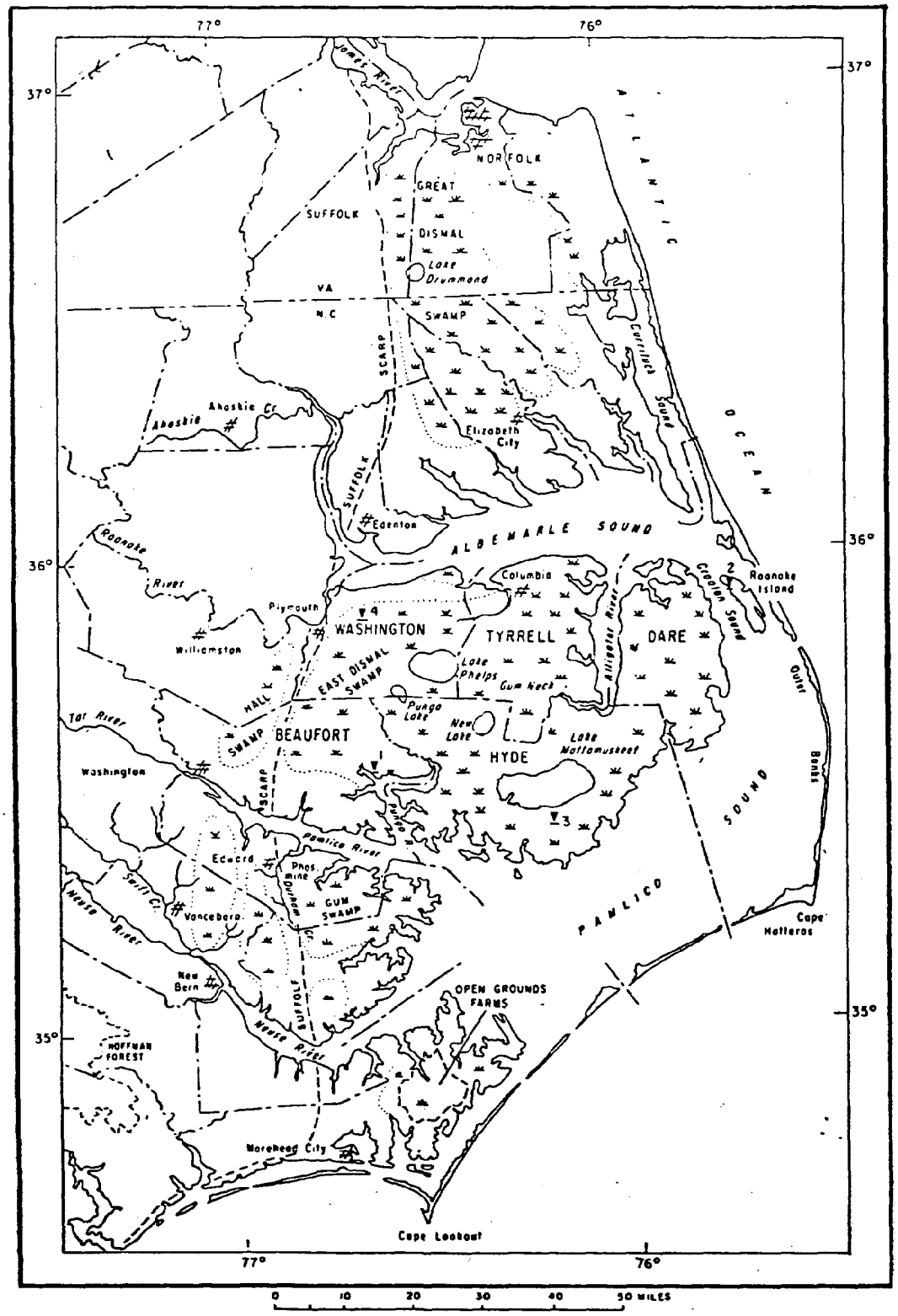

Figure 1. Regional setting of the Albemarle-Pamlico peninsula (from Heath 1975).

drainage systen.

Natural drainage on the Albemarle-Pamlico peninsula is affected by two major characteristics of the area. The shallow depth of the water table causes it to expand quickly during rains, usually bringing it to the surface. The gentle slope of the land surface, coupled with the thick layers of debris, causes slow runoff of surface waters. Wet periods in this area are thus characterized by ponding of water on the surface which then seeps slowly through surface litter either towards streams or the coast, a process taking many days or weeks. Apparently there were historically few streams in the area and they extended only a few miles into the interior (Heath 1975). Discharge from lakes in the area was also apparently by sheet-like flow over the surface. Lake Mattamuskeet, for example, drained northward through the swamp to the Alligator River (Heath 1975).

Early efforts to utilize this area were concentrated mainly on logging and farming operations. However, until the State and Federal Government began funding projects aimed at opening lake bottoms to farming during the 1930s (Doucette and Phillips 1978), the peninsula remained relatively unsettled. The canals constructed to drain Lake Mattamuskeet for farming are of particular interest since two of them enpty into primary nursery areas for fish, shrimp, and crabs. It is also interesting to note that the Rose Bay, Outfall, and Lake Landing canals all provide drainage from the lake opposite the direction natural flow would take and empty this drainage into the more saline waters of Pamlico Sound. Only the Fairfield Canal carries runoff into the Alligator River where it would drain naturally.

Canals were also constructed to open other areas around lakes for farming, and eventually several small communities were formed. Lack of the large equipment necessary to clear and drain areas made conversion of swamp land to usable land difficult, and until 1956, the amount of land under cultivation was relatively small. However, land immediately south and southeast of Lake Mattamuskeet has been under cultivation since 1938 (Heath 1975). This area is heavily ditched and freshwater runoff is flushed quickly into the headwaters of many of the most productive nursery areas along Northern Pamlico Sound.

Drainage Methods

Artificial drainage systems necessary for land cultivation prevent ponding of water on the surface by rapidly removing runoff. Drainage is accomplished through a series of ditches and canals. The first canals constructed in an area to be drained are the main canals (10-15 ft deep) which are connected to existing streams. The collector ditches are dug next. They are usually spaced about one-half mile apart and are approximately 6-8 ft deep. The wedge-shaped field ditches are spaced from 260-300 ft apart and are constructed last. Heath illustrated the ditching system (1975:63). Land under cultivation has, on the average, about 20 miles of channels per square mile (Heath 1975). The result in the heavily drained areas of the Albemarle-Pamlico peninsula,is that maximum and minimum rates of runoff are much more extreme than they were under natural conditions.

Heath (1975) stated that runoff from the Albemarle-Pamlico peninsula could be the most important problem posed by agricultural development. He also explained that overall salinities in Pamlico Sound would probably not be significantly affected by runoff from this region since it contributed such a small portion (6-8%) of the total freshwater inflow. A more dramatic effect on salinities would occur with drainage into smaller streams and bays. On a local scale this is true, but the overall problem of urban, silviculture and agriculture drainage has reduced salinities in Pamlico Sound throughout the years as indicated in a preliminary report on salinity levels in Pamlico Sound by Sholar (1980).

Environmental Effects

Although intensive water quality studies have not been performed in the area in which this study took place, work by Kirby-Smith and Barber (1979) on water quality of South River showed substantial changes in salinity, turbidity and nutrient levels associated with agricultural drainage into this system.

In the early 1970s the North Carolina Division of Marine Fisheries recognized the importance of primary nursery areas for estuarine fishery production and began a program to delineate such areas. In 1977, a regulation was enacted by the North

Carolina Marine Fisheries Commission to "establish and protect those fragile estuarine areas which support juvenile populations of economically important seafood species." (North Carolina Division of Marine Fisheries 1981:40.) In addition, nursery areas were defined as:

> "...those areas, in which for reasons such as food, cover, bottom type, salinity, temperature and other factors, young finfish and crustaceans spend the major portion of their initial growing season:
>
> (1) Primary nursery areas are those areas in the estuarine system where initial post-larval development takes place. These areas are usually located in the uppermost sections of a system where populations are uniformly very early juveniles." (North Carolina Division of Marine Fisheries 1981:40).

Runoff from man-made drainage systems can affect salinity and contribute substantial amounts of bacteria, nutrients, pesticides, and sediments to the waters into which they drain. Variations in salinity may be the most important problem posed by artificial drainage to the marine environment. This problem is of particular importance to the Albemarle-Pamlico area because the tributaries along the southeast portion of the peninsula have been shown to be important nursery areas for shrimp, crabs, and finfish (Purvis 1976). Valuable oyster beds are also found in this area. Freshwater runoff into these tributaries could cause many of the salinity sensitive organisms to move into areas that do not afford them adequate food or cover. Since these areas are responsible for the basic productivity of the Pamlico Sound estuary, their loss as nursery areas due to decreased salinity could greatly reduce the fishery resources of the area.

The effect that altered runoff may have varies with the different economically important species found within the estuary. Oyster beds and juvenile shrimp populations are probably most affected by extreme changes in estuarine water quality. Adult oysters, being sedentary, are unable to escape wide variations in water quality and must rely on their own physiological reactions for survival. Juvenile shrimp, although mobile, are bound to food-rich areas and adequate cover for survival. Juvenile blue crabs and finfish are able to move away from nursery areas made undesirable by changes in water quality caused by excessive runoff.

Brown Shrimp Biology

Brown shrimp spawn at sea during late winter-early spring. Egg and larval development occupies several weeks during which currents carry developing shrimp from the saline offshore spawning area to the brackish inside marshes and estuaries that serve as nursery grounds. The bottom-dwelling postlarvae soon grow into juveniles. Growth is very rapid, particularly when water temperature exceeds 70°F (21°C). As shrimp grow, they gradually move seaward, presumably in response to salinity or habitat preferences. By the time shrimp become adults, they move out of the estuarine areas into the ocean. Most brown shrimp, which enter coastal waters as postlarvae in spring and early summer, move offshore during late summer and fall; by late fall almost all have left inshore waters.

Salinity, along with other factors (primarily temperature), has been found to be the controlling factor in the survival, distribution, and growth of brown shrimp (*Penaeus aztecus*) by Gunter (1956); St. Amant, Corkum, and Broom (1962); Gunter, Christmas, and Killebrew (1964); St. Amant, Broom, and Ford (1965); Gunter and Edwards (1969); Ford and St. Amant (1971); Gaidry and White (1973); and Barrett and Gillespie (1973). The total area of available nursery grounds with salinities of 10 parts per thousand (ppt) or greater has been cited as probably the most important factor controlling brown shrimp production in Louisiana (Barrett and Gillespie 1975). It has been further noted that high salinities occurring naturally do not prohibit the presence of brown shrimp, but higher concentrations of juveniles were usually found in salinities in the 10 to 20 ppt range. Favorable salinities are probably most important during the April-June recruitment period. Salinity preferences vary upward with increasing size (Joyce 1965). Relative abundance of juvenile brown shrimp in tributaries of northern Pamlico Sound has shown a general correlation with salinity (Hunt et al. 1980). For the period 1973-76, brown shrimp catches were lowest in 1973 when salinities in May averaged 5.3 ppt and highest in 1974 when they averaged 13.8 ppt. Commercial landings from Pamlico Sound for 1973 and 1974 were 0.8 and 1.6 million lb (heads off), respectively. In 1975, brown shrimp landings were 0.7 million lb with an average May salinity of 9.6 ppt. Although the average May salinity in

1976 was 14.6 ppt, brown shrimp landings for that year were only 1.6 million lb, (Table 1) showing that salinity, although important is not the only controlling factor in production.

Data collected over a four-year period prior to this study indicated that the primary nursery areas which were receiving artificial drainage were relatively less productive than areas with unaltered drainage basins (Unpublished Division of Marine Fisheries data). This finding encouraged a more thorough investigation of the impacts of freshwater drainage into primary nursery areas on brown shrimp (*Penaeus aztecus*), the target species of this project. It was soon discovered that other commercially important species were also affected, and the effects on these species will also be discussed.

MATERIALS AND METHODS

This study began in May 1977 with the selection of three sampling areas to compare salinity patterns and utilization by brown shrimp between areas with natural drainage patterns and areas receiving drainage through man-made waterways. Field work ended in October 1980. Each site was selected to provide, as nearly as possible, only one variable-freshwater inflow through ditches. Due to the extensive network of ditching in the study areas, sites with natural drainage patterns which provided suitable habitat for brown shrimp production were limited, which lessened the comparability between unaltered and altered sites. Therefore, some differences between water depth and bottom types did exist between the stations. The extent to which these differences affected overall productivity is not fully known.

In 1977, the study area consisted of two altered sites and one unaltered site. In an effort to eliminate any bias and provide a more detailed comparison between altered and unaltered drainage basins, a second unaltered site was added in 1978. The sampling stations are shown on Figure 2 and are designated RB-1 and SQ-1 for the altered areas, and RB-2 and GB-1 for the unaltered areas.

In order to accurately record the effects of natural drainage versus altered drainage on salinity, recording salinometers were installed at sites RB-1, SQ-1 and GB-1 to record salinity changes on a 24-hour basis in conjunction

Table 1. Yearly harvest of brown shrimp in Pamlico Sound, NC, 1973-1980 in lb (heads off).

