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SURFACE WATER QUALITY, CAPE HATTERAS NATIONAL SEASHORE,
NORTH CAROLINA: ANNUAL REPORT--1990

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INTRODUCTION

Cape Hatteras National Seashore (CAHA) has long viewed potential water quality degradation as an area of special concern. An interdisciplinary advisory group (Aquatic Advisory Team 1986) specifically set water quality monitoring as a goal for CAHA. As a result of this general interest, long-term funds were secured and a monitoring program initiated in August 1988. Sites on Bodie Island have been sampled since August 1988, while locations within Buxton Woods have been sampled since February 1989. This report provides a summary of the data to date.

METHODS

Sample Sites. Sample locations for Bodie Island are shown in Figure 1 but also summarized here. As a reference point, the drainage ditches connecting south Nags Head with CAHA are numbered 1-5, beginning at Whalebone Junction and moving south towards Oregon Inlet. Sample station 1 is located proximate to the boardwalk extending into the marsh by the Bodie Island Lighthouse. Station 2 is located in the ditch approximately 1/2 km up the north side of the road going to the Navy communications tower and the old CAHA water tank. Station 3 is found immediately adjacent to the east side of CAHA hunting blind #9, and station 4 is situated at the edge of the borrow pond by the viewing stand located to the north of the entrance to blind #9. Station 5 is ditch #5 and station 6 is ditch #4. The waters of the marsh immediately adjacent, and to the east, of hunting blind #5 constitute station 7, while station 8 is established in the large ditch running north-south approximately 300 m north of station 7 and connecting with Roanoke Sound. Station 9 is located on the edge of the marsh roughly 50 m to the east of hunting blind #3 (within the open water surrounding the blind). Stations 10, 11, and 12 are located in ditches 3, 2, and 1, respectively (all ditch sample locations are adjacent to NC-12). Station 13 is found off of Old Oregon Inlet Road at the gazebo pool on property owned by Mr. Jerry McManus (approximately 1 km south of the south Nags Head fire station). These 13 locations were chosen so as to represent both open marsh and drainage ditch environments within and adjacent to CAHA property on Bodie Island. Sites 1,3,4,7,9, and 13 are designated as marsh sites, while sites 2,5,6,8,10,11, and 12 are ditches.

Buxton Woods sample locations are shown in Figure 2 and summarized below. Station BW1 (Buxton Woods 1) is located on the northern end of Jennette Sedge off the CAHA nature trail, approximately 0.25 km north of the Buxton Ranger Station. Station BW2 is located north of Open Pond Road on the southern end of the eastern terminus of Open Pond itself. This site can be found approximately 150 m west of the permanent park gate located about 1.5 km from the Cape Point Road. Station BW3 is found on the recently acquired state lands immediately adjacent to CAHA. This area is about 0.75 km from the end of the access road shown in Figure 2. Station BW4 is situated on the northern side of the eastern end of Round Pond. This site is accessed by walking the northern CAHA boundary trail for approximately 2 km from the end of the trail leading from the Cape Hatteras Water Association (CHWA) Road. Station BW5 is to be found on this CHWA trail at the northeastern side of the intersection of the trail and the CAHA boundary.

Parameters. Parameters measured at all stations at both sites (Bodie Island and Buxton Woods) include fecal coliform bacteria (Mean Probable Number (MPN)), pH, dissolved oxygen (mg/l), salinity (ppt), conductivity ($\mu\text{mhos/cm}$), temperature ($^{\circ}\text{C}$) and water depth (stage (m)). Parameters measured only on Bodie Island (due to the influences of tides and wind tides), include wind direction and wind speed (kph). It should be noted that, to date, measurement of pH has been problematical at best, primarily due to malfunctioning equipment.

Quarterly collection of optical brightener levels began on Bodie Island in October 1988 and in Buxton Woods in October 1989. This involved the use of undyed cotton samplers collecting optical brighteners over a one week period, and then testing in a spectrofluorometer for fluorescence. This then provides a relative measure of optical brightener levels. (Optical brighteners are found in laundry detergents and are an unambiguous indicator of human caused pollution. See Aley (1985)).

Analysis. Analysis of variance (ANOVA) (Zar 1984) was used to test for differences in water quality on Bodie Island between the two groups (ditches and marshes), as well as between all sites in Buxton Woods.

RESULTS

Bodie Island

Marsh waters on Bodie Island are generally slightly alkaline, fresh, moderately enriched in dissolved oxygen, with moderate to low fecal bacterial concentrations (Table 1). In contrast, ditch sites are slightly (though significantly) less alkaline and significantly higher in salinity and conductivity. Dissolved oxygen is much lower and bacterial levels are over four times those found in the marshes (Table 2).

Sufficient data for seasonal analyses is available only for pH, salinity, conductivity, dissolved oxygen and bacterial levels for both marsh and ditch sites (Figures 3-7). All of these parameters show significant seasonal trends (ANOVA $p < 0.001$; Table 3). (Note: Although seasonal data do exist for other water variables (alkalinity, copper, total hardness, iron, manganese, nitrite, ammonia and phosphate), substantial gaps in the data preclude their use.) Regrettably, equipment problems during 1989 prevented continual measurement of pH, thus creating a large gap in the data (to be filled during the summer of 1990). However, based upon this incomplete data, pH appears to increase



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slightly during the year. Salinity and conductivity show expected seasonal patterns where lower values coincide with increased winter and spring rainfall (see Figure 8). Values for both are always higher in the ditches than the marshes. In contrast, dissolved oxygen is always greater in the marshes than the ditches throughout the year, although both groups exhibit seasonal declines. This is due, at least in part, to increased water temperatures and subsequent diminished oxygen carrying capacity. This does not explain, however, the large differences between the two groups each month. Bacterial levels do not appear to indicate seasonal behavior. Levels are higher at the ditch sites for every month but January (this may be indicative of high waterfowl populations in the marshes during that period).

Optical Brighteners. Since sampling began in October 1988, optical brighteners have been found at all marsh and ditch sites at some time (Table 4). Typically, values have been low in intensity, and sporadic in occurrence and pattern. Of the six sample periods measured to date, only five of 13 sites have shown as many as three occasions of measurable optical brighteners. There have been only three occurrences of moderately intensive results, two of which occurred at marsh sites. Only one ditch site has consistently shown positive optical brightener readings.

Buxton Woods

Surface water pH for the five Buxton Woods sites is slightly to moderately alkaline (Table 5). All are very fresh water sites, with low to zero salinity and low conductance. Dissolved oxygen is also moderate to low, and bacterial levels have been low to moderate as well. The five sites differ significantly with respect to pH, conductance, dissolved oxygen, ammonia, and phosphate (Tables 5 and 6). [Although other parameters also differed across sites, sample sizes have been small, thus casting some doubt on the reliability of the ANOVA.] Alkalinity and total hardness are high, reflecting the calcareous nature of the substrate (thus buffering pH as well). Iron concentrations are moderate to high, a well-known phenomenon on the island possibly reflecting a buried organic layer.

As with Bodie Island, sufficient data for seasonal analyses are available only for pH, salinity, conductivity, dissolved oxygen, and bacteria. Patterns for pH are incomplete (reflecting equipment problems) but do not show much pattern (Figure 9). Salinity (Figure 10) shows a minor peak in spring but the levels are very low and no salinity is present at all for the remainder of the year. As a related measure, conductance also is low (Figure 11), although showing a seasonal increase during the summer months as water levels fall and dissolved materials are concentrated in the remaining water. Dissolved oxygen (Figure 12) follows much the same pattern, although bacteria (Figure 13) manifests little seasonality.

Optical brightener data for Buxton Woods is very preliminary at this date. Only one sample has been collected with only one site (Open Pond) showing moderate optical brightener intensity.

DISCUSSION

Bodie Island

Additional analysis of the water quality data has not significantly altered earlier results (Cole, 1989). One exception has been the addition of pH as a variable whose values statistically differ between marsh and ditch sites. In this case, however, absolute differences are small and do not indicate any ecological significance. Salinity and conductance continue to be lower in marsh sites, likely symptomatic of increased organic matter loading in the ditch systems. Dissolved oxygen remains higher in the marshes, again suggesting lower demand for oxygen by decomposers.

