EVALUATION OF PRE-RESTORATION CONDITIONS INCLUDING IMPACTS FROM TIDAL RESTRICTION IN LITTLE RIVER MARSH, NEW HAMPSHIRE

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EXECUTIVE SUMMARY

Improved tidal exchange was planned and successfully implemented for Little River Marsh, which extends across the town boundaries of Hampton and North Hampton. The project was stimulated by concern over ecological impacts to coastal wetlands, fisheries and wildlife from inadequate tidal exchange to the marsh, as well as problems with local flooding of roads and homes. A cooperative program to develop a base map and baseline data was coordinated by the Office of State Planning to assess impacts to the marsh. A broad suite of data has been collected prior to tidal restoration of the Little River Marsh. The information is critical for future assessment of management activities at Little River Marsh, as marsh sediments, plants and animals respond to the beneficial changes brought about as greater tides pass through the improved culvert.

INTRODUCTION

Since the early 1990s, tidal restrictions from roads, railways and earthen berms have been recognized to cause severe impacts to the ecological structure and functioning of salt marshes. For example, tidal restrictions have led to the proliferation of invasive plants such as *Phragmites australis* (common reed), and insect pests such as mosquitoes (Roman et al. 1984, Burdick et al. 1994, Morgan et al. 1998).

Little River Marsh is a back barrier marsh, approximately 200 acres in extent, which includes the Towns of Hampton and North Hampton. The marsh has a long history of problems associated with its inlet to the Gulf of Maine (Ammann et al. 1999). Little River Marsh has been effectively cut off from normal tidal flow by Route 1A. Over the past three decades, all tidal flow passed through a round, 48 inch (1.2 m) culvert running under Route 1A at the northern end of the marsh (Figure 1). Inadequate size of the culvert was blamed on flooding during snowmelt in spring and extreme rainfalls that flooded basements and some first floors of homes surrounding the basin. Further development has resulted in two causeways built across southern portions of the marsh to access residential homes on islands within the marsh: Appledore Road and Huckleberry Road. The site was categorized as impacted by tidal restrictions in a recent survey of coastal marshes (USDA 1994). Personnel from several agencies agree that the system has been negatively impacted from tidal restriction and is currently degraded (New Hampshire Coastal Program, US Fish & Wildlife Service, Natural Resource Conservation Service, US Army Corps of Engineers).

The Coastal Program and the Town of North Hampton, aided by state and federal officials and in cooperation with local landowners, proposed to replace the existing culvert with two larger culverts. Two 6 by 12 foot culverts would lie side-by-side to would reduce spring flooding and restore greater tidal flow to this impacted marsh. The new set of box culverts was installed at the site in November 2000. In addition, the artificial creek serving the inlet was widened to 24 feet, where needed, to match the width of the new culverts. The section of creek proximal to the culvert was also deepened and a low dam was found and strengthened to retain water in the main creek to enhance fish habitat. Further, several deeper pools were excavated along main tidal creeks to provide low tide refugia for fish. Other activities were also performed to enhance marsh function. A side creek was plugged to ensure water flow along the main creek and secondary creeks (ditches) draining large pannes on the eastern flank of the marsh were plugged. The previous year, a large box culvert replaced the small culvert under Appledore Road. With the improved tidal flow under Route 1A, the larger culvert under Appledore Road was ready to allow additional flow to the southern reaches of the Little River Marsh.

Figure 1. Old and new culverts: upper left shows outlet (Gulf of Maine side) of the original 48 inch culvert; pictured at lower right is the marsh side of the new culvert (two side-by-side 6 by 12 foot culverts).

In order to assess impacts to the marsh, and especially benefits from restoration, a cooperative program to develop a base map and perform data collections was coordinated by the New Hampshire Coastal Program (NHCP) of the Office of State Planning. Data were collected by staff from NHCP, University of New Hampshire (UNH), and the Audubon Society of New Hampshire (ASNH). Recently, marsh structural and functional indices have been developed to quantify critical changes in marshes specifically associated with the impacts from tidal restriction and the restoration of tidal exchange. Preliminary results from a meeting to develop regional methods and standards for monitoring marsh restoration projects were used to develop a monitoring plan for the Little River Marsh (Neckles and Dionne 2000). This report, pre-restoration conditions at Little River Marsh, is an assessment including several different types of data collection using the protocols where possible. These methods will continue to improve as they are used and tested more widely. It is hoped that such monitoring programs will provide the data for site as well as programmatic evaluation of the efforts to improve marsh health through the removal of tidal restrictions in the Gulf of Maine.

A monitoring program that will provide most of the data necessary to evaluate the site was set up to cooperatively perform several different types of data collection. All of the data collection efforts were assisted by Ted Diers (NHCP). UNH collections directed by the author were assisted by undergraduate students: Katey Cullen, Arin Daggett, Jess Alexander, and by graduate students: Ray Konisky, Cathy Bozek and Alyson Eberhardt. Collection efforts are described, the data are presented in the appendices, and the results are described and interpreted herein.

- **Base Map Development** was directed by Ted Diers (NHCP).
- **Tidal Signal** was measured by UNH.
- **Soil Measurements**, including salinity and bulk properties, were collected by personnel and students of UNH and NHCP.
- **Vegetation Surveys** using transects and plots were performed by Ted Diers and intern Suzanne Greene (NHCP).
- **Fish Surveys** were performed by UNH, aided by students in field courses.
- **Bird Surveys** were conducted by the ASNH, aided by volunteers.

The data will increase in value over time. They will be available to assess the management program for Little River Marsh in the future, as marsh sediments, plants, and animals respond to the beneficial changes brought about as greater tides pass through the improved culvert. The data will also be available to assess habitat restoration in the region that will be conducted as part of an international program to promote and improve restoration of tidal marshes in the Gulf of Maine (Neckles and Dionne 2000).

METHODS

Base Map. The base map is a Geographic Information System (GIS) and was constructed with Arc Info using data digitized from orthoquad maps. Wetland areas were delineated and supplied by Verra and Associates and sampling stations and vegetation areas were applied using Geographic Positioning System (GPS) data.

Hydrologic Conditions. Measurements of water levels were conducted in October and November 2000 using two automatic tide gauges to quantify the impact of the tidal restriction on the tide range. On October 6, automatic tide gauges were installed at the dogleg of the main creek serving the culvert under Route 1A (Figure 2), and in the creek immediately downstream of Appledore Road; recording data until October 20. On October 26, data were downloaded from both gauges and the gauge at Appledore Road was removed and placed near the main creek in Awcomin Marsh, an unrestricted back barrier marsh serving as a reference site. This second set of water level data was collected until November 19, 2000. Water level gauges and recorders were produced by Infinities USA, Inc. and were mounted on iron derricks. The gauge operates by measuring the time lag between emission and reception of an ultrasonic signal as it travels through a PVC pipe, which also serves as a stilling well. Rainfall data for Portsmouth used to interpret the water levels was obtained from the National Weather Service (http://tgsv5.nws.noaa.gov/er/box/clstns.htm).

Soil Conditions. Salinity is a critical indicator of tidal restrictions that impede salt water flow into marshes as well as fresh water flow exiting marshes. In addition, soil salinity is an important stress (equal to flooding) that structures the plant community of coastal marshes. The interstitial water of the sediment was collected from wells and salinity was measured using a hand-held optical refractometer (+/- 1 ppt with temperature correction). The wells were made from PVC pipe with a series of holes (3 mm in diameter), extending from 5 to 20 cm (2 to 8 inches) deep in the marsh sediment. The wells were sealed at the base and covered at the top to prevent water from entering.

Wells were installed at eight stations in Little River Marsh and five stations at the reference marsh (Awcomin Marsh). The well pattern at Awcomin Marsh followed the standard protocol (Burdick 2000), but pattern at Little River Marsh was modified. The change was needed to accommodate the southern portion of the Little River at it flowed under Appledore and Huckleberry Roads toward the original tidal inlet that is now sealed (Ammann et al. 1999).

Salinity samples were collected on fourteen occasions prior to restoration, from August 1999 to September 2000. During this period samples were taken twice at Awcomin Marsh. This report also presents salinity collected on four occasions following the installation of the new culverts from May to June 2001. Sampling included both the spring and neap lunar tide periods. The salinity of the surface waters was collected irregularly at several locations in the study area.