Year*	Landings (lb)
1973	771,875
1974	1,555,000
1975	738,125
1976	1,587,500
1977	1,652,500
1978	460,954
1979	463,566
1980	2,113,685

*1973-1977 data from (Hunt et al.,1980), 1978-1980 data from (unpublished N.C. Division Marine Fisheries data).

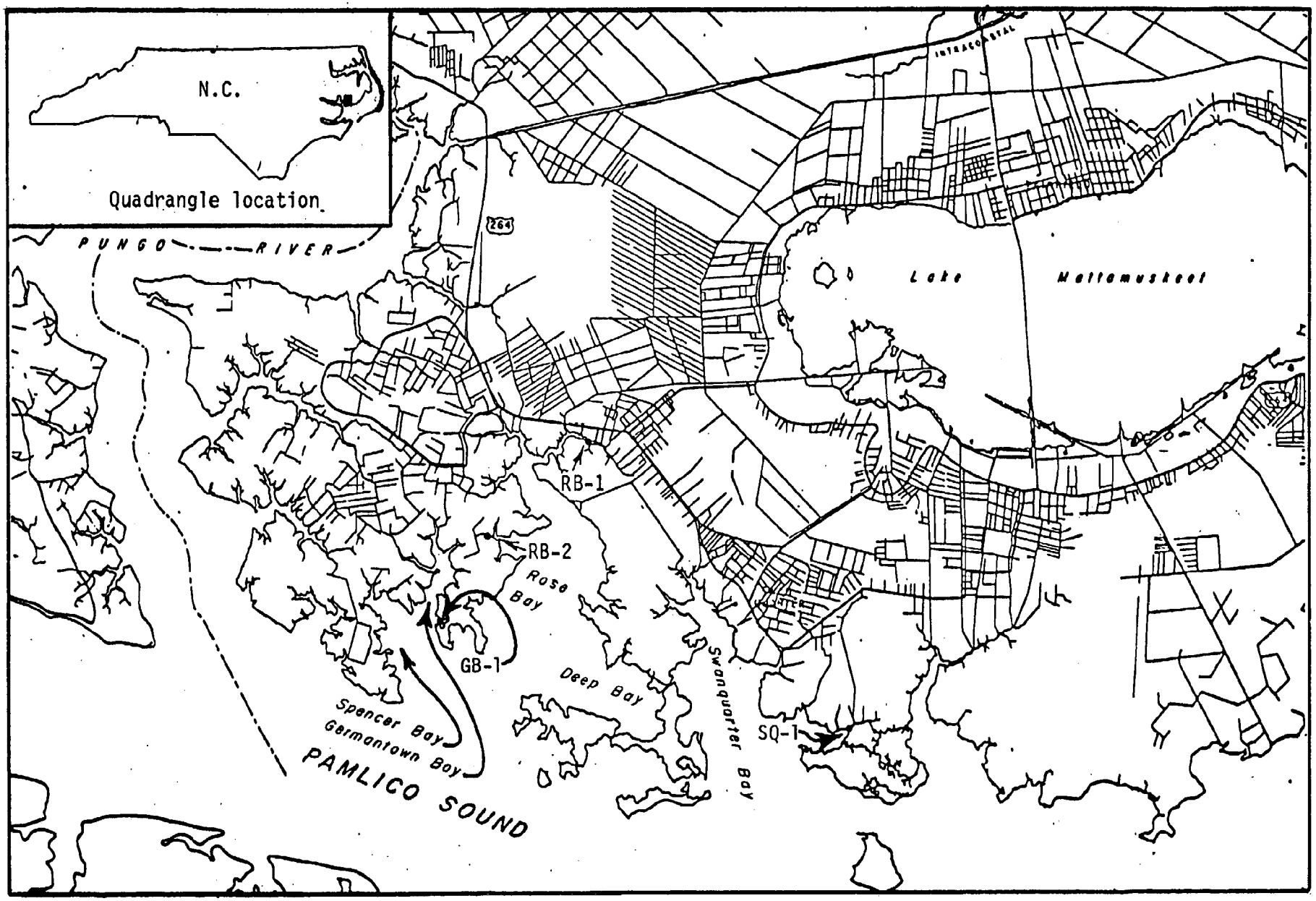

Figure 2. Location of study area, sampling sites and ditches draining into the tributaries of northern Pamlico Sound (ditch system from Daniels 1978).

with freshwater runoff and thus observe population fluctuations on brown shrimp. Salinity readings were recorded approximately 12 in (30 cm) from the bottom since changes in bottom salinities would have the most effect on the utilization of the area by juvenile brown shrimp which are characteristically associated with the substrate. A 24-hour recording weather station was centrally located within the study area at Swanquarter National Wildlife Refuge in an attempt to record meteorological conditions which might affect salinity levels in the area. The weather station consisted of a 24-hour recording wind and rain guage. Rainfall data were also collected from Mattamuskeet National Wildlife Refuge which acts as a weather recording station for the National Weather Service. Rainfall data were recorded in an effort to relate various amounts of rainfall to changes in salinity values at each site. Wind speed and direction were recorded to obtain information on salinity changes due to tidal fluctuations. Lunar tides in Pamlico Sound are evident only near inlets (Marshall 1951, Posner 1959); wind tides are dominant (Roelofs and Bumpus 1953). In order to accurately measure tidal changes in relation to wind speed and direction, a 24-hour tide guage was installed in the Rose Bay drainage system.

At the onset of the project, sampling was conducted at three locations within each area to measure movement of organisms responding to freshwater inflow. Statistical analysis at the end of the first year showed there was no significant difference between the number of organisms sampled at the three locations. The number of sampling sites was then reduced to two sites, an upper and lower in each area. Data from these two sites were combined at the end of the project when analyses showed that no significant movement was evident between the upper and lower points of each sampling area.

Each station was sampled with a 15 ft (3.96 m) headrope, flat otter trawl 1/4 in bar mesh (6.4 mm) with a knitted 1/8 in (0.32 cm) bar mesh tail bag. Each sample consisted of trawling for a distance of 45 m between fixed markers. One tow was considered as one unit of effort. At the end of each sample, salinity and temperature readings were taken with a portable meter. Each area was sampled three times per week during the shrimp nursery season (May through July) from 1977 through 1980. Sampling was then reduced to twice per week through October in order to monitor other organisms within the system. Each

sample was placed on ice in the field and examined in the laboratory. All specimens were identified, counted and measured. Measurements were recorded in 10 mm modal groups. Shrimp measurements were taken from the tip of the rostrum to the tip of the telson. Blue crabs were measured from spike to spike. Fork length measurements were taken on finfish when applicable; otherwise total length measurements were used.

Figure 2 is a reproduction of a map prepared by the U.S. Geological Survey (Daniels 1978) showing the location of all drainage ditches in the area surrounding the study sites as of 1974. This map shows the extensive drainage going into the area sampled and the size of the area which is being drained.

DESCRIPTION OF STUDY AREA

Three bays encompassed the four areas which were studied, Rose Bay, Swanquarter Bay, and Germantown Bay, which is part of the larger Spencer Bay (Figure 2). Rose Bay encompasses an area of approximately 6,198 acres (2,508.3 ha) including Deep Bay. The surrounding area is characterized by low-lying pine pocosin with black needlerush (*Juncus roemerianus*) marsh bordering the open water areas. A high producer of brown shrimp in some years, Rose Bay's principal commercial activities also include oyster dredging during the winter and crab potting and long haul seining during the rest of the year.

Swanquarter Bay contains approximately 4,163 acres (1,684 ha) of water and empties into Pamlico Sound in a southerly direction, much the same as Rose Bay. Swanquarter Bay is bordered by low-lying pine pocosin and has an estuarine border consisting primarily of black needlerush marsh. Principal commercial activities consist of oyster dredging, crab potting and long hual seining.

Germantown Bay contains approximately 849 acres (343.7 ha) of water and joins Spencer Bay on its northern side. The surrounding area is also characterized by low-lying pine pocosin and a bordering which consists primarily of black needlerush. The main commercial activities in this area are crab potting and oyster dredging.

Within Rose Bay two study areas were chosen, one altered and one unaltered. The altered area was Rose Bay Creek, (RB-1, Figure 3). This tributary lies at the head of Rose Bay and empties into the bay in a southwesterly direction. The surrounding area is characterized by low-lying pine pocosin while the marsh

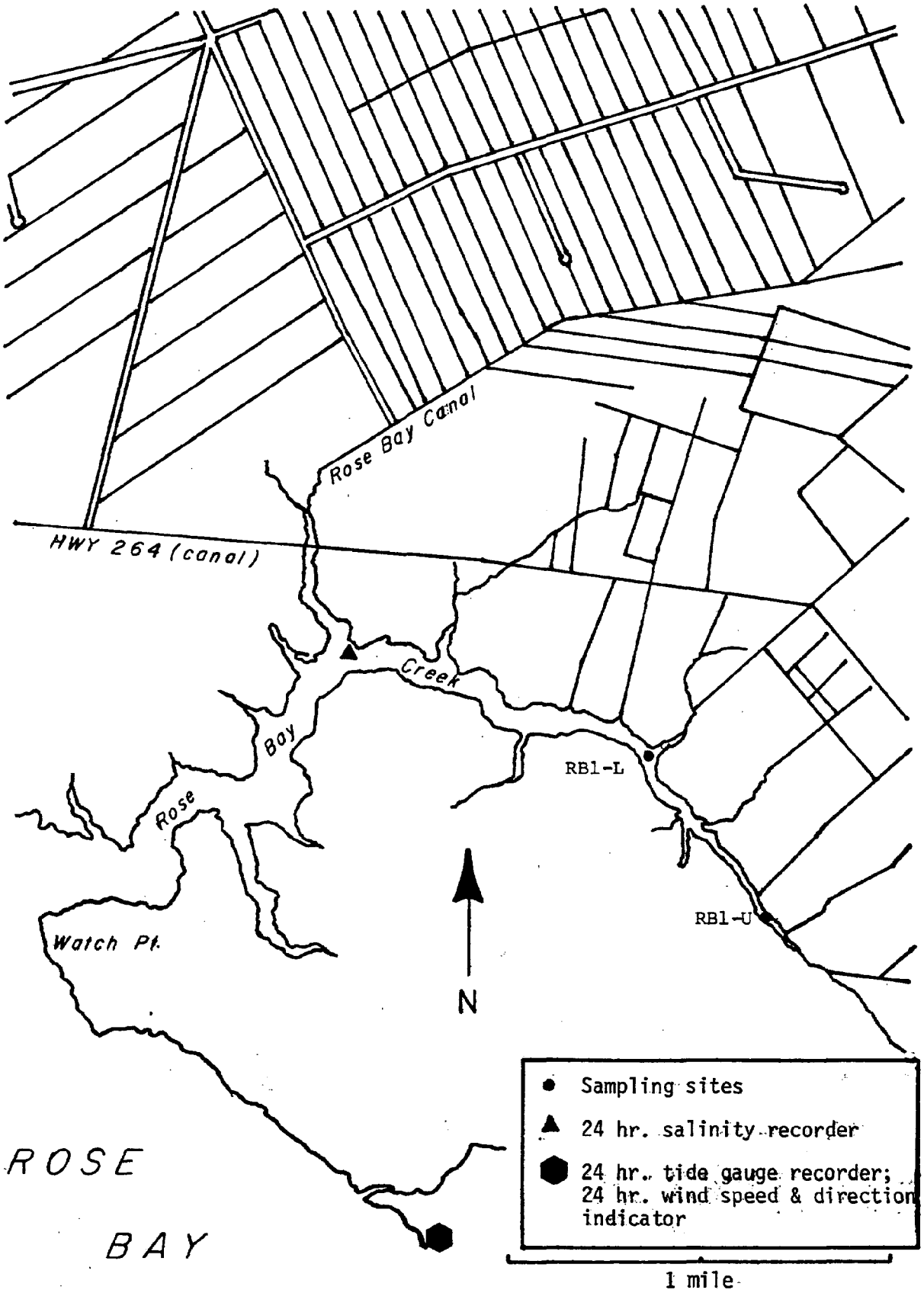

Figure 3. Altered site Rose Bay Creek (RB-1).

surrounding the creek itself consists mainly of black needlerush. Sporadic patches of mixed low myrtle (*Ica frufescense*) and sawgrass (*Claudium jamaicense*) accompany the black needlerush. Water depths range about 6 ft (1.83 M) to 9 ft (2.74 m), and the muddy bottom is overlain with coarse organic detritus. Rose Bay Creek has seven drainage ditches (similar in size to collector ditches) emptying into its north side in the vicinity of the sampling area. These ditches join the large network of canals further north. One large canal (Rose Bay Canal) also enters the creek, and in addition to agricultural drainage, is used as a water control outlet for management of Lake Mattamuskeet.

The unaltered site chosen in Rose Bay was Tooley Creek (RB-2). This creek lies approximately midway up Rose Bay on the western side and empties into the bay in an easterly direction (Figure 4). The surrounding area consists of low-lying pine pocosin along with a mixture of live oaks (*Quercus virginiana*) and low myrtle. The principle marsh growth is black needlerush along with some sawgrass. Water depth ranges from 1 ft (0.30 m) to 4 ft (1.47 m) and the bottom type is a mixture of deep mud, detritus and shell material. There are two ditches entering the headwaters of this creek; however, these ditches do not carry drainage from any non-wetland areas; therefore, the creek was considered unaltered. This is the only station which did not have a 24-hour salinity recorder.