Septic Pollution. Although few nutrient samples have been collected to date, early results for two parameters, ammonia and phosphate, tend to corroborate the bacteria and optical brightener data. Both ammonia and phosphate are indicative of septic pollution (HACH Company, 1987; Wetzel, 1975) and are significantly higher in the ditch systems. Fecal bacterial counts continue to show large values present in the ditches from Nags Head, approximately four times those of the marshes. No additional evidence has come to light which would point to any other source for bacteria than failing septic systems in Nags Head. Optical brighteners continue to be seen sporadically in both marsh and ditch sites, although prevalence seems to have abated somewhat. We do not yet have enough data to assess seasonality.

Buxton Woods

Additional data collection for this region also has not transformed previous conclusions (Cole, 1989) as pH remains slightly alkaline, waters very fresh, and dissolved oxygen moderately low. Low oxygen levels are likely due to the shallow nature of the sites in conjunction with higher water temperatures and a significant amount of decaying organic matter, thus leading to increased activity of decomposers and a decline in dissolved oxygen. Fecal bacterial levels are low at two sites, moderate at two others, and high only at one site (Nature Trail). It is worth noting that the Nature Trail site is the closest to housing development on the northern rim of the Seashore at Buxton Woods. This site had levels high enough to warrant some concern over source. Unfortunately, not enough optical brightener data is yet available to assess possible septic input. The only site showing optical brighteners to date (Open Pond) is some distance away from the Nature Trail area.

Several variables differed across the five sites, reflecting a wide variability in water quality throughout what ostensibly is a single groundwater lens. Although hardly conclusive, the data do suggest the potential for several different, or distinct, aquifers beneath the Woods.

CONCLUSIONS

Degradation of the surface water quality in the Nags Head region should continue to pose some concern for the Seashore. Bacterial levels in the ditches, in conjunction with areal distribution of optical brighteners, and the early analysis of ammonia and phosphate, indicate continued septic effluent input into the Seashore.

Buxton Woods water quality continues to remain relatively high. Certainly, the Woods has a very different water regime. As already noted (Cole, 1989) water quantity, not quality, is of prime concern in the Buxton Woods area. However, the presence of high bacterial counts at the Nature Trail site on the northeastern park border is a negative phenomenon to be watched carefully.

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Table 1. Mean values for water parameters for both marsh and ditch sites on Bodie Island, Cape Hatteras National Seashore, North Carolina. ANOVA tests for differences between all 5 sites. * = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$

Variable	Marshes	ANOVA	Ditches
pH	7.53 (1.17)	**	7.33 (0.48)
Salinity (ppt)	1.92 (1.92)	***	3.42 (3.15)
Conductivity (umhos)	3197 (2192)	***	5506 (4999)
Dissolved oxygen (mg/l)	6.76 (1.83)	***	4.56 (2.00)
Bacteria (MPN)	70.48 (212.87)	***	288.91 (368.50)
Alkalinity (mg/l CaCO ₃)	229.20 (219.13)		259.26 (201.18)
Copper (mg/l)	0.03 (0.02)		0.05 (0.05)
Total hardness (mg/l CaCO ₃)	360.71 (345.83)		780.53 (1565.90)
Iron (mg/l)	1.13 (1.02)		1.12 (0.82)
Manganese (mg/l)	0.02 (0.04)		0.01 (0.03)
Nitrite (mg/l)	0.02 (0.06)		0.01 (0.02)
Ammonia (mg/l)	0.97 (0.75)	***	1.52 (0.63)
Phosphate (mg/l)	0.06 (0.03)	***	0.33 (0.33)

Table 2. Analysis of variance (ANOVA) table for variables differing significantly between marsh and ditch sites on Bodie Island, Cape Hatteras National Seashore, North Carolina.

Variable	SS ^a	df	MS	F	p
pH	6.89 481.89	1 684	6.89 0.70	9.78	0.002
Salinity	685.55 9254.44	1 1261	685.55 7.34	93.41	0.0001
Conductivity	1.6x10 ⁹ 2.3x10 ⁹	1 1249	1.6x10 ⁹ 1.8x10 ⁹	89.27	0.0001
Dissolved oxygen	1387.33 4380.40	1 1177	1387.33 3.72	372.77	0.0001
Bacteria	1.1x10 ⁷ 9.9x10 ⁶	1 964	1.1x10 ⁷ 1.0x10 ⁶	104.88	0.0001
Ammonia	9.79 61.0	1 130	9.78 0.47	20.86	0.0001
Phosphate	1.72 6.99	1 95	1.72 0.07	23.31	0.0001

^a Model SS above, error SS below.

Table 3. Analysis of variance (ANOVA) for significant water variables in the marshes and ditches of Bodie island, Cape Hatteras National Seashore, North Carolina.

MARSHES					
Variable	SS ^a	df	MS	F	p
pH	66.61 321.98	8 274	8.33 1.18	7.09	0.0001
Salinity	588.16 1333.03	11 511	53.47 2.61	20.50	0.0001
Conductivity	1.3x10 ⁹ 3.1x10 ⁹	11 506	1.2x10 ⁸ 6.1x10 ⁸	19.00	0.0001
Dissolved oxygen	641.33 985.23	11 476	58.30 2.07	28.17	0.0001
Bacteria	1.4x10 ⁶ 1.5x10 ⁷	11 344	1.3x10 ⁵ 42782	3.00	0.0001
DITCHES					
pH	9.48 83.82	8 394	1.19 0.21	5.57	0.0001
Salinity	1154.78 6177.31	11 727	104.98 8.50	12.35	0.0001
Conductivity	3.5x10 ⁹ 1.5x10 ¹⁰	11 720	3.1x10 ⁸ 2.1x10 ⁹	15.27	0.0001
Dissolved oxygen	652.66 2099.58	11 678	59.33 3.10	19.16	0.0001
Bacteria	6.1x10 ⁵ 7.6x10 ⁷	11 597	5.6x10 ⁴ 1.3x10 ⁵	4.34	0.0001

^a Model SS above, error SS below

Table 4. Presence and intensity of optical brighteners in the marshes and ditches on Bodie Island, Cape Hatteras National Seashore, North Carolina.

		MARSHES					
		OCT88	JAN89	APR89	JULY89	OCT89	JAN90
Site number	1	+	+	+	0	0	0
	3	.	+	0	0	0	0
	4	+	+	0	0	++	.
	7	+	+	0	0	0	0
	9	0	.	0	0	++	0
	13	+	+	+	0	0	+
		DITCHES					
	2	+	+	0	0	0	0
	5	0	+	.	0	0	0
	6	+	0	0	0	0	0
	8	+	0	0	0	0	0
	10	+	0	0	0	0	0
	11	+	+	+	0	0	0
	12	+	+	+	0	+	++
.	Missing data						
0	Negative (no) fluorescence/septic pollution						
+	Weakly positive fluorescence/septic pollution						
++	Moderately positive fluorescence/septic pollution						
+++	Strongly positive fluorescence/septic pollution						

Table 5. Mean values for water parameters in Buxton Woods, Cape Hatteras National Seashore, North Carolina. ANOVA tests for differences between all 5 sites. * = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$

Variable	Nature Trail	Open Pond	State Land	Round Pond	Water Plant
pH	7.5	8.2	7.2	7.6	7.4
***	(0.4)	(0.6)	(0.2)	(0.1)	(0.2)
Salinity	0.02	0.00	0.00	0.01	0.01
***	(0.10)	(0.0)	(0.0)	(0.06)	(0.07)
Conductivity	392.1	240.3	354.5	306.1	309.5
***	(101.2)	(54.6)	(114.8)	(71.6)	(70.6)
Dissolved oxygen	3.5	6.7	2.8	4.5	3.8
***	(1.7)	(1.7)	(1.0)	(1.9)	(1.6)
Bacteria	126.2	18.5	59.6	72.5	24.9
	(229.1)	(19.2)	(64.1)	(130.9)	(28.2)
Alkalinity	1201.3	1020.0	1098.8	1085.0	1163.8
	(1704.0)	(1658.8)	(1686.0)	(1655.9)	(1717.9)
Copper	0.1	0.04	0.03	0.05	0.05
***	(0.05)	(0.01)	(0.03)	(0.01)	(0.01)
Total hardness	298.2	166.8	222.2	196.9	245.8
*	(122.6)	(97.8)	(58.9)	(83.3)	(100.3)
Iron	1.8	0.6	2.2	1.1	1.2
***	(0.5)	(0.3)	(0.7)	(0.6)	(0.3)
Manganese	0.01	0.01	0.02	0.02	0.01
	(0.02)	(0.03)	(0.04)	(0.04)	(0.03)
Nitrite	0.01	0.02	0.01	0.02	0.02
	(0.01)	(0.03)	(0.03)	(0.04)	(0.04)
Ammonia	0.8	0.3	1.2	0.5	0.6
***	(0.2)	(0.1)	(0.4)	(0.2)	(0.1)
Phosphate	0.1	0.1	0.1	0.1	0.1
***	(0.1)	(0.03)	(0.1)	(0.03)	(0.1)

Table 6. Analysis of variance (ANOVA) for significant water variables in the Buxton Woods wetlands, Cape Hatteras National Seashore, North Carolina.