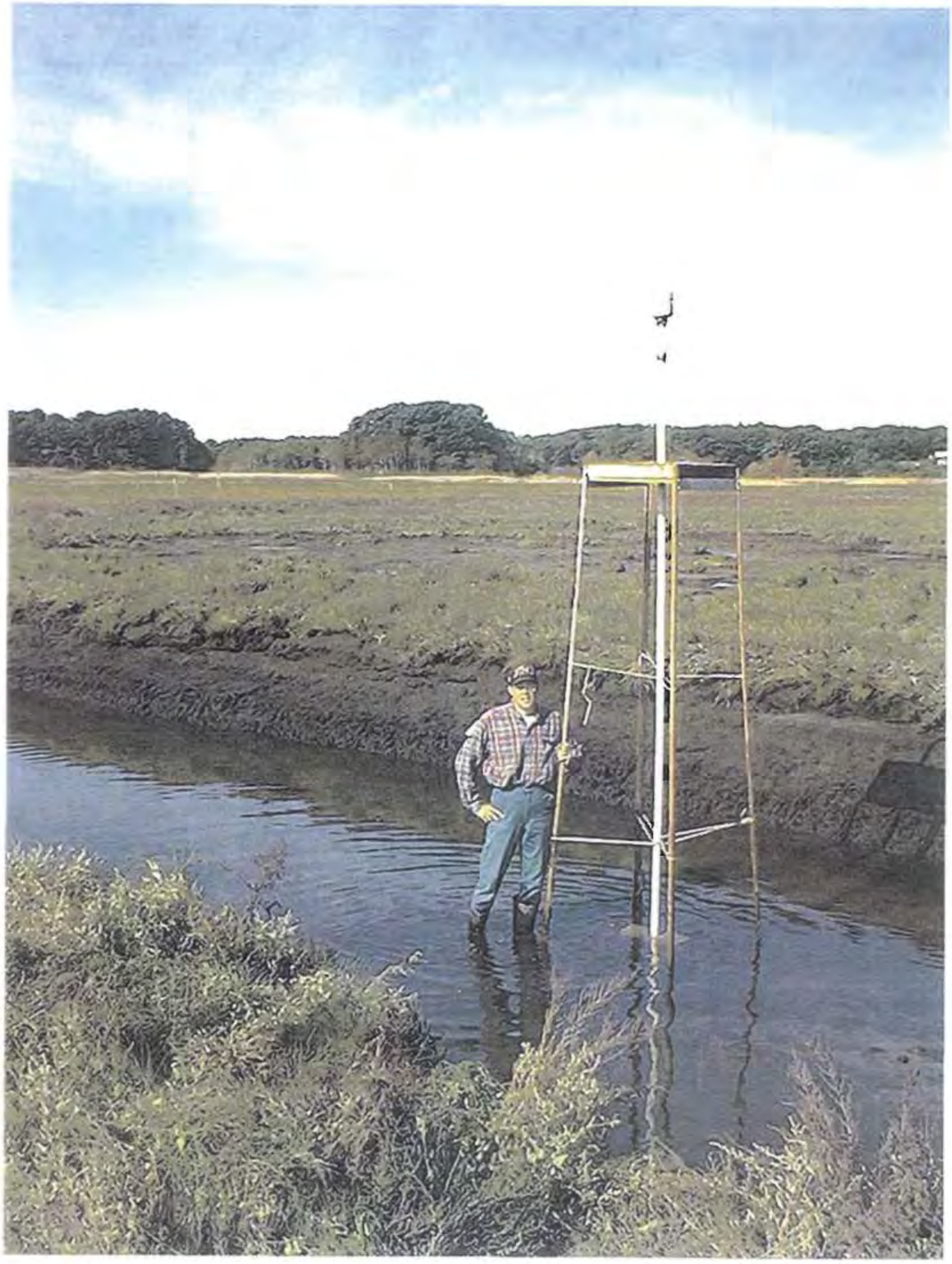


Figure 2. Tidal gauge set on stilling pipe and supported by derrick in the dogleg of the main tidal creek, fall 2001. (Ray Konisky is pictured).

Soil characteristics were measured on cores collected on one date at all eight permanent stations in the Little River Marsh. Each core, 3.6 cm (1.43 inches) in diameter and 20 cm (8 inches) in depth, was divided into four segments (5 cm in length), and the segments were placed in plastic bags until return to the lab. At the lab, the samples were refrigerated at 4° C and analyzed within one week. Samples were weighed fresh, dried and weighed again, then combusted at 450° C for four hours before weighing to gravimetrically determine bulk density, moisture, and organic matter, respectively (Burdick 2000).

Vegetation. Emergent plant communities in the marsh were assessed using on the ground photography, permanent stations, and stations along permanent transects. In addition, beds of widgeon grass, *Ruppia maritima*, were found in pools and creeks south of Appledore Road. These plants indicate the presence of a special sub-tidal habitat, submerged aquatic vegetation (SAV), known to be important for fish and wildlife. Therefore, a specific sampling plan was developed to assess this vegetation type. Ground level photography of the marsh was taken with a Minolta™ model #7000 digital camera. Vantage points were chosen and photos were taken along several orientations to establish the general conditions over the entire site.

The vegetation survey recorded percentage cover of each plant species encountered on several transects established perpendicular to the axis of the main tidal creek. Vegetation was assessed in quadrats (0.25 m^2 area) placed every 15 m (50 feet). The stem density and height of common reed (*Phragmites australis)* purple loosestrife (*Lythrum salicaria*), and cattail (*Typha spp.*) were measured, where present. These metrics were applied to species of concern, since height and stem density are potential indicators of stress to invasive weeds (Diers 2000). Additional stations were established in colonies of invasive plants to examine the effects of greater tides on species of concern. Twelve stands of *Lythrum salicaria* and 20 stands of *Phragmites australis* were characterized using 5 plots, 0.25 m^2 in size, for cover, shoot density, and plant height (three tallest individuals; Diers 2000).

Ruppia maritima, a submerged aquatic seagrass known regionally as widgeon grass, was assessed in August 1999 in large sub-tidal pools and creeks south of Appledore Road. In each of nine pools and creeks containing SAV, a 0.25 m^2 quadrat was tossed in a haphazard fashion and percentage cover, number of shoots and the three tallest shoot lengths were measured at three locations (plots). Salinity and water depth were also measured at each plot.

Nekton. Fish were sampled prior to hydrologic restoration in 1999 using minnow traps and seines and again in 2000 using minnow traps and throw traps. Minnow traps were deployed for 90 minutes in pannes and creeks. The seine used was 3.7 m (12 feet) wide with 6 mm (0.25 inch) mesh. Seining was done in a moderate sized creek with hard bottom near the Route 1A culvert, and distance fished was recorded. The throw trap was square and 1 m (3.3 feet) on a side with 3 mm (0.125 inch) mesh according to Kushlan (1981). Large aquarium nets were used to collect captured fish and all fish were considered taken following 10 consecutive empty sweeps. Once collected, all fish were held in buckets until identified to species and measured. The first 30 fish of the same species captured within each sample were measured (Dionne 2000), for length (fish board) and volume (by displacement using a graduate cylinder). Shrimp were enumerated but not measured and crabs were measured for carapace width. All animals were returned to the site of capture within about 30 minutes.

Avifauna. Birds were sampled by ASNH using standardized Breeding Bird Survey point counts on the marsh. Four survey points were established, and 10 minute counts were made, including detection method (vocalization, sighting), distance from point and time of observation within the 10-minute period. Observations were made using 10 X 50 power binoculars at least once monthly. Sampling began in April 2000 and continued through May 2001, with 11 survey dates prior and 11 dates following tidal restoration. Results focus on species occurrence and relative abundance.

RESULTS

Base Map. The base map is shown in Figure 3. It includes the upland areas surrounding the marsh, the major plant associations, with a focus on species of concern, as well as salinity and soil stations. The eastern portion of the marsh divided by the artificial tidal creek is primarily typical salt marsh, composed of short meadow grasses dominated by salt hay. Most of the system is to the west and south of the artificial creek and drains into the Little River. These areas have been invaded by stands of common reed and purple loosestrife. The reference site is Awcomin Marsh (portions unimpacted by dredge disposal activities), located behind Rye Harbor, several miles north of Little River. Awcomin Marsh is shown in Figure 4, with salinity stations marked.

Hydrology. The water level gauges were set up near the ocean inlet on the dogleg of the main creek and just downstream of the crossing at Appledore Road. A selection of data from the automated gauges (60 out of over 2,500 observations) is shown as an example, in Appendix 1. The data record covers both neap and spring tide periods (Figure 5). Water levels in the main tidal creek can vary from as little as 8 inches (20 cm) during neap tides, to as much as 26 inches (66 cm) during a typical spring tide (predicted tidal amplitude for the New Hampshire coast was 128 inches on October 15). The record is similar but muted at Appledore Road, with most neap tides producing no signal whatsoever in the tidal creek and spring tides resulting in about 10 inch (25 cm) differences in water levels. Near the end of the record, spring tides were diminishing, but rainfall led to water levels at high tide similar to spring tides and water levels at low tide 8 to 15 inches greater than normal. Daily precipitation data for Portsmouth is presented in tabular form in Appendix 2 and graphically in Figure 6. Even a rainfall of less than 0.5 inches as occurred on October 16 appears to increase water levels at low tide. The tidal records indicate that the restriction at Route 1A severely impedes drainage from the system, especially during rainfall events.

Water levels during the next two spring tide periods and one neap tide period were measured near the inlet of the main tidal creeks in both Little River Marsh and Awcomin Marsh. These data are presented in Figure 7, and indicate that all tides at Little River were restricted by the undersized culvert that ran under Route 1A. By comparing the two data sets (Little River vs. Awcomin), tidal restriction was evident during both spring and neap periods.