In Swanquarter Bay one altered area was chosen, Caffee Bay, which is located near the mouth of Swanquarter Bay on the east side (Figure 5). Connected with Juniper Bay to the east by a series of natural tributaries, the area is surrounded by a marsh of black needlerush, sawgrass and low myrtle. Drainage into this area is through ditches extending from an extensive inland area. There are four additional ditches draining into the area which terminate in the adjacent wetland area and do not appear to carry any non-wetland drainage. Water depths in this study area range from 2 ft (0.61 m) to 3 ft (0.91 m), and the bottom consists of a mixture of mud and detritus.

In Germantown Bay, the second unaltered area, Swan Creek (GB-1) was chosen (Figure 6). This area was established in 1978 to give an equal number of altered and unaltered area. Swan Creek is completely surrounded by an undisturbed marsh of black needlerush. There are no ditches draining into this area, and the bottom

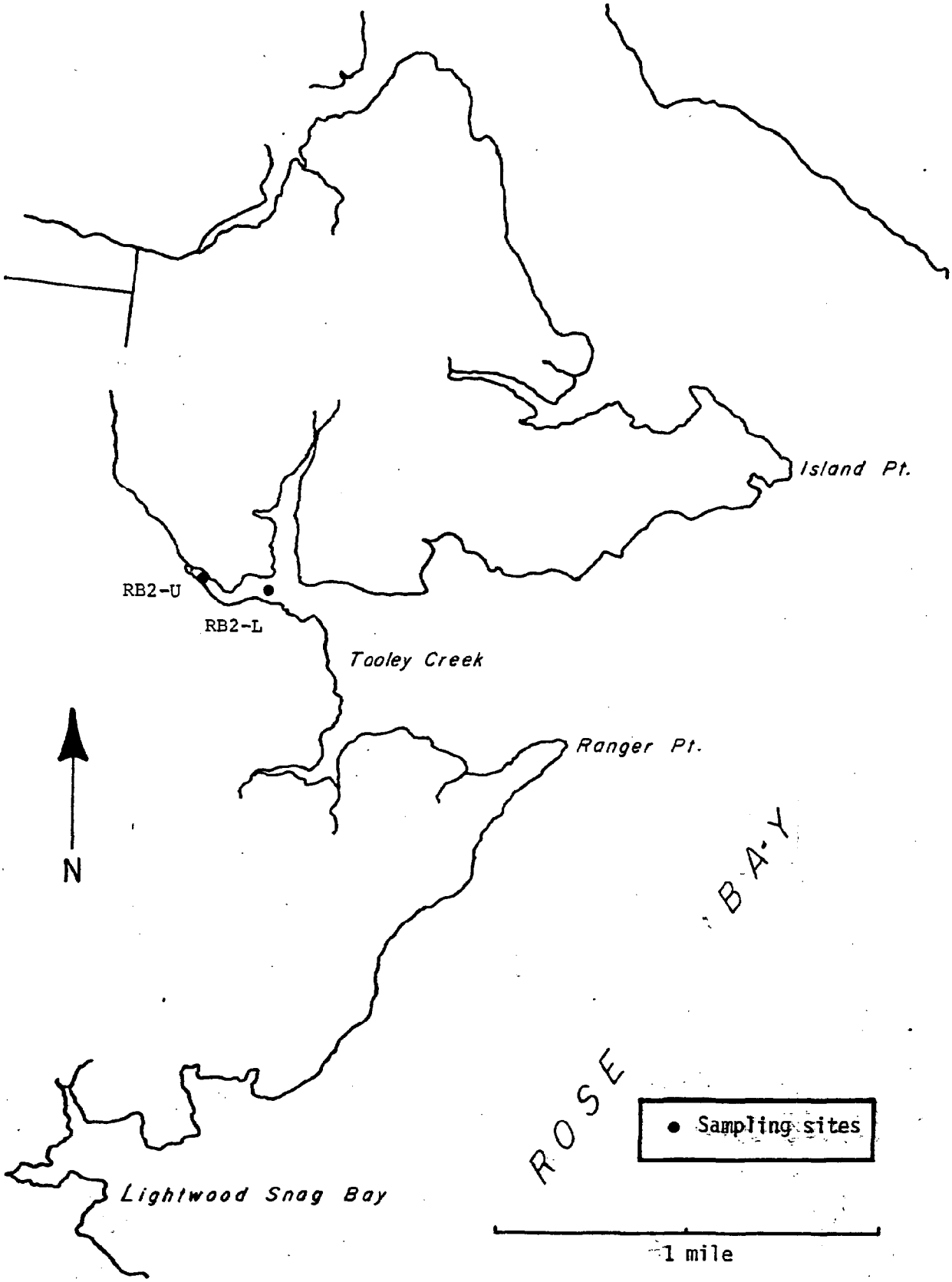

Figure 4. Unaltered site Tooley Creek (RB-2).

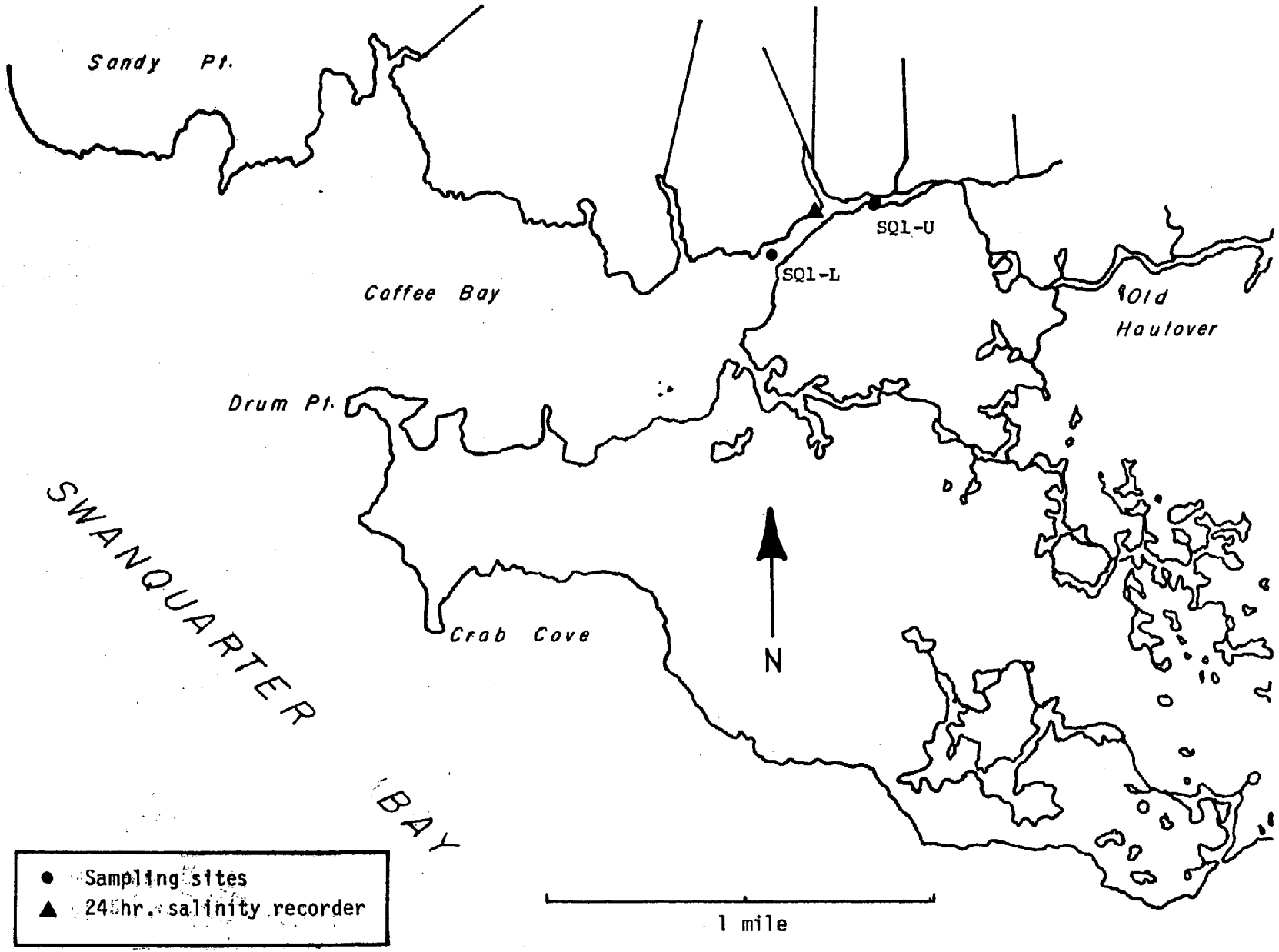

Figure 5. Altered site Caffee Bay (SQ-1).

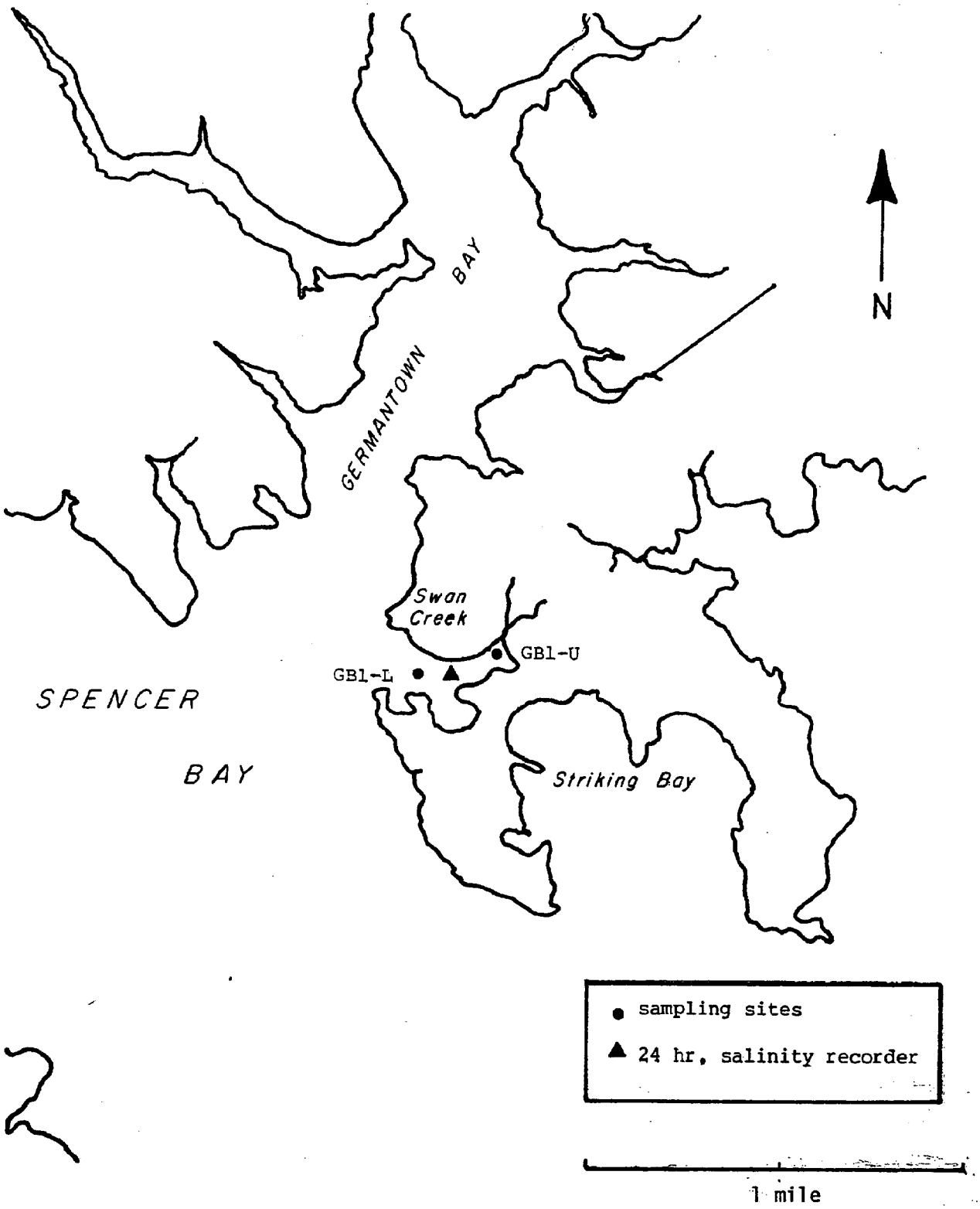

Figure 6. Unaltered site Swan Creek (GB-1).

consists of soft mud, detritus and marine shells. Water depths range from 2 ft (0.61 m) to 4 ft (1.27 m).

RESULTS AND DISCUSSION

One potential stress to organisms in the study area is precipitation and resulting changes in salinity. Under natural conditions, rainfall on areas adjacent to the primary nursery areas enters the system slowly by means of filtering through surface litter and the surrounding marsh. Through this process salinity patterns are not rapidly affected. As a result of the altered drainage situation in the study area, the total amount of freshwater entering the system has not significantly increased, but the rate at which runoff enters the system has been significantly altered. Peak outflow rates are three to four times higher for developed areas than for undeveloped areas (Skaggs et al. 1980). Because of this change in rate of flow, salinities are dramatically affected, contributing to a stressful environment which affects productivity of the system, particularly organisms of value to man.