Variable	SS	df	MS	F	p
pH	22.39	4	5.60	28.19	0.0001
	34.74	175	0.20		
Conductivity	938427	4	234607	32.13	0.0001
	2592114	355	7302		
Dissolved oxygen	475.62	4	118.91	46.55	0.0001
	715.26	280	2.56		
Copper	0.10	4	0.02	31.40	0.0001
	0.08	100	0.001		
Total hardness	129592	4	32398	3.59	0.01
	540908	60	9015		
Iron	32.18	4	8.04	33.16	0.0001
	24.26	100	0.24		
Ammonia	8.93	4	2.23	40.06	0.0001
	5.57	100	0.06		
Phosphate	0.11	4	0.03	9.20	0.0001
	0.30	100	0.003		

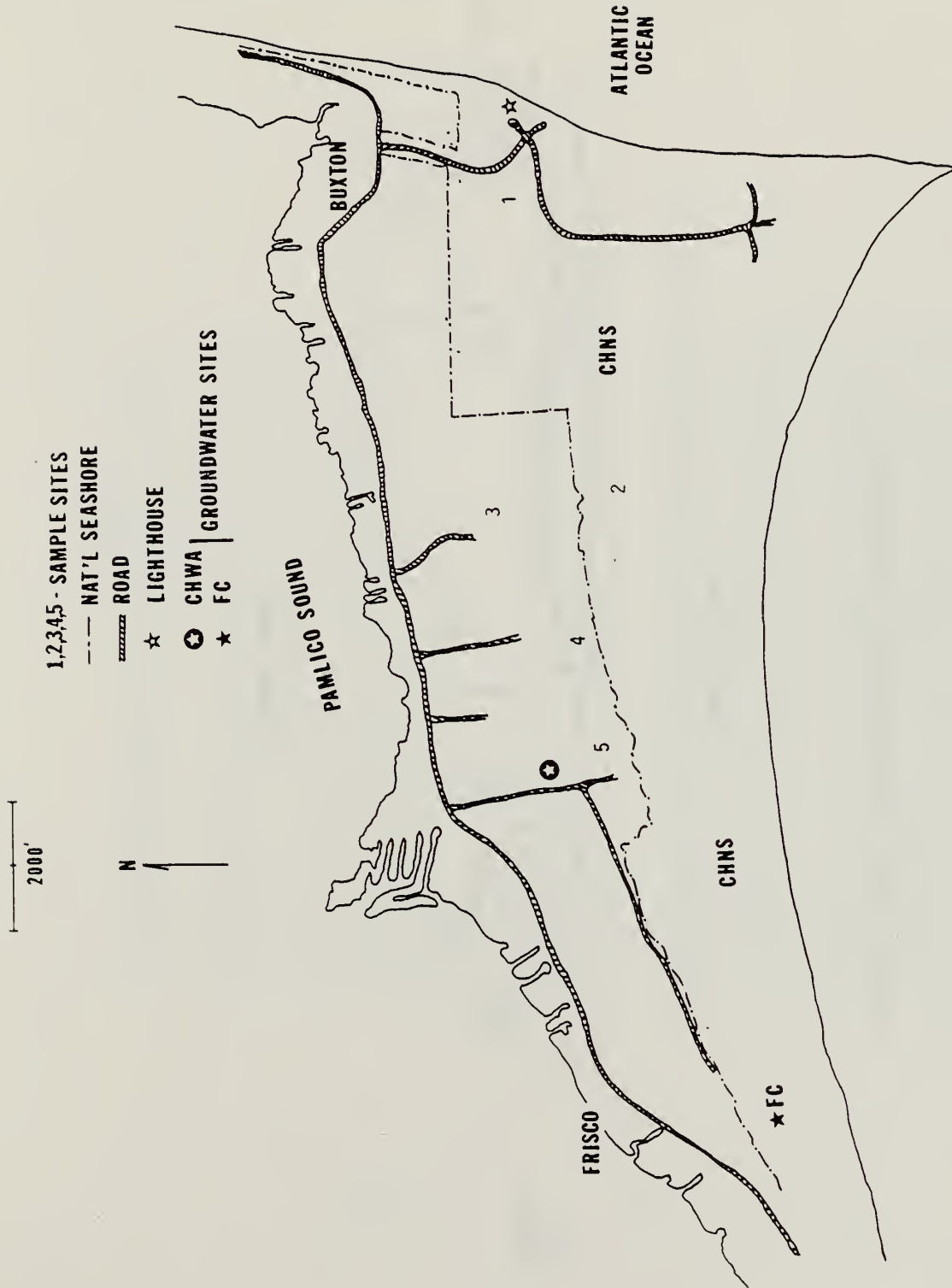


FIGURE 2 . WATER QUALITY MONITORING SITES IN BUXTON WOODS

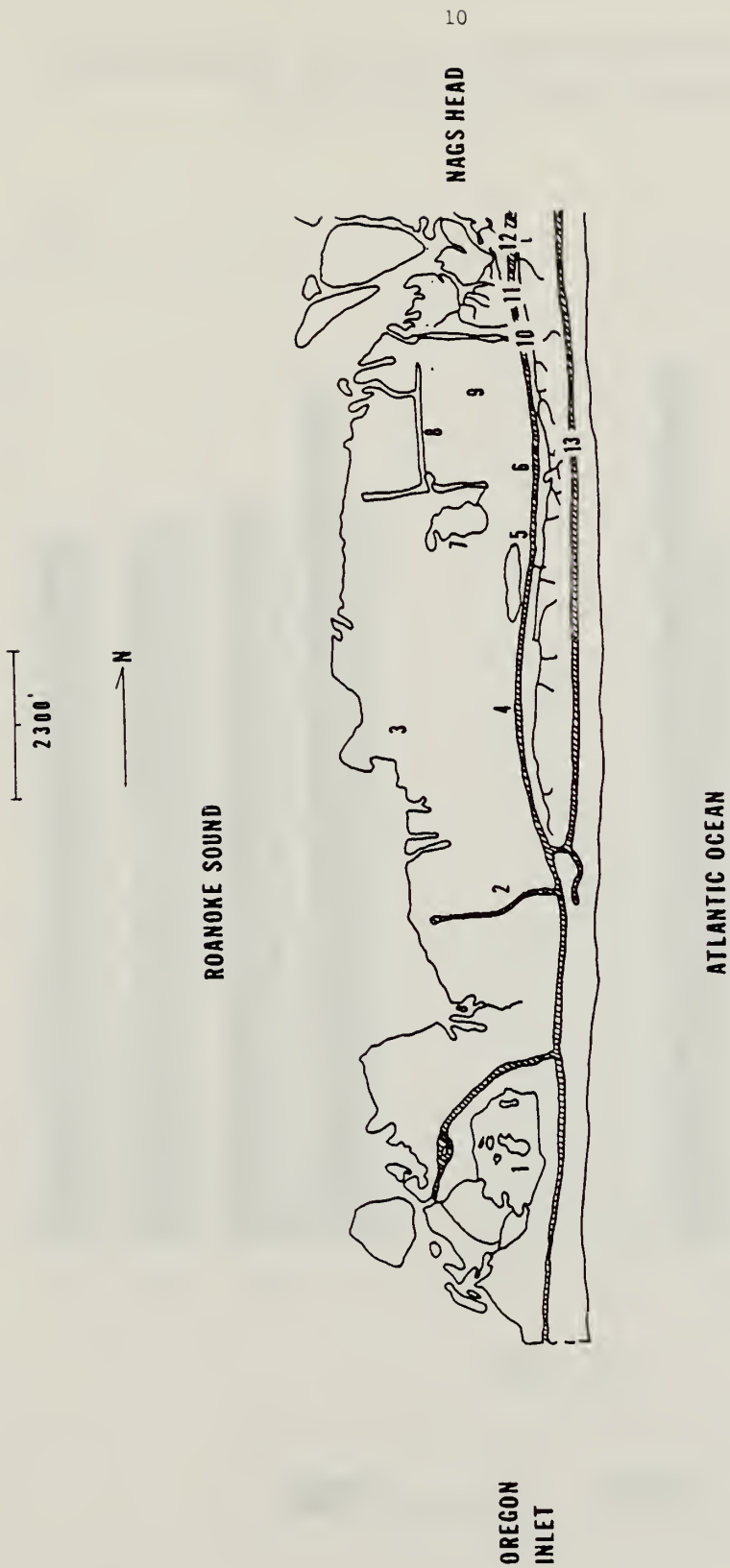


FIGURE 1. BODIE ISLAND WATER QUALITY MONITORING SITES

Figure 3.

Seasonal water chemistry: CAHA 1990.
Marsh sites versus ditch sites.

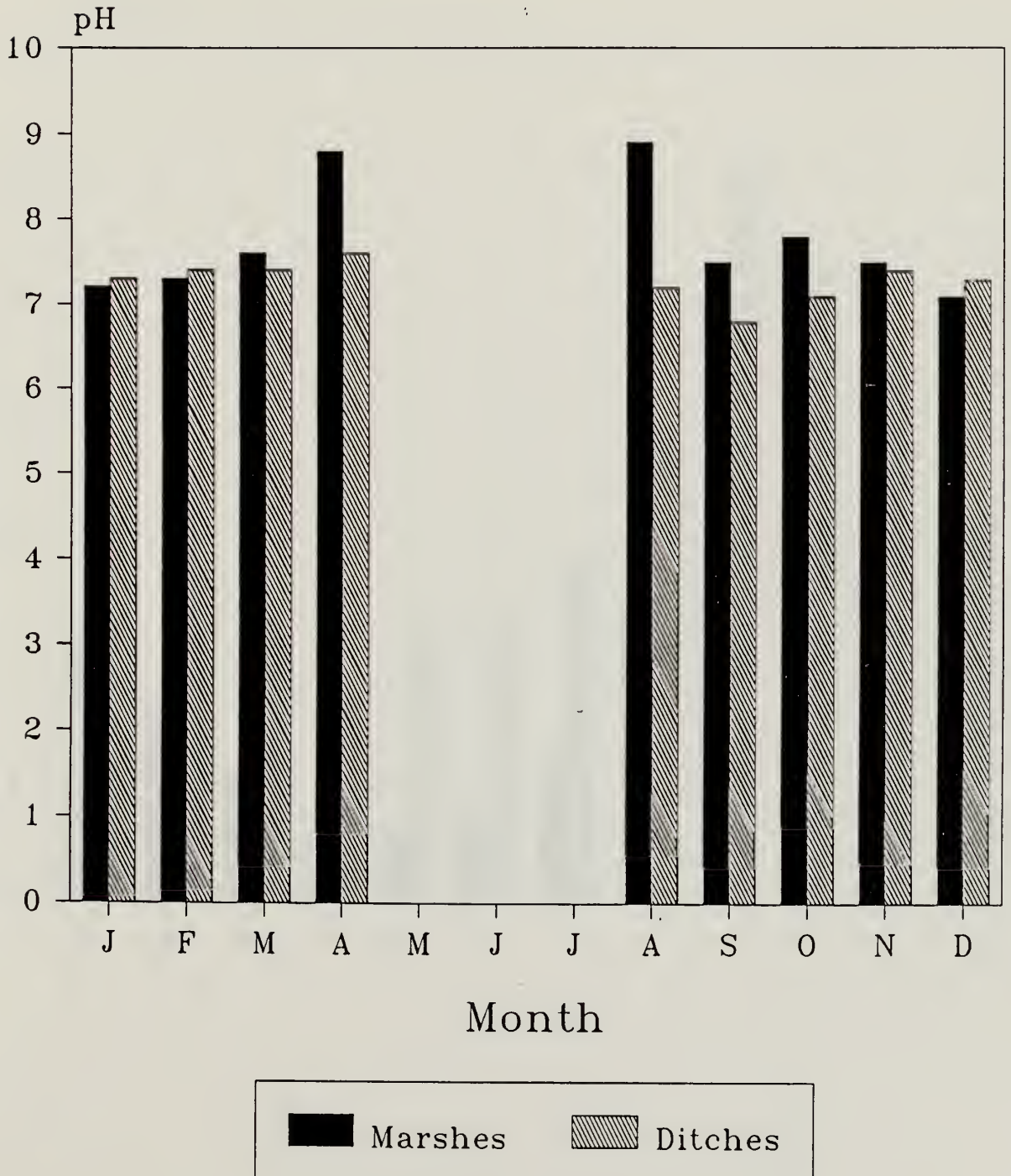


Figure 4.

Seasonal water chemistry: CAHA 1990.
Marsh sites versus ditch sites.

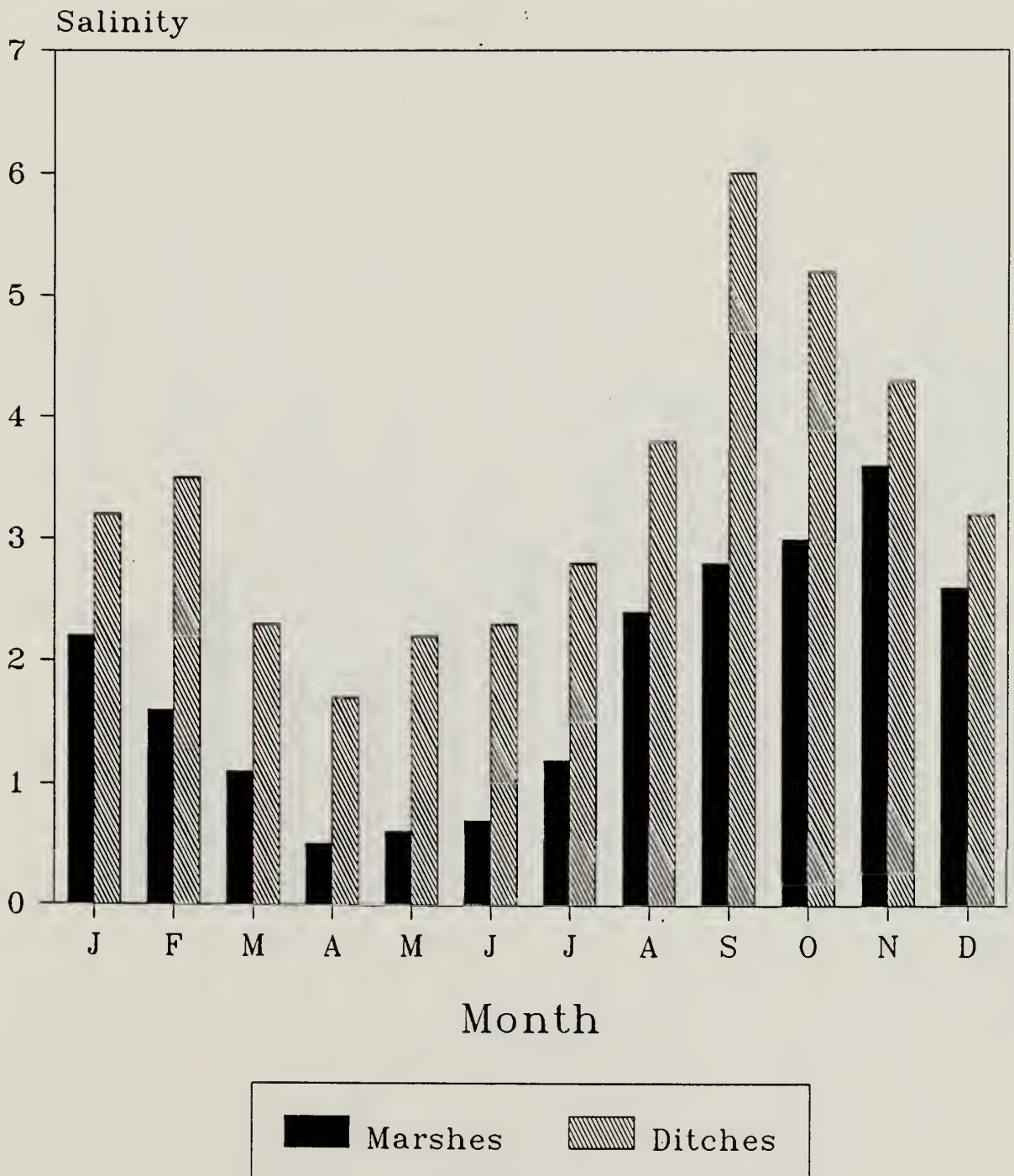


Figure 5.