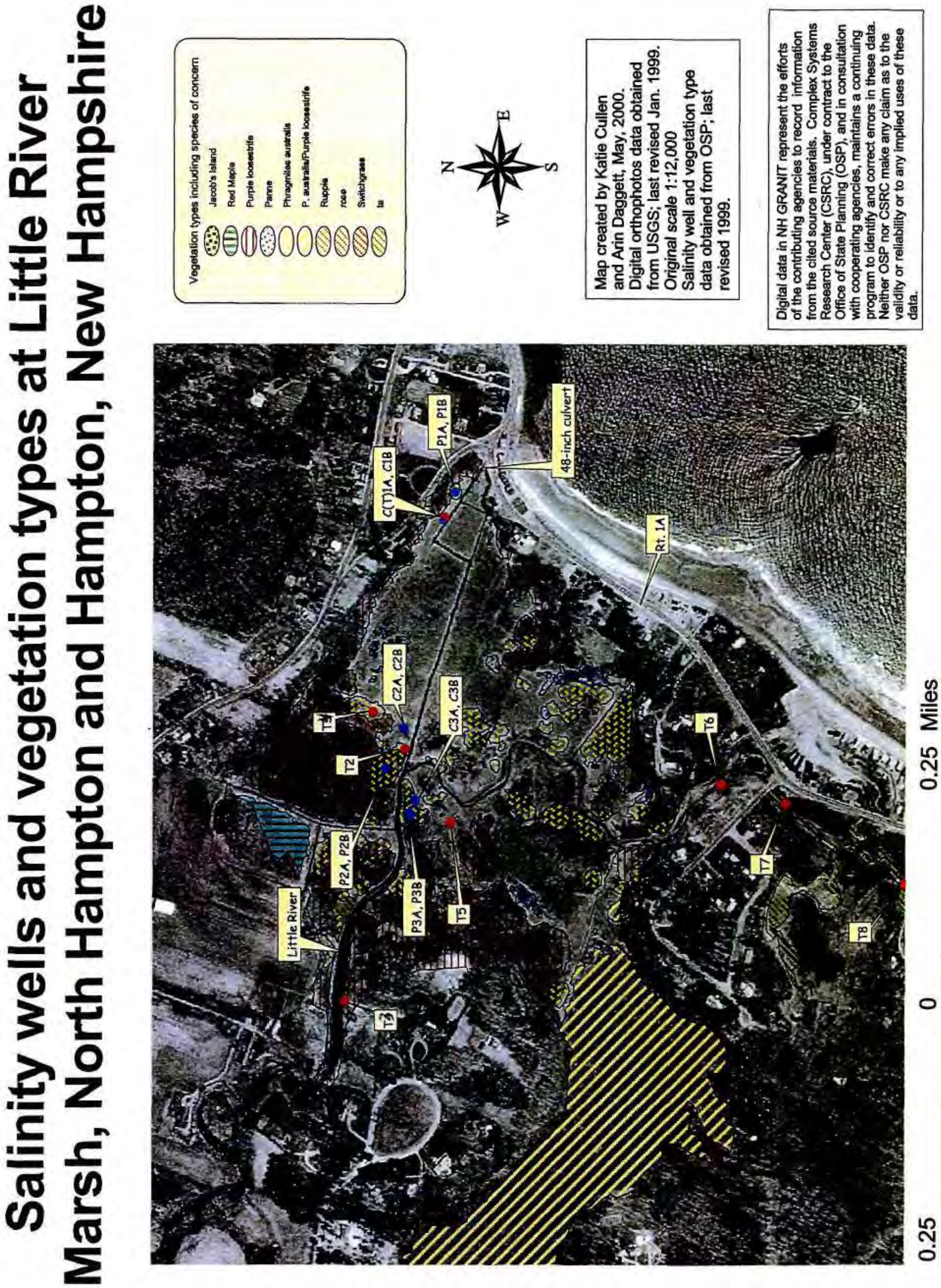


Figure 3. Soil water salinity stations and major invasive plant communities mapped for Little River Marsh.

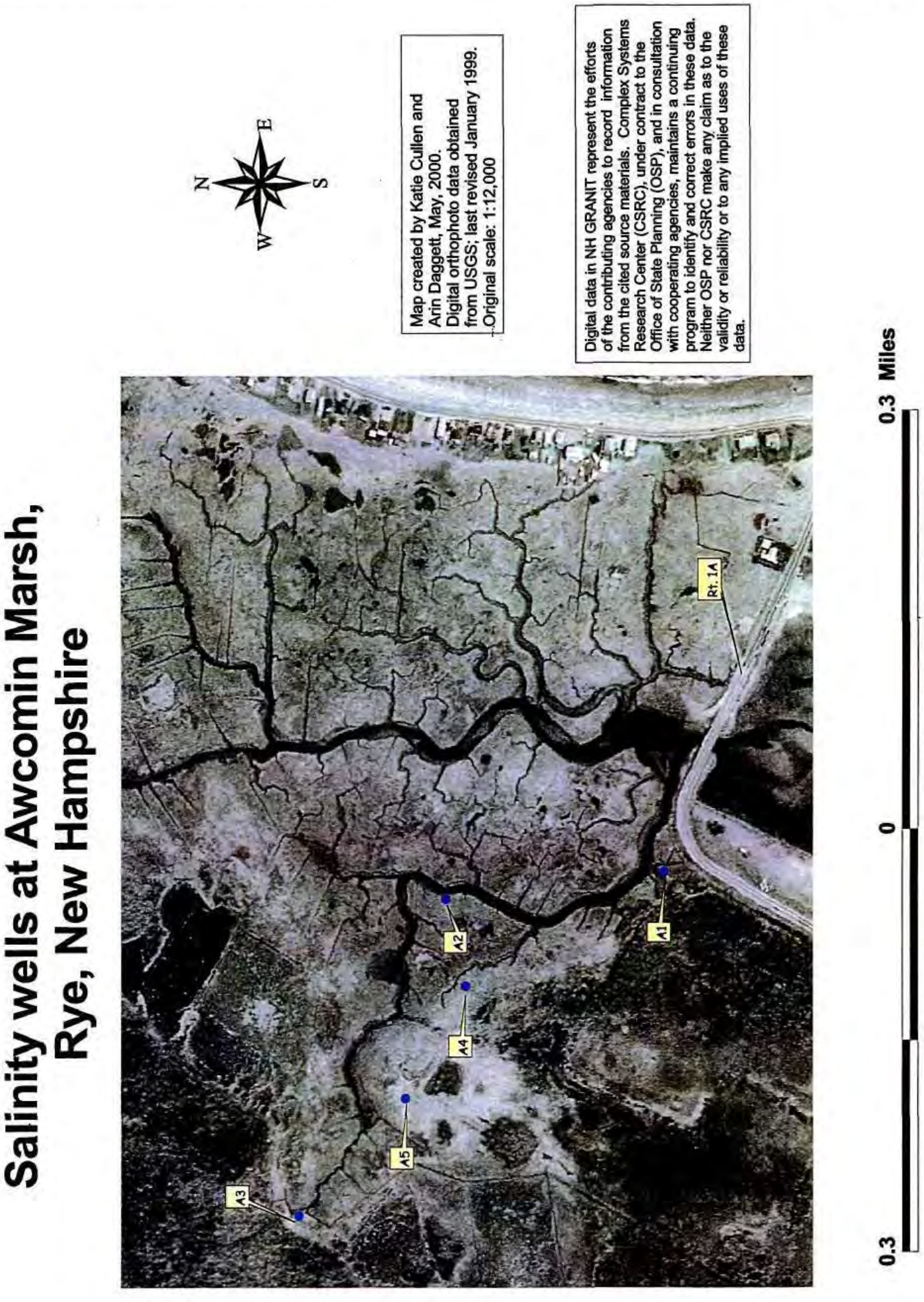
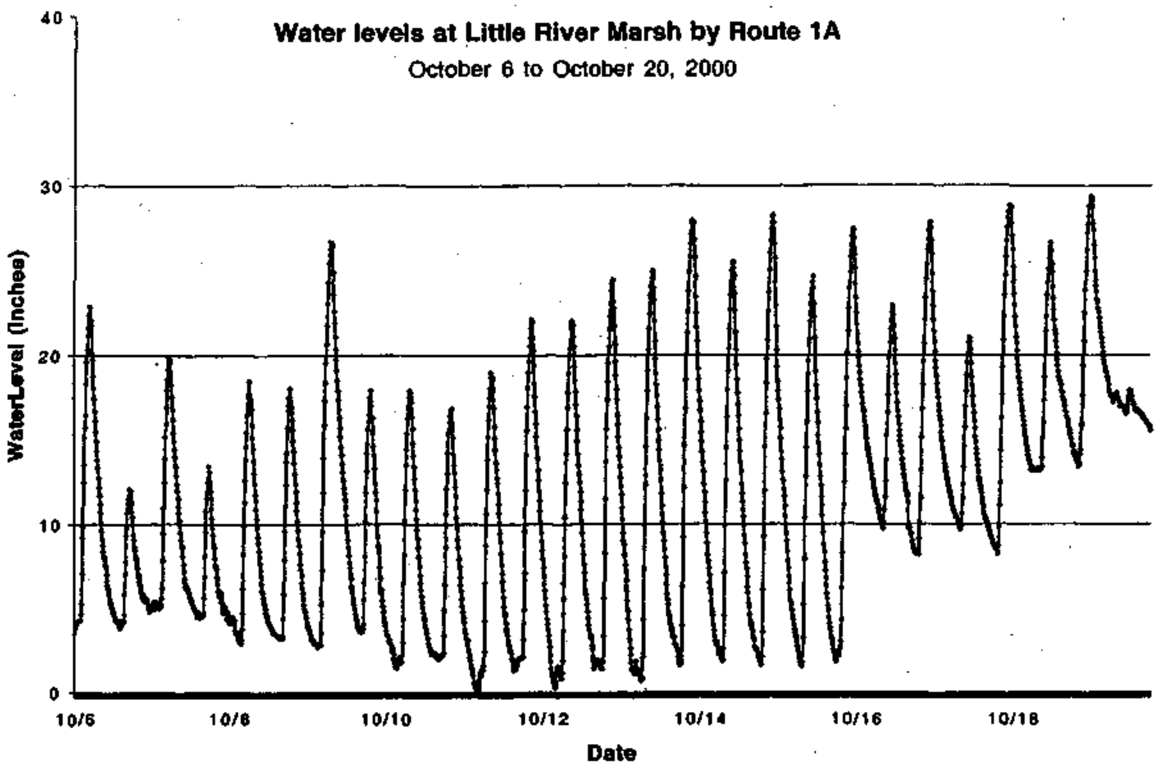


Figure 4. Soil water salinity stations mapped for Awcomin Marsh.