Initially the project was designed to examine the relationship between juvenile shrimp movement and freshwater inflow. In order to accomplish this goal, favorable environmental conditions would have had to exist, including salinity patterns, to allow extensive utilization of the nursery areas. Any movement, then, could have been related to freshwater drainage by a continuous monitoring of salinity and rainfall data on a 24-hour basis. However these "ideal" conditions never occurred during the study period. Conditions ranged from extremely dry in 1977 to extremely wet in 1978.

Salinity and 1977 Shrimp Production

At the onset of sampling in 1977 conditions proved excellent with favorable salinity patterns, including a steady increase in salinities from May through August (Table 2). The salinity increase was due to unseasonably dry conditions that prevailed throughout the summer. Rainfall for this particular study period was well below the normal amount of rainfall which

Table 2. Mean salinities (top/bottom) at sampling sites May through August, 1977 - 1980.

1977

	RB-1	SQ-1	RB-2
May	8.7/9.5	11.0/12.0	10.0/11.0
June	13.0/13.0	16.0/16.0	15.0/15.0
July	12.0/14.0	16.0/18.0	15.5/15.5
August	15.0/15.0	18.0/18.0	16.0/16.0

1978

	RB-1	SQ-1	RB-2	GB-1
May	2.5/3.5	6.0/6.0	6.0/6.0	6.0/6.0
June	2.0/3.0	7.0/7.0	6.0/6.0	6.0/6.0
July	5.0/5.0	8.0/8.0	7.0/7.0	7.0/7.0
August	6.0/6.0	8.5/8.5	7.5/7.5	7.5/7.5

1979

	RB-1	SQ-1	RB-2	GB-1
May	2.5/3	5/5.5	5/5	5/5
June	4/4	7/7	5.5/5.5	5.5/5.5
July	4/4	5/5	5/5	6/6
August	4/4.5	5.5/6	5/5	7/7

1980

	RB-1	SQ-1	RB-2	GB-1
May	2/4	6.5/6.5	6/6	6/6
June	3.5/4	7.5/8	7/7	7.5/7.5
July	7/7	11.5/11.5	9/9	10/10
August	9/9.5	14/14	12/12	12.5/12.5

occurs in this area for that time of year. During April-June, rainfall was 4.56 in (11.58 cm) below normal, with a departure of -13.26 in (-33.68 cm) from normal rainfall during the five month sampling period (Table 3). This lack of rainfall gave rise to the increase in salinity levels, consequently producing favorable conditions. Due to these favorable conditions, both altered and unaltered sites served as productive nursery areas.

These conditions were particularly important with regards to station RB-1, located in the most altered system. Sampling prior to this study shows that Rose Bay Creek could be considered only marginally productive for shrimp (Unpublished Division of Marine Fisheries data). Sampling at RB-1 during 1977, however, yielded catches equal to or exceeding those at the other sampling stations. Catch-per-unit-of-effort (CPUE) steadily decreased throughout the months of May through August at stations RB-2 and SQ-1 but increased at RB-1 during June when 231% more shrimp were captured than were taken at SQ-1 during May and June combined (Table 4). Considering salinity levels and the pattern of shrimp distribution in RB-1, it is reasonable to assume that at high and stable salinity levels the ditches actually functioned as shrimp nursery areas during the spring and summer of 1977.

June was the most productive month for all stations. This productivity was likely caused by continuous recruitment without appreciable migration.

Length-frequency distribution data presented in Table 5 indicates that Tooley Creek (RB-2) supported the greatest number of early juvenile brown shrimp (25 - 35 mm). Tooley Creek length-frequency data for June had no well-defined modal group, indicating extensive recruitment during May and June. This was not the case at the altered stations.

Salinity and 1978 Shrimp Production

In 1978, sampling again started in early May, and the second unaltered site, Swan Creek (GB-1) was included. During this study period, excessive rainfall occurred reducing mean salinity levels at all stations during the time of peak recruitment (Table 2). As shown in Table 6, rainfall during the major recruitment period, April through June, totaled 18.91 in (48.03 cm). This amounted to 11.68 in (29.67 cm) more than was received during the same

Table 3. Daily rainfall (in) and departure from normal rainfall (in) April-August, 1977, New Holland, N.C. (National Weather Service).

Date	April	May	June	July	August	Total
1						
2				0.93		
3			0.03	0.33	0.14	
4						
5	0.26					
6		0.12				
7			0.18			
8		0.92				
9			0.24			
10			0.04			
11						
12						
13					0.20	
14					0.20	
15			0.39		0.09	
16	0.05				0.19	
17						
18						
19		0.05			0.33	
20		0.05			0.12	
21				1.95		
22						
23			0.27	0.04		
24	1.10	2.10	0.11			
25		0.04	0.06			
26	0.41		0.20	0.44	0.03	
27						
28		0.08				
29	0.05					
30				0.04		
31						
Total	1.87	3.36	2.00	3.77	1.30	12.30
Departure from normal	-1.01	-0.36	-3.19	-3.39	-5.31	-13.26

Table 4. Numbers of brown shrimp captured and CPUE for each sampled area May-August, 1977-1980.

	RB-1		SQ-1		RB-2		GB-1	
	Number captured	CPUE	Number captured	CPUE	Number captured	CPUE	Number captured	CPUE
1977								
May	250	10.4	286	11.9	2,459	117.1		
June	1,515	38.6	369	9.5	1,680	43.1		
July	76	2.0	247	6.3	386	9.9		
August	27	0.6	120	2.9	43	2.0		
Total	1,868	13.0	1,022	7.1	4,568	32.4		
1978								
May	0	0	9	0.4	44	1.8	3	0.1
June	2	0.1	208	9.5	592	24.7	45	2.1
July	8	1.0	65	8.1	54	6.8	24	3.0
August	44	4.4	57	5.7	31	3.1	20	2.0
Total	54	0.8	339	5.3	721	10.9	92	1.4
1979								
May	0	0	112	9.3	114	9.5	42	3.5
June	66	3.3	706	35.3	678	33.9	373	18.6
July	75	4.0	259	13.6	128	6.7	140	7.4
August	0	0	26	3.3	8	1.0	33	4.1
Total	141	2.4	1,103	18.7	928	15.7	588	10.0
1980								
May	0	0	992	38.2	1,269	57.7	347	13.4
June	63	3.9	475	26.7	577	41.2	628	39.3
July	335	21.0	202	12.6	110	9.2	306	19.1
August	9	0.6	78	5.6	28	3.1	51	3.6
Total	407	5.7	1,747	24.3	1,984	34.8	1,332	18.5

Table 5. Summary of length-frequency distribution (expressed in total number by 10 mm size group) of brown shrimp sampled May through August, 1977.

RB-1

Length (mm)	May	June	July	August
15				
25				
35	18			
45	31	4		
55	83	23		
65	97	90		
75	17	234	1	
85	4	311		
95		294	10	
105		217	15	
115		38	17	1
125		4	19	5
135			9	5
145			1	8
155				7
165				1

RB-2

Length (mm)	May	June	July	August
15	2			
25	158	13		
35	742	166		
45	690	430	3	
55	264	254	2	
65	78	158	12	
75	35	142	28	
85	9	111	39	
95		134	68	1
105		134	106	6
115		78	63	8
125		27	46	11
135		1	13	7
145			2	7
155				2
165				1

SQ-1

Length (mm)	May	June	July	August
15				
25	34	2		
35	111	26		
45	83	103		
55	37	69	4	
65	18	54	7	1
75	2	34	6	
85	1	29	29	
95		24	45	8
105		17	56	19
115		9	47	27
125		2	40	36
135			12	17
145			1	9
155				
165				3

TOTAL

Length (mm)	May	June	July	August
15	2			
25	192	15		
35	871	192		
45	804	537	3	
55	384	346	6	
65	193	302	19	1
75	54	410	35	
85	14	451	68	
95		452	123	9
105		368	177	25
115		125	127	36
125		33	105	52
135		1	34	29
145			4	24
155				9
165				5

Table 6. Daily rainfall (in) and departure from normal rainfall (in) April-August, 1978, New Holland, N.C. (National Weather Service)

Date	April	May	June	July	August	Total
1		0.19	1.58		0.08	
2		0.09			0.33	
3					0.02	
4		0.78		0.16		
5		0.08	0.40		1.63	
6						
7						
8		1.82				
9		1.70	0.33			
10			0.07	0.15		
11				0.44	0.19	
12					0.01	
13	0.77					
14		0.81			1.15	
15		0.02				
16		0.19		1.00		
17				0.03		
18	1.56	0.35				
19	0.53					
20				0.58		
21				0.17		
22	0.18	0.15				
23		0.04	0.39			
24		0.26				
25	0.06		0.55	0.75		
26	4.70			0.01		
27						
28						
29						
30		0.39				
31		0.92				
Total	7.80	7.79	3.32	3.29	3.41	25.61
Departure from normal	+4.92	+4.07	-1.87	-3.87	-3.26	-0.01

period of 1977. Salinity levels were depressed at all stations, resulting in decreased juvenile shrimp catches at the four sampling stations compared to 1977 samples (Table 7). Nursery area sampling throughout the entire region in 1978 reflected the lowest level of juvenile recruitment ever recorded, and resulted in a record low brown shrimp harvest (Table 1).

Length-frequency distribution data presented in Table 7 shows the adverse effects of the heavy rainfall on the recruitment of juvenile brown shrimp. Station RB-1 was almost void of shrimp during the four months of sampling except for a few large shrimp captured in August when salinities rose to a high of 6 ppt. Catch-per-unit-effort data (Table 4) show that only minor recruitment took place at RB-2, GB-1 and SQ-1, probably during June when rainfall declined to a level of 1.87 in (4.75 cm) below normal for that month. Length-frequency data for the total catch during June shows a single definable modal group, giving evidence of a reduced recruitment period for 1978 (Table 8) compared to 1977. The most significant recruitment occurred at unaltered site RB-2 (Table 7). Unfortunately, during the 1978 sampling period, the 24-hour salinity recorders were non-functional and were being repaired at the time of these adverse weather conditions. Because of this situation, changes in salinities on a 24-hour basis and their relation to shrimp migration could not be observed. It seems quite evident however, that during periods of excessive rainfall, unaltered areas as well as altered areas suffer a decline in salinity due to total saturation of the drainage basin.

Although 24-hour salinity readings were not available, top and bottom salinities were recorded at each station during each sampling day. These salinity readings showed the effects of the drainage into the altered areas in relation to the unaltered areas during the same time period. Figure 7 shows that during May, 1978, altered sites experienced significant differences in top and bottom salinities, indicating increased drainage rates, while the unaltered sites remained relatively stable.

Salinity and 1979 Shrimp Production

Sampling during 1979 showed an increase in brown shrimp catches when compared to those of 1978. During the recruitment months of April, May, and June

Table 7. Summary of length-frequency distribution (expressed in total number by 10 mm size group) of brown shrimp sampled May through August, 1978.

RB-1

Length (mm)	May	June	July	August
15				
25		2		
35				
45				
55				
65				
75				
85				
95				3
105				4
115			1	5
125			1	6
135				10
145				8
155				6
165				

RB-2

Length (mm)	May	June	July	August
15	10	2		
25	21	83		
35	13	253		
45		92		
55		66	2	
65		36	5	
75		7	6	
85		4	1	2
95			3	6
105			7	6
115			2	13
125			1	
135				2
145				2
155				
165				

GB-1

Length (mm)	May	June	July	August
15				
25	1	2		
35	1	12		
45		11		
55		12		
65		10	2	
75		3	2	
85			5	
95			3	1
105			7	1
115			4	2
125			1	3
135				5
145				6
155				1
165				1

SQ-1

Length (mm)	May	June	July	August
15		6		
25	7	15		
35	2	77	2	
45		63	6	
55		26	14	
65		13	5	1
75		4	5	2
85		1	3	6
95			11	7
105			6	10
115			3	12
125				11
135			1	5
145				
155				
165				

Table 8. Total length-frequency distribution of brown shrimp for all locations (expressed in total number by 10 mm size group) May through August, 1978.