Seasonal water chemistry: CAHA 1990.
Marsh sites versus ditch sites.

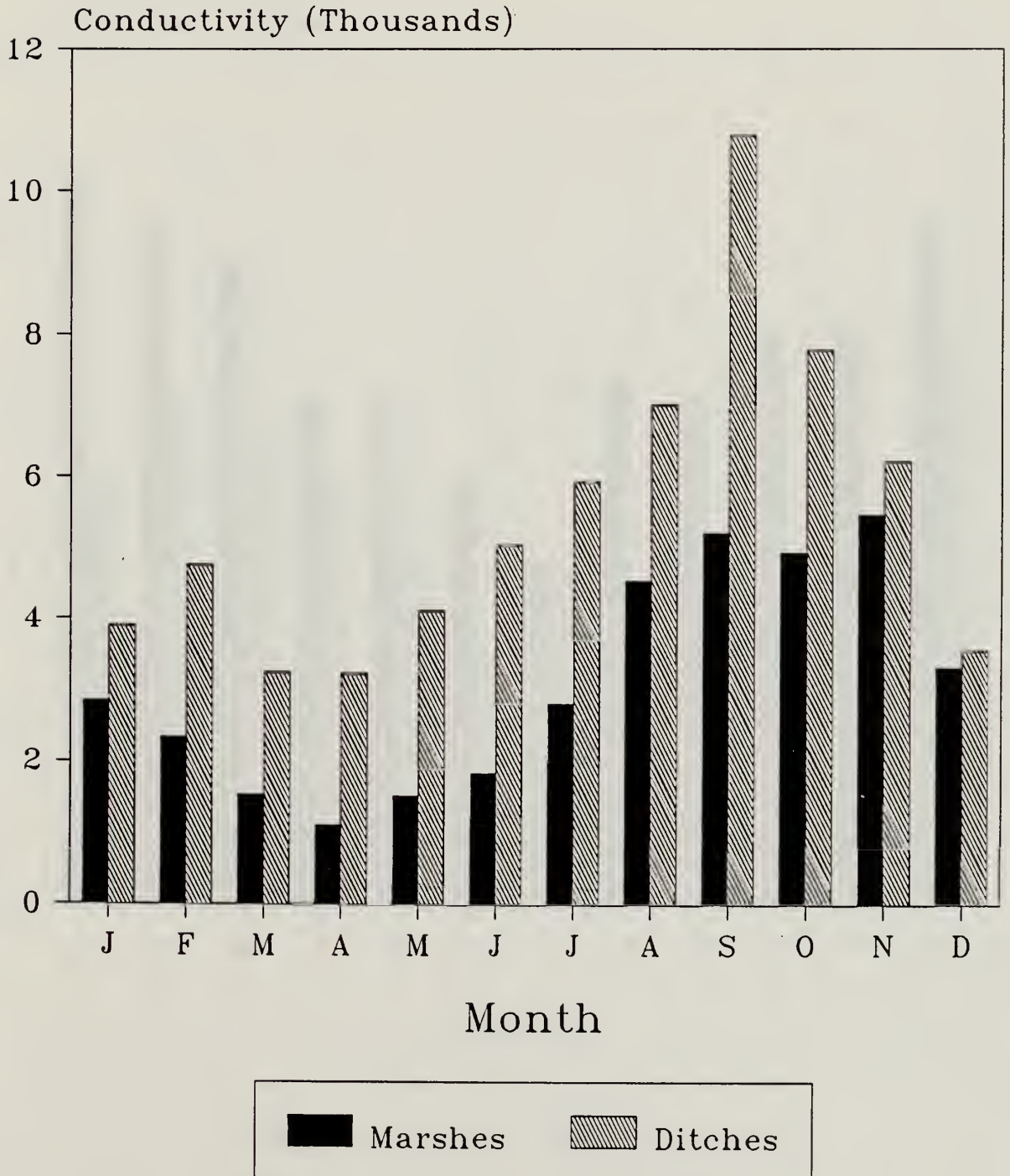


Figure 6.
Seasonal water chemistry: CAHA 1990.
Marsh sites versus ditch sites.

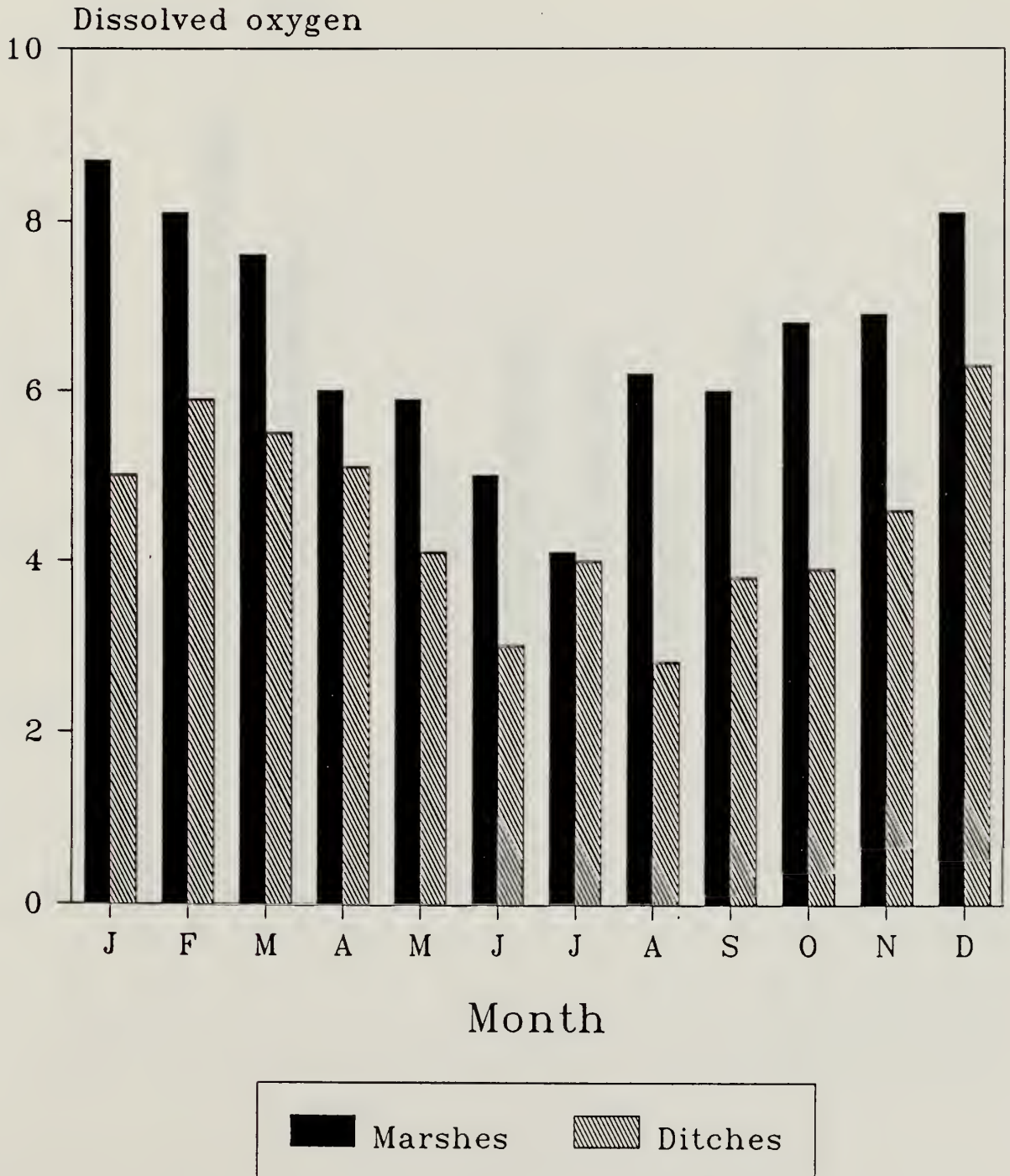


Figure 7.