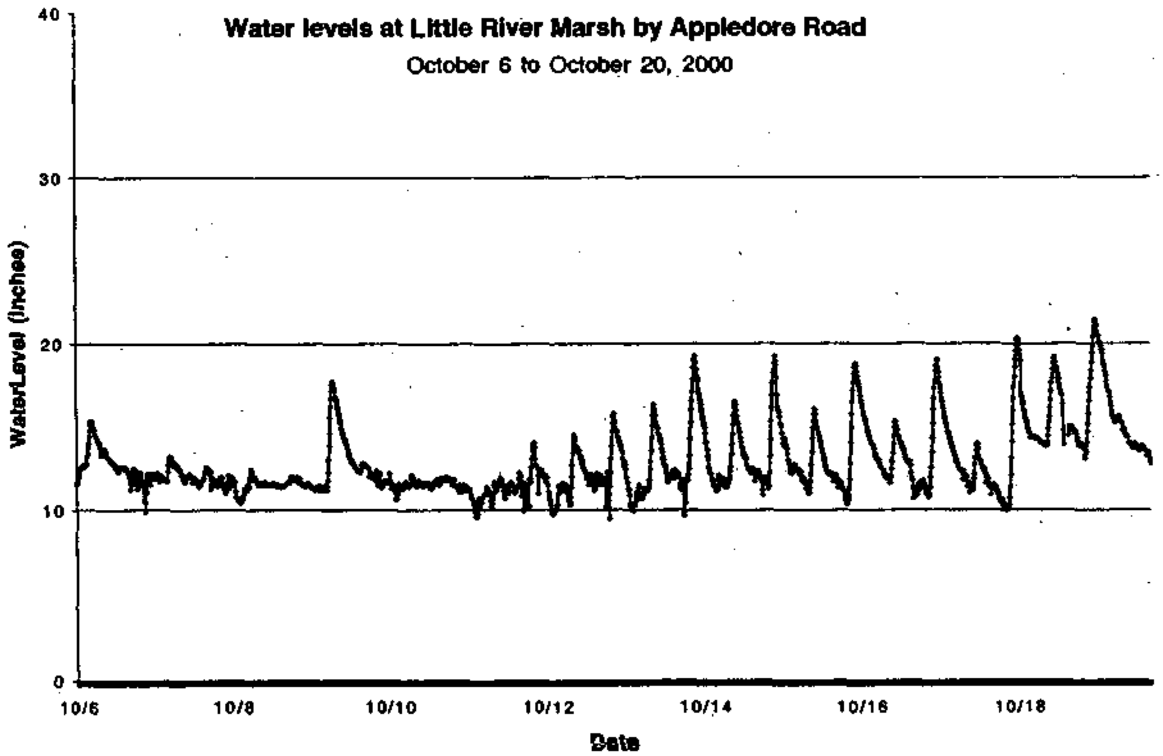
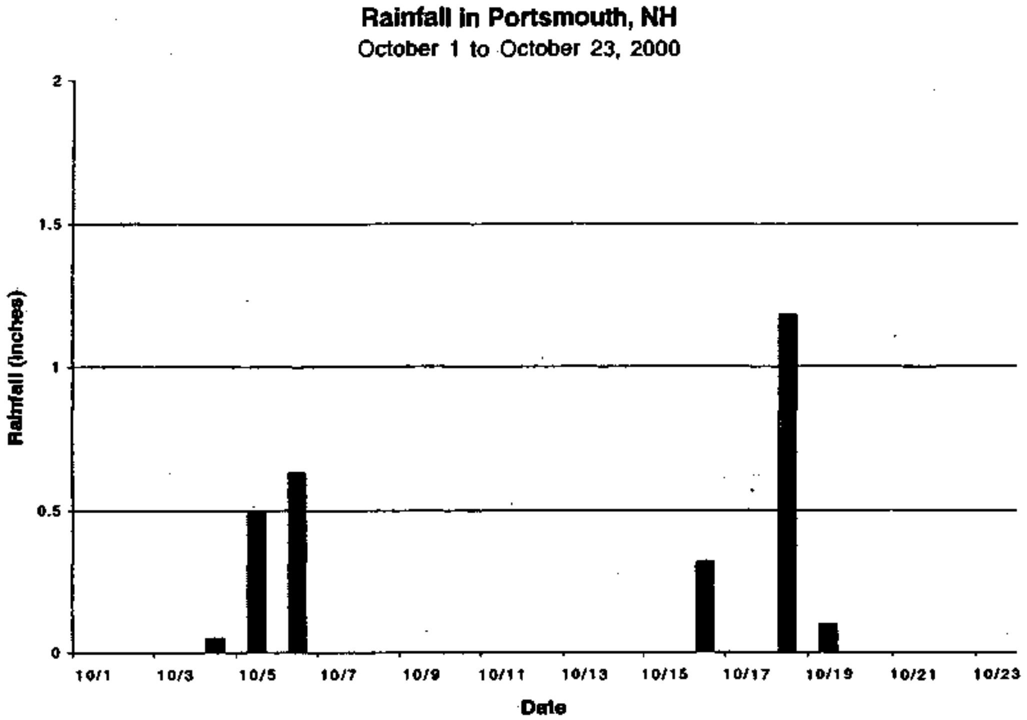


Figure 5. Hydrologic records at the dogleg by the Route 1A culvert and the creek north of Appledore Road from October 6 to October 20, 2000.



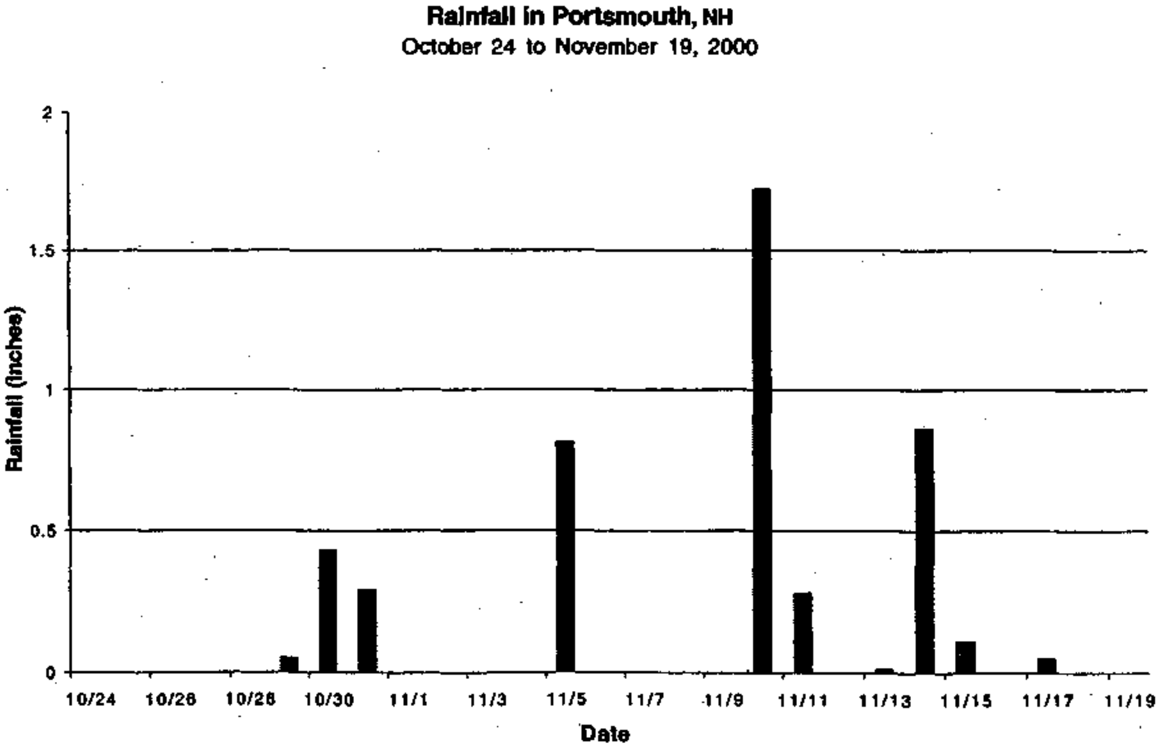


Figure 6. Daily precipitation data for Portsmouth, NH obtained from the National Weather Service.

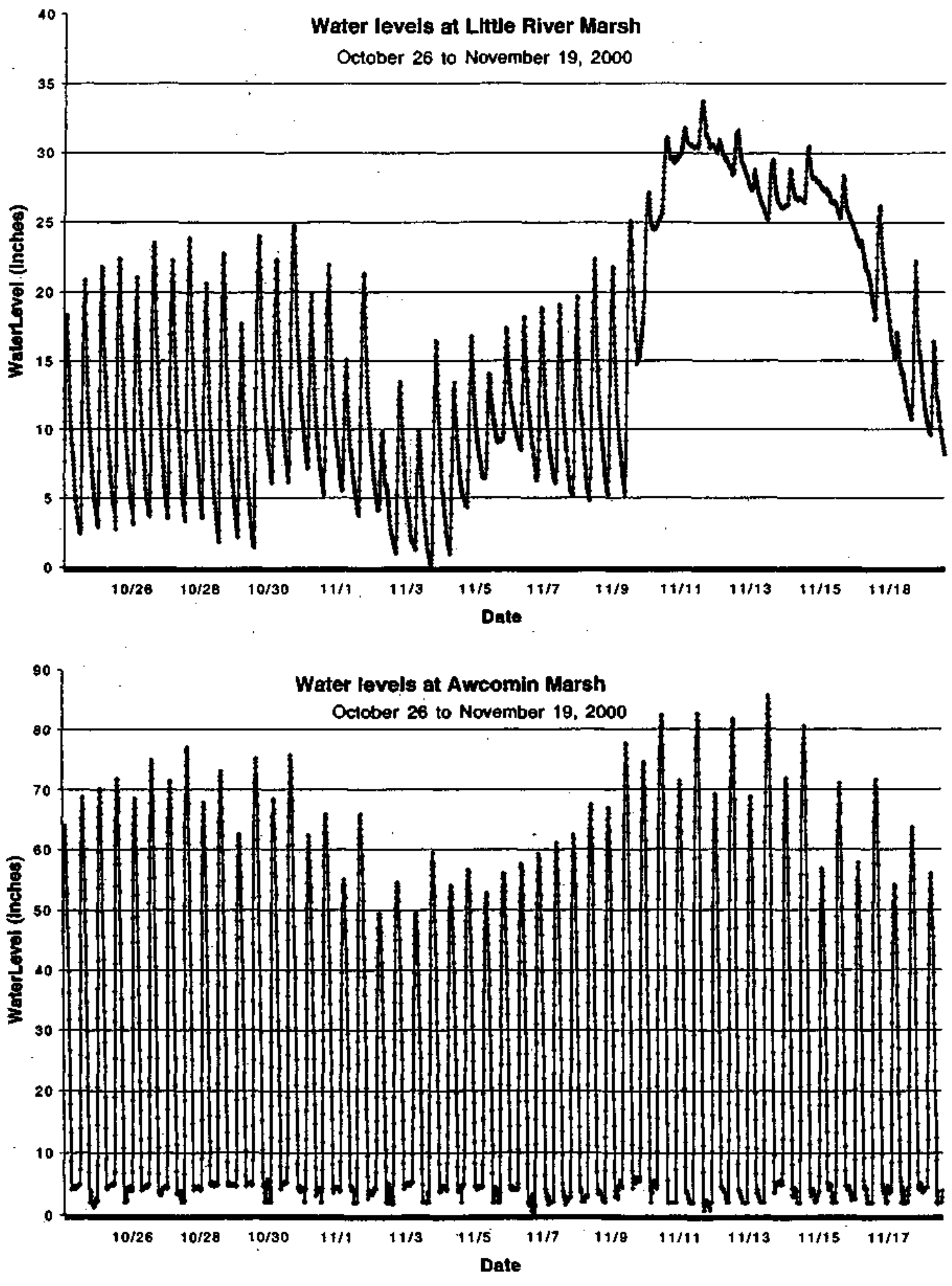


Figure 7. Hydrologic records at the dogleg by the Route 1A culvert and the creek at the Awcomin Marsh reference site from October 26 to November 19, 2000.