Length (mm)	May	June	July	August
15	10	8		
25	29	102		
35	16	342	2	
45		166	6	
55		104	16	
65		59	12	1
75		14	13	2
85		5	9	8
95			17	17
105			21	21
115			10	32
125			2	20
135			1	20
145				16
155				7
165				1

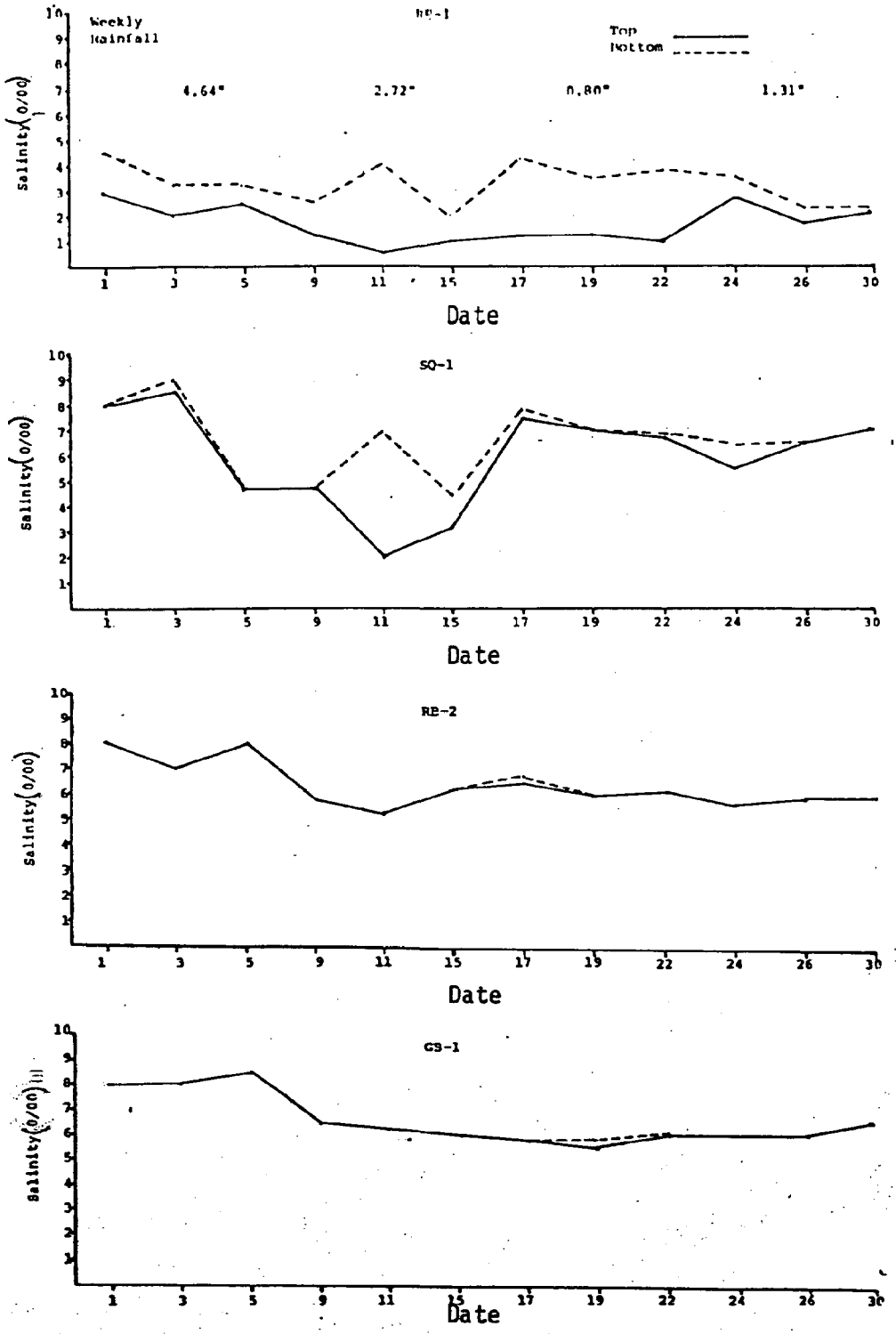

Figure 7. Comparison of salinities, (top/bottom) between altered and unaltered sampling sites during May, 1978.

rainfall totalled 12.83 in (32.59 cm) which was only 1.83 in (4.65 cm) above normal for this time period (Table 9). Rainfall during April-June was 6.08 in (15.44 cm) less than was received during the same time in 1978. When mean salinity levels of 1979 (Table 2) are compared to those of 1978, the 1979 values are considerably lower. This apparent anomaly is due to a "buffering effect", as follows. Although more rainfall was recorded during 1978, the extremely dry year of 1977 yielded record high salinities in the study area, reaching 22 ppt during October, 1977. When the higher-than-average rainfall started during 1978, high salinities resulting from the 1977 drought buffered the effects of the rainfall and prevented salinities from dropping below levels recorded during the 1978 study period. Heavy rainfall occurred during January of 1979, but salinities were not high enough to buffer these effects, which led to the lower mean salinities recorded during 1979. Fortunately, rainfall was relatively light during the recruitment period resulting in more stable day-to-day salinities and a higher recruitment level than during 1978. However, brown shrimp landings for Pamlico Sound in 1979 increased only 2,612 lb from those of 1978 (Table 1). A probable cause of this very slight increase is that fishing effort during 1979 was less than during 1978 (Division of Marine Fisheries unpublished data).

When sampling began in early May, 1979, brown shrimp recruitment was at a low level and did not increase significantly until June (Table 10). Total length-frequency distribution data presented in Table 11 show no evidence of protracted recruitment, as occurred during 1977 (Table 5). Station RB-1 again was unproductive, with mean salinities averaging only 4 ppt throughout the sampling period.

Final installation of the salinity recorders was completed on 13 June, finally providing day-to-day data on effects of individual rainfall events. Salinity patterns were relatively stable at that time with only minor pulses occurring within the altered sites, RB-1 and SQ-1. From 13 June until 18 July, only light rainfall occurred within the study area. However, during the week of 19 to 25 July, 4.79 in (12.17 cm) of rain fell (Table 9). Extreme declines in salinity occurred within both altered areas (RB-1 and SQ-1) while station GB-1 retained a nearly-level salinity pattern (Figure 8). Approximately one week after 25 July, the altered areas regained their previous salinity levels and stabilized.

Table 9. Daily rainfall (in) and departure from normal rainfall (in) April-August, 1979, New Holland, N.C. (National Weather Service)

Date	April	May	June	July	August	Total
1						
2				0.03		
3						
4	0.39		1.10	0.30		
5		0.45				
6						
7						
8						
9	0.98					
10				0.13		
11			0.10	0.35		
12					1.19	
13	1.10					
14		1.96				
15		1.97				
16						
17						
18		0.35				
19		0.88		1.80		
20				1.95	0.23	
21				0.72	1.70	
22				0.02		
23		0.08		0.30		
24	0.09	0.35				
25			1.17	0.04		
26	0.99	0.09				
27						
28	0.78				2.25	
29					0.46	
30						
31						
Total	4.33	6.13	2.37	5.64	5.83	24.30
Departure from normal	+1.45	+2.41	-2.03	+1.52	-0.84	-0.53

Table 10. Summary of length-frequency distribution (expressed in total number by 10 mm size group) of brown shrimp sampled May through August, 1979.

RB-1

Length (mm)	May	June	July	August
15				
25				
35				
45				
55		3	1	
65		9	2	
75		17	5	
85		18	10	
95		12	17	
105		4	26	
115		1	7	
125			7	
135				
145				
155				
165				

RB-2

Length (mm)	May	June	July	August
15	2	1		
25	59	47		
35	37	252	1	
45	15	247	1	
55	1	90	27	
65		20	34	
75		14	23	
85		5	18	
95		1	10	
105			8	1
115			3	1
125			2	2
135				2
145				
155				1
165				

GB-1

Length (mm)	May	June	July	August
15	2			
25	9	16		
35	17	50	1	
45	4	107	1	
55		93	6	
65		45	16	
75		32	15	
85		14	20	
95		7	24	1
105		5	28	2
115			15	7
125			6	9
135			5	1
145			2	6
155				7
165				

SQ-1

Length (mm)	May	June	July	August
15				
25	7	11		
35	41	128	1	
45	53	286	10	
55	11	146	34	
65		58	43	1
75		31	49	1
85		24	36	2
95		8	35	1
105		7	30	2
115		1	11	8
125			8	6
135			2	4
145				1
155				
165				

Table 11. Total length-frequency distribution of brown shrimp for all locations (expressed in total number by 10 mm size group) May through August, 1979.

Length (mm)	May	June	July	August
15	4	1		
25	75	74		
35	95	430	3	
45	72	643	12	
55	12	332	68	1
65		132	95	1
75		94	92	2
85		61	84	2
95		28	86	5
105		16	92	16
115		2	36	17
125			23	7
135			7	7
145			2	8
155				
165				

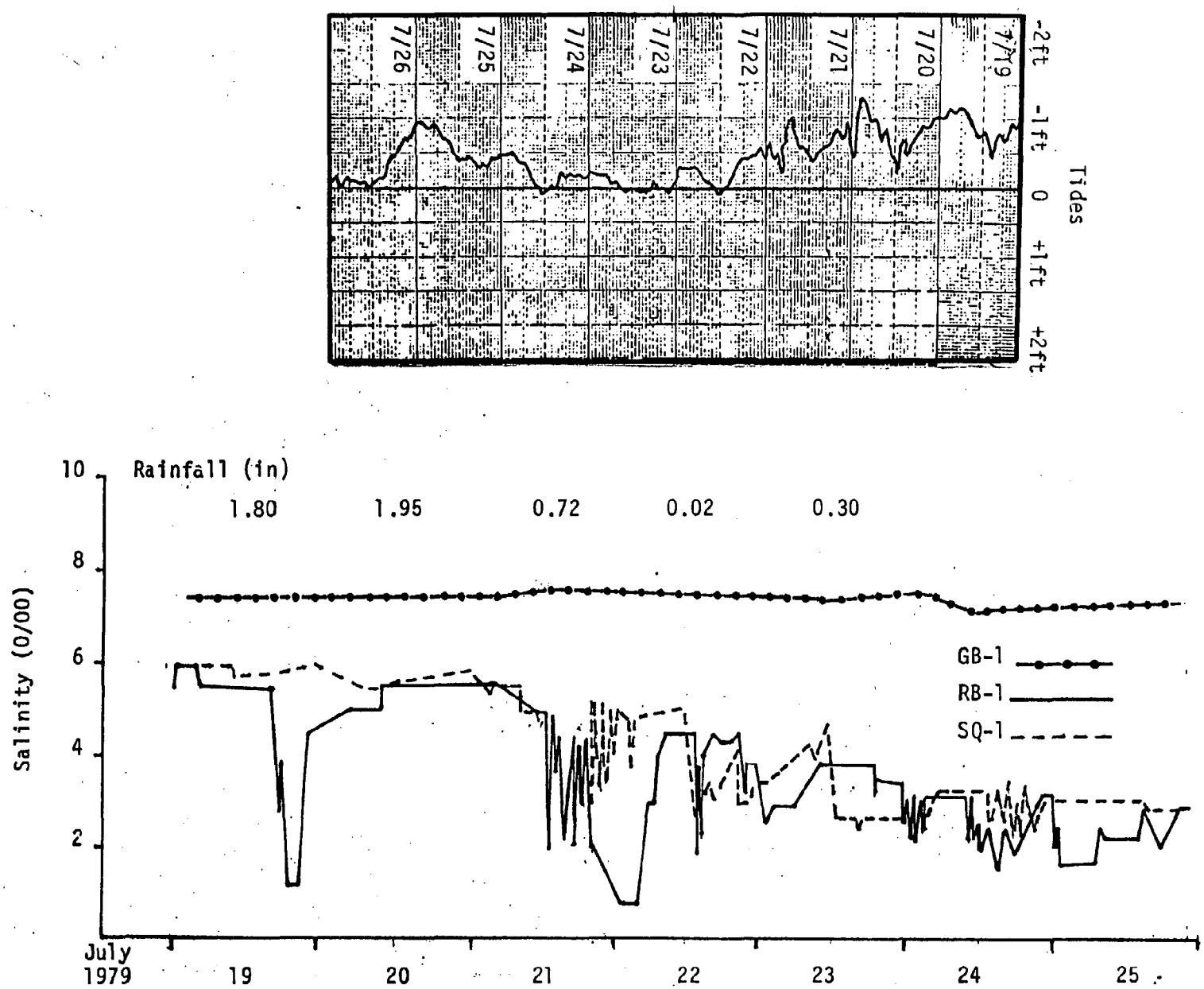

Figure 8. Tide fluctuations and salinity changes during a period of heavy rain, 20 July-25 July, 1979.

During this same time period, tidal fluctuations in relation to wind speed and direction were examined. The extent and frequency of salinity fluctuations can be influenced by the duration of tidal fluctuations induced by wind speed and direction. Southwesterly winds in Pamlico Sound tend to decrease water levels and pull water out of the tributaries, including the field ditches. Northeasterly winds tend to increase tidal levels and "push" water into field ditches and canals. Figure 9 shows the effects of wind direction on tidal levels over a ten-day period during 1980.

During 19-25 July, winds were predominantly out of the southwest resulting in lowered tide levels, down to -1.75 ft (-0.54 m) (Figure 8). This situation undoubtedly increased freshwater discharge into the altered sites. Although tide levels were decreased to the same level at GB-1, salinities remained constant. At the time of these observations, the majority of the shrimp population had migrated from the study area and no relationship between the sudden salinity fluctuations and shrimp behavior could be made.

Salinity and 1980 Shrimp Production

Rainfall patterns during the 1980 recruitment period were nearly average, and nursery area sampling showed a more normal condition. Rainfall during the major three month recruitment period was 10.59 in (26.90 cm) (Table 12), only 1.21 in (3.07 cm) below normal for the period. Good recruitment levels in May were evident for the first time since 1977 resulting in landings of 2,113,685 lb (heads-off). Significant numbers of shrimp over a wide size range were captured during May indicating utilization of the nursery areas as early as April. Length-frequency distribution presented in Table 13 shows that station RB-2 produced the greatest number of juvenile brown shrimp (25-35 mm). Good levels of recruitment were also noted at station SQ-1. Recruitment was not as high at station GB-1, but was significantly higher than during 1978 and 1979. The total catch length-frequency distribution presented in Table 14 shows an indefinable modal group in June giving evidence of protracted recruitment. The presence of 35-45 mm shrimp as late as August suggests recruitment well beyond the normal period. Mean salinities presented in Table 2 were relatively uniform throughout the study area during May except at station RB-1. Salinities at this station were again low, and no shrimp were captured during this month at RB-1.