Seasonal water chemistry: CAHA 1990.
Marsh sites versus ditch sites.

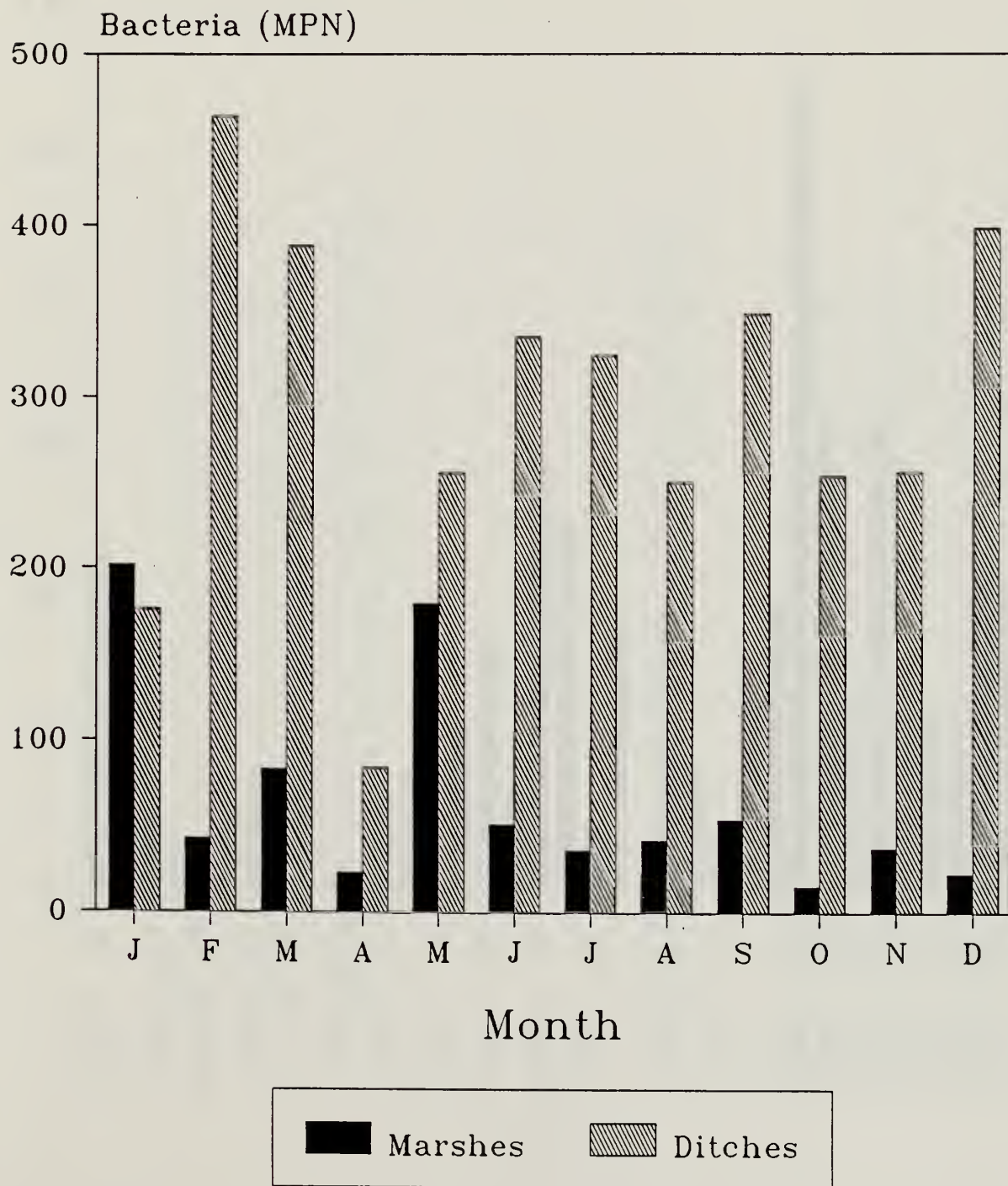


Figure 8.

Rainfall on Bodie Island: 1988-1990.
Cape Hatteras National Seashore

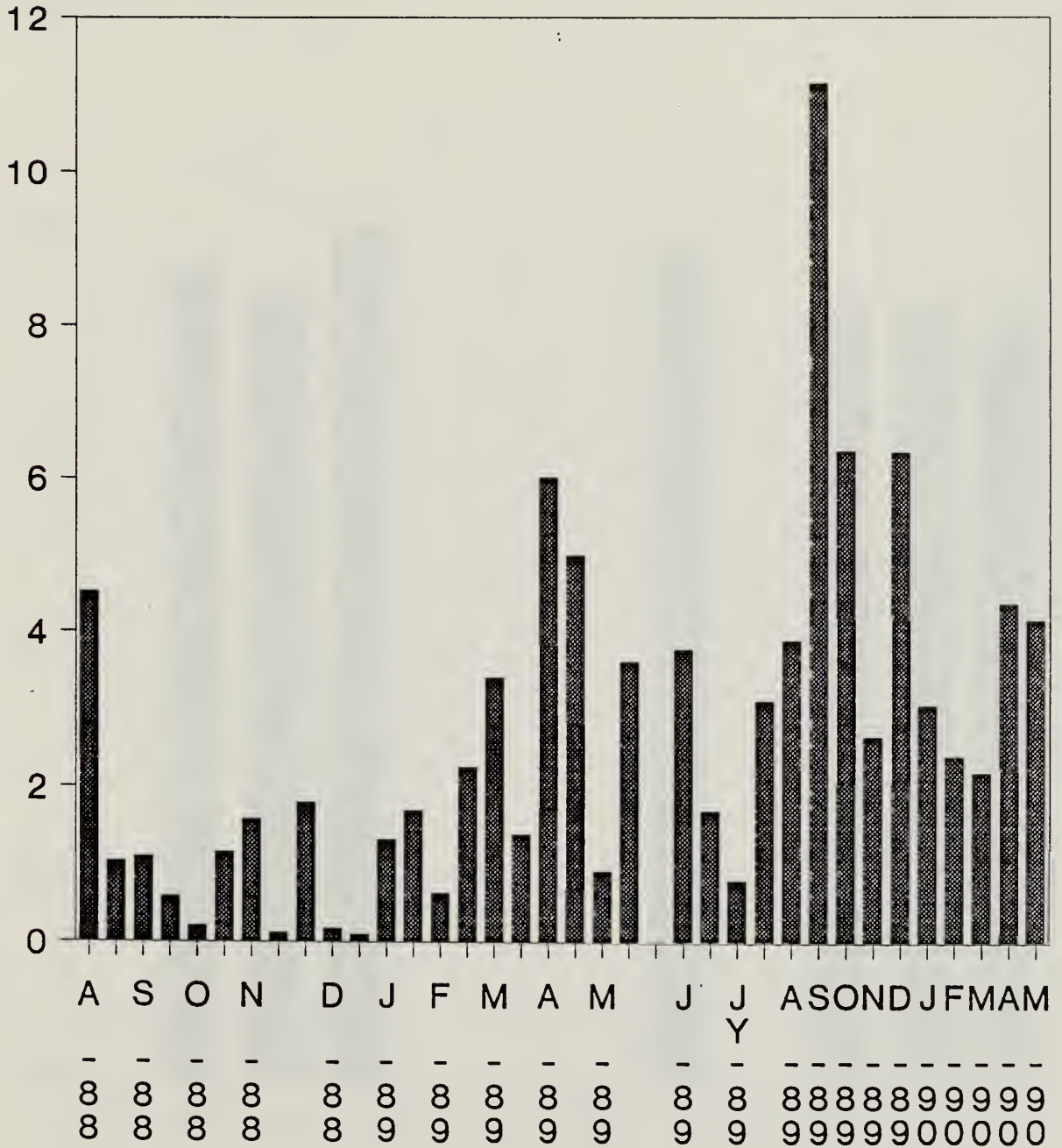


Figure 9.
Water chemistry-Buxton Woods.