The first spring tide range was about 75 inches (190 cm) and neap tides were about 50 inches (125 cm) at Awcomin Marsh compared to 22 inches and 10 inches for these periods at Little River Marsh. The tidal amplitude in Little River was only 1/3 of that observed at Awcomin Marsh, indicating the original culvert was restricting flow. Direct calculations of reductions in tidal amplitudes due to the tidal restriction at the Little River inlet are not particularly useful because these are different salt marsh systems separated by several miles of coastline. More importantly, the bottom of the artificial creek at Little River is higher in elevation than the creek at Awcomin Marsh.

Another way to examine the degree of restriction is by comparing the difference in peak tide height from spring to neap tide. The difference in high tide was 15 inches at Little River, but 26 inches at Awcomin Marsh. In one assumes the neap tides were the same at both locations (the tide where the least volume of water passed through both inlets), the higher spring tides at Little River were reduced by 11 inches.

Interestingly, the Little River Marsh can flood as much as Awcomin at certain times, and this information is captured at the end of the tidal record following a 2 inch rainfall (November 10-11, Figure 7). The watershed that drains into the Little River Marsh is small, only 6.5 square miles in area (US Army Corps of Engineers 1999), so there is little time delay between the end of the rain and the peak runoff into the marsh. This portion of the record shows two important lines of evidence needed to inform management. First, the culvert was too small to allow drainage of rainfall and is likely the direct cause of the severe flooding that impacts homeowners surrounding the marsh. Both managers and the public had already made this inference (US Army Corps of Engineers 1999), but it is instructive to see the data that support the idea. Secondly, the rainfall event occurred during a set of spring tides and the tide levels outside the culvert were still high enough to drive more water into the marsh around the high tide. The differences in spring tide ranges in Figure 6 suggest an inlet without constriction would produce tidal amplitudes of at least 35 inches during spring tides at Little River Marsh. This is even greater than the level of hydrologic restoration proposed for the site (two 6 by 12 foot culverts), which would increase tidal amplitude to about 30 inches during normal spring tides according to the UNET model (US Army Corps of Engineers 1999).

Salinity. Salinity was measured in the interstitial soil water collected from shallow wells at 8 stations at Little River (Figure 3) and 5 stations at Awcomin Marsh (Figure 4). Well water salinities were collected at Little River 14 times prior to restoration and 4 times following restoration and these data are presented in Figure 8. Salinity varied from 2 to 35 ppt and was generally lower in spring and fall and highest in late summer. Soil salinity was higher at creek bank at the center of the marsh (Station 2) and was lower up toward the fresh water source (Station 3) and lower at the stations along the southern arm of the creek (Stations 6-8). Well and surface water salinity data are presented in Appendix 3.

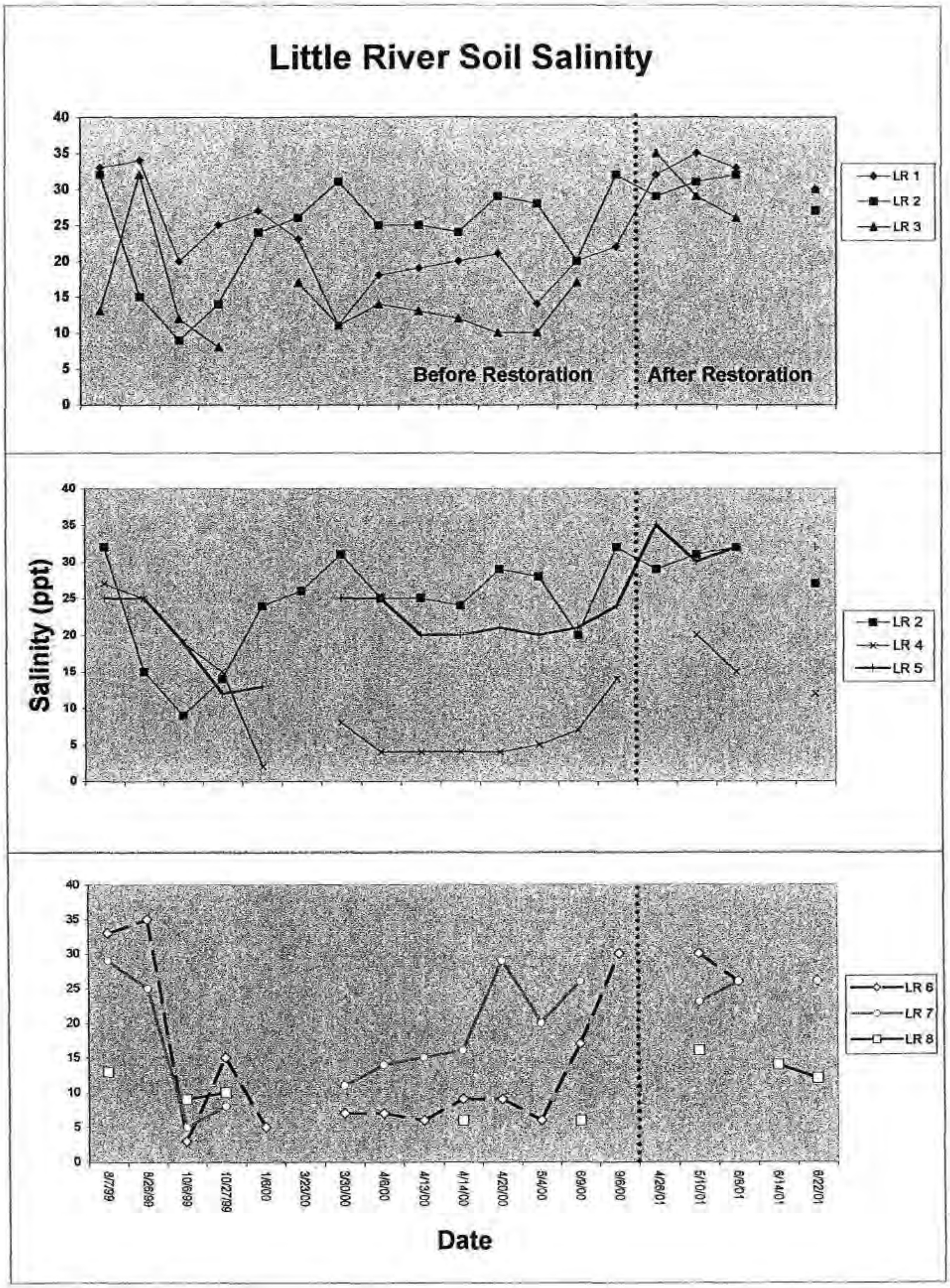


Figure 8. Soil water salinity from wells at Stations 1 through 8 collected on 14 dates at Little River Marsh.

Salinity was collected twice at both Little River and Awcomin Marsh and the five equivalent stations are compared in Figure 9. In general, reference wells (Awcomin Marsh) had saltier water than wells in the tidally restricted marsh at Little River ($P<0.05$). Data from the reference marsh showed the same trends as in Little River, with Station 3 being the freshest, Stations 1 and 2 being the saltiest, and Stations 4 and 5 intermediate (Figure 9).

Soil Physical Characteristics. Shallow soil cores (20 cm) collected at each of the 8 stations showed that sediments varied greatly depending on location and depth. Sediment bulk properties are presented for each station and depth in Appendix 4. The percentage of moisture and organic matter in the soils varied together ($r^2 = 0.900$) and inversely with bulk density ($r^2 = -0.953$), so only organic matter will be examined in detail. The organic matter at Station 1 was relatively high for an inlet (Figure 10), indicating the artificial nature of the opening. Stations 2, 4 and 5 were all similar, except organic matter did not increase with depth at Station 5 as it did with the other stations.

Stations 3 and 6 were located along the creek banks downstream of a dam (Station 3) and a very severe tidal restriction (Station 6). The soil at these two locations had the greatest organic matter (Figure 10). Further along the southern arm of the creek, at Stations 7 and 8, organic matter was high only in the upper portion of the core. The trends support the historical evidence that the southern arm was once a high-energy environment when it conducted waters to the main inlet for the Little River. The creek became a quiet backwater that accumulated organic matter at the surface once the inlet to the south was closed.

Vegetation.

Photography : Most of the photo stations were located at easily accessible sites with good views and include the Route 1A culvert, near the Willow tree on the Mixner property, at the weir (head of tide), behind #12A Viano Road, at the Appledore Road Culvert, behind #5 and #11 Appledore Road, behind Boulters Cove, and at the Huckleberry Road culvert. Photographs are printed, along with descriptions, in Appendix 5.