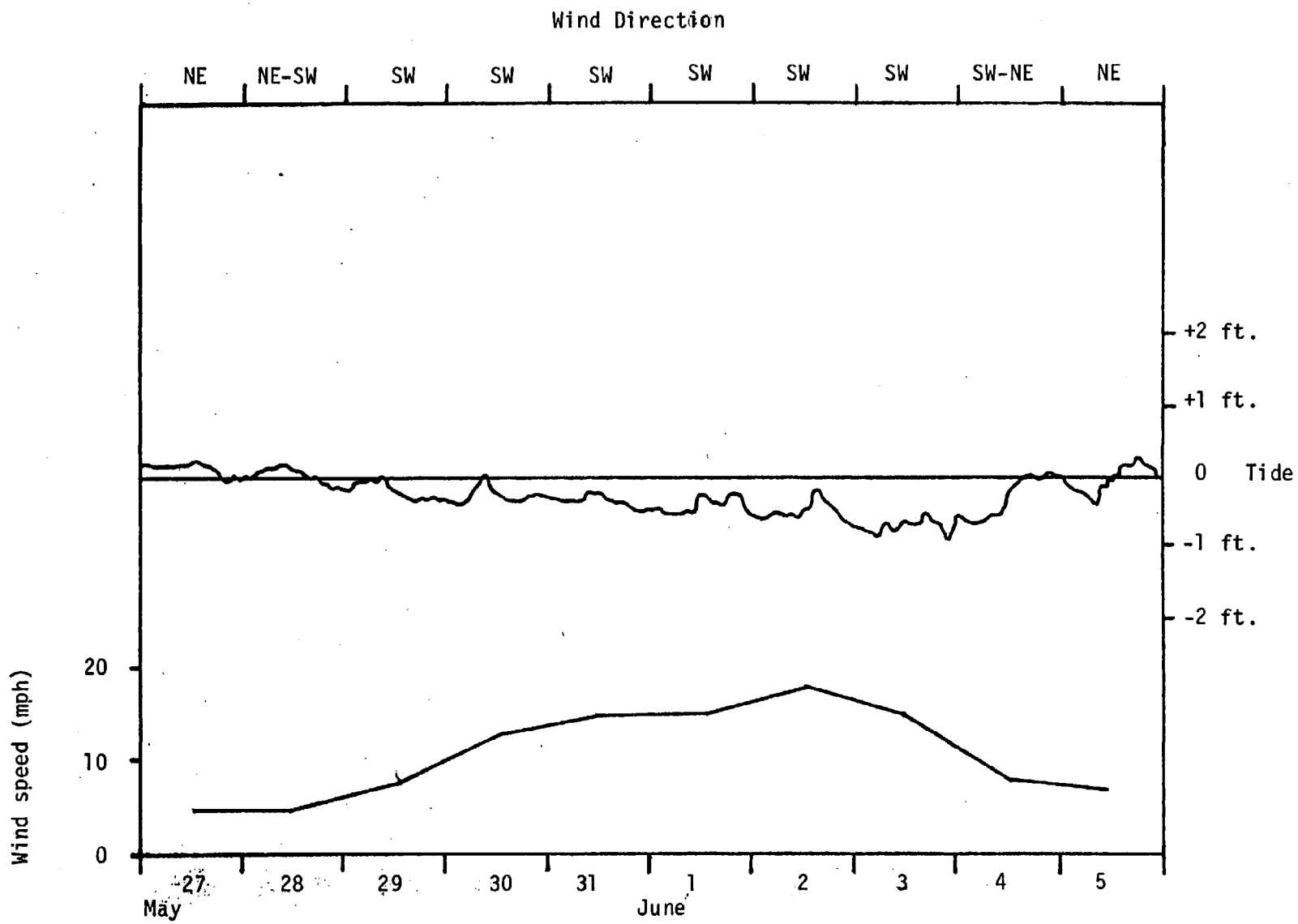

Figure 9. Tidal fluctuations due to wind speed and direction, 27 May to 5 June, 1980.

Table 12. Daily rainfall (in) and departure from normal rainfall (in) April-August, 1980, New Holland, N.C. (National Weather Service)

Date	April	May	June	July	August	Total
1	0.01					
2						
3						
4					0.26	
5						
6						
7	0.27			0.67		
8		0.03				
9	0.13	0.17				
10						
11				0.38		
12						
13						
14	0.65					
15	0.10					
16						
17			0.48			
18			0.67			
19		0.36	0.18		1.03	
20		0.03				
21	0.02	2.26				
22						
23						
24				1.37		
25			0.24			
26			2.10			
27	1.79	0.12	0.11			
28	0.02			0.24		
29	0.01					
30			0.84	0.10		
31						
Total	3.00	2.97	4.62	2.76	1.29	14.64
Departure from normal	+0.11	-0.75	-0.57	-4.40	-5.38	-10.99

Table 13. Summary of length-frequency distribution (expressed in total number by 10 mm size group) of brown shrimp sampled May through August, 1980.

RB-1

Length (mm)	May	June	July	August
15				
25				
35				
45		3		
55				
65		6		
75		20	19	
85		21	26	
95		9	65	
105		2	93	
115		2	86	3
125			36	3
135			5	3
145				
155				
165				

RB-2

Length (mm)	May	June	July	August
15	74			
25	498	21		
35	519	106	1	1
45	135	133	2	
55	37	117	8	3
65	9	92	22	
75		55	19	
85		33	26	
95		10	15	1
105		7	13	3
115		3	4	2
125				6
135				4
145				8
155				
165				

GB-1

Length (mm)	May	June	July	August
15	8			
25	60	7		
35	103	30		1
45	131	122	2	2
55	22	150	12	4
65	4	132	17	7
75		86	30	4
85		46	44	2
95		37	55	2
105		10	57	1
115		4	50	2
125		1	27	9
135			10	5
145			2	7
155				
165				

SQ-1

Length (mm)	May	June	July	August
15	24	2		
25	404	55		
35	441	147	5	
45	104	123	11	4
55	18	58	27	7
65		24	28	3
75		19	31	7
85		16	21	5
95		18	28	7
105		3	23	14
115		2	16	18
125			8	6
135			2	5
145				2
155				
165				

Table 14. Total length-frequency distribution of brown shrimp for all locations (expressed in total number by 10 mm size group) May through August, 1980.

Length (mm)	May	June	July	August
15	106	2		
25	962	83		
35	1,063	283	6	2
45	370	381	15	6
55	77	325	47	14
65	13	254	67	10
75		180	99	11
85		116	117	7
95		74	163	10
105		22	186	18
115		11	156	25
125		1	71	24
135			17	17
145			2	17
155			1	5
165				

Recruitment did not occur within RB-1 until late June and July when salinities were higher and more stable.

The differences in top and bottom salinities at RB-1 were indicative of the drainage into this study area. Twenty-four hour recorders showed highly erratic salinity patterns during the early recruitment period with only short periods of stabilization at RB-1. Station SQ-1 was relatively stable during this period with only minor pulses with the exception of one 24-hour period of heavy rainfall which occurred on 21 May. As shown in Figure 10, all three areas were affected during this 2.26 in (5.74 cm) rainfall. Station RB-1, located in the most altered system, exhibited the greatest fluctuations in salinity levels, as much as 3 ppt at intervals of approximately 1.5 hr. Altered area SQ-1 also had sharp pulses, with salinities varying as much as 2.5 ppt at 1.5 hr intervals. Salinities at SQ-1 stabilized once the rains ended, although 36 hours later salinities began to fluctuate again, but not as much. This situation probably resulted from additional drainage which originated further inland during the same rain event on 21 May but took 36 hr to reach Caffee Bay.

After the rainfall on 21 May, salinity fluctuations at station RB-1 gradually diminished and the salinity generally increased above the level existing before 21 May. Then the secondary drainage reached the creek, and the salinity fell by over 50%. In contrast, the salinity at SQ-1 restabilized within 27 hr of the rainfall.

It is apparent that the effects of the rainfall of 21 May on the study areas is related to the degree of alteration of natural drainage into each area. Rose Bay Creek is the most altered and received the greatest amount of inland drainage; it suffered the greatest salinity fluctuations. Swan Creek (GB-1) is unaltered and exhibited only a brief, minor change in salinity.

The extremely erratic salinity pattern displayed at RB-1 was evident when the first salinity meter recordings were examined on 25 April 1980. Rainfall, up until this date, was only 1.18 in(3.00 cm) for the month (Table 12) and it seems unlikely that such low rainfall would cause such fluctuations. Because the main drainage received at RB-1 is from the canal connected to Lake Mattamuskeet, drainage information was obtained from management personnel at Mattamuskeet National Wildlife Refuge. The data showed that, at certain periods, water was either pumped or gravity-drained into Rose Bay Canal from Lake

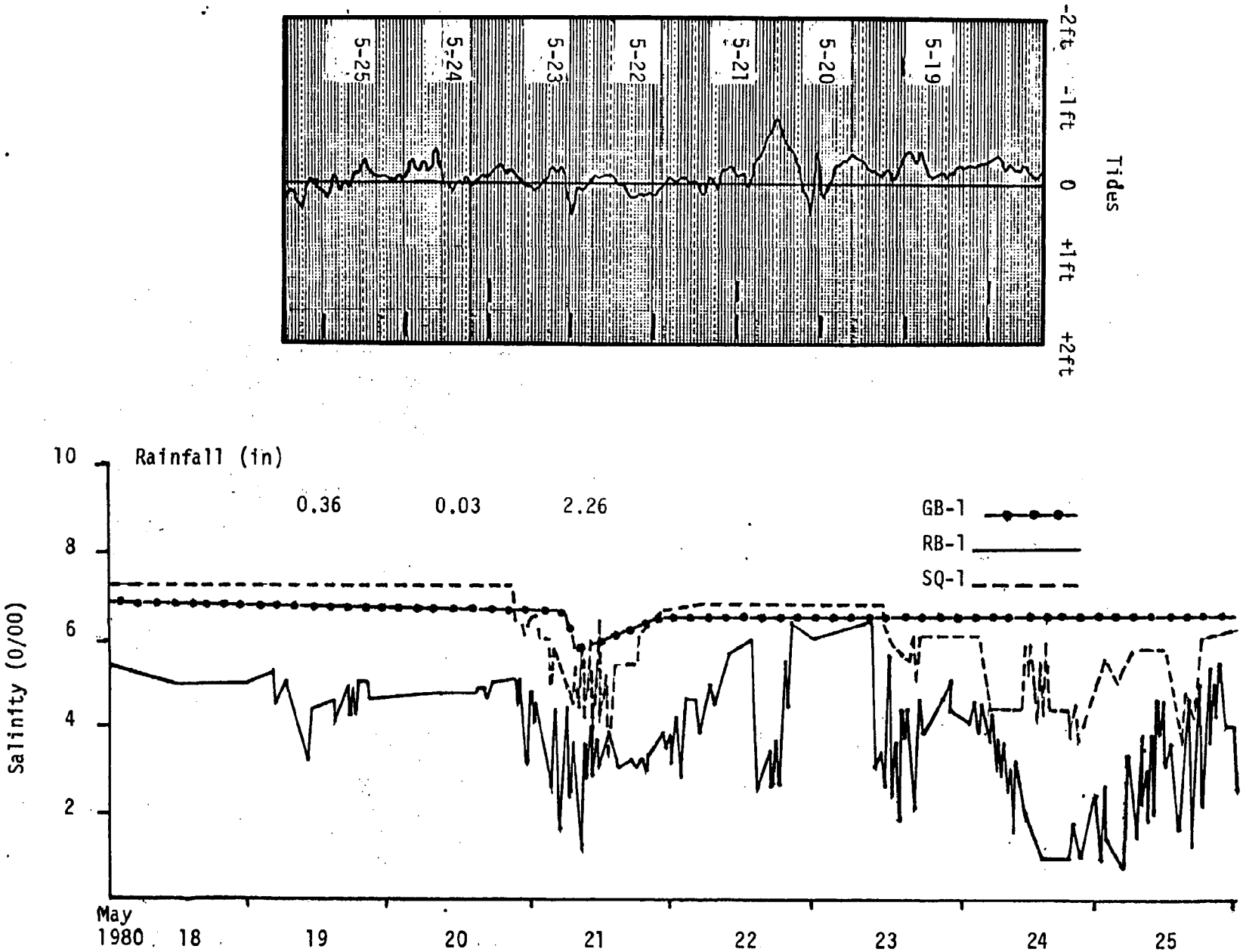

Figure 10. Tide fluctuations and salinity changes during a period of heavy rain, 18 May-25 May, 1980.