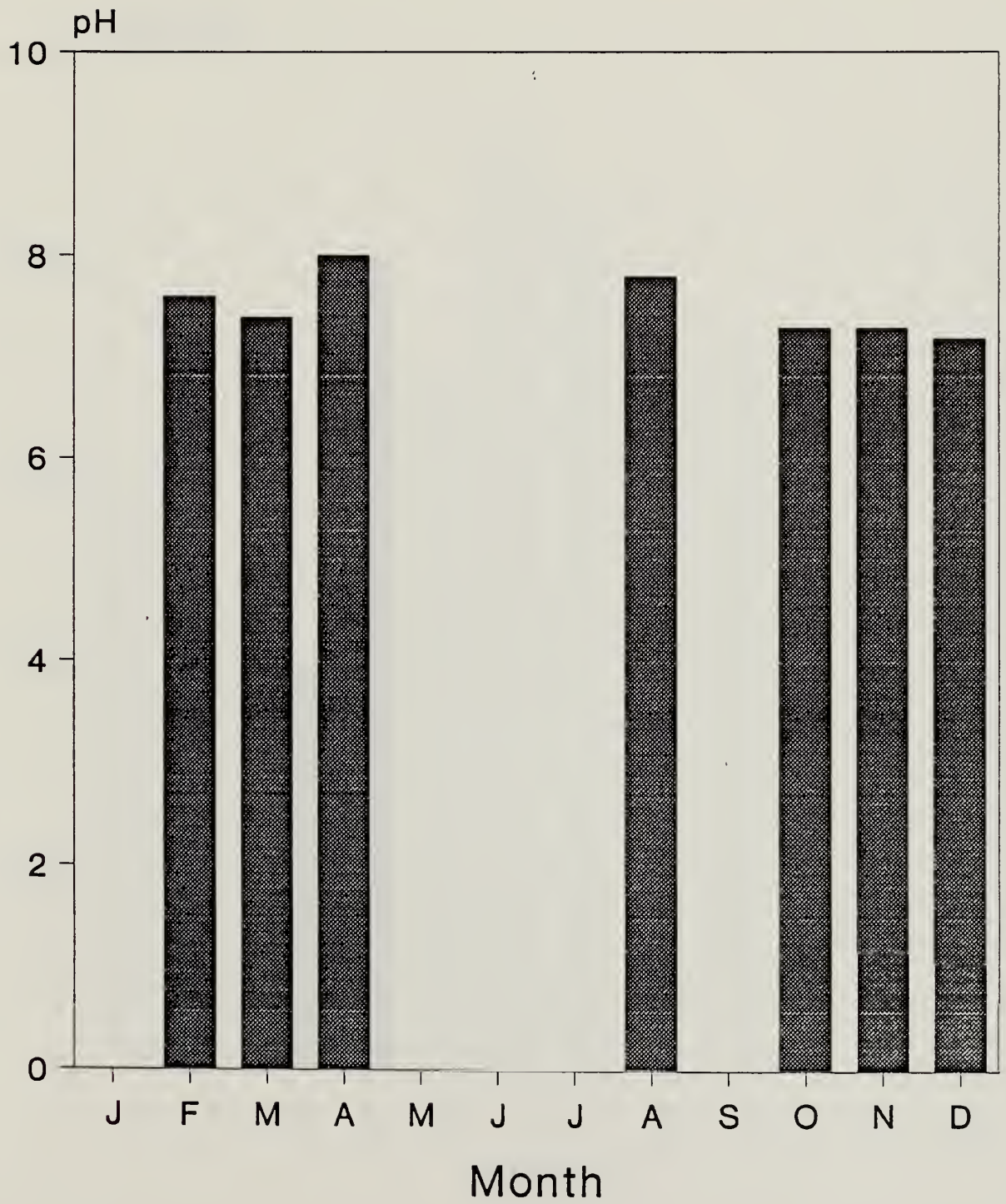


Figure 10.
Water chemistry-Buxton Woods.

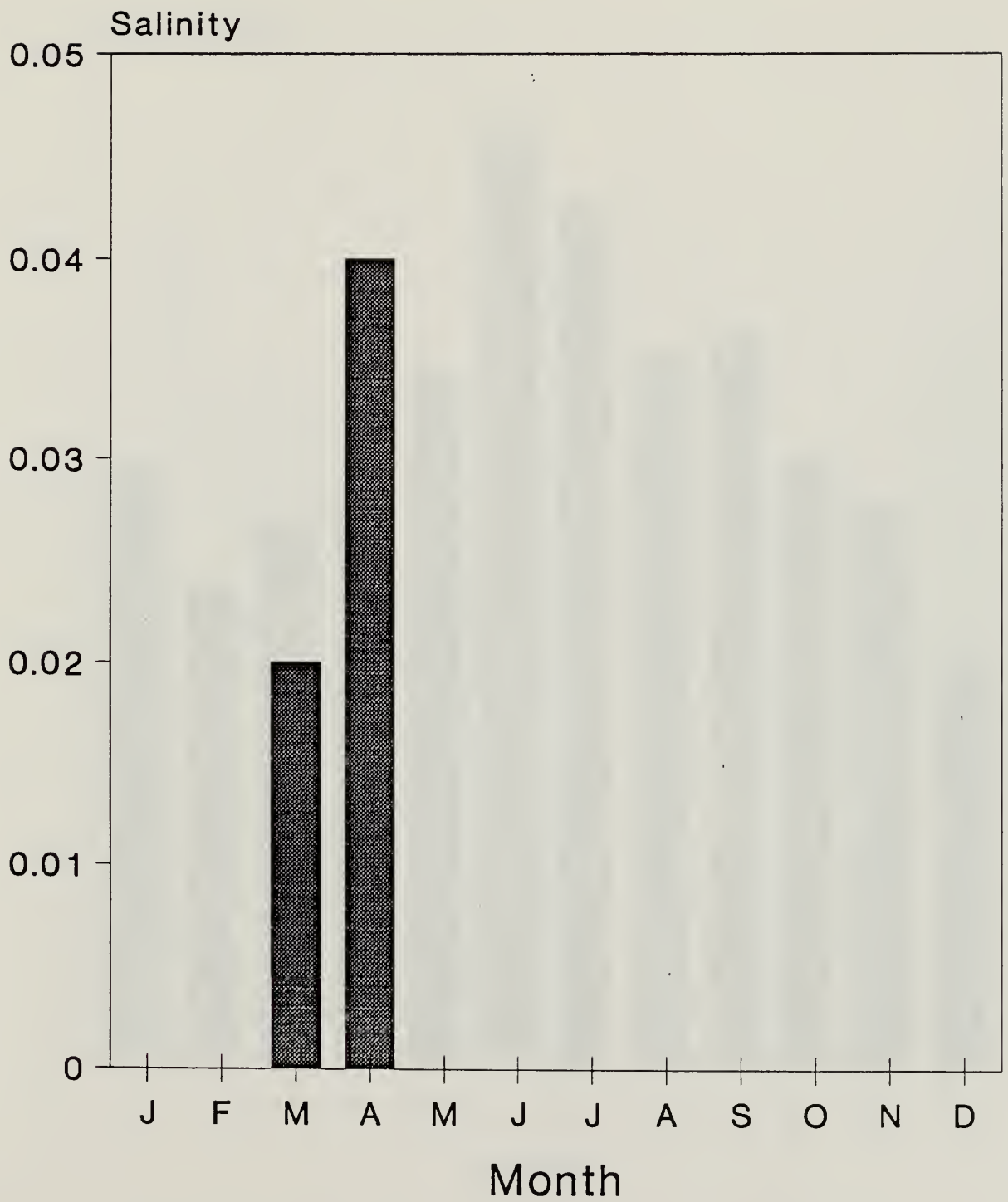


Figure 11.
Water chemistry-Buxton Woods.