Submerged Vegetation Survey: Nine of ten *Ruppia* beds found in pools and creeks south of Appledore Road (Figure 11) could be accessed by canoe and were sampled using three quadrat plots. The average plant cover for all samples was 33.4% and ranged from sparse (5%) to dense (85%) in these shallow (20 cm), surprisingly saline (32 ppt), water bodies. A Power analysis conducted following the survey indicated that the minimum detectable change in overall percentage cover would be about 13%, assuming that the second sampling would occur at the same intensity and 90% Power. Shoot length averaged 34 cm for the nine sites, and an average of 3.0 shoots were found per quadrat (1 to 7 shoots). ANOVAs performed on untransformed data indicated no significant differences in vegetative characters among the nine sites. Raw data are presented in Appendix 6.

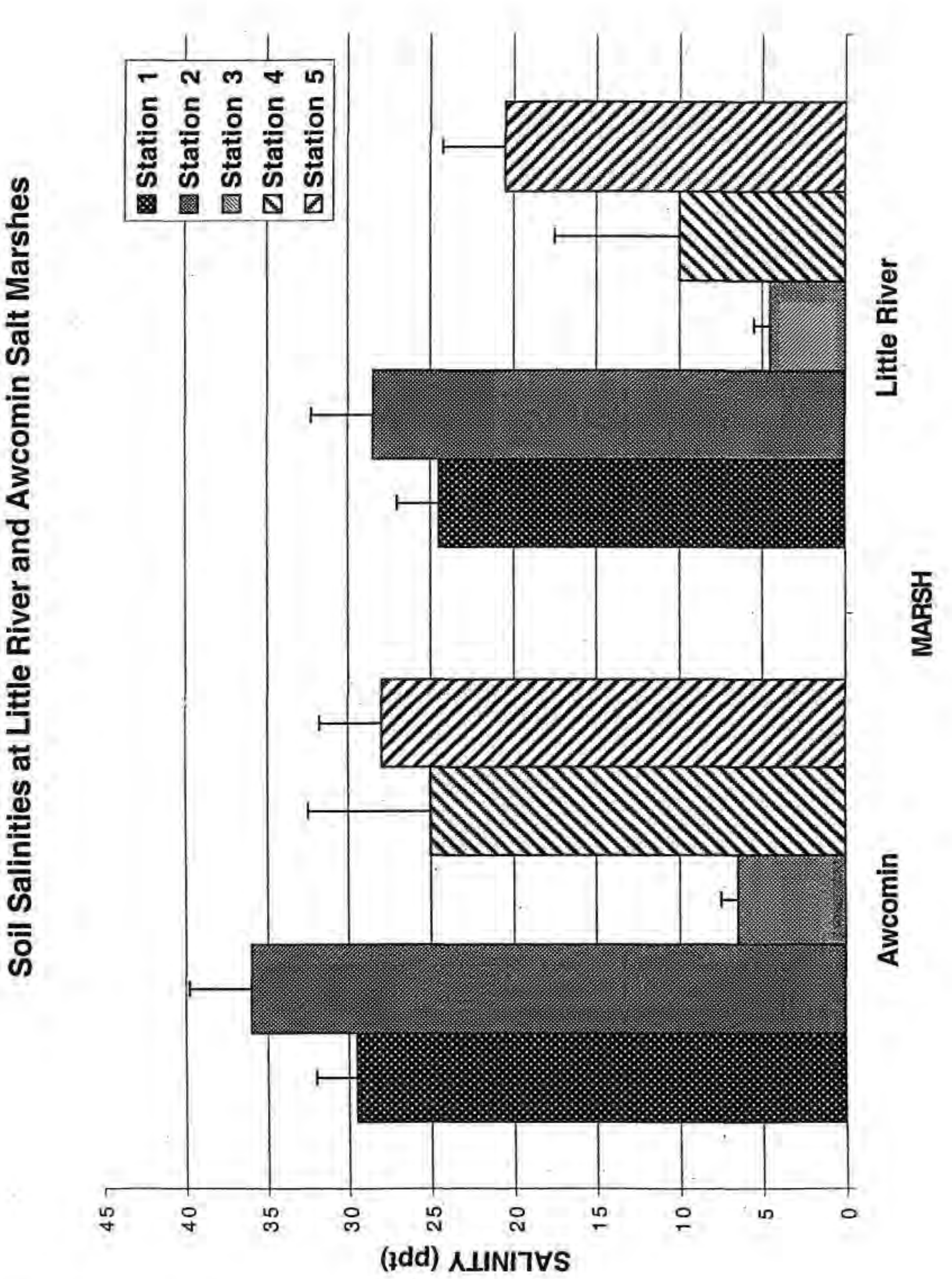


Figure 9. Average soil water salinity from well stations #1 through #5 collected on two dates at Little River Marsh compared with Awcomin Marsh.

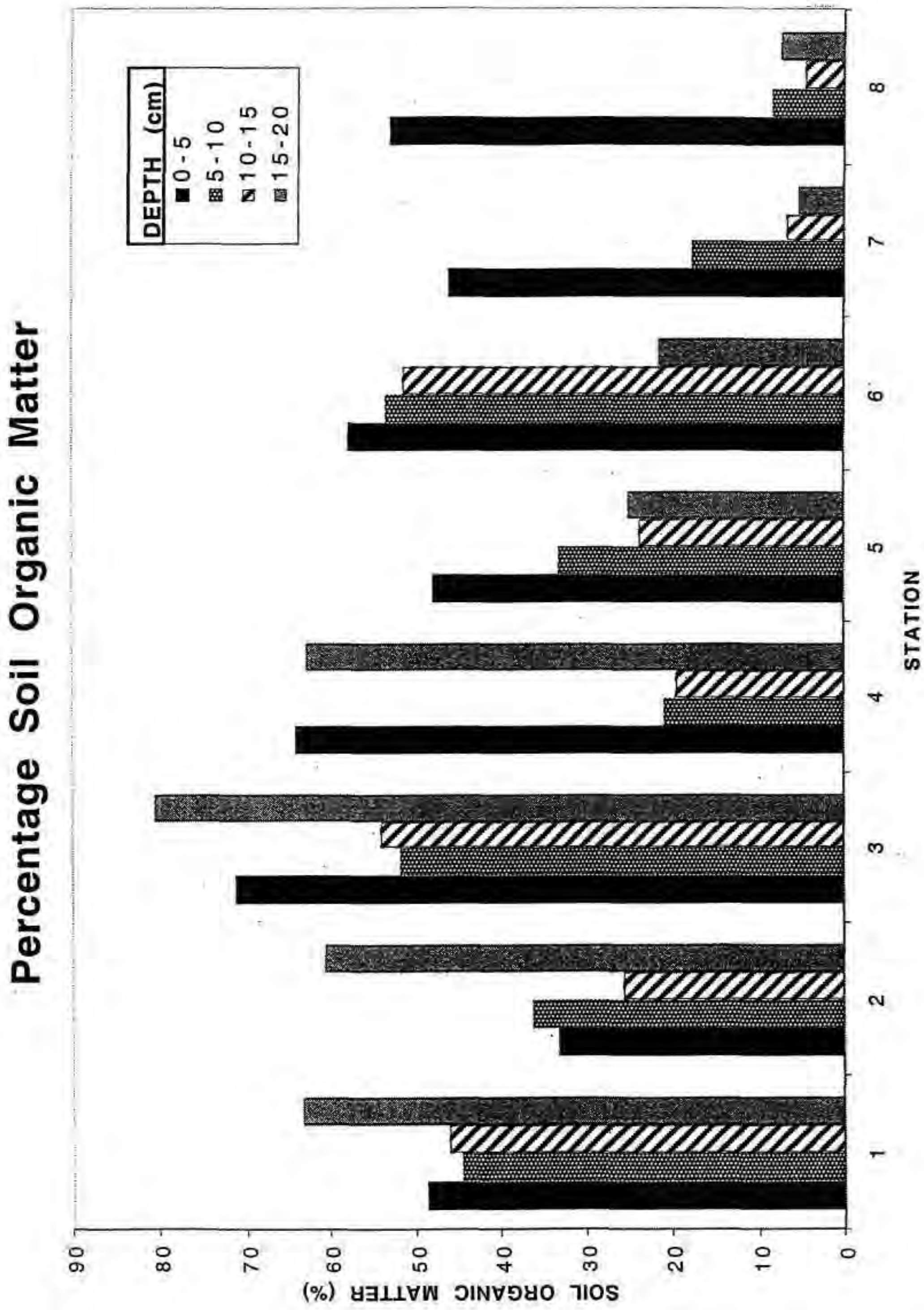


Figure 10. Soil percentage organic matter determined as loss on ignition for each of four depth intervals for each of the 8 Stations at Little River Marsh.

Figure 11. Sampling locations for SAV habitat in *Ruppia maritima* beds of the Little River Marsh.

Emergent Plant Survey: Emergent plants were surveyed using 0.25 m^2 quadrats along a set of 6 transects originating at the main creek and proceeding to the upland edge. Pre-restoration sampling did not include a reference marsh, but vegetation transects at Awcomin Marsh will be used for post restoration comparisons in the future. Overall, 88 quadrats were sampled, yielding 26 vascular species identified to species and 3 identified to genus. The data from vegetation transects are presented in Appendix 7.

Samples were divided up into the typical habitat types: creek edge (19 samples), high marsh (61), open water (1), and upland edge (7). Generally, the greatest cover was found within 10 feet of the creek bank and along the upland edge (85%). There was slightly lower cover found in the high marsh (73%). Along the creek bank and over the high marsh, *Spartina patens* (salt hay) was the dominant plant with about 50% cover (Figure 12). Following with 3 down to 1% cover were: *Lythrum salicaria* (purple loosestrife), *Phragmites australis* (common reed), *Distichlis spicata* (spike grass), *Spartina pectinata* (rough cordgrass) and *Spartina alterniflora* (smooth cordgrass). Community analysis of the data should be used to develop plant community types for the transect data that can be used to compare changes in communities over time following the restoration.

Cover of the dominant grass, *Spartina patens*, was significantly lower at the upper edge of the marsh. Cover of other typical marsh species did not exhibit significant differences between habitat types. However, both *Lythrum salicaria* and *Typha* species (*T. angustifolia* and *T. latifolia* were grouped together) were significantly associated with the upland edge samples (Figure 12). Although the differences were not significant, *Phragmites* was as likely to be found at the creek bank as on the high marsh, but less important at the upper marsh edge.