Mattamuskeet for management purposes. Periods of discharge lasted for two weeks. However, when these two week periods were compared with the available 24-hour salinity readings, no periods of salinity fluctuations were evident which indicated that this discharge was not responsible for the erratic patterns recorded. When water was discharged for two weeks beginning on 10 July 1979, salinities maintained an average reading of 6 ppt without pulsating. When water was discharged beginning 16 June 1980 salinities averaged 5.5 ppt and did not fluctuate during the two week period. As shown in Figure 3 the salinometer was located in the direct path of flow from the canal. The most plausible explanation for the salinity patterns at station RB-1 during periods of below average rainfall is the seepage of ground water into this canal. The deeper ditches within the region tend to have primary control on the location of the water table. Studies performed on streams before and after channelization showed a higher discharge rate during fair weather after channelization reflecting increases in ground-water discharge into the deeper channels (Heath 1975).

Summary of Salinity and Shrimp Production

Overall comparisons of each area throughout the four year sampling period show the relationship between mean salinity and recruitment levels represented in Tables 15 through 18. Note should be taken of the previous discussion on salinities during 1978 and 1979 (p. 27). The data for 1977 show that even a severely-altered system can function as a productive nursery area when environmental conditions are favorable (Table 15). Subsequent years produced only small numbers of shrimp, and then only during later months when salinities had increased.

Station SQ-1 had its best recruitment in 1977 and 1980 (Table 16). Although this system is altered, shrimp production in 1980 was significant and related to salinity levels which were increasing throughout the spring. Salinity levels were 2-3 ppt higher than at RB-1 and did not have frequent fluctuations during the recruitment period.

Station RB-2 was also most productive in 1977 and 1980, with fair recruitment in June of 1978 and 1979 (Table 17). Catch-per-unit-effort data presented in Table 4 show that RB-2 was the most productive area sampled overall.

Table 15. Summary of length-frequency distribution (expressed in total number by 10 mm size group) of brown shrimp sampled during the months of May-August, at station RB-1(1977-1980)in relation to mean salinity levels.

May					June				
Length (mm)	1977	1978	1979	1980	Length (mm)	1977	1978	1979	1980
15					15				
25					25		2		
35	18				35				
45	31				45	4		3	3
55	83				55	23		3	
65	97				65	90		9	6
75	17				75	234		17	20
85	4				85	311		18	21
95					95	294		12	9
105					105	217		4	2
115					115	38		1	2
125					125	4			
135					135				
145					145				
155					155				
165					165				
Mean salinities top/bottom	9/9	2.5/3	2.5/3	2/4	Mean salinities top/bottom	13/13	2/3	4/4	3.5/4

July					August				
Length (mm)	1977	1978	1979	1980	Length (mm)	1977	1978	1979	1980
15					15				
25					25				
35					35				
45					45				
55			1		55				
65			2		65				
75	1		5	19	75				
85			10	26	85				
95	10		17	65	95		3		
105	15		26	93	105		4		
115	17	1	7	86	115	1	5		3
125	19	1	7	36	125	5	6		3
135	9			5	135	5	10		3
145	1				145	8	8		
155					155	7	6		
165					165	1			
Mean salinities top/bottom	12/14	5/5	4/4	7/7	Mean salinities top/bottom	15/15	6/6	4/4.5	9/9.5

Table 16. Summary of length-frequency distribution (expressed in total number by 10 mm size group) of brown shrimp sampled during the months of May-August, at station SQ-1(1977-1980)in relation to mean salinity levels.

May

Length (mm)	1977	1978	1979	1980
15				24
25	34	7	7	404
35	111	2	41	441
45	83		53	104
55	37		11	18
65	18			
75	2			
85	1			
95				
105				
115				
125				
135				
145				
155				
165				
Mean salinities top/bottom	11/12	6/6	5/5.5	6.5/6.5

June

Length (mm)	1977	1978	1979	1980
15		6		2
25	2	15	11	55
35	26	77	128	147
45	103	63	286	123
55	69	26	146	58
65	54	13	58	24
75	34	4	31	19
85	29	1	24	16
95	24		8	18
105	17		7	3
115	9		1	2
125	2			
135				
145				
155				
165				
Mean salinities top/bottom	16/16	7/7	7/7	7.5/8

July

Length (mm)	1977	1978	1979	1980
15				
25				
35		2	1	5
45		6	10	11
55	4	14	34	27
65	7	5	43	28
75	6	5	49	31
85	29	3	36	21
95	45	11	35	28
105	56	6	30	23
115	47	3	11	16
125	40		8	8
135	12	1	2	2
145	1			
155				
165				
Mean salinities top/bottom	16/16	8/8	5/5	11.5/11.5

August

Length (mm)	1977	1978	1979	1980
15				
25				
35				
45				4
55				7
65	1	1	1	3
75		2	1	7
85		6	2	5
95	8	7	1	7
105	19	10	2	14
115	27	12	8	18
125	36	11	6	6
135	17	5	4	5
145	9		1	2
155	1			
165	3			
Mean salinities top/bottom	18/18	8.5/8.5	5.5/6	14/14

Table 17. Summary of length-frequency distribution (expressed in total number by 10 mm size group) of brown shrimp sampled during the months of May-August, at station RB-2(1977-1980) in relation to mean salinity levels.

May

Length (mm)	1977	1978	1979	1980
15	2	10	2	74
25	158	21	59	498
35	742	13	37	519
45	690		15	135
55	264		1	37
65	78			9
75	35			
85	9			
95				
105				
115				
125				
135				
145				
155				
165				
Mean salinities top/bottom	10/11	6/6	5/5	6/6

June

Length (mm)	1977	1978	1979	1980
15		2	1	
25	13	83	47	21
35	166	253	252	106
45	430	92	247	133
55	254	66	90	117
65	158	36	20	92
75	142	7	14	55
85	111	4	5	33
95	134		1	10
105	134			7
115	78			3
125	27			
135	1			
145				
155				
165				
Mean salinities top/bottom	15/15	6/6	5.5/5.5	7/7

July

Length (mm)	1977	1978	1979	1980
15				
25				
35			1	1
45	3		1	2
55	2	2	27	8
65	12	5	34	22
75	28	6	23	19
85	39	1	18	26
95	68	3	10	15
105	106	7	8	13
115	63	2	3	4
125	46	1	2	
135	13			
145	2			
155				
165				
Mean salinities top/bottom	15.5/15.5	7/7	5/5	9/9

August

Length (mm)	1977	1978	1979	1980
15				
25				
35				1
45				
55				3
65				
75				
85		2		
95	1	6		1
105	6	6	1	3
115	8	13	1	2
125	11		2	6
135	7	2	2	4
145	7	2		8
155	2		1	
165	1			
Mean salinities top/bottom	16/16	7.5/7.5	5/5	12/12

Table 18. Summary of length-frequency distribution (expressed in total number by 10 mm size group) of brown shrimp sampled during the months of May-August, at station GB-1(1978-1980) in relation to mean salinity levels.

May					June				
Length (mm)	1977	1978	1979	1980	Length (mm)	1977	1978	1979	1980
15			2	8	15				
25		1	9	60	25		2	16	7
35		1	17	103	35		12	50	30
45			4	131	45		11	107	122
55				22	55		12	93	150
65				4	65		10	45	132
75					75		3	32	86
85					85			14	46
95					95			7	37
105					105			5	10
115					115				4
125					125				1
135					135				
145					145				
155					155				
165					165				
Mean salinities top/bottom		6/6	5/5	6/6	Mean salinities top/bottom		6/6	5.5/5.5	7.5/7.5

July					August				
Length (mm)	1977	1978	1979	1980	Length (mm)	1977	1978	1979	1980
15					15				
25					25				
35			1		35				1
45			1	2	45				2
55			6	12	55				4
65		2	16	17	65				7
75		2	15	30	75				4
85		5	20	44	85				2
95		3	24	55	95		1	1	2
105		7	28	57	105		1	2	1
115		4	15	50	115		2	7	2
125		1	6	27	125		3	9	9
135			5	10	135		5	1	5
145			2	2	145		6	6	7
155					155		1	7	5
165					165		1		
Mean salinities top/bottom		7/7	6/6	10/10	Mean salinities top/bottom		7.5/7.5	7/7	12.5/12.

The highest recruitment year at station GB-1 was 1980, which reflects the favorable salinity patterns of that year (Table 18). No comparisons with 1977 could be made since the station was not sampled during 1977. Although station GB-1 exhibited very favorable salinity patterns, and mean salinity readings equal to or exceeding those of RB-2, large numbers of shrimp were not evident within this system. Rose Bay Creek, Caffee Bay and Tooley Creek were all capable of supporting large numbers of shrimp under favorable conditions. Station GB-1, however, was the smallest water body of the four areas sampled, and shrimp production could have been limited by the amount of habitat available.

Salinity and Other Species

Although shrimp catches were not as high at GB-1, production of other commercially important species was extremely high within this system as well as at station RB-2, when compared with the altered sites RB-1 and SQ-1. The most abundant commercially important species found within the study area were brown shrimp (*Penaeus aztecus*), blue crab (*Callinectes sapidus*), southern flounder (*Paralicthys lethostigma*), spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonias undulatus*) and Atlantic menhaden (*Brevoortia tyrannus*). The catches of each of these species at the two altered areas and the two unaltered areas for each month, May through August, 1977-1980, were calculated to determine the difference in CPUE between the altered and unaltered areas. The results were analyzed by a students t-test at the 95% confidence level to determine if there were significant differences in utilization of the areas by brown shrimp, blue crabs, southern flounder, spot, croaker and menhaden. Results are shown in Tables 19 - 24.

The utilization by brown shrimp of the unaltered sites during 1977 proved to be significant during the months of May through July (Table 19). In August, the altered areas had an insignificantly higher CPUE. However, the altered sites were still the least productive. When the four month period was combined, the unaltered sites were more productive in catch value which was significant at the 95% confidence level.

Table 19. Numbers of brown shrimp captured, CPUE, and t-values comparing altered and unaltered areas, May-August, 1977-1980.

	Altered areas		Unaltered areas		
	Number captured	CPUE	Number captured	CPUE	t-Value calculated
1977					
May	536	11.2	2,459	117.1	15.027 *
June	1,884	24.2	1,680	43.1	2.567 *
July	323	4.2	386	9.9	4.500 *
August	147	1.8	43	1.1	1.510
Total	2,939	10.2	4,568	32.4	8.324 *
1978					
May	9	0.2	47	1.0	1.197
June	210	4.6	637	13.9	2.904 *
July	73	4.6	78	4.9	0.187
August	101	5.1	51	2.6	1.700
Total	386	3.0	813	6.3	2.756 *
1979					
May	112	4.7	156	6.5	0.563
June	772	19.3	1,051	26.3	1.506
July	334	8.8	268	7.1	0.944
August	26	1.7	41	2.6	0.927
Total	1,244	10.6	1,516	12.9	1.014
1980					
May	992	19.1	1,616	33.7	1.677
June	538	16.9	1,205	40.2	3.825 *
July	537	16.8	416	14.9	0.399
August	87	3.1	79	3.5	0.367
Total	2,154	15.0	3,316	25.7	2.657 *

* Significant at 95% confidence level

Table 20. Numbers of blue crabs captured, CPUE, and t-values altered and unaltered areas, May-August, 1977-1980.

	Altered areas		Unaltered areas		
	Number captured	CPUE	Number captured	CPUE	t-Value calculated
1977					
May	56	1.2	57	2.8	2.819 *
June	25	0.4	112	2.9	6.567 *
July	31	0.4	106	2.8	7.132 *
August	49	0.6	92	2.2	4.971 *
Total	161	0.6	367	2.6	11.291 *
1978					
May	52	1.1	58	1.2	0.371
June	35	0.8	118	2.6	3.680 *
July	11	0.7	86	5.4	3.481 *
August	42	2.1	132	6.6	2.429 *
Total	140	1.1	394	3.1	4.598 *
1979					
May	33	1.4	253	10.6	3.476 *
June	41	1.1	154	3.9	4.700 *
July	36	1.0	130	3.5	3.874 *
August	16	1.0	67	4.2	3.523 *
Total	126	1.1	604	5.2	6.110 *
1980					
May	109	2.1	781	16.3	5.080 *
June	51	1.6	579	19.3	5.151 *
July	34	1.1	231	8.3	5.108 *
August	26	1.0	163	7.1	3.844 *
Total	220	1.6	1,754	13.6	8.530 *

* Significant at 95% confidence level

Table 21. Numbers of southern flounder captured, CPUE, and t-values comparing altered and unaltered areas, May-August, 1977-1980.

	Altered areas		Unaltered areas		
	Number captured	CPUE	Number captured	CPUE	t-Value calculated
1977					
May	54	1.2	51	2.5	2.664 *
June	17	0.3	127	3.3	8.024 *
July	9	0.2	22	0.6	2.901 *
August	7	0.1	5	0.2	0.485
Total	87	0.3	205	1.5	7.139 *
1978					
May	8	0.2	27	0.6	2.272 *
June	2	0.1	36	0.8	4.972 *
July	1	0.1	3	0.2	0.835
August	1	0.1	5	0.3	1.506
Total	12	0.1	71	0.6	5.281 *
1979					
May	35	1.5	72	3.0	1.700
June	16	0.4	56	1.4	2.856 *
July	8	0.3	59	1.6	4.385 *
August	0	0	21	1.4	4.032 *
Total	59	0.5	208	1.8	5.032 *
1980					
May	83	1.6	299	6.3	6.387 *
June	38	1.2	124	4.2	3.877 *
July	15	0.5	89	3.2	3.997 *
August	13	0.5	59	2.6	3.142 *
Total	149	1.1	571	4.5	8.644 *

* Significant at 95% confidence level

Table 22. Numbers of spot captured, CPUE, and t-values comparing altered and unaltered areas, May-August, 1977-1980.