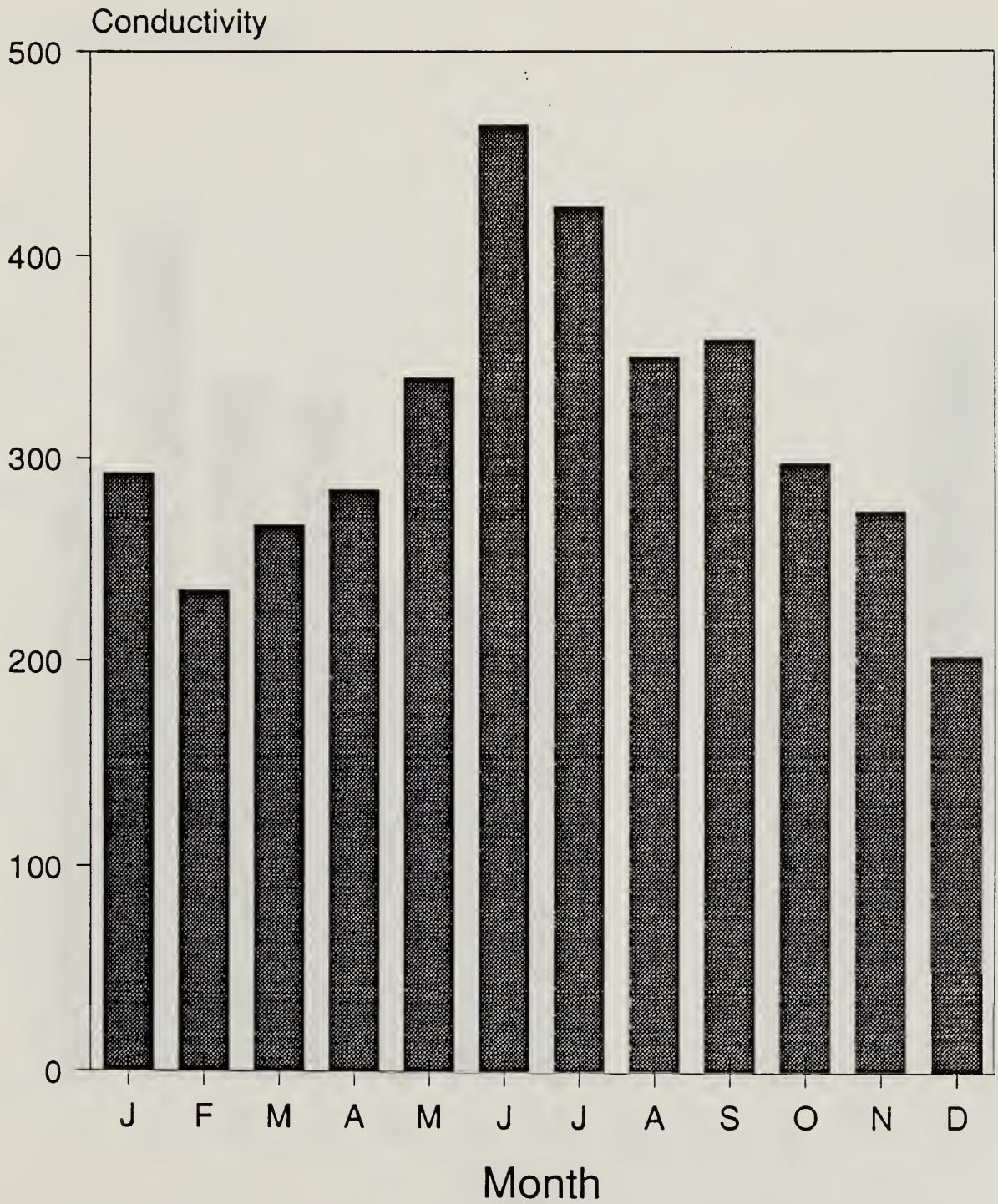


Figure 12.
Water chemistry-Buxton Woods.

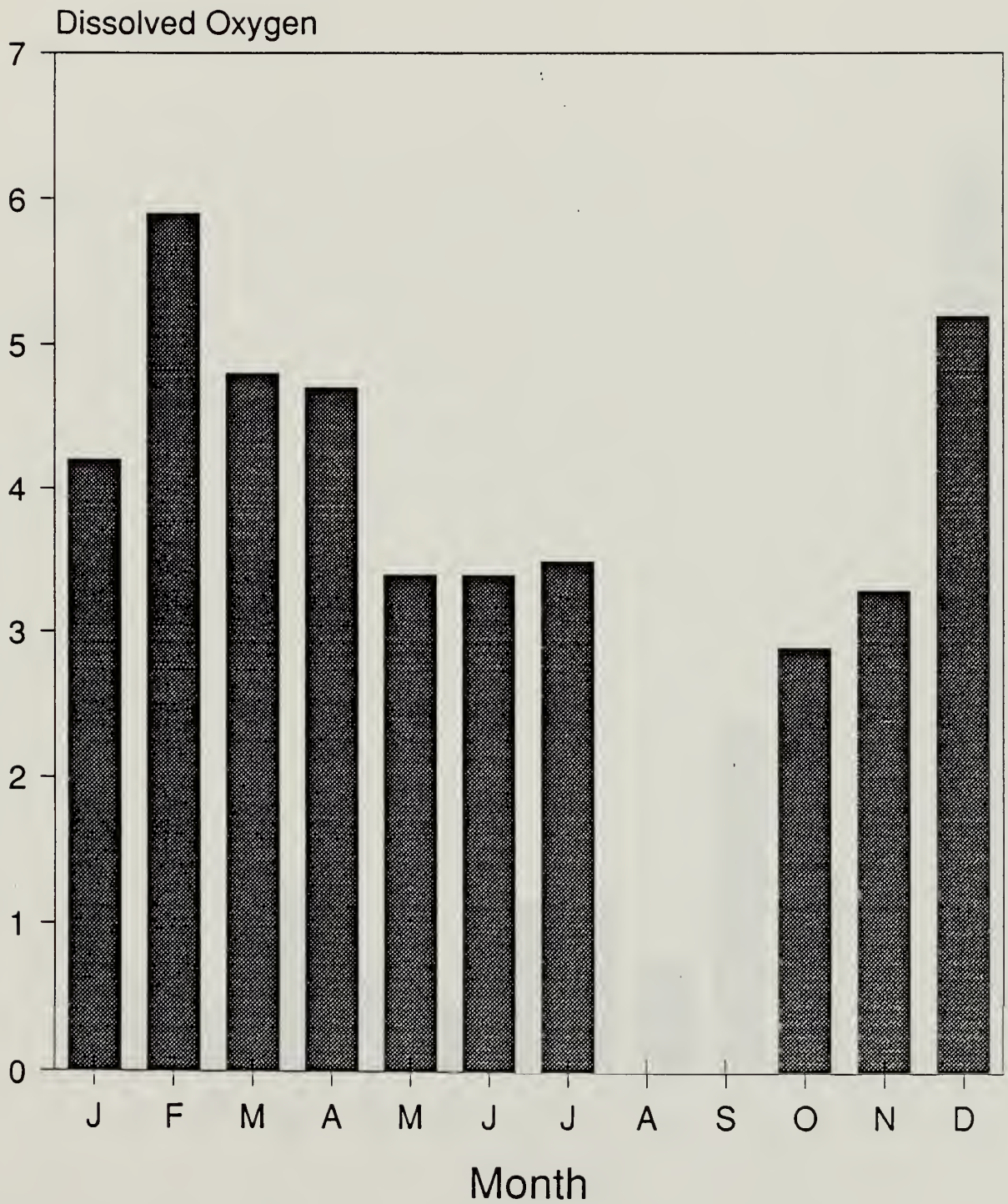


Figure 13.
Water chemistry-Buxton Woods.