In addition to the transect survey, 32 colonies of species of concern were characterized using 5 plots at each colony. Twelve colonies of *Lythrum salicaria* and 20 colonies of *Phragmites australis* were characterized with respect to stem density, percentage cover, and height of the three tallest shoots (Figure 13). Shoot densities averaged from 18 to almost 200 for *Phragmites* and from 37 to 150 for *Lythrum*. Despite being quite different types of plants (woody dicot shrub and monocot grass) the shoot density and cover were similar within stands of these two species. Height of the tallest *Phragmites* stems averaged 160 cm, much taller than *Lythrum* (Figure 13). Complete data from sampling stations for Species of Concern is included as Appendix 8.

Nekton. Fish were sampled at Little River Marsh in 1999 and 2000, prior to the restoration of tidal exchange. A total of 630 fish and 9 crabs were captured using minnow traps, throw traps, and seines in three habitat types: main creeks, secondary creeks and pannes. Fish data are summarized in Table 1 and the complete data set for the fish collections are presented in Appendix 9. Mummichogs (*Fundulus heteroclitus*) outnumbered all other species captured for both sampling years. Overall, mummichogs were larger by volume than the silversides (*Menidia menidia*) and sticklebacks (*Apeltes quadracus*), but only slightly greater in length.

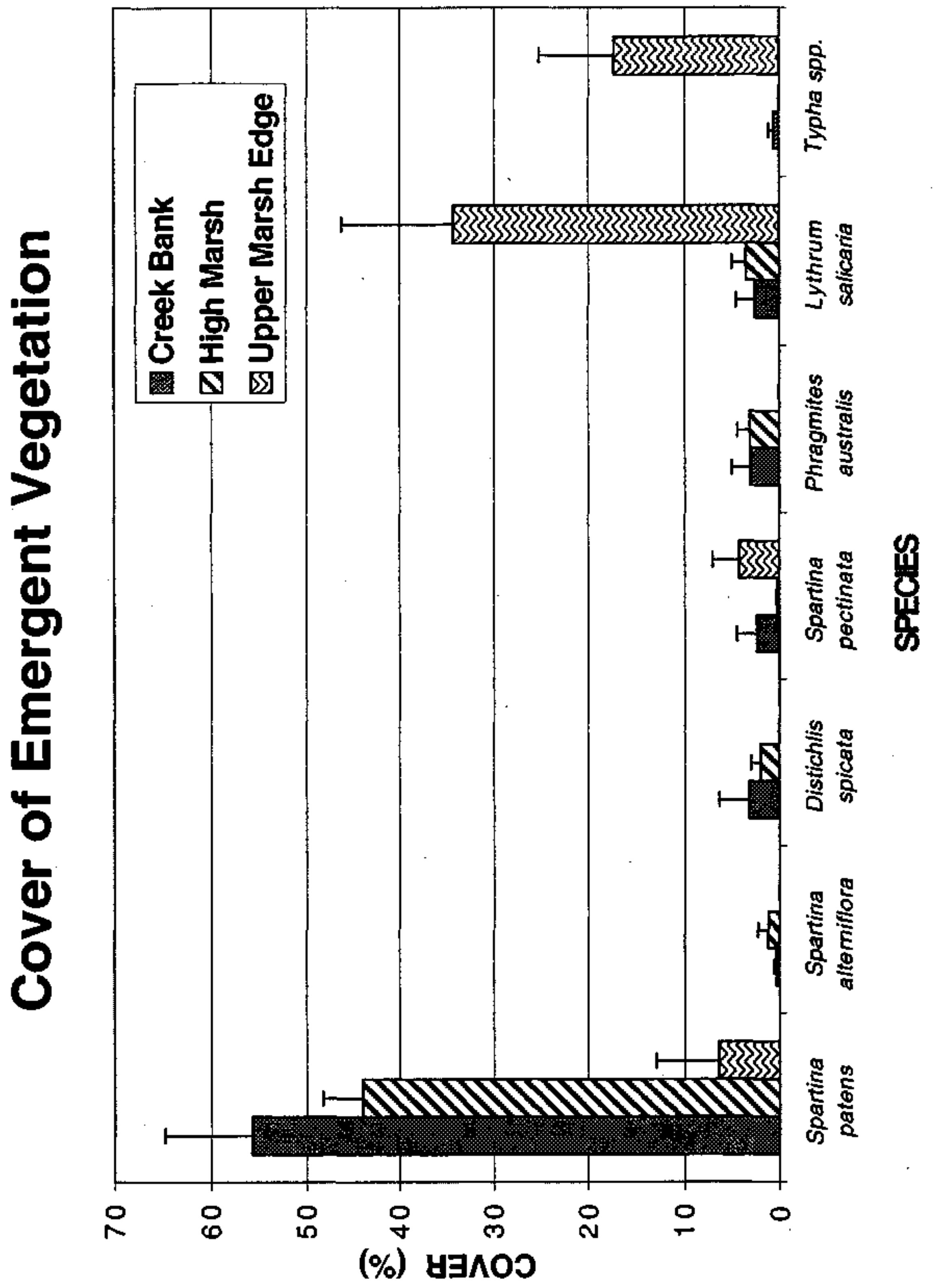


Figure 12. Average cover of the most common vascular plants at Little River Marsh.

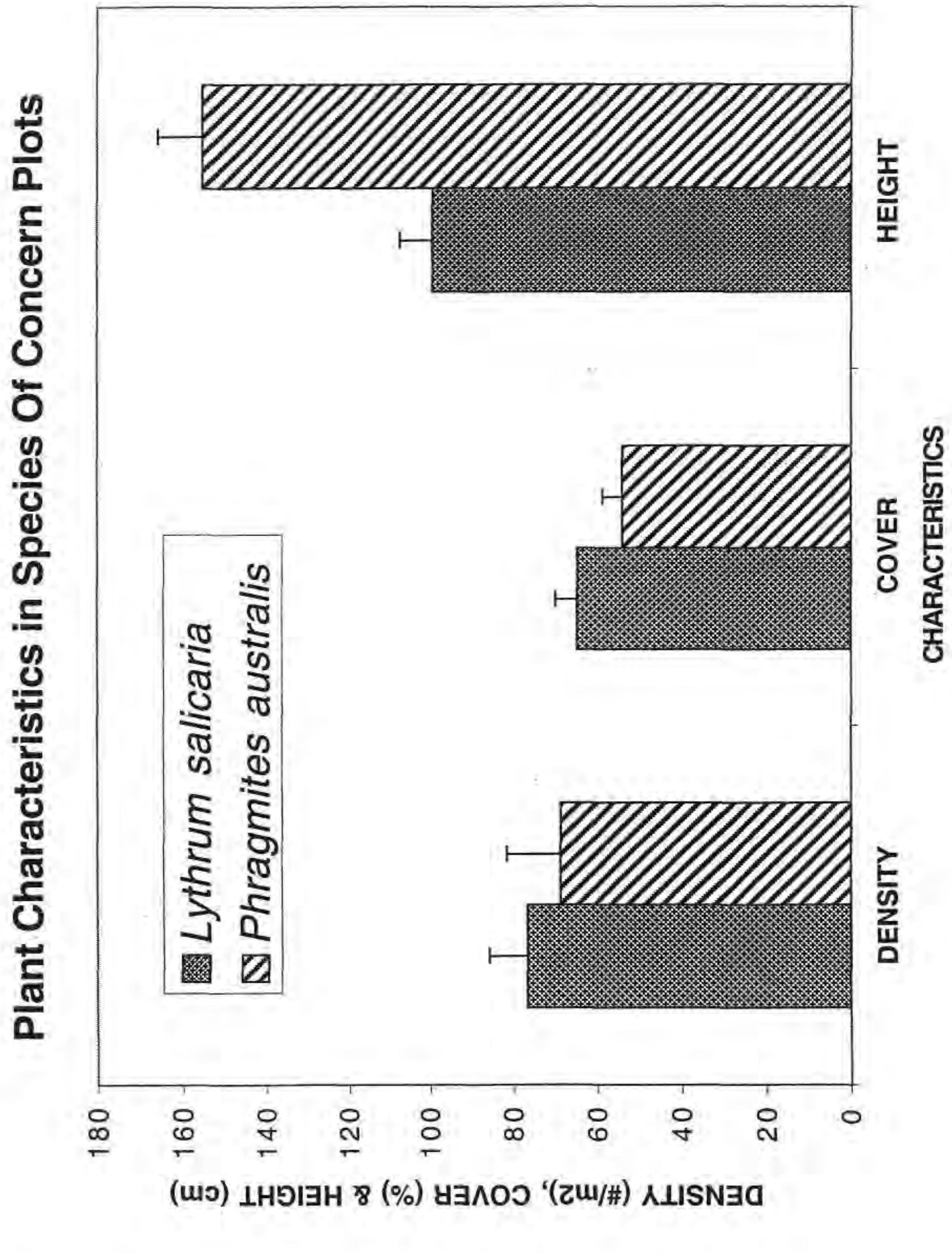


Figure 13. Plant characteristics within stands of species of concern at Little River Marsh.

Table 1. Nekton abundance, average length and volume ± standard deviation.					
	Fundulus heteroclitus	*Menidia menidia*	*Apeltes quadracus*	*Carcinus maenus*	Unknown (Likely adult F.h.)
1999	80	52	10	8	0
2000	485	0	0	1	3
Total	565	52	10	9	3
Length, Mean ±SD	51.0 ±12.4	46.0 ±9.2	44.1 ±4.3	25.3 ±4.5	79.0 ±14.1
Volume, Mean ±SD	1.71 ±0.78	0.68 ±0.21	0.63 ±0.30	-	-

Mummichogs were captured in all habitat types and by all collection methods. Distribution of mummichogs was similar throughout all habitat types (Table 2). For example, minnow traps caught similar numbers of mummichogs in main creeks, secondary creeks and pannes. Atlantic silversides were captured in main creeks only. This is expected due to their schooling behavior and method of prey capture (i.e., filter feeding for zooplankton. Furthermore, silversides were caught only by seine. Four spined sticklebacks (*Apeltes quadracus*) were mostly collected from main creeks. One individual was captured in a panne. Sticklebacks prefer shallow water habitats; therefore, it is expected that they would be found in all habitat types. Green crabs (*Carcinus maenus*) were captured by minnow traps only, and were collected in main creeks and pannes (Table 2). These data suggest that, prior to tidal restoration, the greatest nekton abundance and richness were found in the main creeks.