	Altered areas		Unaltered areas		
	Number captured	CPUE	Number captured	CPUE	t-Value calculated
1977					
May	4,757	99.1	8,625	410.8	4.497 *
June	6,005	77.0	5,470	140.3	5.006 *
July	2,057	26.4	1,772	45.5	4.250 *
August	1,019	12.2	1,615	38.5	7.824 *
Total	13,838	48.1	17,482	124.0	5.841 *
1978					
May	1,216	25.4	11,481	239.2	13.046 *
June	529	11.5	3,870	84.2	9.692 *
July	127	8.0	357	22.4	5.426 *
August	75	3.8	305	15.3	6.144 *
Total	1,947	15.0	16,013	123.2	22.809 *
1979					
May	3,410	142.1	3,457	144.1	0.061
June	2,924	73.1	3,898	97.5	1.648
July	1,148	30.3	2,337	61.5	3.204 *
August	238	14.9	770	48.2	2.853 *
Total	7,720	65.5	10,462	88.7	2.276 *
1980					
May	1,808	34.8	7,200	150.0	6.920 *
June	877	27.4	1,573	52.5	4.804 *
July	414	13.0	891	31.9	4.665 *
August	231	8.3	786	34.2	8.480 *
Total	3,330	23.2	10,450	81.0	7.430 *

* Significant at 95% confidence level

Table 23. Numbers of Atlantic croaker captured, CPUE, and t-values comparing altered and unaltered areas, May-August, 1977-1980.

	Altered areas		Unaltered areas		
	Number captured	CPUE	Number captured	CPUE	t-Value calculated
1977					
May	31	0.7	5	0.3	1.060
June	39	0.5	18	0.5	0.191
July	39	0.5	4	0.1	2.928 *
August	8	0.1	3	0.1	0.405
Total	117	0.4	30	0.3	2.143 *
1978					
May	83	1.8	17	0.4	3.695 *
June	93	2.1	88	1.9	0.214
July	41	2.6	25	1.6	1.408
August	27	1.4	13	0.7	0.348
Total	244	1.9	143	1.1	3.000 *
1979					
May	351	14.7	1,174	49.0	5.263 *
June	450	11.3	1,154	28.9	5.212 *
July	162	4.3	548	14.5	6.758 *
August	60	3.0	116	7.3	2.304 *
Total	1,023	7.9	2,992	25.4	7.385 *
1980					
May	817	15.8	2,292	47.8	5.694 *
June	490	15.4	831	27.7	3.680 *
July	162	5.1	423	15.1	5.483 *
August	85	3.1	208	9.1	4.438 *
Total	1,554	10.8	3,754	29.1	11.932 *

* Significant at 95% confidence level

Table 24. Numbers of Atlantic menhaden captured, CPUE, and t-values comparing altered and unaltered areas, May-August, 1977-1980.

	Altered areas		Unaltered areas		
	Number captured	CPUE	Number captured	CPUE	t-Value calculated
1977					
May	1,060	22.1	1,203	57.3	1.075
June	243	3.2	369	9.5	1.735
July	60	0.8	649	16.7	3.420 *
August	11	0.2	220	5.3	5.345 *
Total	1,374	4.8	2,441	17.4	2.340 *
1978					
May	135	2.9	493	10.3	2.625 *
June	457	10.0	241	5.3	1.256
July	22	1.4	67	4.2	1.005
August	0	0	26	1.3	1.230
Total	614	4.8	827	6.4	0.916
1979					
May	168	7.0	495	20.7	1.514
June	62	1.6	1,403	30.5	2.980 *
July	14	0.4	474	12.5	2.703 *
August	2	0.2	100	5.0	1.484
Total	246	2.1	2,472	21.0	4.156 *
1980					
May	89	1.8	230	4.8	2.386 *
June	48	1.5	173	5.8	1.216
July	7	0.3	19	1.5	1.004
August	0	0	16	0.7	1.448
Total	144	1.0	438	3.4	2.522 *

* Significant at 95% confidence level

In 1978, CPUE values were higher during May-July for the unaltered sites, but significantly higher only in June, which was the month of peak recruitment. Shrimp production for the year was significantly higher in the unaltered sites.

During 1979, the CPUE in the unaltered areas was higher in May, June and August. Overall, however, altered and unaltered areas were similar in shrimp production. Landings data show that 1979 was a very poor year in Pamlico Sound (Table 1).

Sampling in 1980 indicated June to be the only month when significantly more shrimp were collected in the unaltered areas. Otherwise, monthly collections were similar in altered and natural areas. Overall, however, shrimp catches in the unaltered areas was significantly greater than in the altered areas.

Table 20 shows that, for the four years of the study, the natural areas were far more productive for blue crabs than the altered areas.

Southern flounder production was also higher in the unaltered areas as indicated in Table 21. Except for the months of August 1977, July and August 1978 and May 1979, the unaltered areas had significantly higher catches of this species.

Spot were also more abundant in the unaltered areas (Table 22). Productivity was higher for every month of the four year study period in the unaltered areas, although insignificantly so during May and June of 1979.

Croaker proved to rely on the altered areas in 1977 and 1978 and the unaltered areas in 1979 and 1980 (Table 23). Coastwide catches of juvenile Atlantic croaker were much lower in 1977 and 1978 than during 1979 and 1980 (Unpublished Division of Marine Fisheries data). A possible explanation is winter kill of the 1976 and 1977 year classes. Mild winters during 1978-79 and 1979-80 may have increased survival, producing larger year classes which better utilized available nursery areas.

Menhaden proved to be more abundant in the unaltered areas during the sampling periods of 1977, 1979, and 1980 (Table 24). The reason for the higher CPUE in the unaltered areas cannot readily be explained due to the fact

that large numbers of menhaden are often found in fresh water. A potential reason might be the distribution of food organisms upon which the menhaden were feeding.

The data presented in these tables points out the value of a primary nursery area in its natural state versus one which has been altered. Based on this study we believe the reason for the greater productivity of the unaltered sites is related to its more favorable patterns of salinity (stable or gradually increasing on a seasonable basis) which not only benefit the species mentioned but the organisms on which these commercially important species depend as food sources.

During the course of this project, no attempts were made to relate food abundance and catch data between the altered and unaltered areas. However, in 1979, personnel from North Carolina State University (NCSU) under the direction of Dr. John Miller, began a research project to determine what food sources were utilized by juvenile spot and croaker within Rose Bay. At the time this report was written, all data which had been gathered by North Carolina State University were not available, but enough was furnished to show a correlation between the high numbers of spot and croakers in the unaltered areas in relation to available food supplies. The studies showed that a large part of the diet of juvenile spot and croaker consisted of siphons from two species of bivalves, *Macoma balthica* and *Macoma phenax* (Benjamin M. Currin, pers. comm. NCSU). The proportion of spot and croaker utilizing these siphons increased directly with the growth rate of both the spot and croaker. Data presented in Tables 25 and 26 show the increased occurrence of this food source in relation to the growth of these finfish.

In the NCSU studies, not only were stomach contents examined, but benthic samples were also taken at different sites within Rose Bay. Two of these sites coincided with the two sites sampled during this project, RB-1 and RB-2.

Two samples were collected monthly at each site during February - September 1979 with the exception of two samples taken in March and none in July (Table 27). Samples were collected with a Ponar grab sampler which measured 6 in (15.24 cm) square. The number of bivalves collected in each

Table 25. Number of spot stomachs examined during the 1979 sampling season in Rose Bay and the percent occurrence of bivalve siphons in relation to size (Benjamin M. Currin, Pers. comm. NCSU).

Standard length (mm)	Number of spot stomachs examined	Percent occurrence of bivalve siphons
10-14	38	5.26
15-19	218	30.73
20-24	143	48.25
25-29	87	58.62
30-34	108	62.04
35-39	75	65.33
40-44	104	66.35
45-49	79	82.28
50-54	68	75.00
55-59	40	82.50
60-64	17	70.59
65-69	18	94.44
70	31	80.65

Table 26. Number of Atlantic croaker stomachs examined during the 1979 sampling season in Rose Bay and the percent occurrence of bivalve siphons in relation to growth (Benjamin M. Currin, pers. comm. NCSU).

Standard length (mm)	Number of croaker stomachs examined	Percent occurrence of bivalve siphons
10-14	35	2.86
15-19	76	11.84
20-24	92	16.30
25-29	97	38.14
30-34	58	63.79
35-39	37	65.57
40-44	42	83.33
45-49	65	83.08
50-54	57	84.21
55-59	42	88.10
60-64	37	86.49
65-69	32	90.63
70	53	90.57

Table 27. Number of bivalves per square meter collected at Tooley Creek and Rose Bay Creek during 1979 sampling period (Benjamin M. Currin, pers. comm. NCSU).

1979	Tooley Creek (RB-2)	Rose Bay Creek (RB-1)
Feb 15	1,162	0
	0	0
Mar 1	0	387
	0	86
Mar 15	775	172
	4,090	172
Apr 12	1,808	43
	1,808	344
May 17	1,076	474
	1,162	215
Jun 14	258	0
	129	0
Aug 15	172	43
	560	0
Sep 12	1,378	0
	646	0
Total	15,024	1,936

sample was counted, and a conversion factor of 4.036 was applied to each grab sample to provide estimates of the number of bivalves per square meter. Samples taken at station RB-1 yielded a total of 1,936 bivalves, while station RB-2 produced a total of 15,024. The two species of bivalves, *M. balthica* and *M. phenax,* exhibit specific salinity preferences. *Macoma balthica* is found in the mesohaline zone of the estuary, which ranges from 5 to 18 ppt in salinity, while *M. phenax*, mainly occupies the polyhaline zones where salinities are over 18 ppt (Tenore 1970). Due to the low and fluctuating salinity exhibited by Rose Bay Creek during the study period, it is apparent that the differences in populations of the two species of *Macoma* between the two areas probably affected the populations of commercially important species within this study area.

The importance of the habitat of unaltered areas in comparison with altered areas in terms of relative productivity of commercially important species is apparent from the foregoing discussion. Other species of finfish which are important to the State's commercial and recreational fisheries were also captured during the study period, but in insufficient numbers to make valid comparisons between the two types of systems studied. Among these were weakfish (*Cynoscion regalis*) and spotted sea trout (*Cynoscion nebulosus*). The majority of these two species occurred in 1977 when salinities were at their highest. Two other species which are of commercial importance but are more characteristic of freshwater environments were also captured, alewife (*Alosa pseudoharengus*) and white perch (*Morone americana*). These species were captured at all stations in 1978 when rainfall was high and salinities depressed. White perch were again captured in 1980, but were restricted to station RB-1.

CONCLUSIONS

1. Drainage of surface water from upland areas into primary estuarine nursery areas through manmade ditches and canals creates unstable salinity conditions in the nursery areas. The unaltered nursery areas showed much more stable salinity patterns. Following heavy rainfall, altered areas experienced wide fluctuations in salinity while the unaltered systems remained quite stable.
2. Extensive drainage into a single nursery area reduces its value as nursery habitat by reducing average salinities and making it more

sensitive to the effects of rainfall within the drainage basin.

3. Relative productivity of economically important estuarine organisms was lower each year in nursery areas receiving extensive drainage compared to natural areas.
4. The data did not show any mass or complete movements of juvenile shrimp from the nursery areas as a response to rapid changes in salinity. The most serious effects of drainage into nursery areas appear to be the degree of alteration and that alterations will be severe enough to create an unsuitable habitat even during periods of low or normal rainfall.
5. Salinity alterations appear to affect food organisms important in the production of economically important species.

RECOMMENDATIONS

The value of the seafood industry in North Carolina is increasing every year as reflected in the consumer demand for high quality seafood and the value of the industry itself. Changes in land usage surrounding the primary areas are inevitable given the current trends in the rising value of agricultural and silvicultural development; however, attempts should be made to minimize the impacts where this development lies adjacent to these fragile areas.

Due to the large expanse of area in question and pressures on the habitat there is no simple way to approach the needs for drainage as well as maintenance of the estuarine system. In an attempt to deal with these apparently competing needs, local, state and federal agencies should combine their efforts to adopt drainage programs which would be beneficial to the marine resources by correcting present drainage patterns. In order to prevent any further damage to the primary nursery areas, there are two measures which should be implemented:

1. Rerouting existing drainage through the use of diversion canals to a point in the estuary where the least possible damage would occur.
2. Redirecting existing drainage canals to the inland fringes of wooded swamps and marshes, thus allowing runoff to slowly filter through surface vegetation before entering the primary nursery areas.

Should measures of this nature be taken, strict controls should be put on existing activities which would take place while rediversion efforts are being implemented:

1. Controls on additional drainage systems which would possibly discharge into fragile areas of the estuary.
2. Allowing the maintenance of existing ditches and canals to take place only during periods of the least biological activity.

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