Table 2. Fish abundance by species, collection method and habitat.					
Collection method	Habitat	*Fundulus heteroclitus*	*Menidia menidia*	*Apeltes quadracus*	*Carcinus maenus*
Minnow trap	main creek	156	0	0	4
	secondary creek	200	0	0	0
	panne	138	0	1	5
Seine	main creek	20	52	9	0
Throw trap	main creek	34	0	0	0
	panne	17	0	0	0

Avifauna. A total of 79 bird species were recorded during a 14-month period that included 22 survey dates at Little River Marsh. Over 3,000 birds were observed (Figure 14) and two peaks in the number of individuals were found: during the late fall - winter and during the spring migration (April and May of year 2001 only). The data and summaries are located in Appendix 10 (Milligan 2001). Eleven sample dates occurred before the restoration and 11 dates following restoration. During this dormant period when most biological activity is minimal, no appreciable differences (other than increased flooding by high tide) were found at the site and Mike Milligan recommends treating the data as all pre-restoration. Approximately 50 to 60 species of birds were recorded at each of the four sample points, and a little more than half that number was observed directly using the marsh (Figure 15). An exception, Point 4, was surrounded by dense vegetation, and here only 23 species were observed using the marsh.

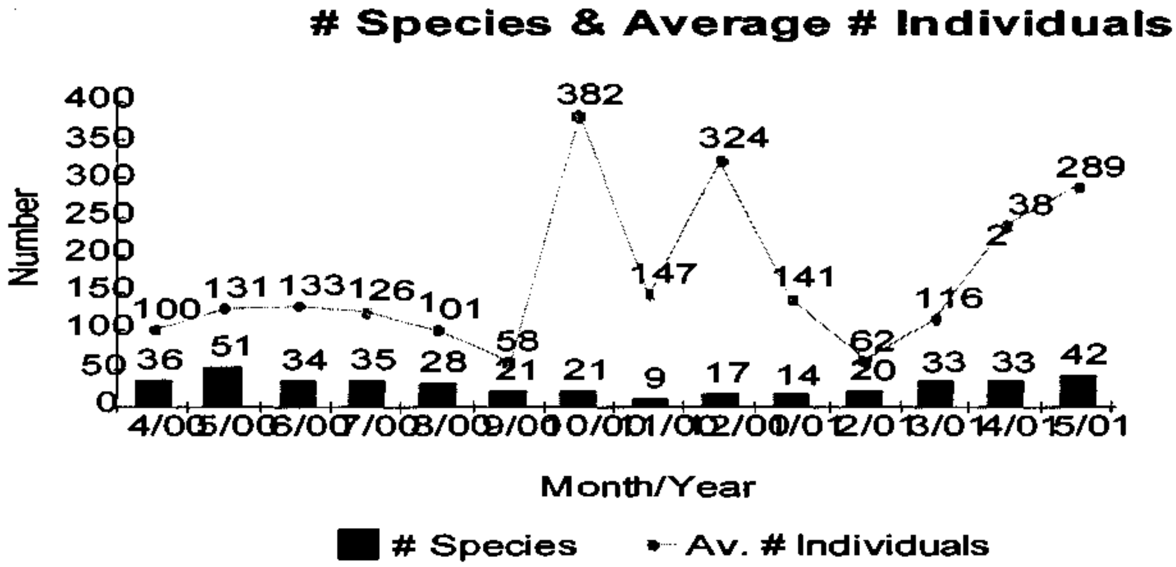


Figure 14. Number of bird species and average total number of individuals counted each month in general study area.

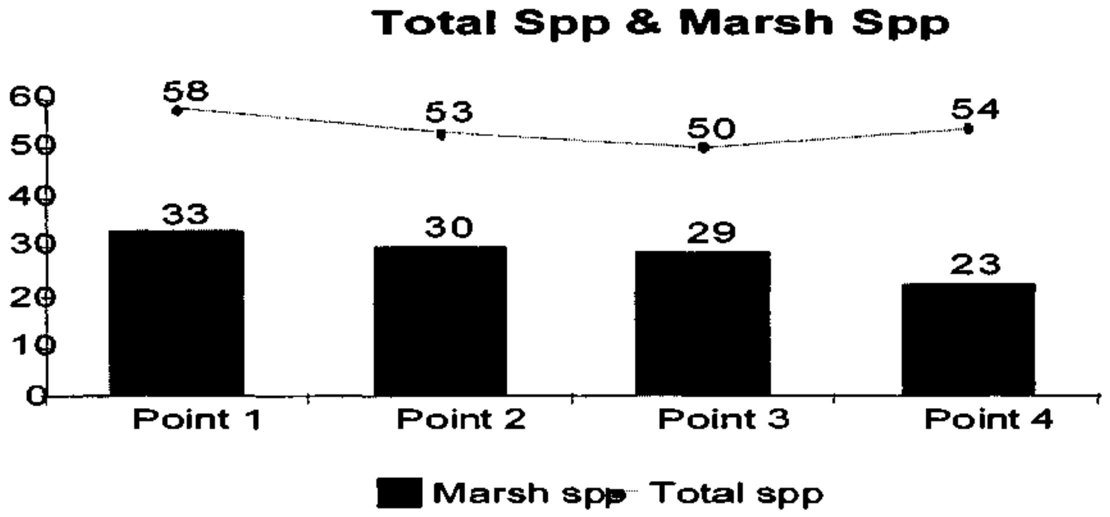


Figure 15. Bird species observed at each sample point during the 14 month monitoring effort.

DISCUSSION

The hydrologic records provide data to support tidal restoration for improved management of this large wetland complex. First, high tides rarely flood the marsh surface due to the tidal restriction imposed by the existing culvert. Second, the flooding to roads and houses reported by residents of the basin is caused by inadequate drainage of the system when it fills with fresh water due to precipitation and runoff events. Third the potential for an expansion of the culvert to drain upstream floodwaters and to conduct high tides of sufficient magnitude to support the long-term maintenance of the salt marsh is very good. It appears that up to 12 inches (30 cm) greater water levels are possible by expanding the culvert to 6 by 24 feet in cross-section. Further, extreme high tides will still be impeded to some extent by the proposed culvert since Route 1A acts as a barrier and runs along the entire eastern edge of the wetland system.

Marsh sediments are composed of inorganic sediments (sand, silt and clays) and organic matter derived from the dominant vegetation that combine to form peat. The inorganic sediments are carried in largely by the tides (especially during storms), and settle in the vegetation, where they combine with the plant organic matter. The plant matter is very slow to break down (especially in the absence of oxygen), and in healthy marshes binds the sediments to make a firm substratum. Sediment supply is a critical physical component necessary for marshes to sustain themselves and build with sea level rise (Warren and Niering 1993, Roman et al. 1997, Ward et al. 1998). Sediment bulk properties sampled in the Little River Marsh support the historical evidence that the southern arm of the River was once connected to a high-energy inlet (sediments were highly inorganic at greater than 5 cm depth). Further, the current inlet that flows through the small culvert is not carrying much inorganic sediment to the marsh. This is illustrated by a greater proportion of the recent sedimentation to be composed of organic matter for most of the Stations (#3-8 in Figure 9). Salinity of the marsh soil showed lower salinity at upstream Stations, and depressed salinity compared to Awcomin Marsh (Figure 9). Results from soil bulk properties and salinity indicate the current tidal restriction is reducing the flow of sediments and salt from the Gulf of Maine. These are two critical material flows necessary to support a healthy salt marsh (Roman et al. 1997, Burdick et al. 1997).

Currently, salt hay (*Spartina patens*) dominates areas still recognized as salt marsh, but much of the salt tolerant vegetation has been replaced by a shrub association dominated by purple loosestrife (*Lythrum salicaria*; Figures 3 and 11). Upper areas of the marsh are dominated by common reed (*Phragmites australis*) and cattail (*Typha* spp.). A large new culvert will likely result in rapid retreat of the shrub association and impact the other two invasive communities dominated by common reed and cattail. Plant species of concern: *Lythrum salicaria* and *Phragmites australis*, are likely to become stunted or reduced in importance where they dominate the plant community following restoration of tides. However, the impacts to *Phragmites* may be slow (Burdick et al. 1997, Rozsa 1996).

Fish and bird populations associated with the salt marsh were not unexpected, but continued degradation and loss would negatively affect those species dependent on salt marsh (mummichog, stickleback, sharp tailed sparrow and rails). Bird stations always included some marsh habitat dominated by salt tolerant grasses, and fish were only sampled where open water was present (adjacent to *Spartina* dominated vegetation). Loss of open water through invasion and dominance by species like *Phragmites* (Able 2002) eliminates fish habitat.

The configuration of the tidal creeks and existing culvert allows most creeks to retain shallow water (6 to 18 inches) through low tides. The shallow waters provide relatively stable environmental conditions that are likely to support significant populations of forage fishes (Dionne et al. 1999), such as the populations of mummichogs and Atlantic silversides that we observed in the creeks.

The primary management objective at the Little River Marsh is to improve the health and functions of the salt marsh impacted by the tidal restriction. A broad suite of data has been collected prior to tidal restoration of the Little River Marsh. The information produced can help us understand the impacts to this dynamic and important coastal habitat from the restriction, and set the stage for understanding how this system will respond to tidal restoration. Further, the data will be available for sharing in a regional database (Neckles and Dionne 2000) to improve tidal restoration across the entire the Gulf of Maine.

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