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PILGRIM LAKE SALINITY AND WATER FLOW
CAPE COD NATIONAL SEASHORE, 1995 - 1997

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Introduction

Since 1868, Pilgrim Lake's hydrology has been drastically altered to provide for road and rail transportation, to reduce the threat of shoaling of Provincetown Harbor, and to control nuisance insects (Redfield and Emery 1977). The lake was known as East Harbor before dike construction in the 19th century. Prior to this construction, East Harbor had a tidal range of about nine feet and was flushed with each tide. After diking, the harbor became a shallow, eutrophic lake with virtually no tidal exchange and an increase in emergent marsh plants and pest insect populations. Various combinations of weirs, culverts, and clapper valves have been in operation since the dike was constructed to allow freshwater to drain and to restrict salt water inflow (Redfield and Emery 1977). Varying lake levels and amounts of salt water entering the lake have dramatically altered conditions several times during the lake's existence. Currently, a weir near High Head Road controls the minimum lake level. Clapper valves installed to prevent salt water intrusion from Cape Cod Bay are currently nonfunctional, allowing salt water flow into the lake at high tides.

Methods

To monitor the occurrence of salt water in the lake, a series of salinity measurements was taken at three locations (Figure 1). Measurements were made weekly from 30 August through 12 December 1995, intermittently from 12 December to 7

February 1996, and bi-weekly from 7 February through 18 November 1997. Salinity was measured at the weir and at the lake bottom from two other points on the west shore (Figure 1). A stainless steel probe (2 mm inside diameter) with a rubber stopper just below 3 small (1.5 mm) orifices at the distal end and a 20cc syringe on top was used to suction water from the lake bottom. All sampling at the weir site was done near the top of the spillway boards. At the other two sampling locations, the probe was inserted into the sediment up to the bottom of the stopper at approximately 60 cm lake depth. The stopper prevented the probe from penetrating the sediment and also provided a stop to sample water from the top of the spillway boards. Three samples were drawn consecutively from each site to rinse the probe and syringe. The third sample was used as the test sample for salinity. We used a hand-held salinity refractometer (Automatic Temp. Comp. model A366ATC) to determine salinity to the nearest 0.5‰ (0.5 ppt). Water depth over the spillway boards on the east side of the weir was measured with a meter stick. Flow direction (in or out) was recorded at the same time. Observations were recorded in a field notebook along with the date, time, observer, and any comments related to the observations (Appendix). Field assistance was provided by K. Lee, T. Studds, and J. Wood. J. Portnoy assisted with study design and reviewed earlier drafts of this report.

Results

Sixty-two observations were made between 31 August 1995 and 18 November 1997 (Figure 2, Appendix). Salinity varied over time from 3-10‰ (Mean = 5.65, SD = 2.153) on the west end, 4-13‰ (Mean = 7.50, SD = 2.520) on the south end, and 4-32‰ (Mean = 15.44, SD = 9.903) at the weir (Table 1). Measurements were taken without regard to tide stage, so many different tidal stages are represented. Incoming flow over the weir was observed on 27 of 62 (44%) observations; conversely, outgoing flow was observed on the remaining 35 (56%) observations (Appendix). Measured salinity declined over the west and south sampling sites from the beginning of the study period through January 1996 (Figure 1). Salinities stabilized after that period for the west and south sampling sites. Great fluctuations in salinity were observed at the weir (Figures 2 and 3), which is not unexpected given seawater flowing through the clapper valves and over the weir.

Discussion

In other studies of Pilgrim Lake conducted since dike construction, salinity was generally much lower than the salinities measured during this study. One exception was a 1968 study when a midge outbreak and fish kill prompted an investigation of lake conditions and the clapper valves were likely inoperable. In that study chloride content was 9,800 ppm (17.5‰ S) near the outlet, 7,700 ppm (13.8‰ S) about one-third of the

distance from the outlet to the Provincetown (west) end of the lake, and 5,800 ppm (10.4‰ S) in the cove at the Provincetown end of the lake (Collins 1968; chloride to salinity conversions using Strickland and Parsons 1972). Emery and Redfield (1969) reported that salinity varied not more than 0.01‰ from 0.68‰ except for 0.53‰ at one station on the west end (all measurements were made on 16 August 1969). Salinity was < 4.0 ppt (4.0‰) at five stations in January, 1991 (Portnoy 1991). In this study, salinities ranged from 3-32‰ (salinity of seawater is 32‰). The reason for the higher salinities in this study are likely the nonfunctional clapper valves and lower spillway. This study recorded the salinity of the lake over a much longer time period than previous studies (> 2 years versus 1 day), giving a better picture of the variability of salinity over time (Figures 2 and 3, Table 1).

The drainage control structure has been altered several times since its installation in 1958. The spillway controls the minimum level of the lake and how much saltwater flowing landward through the clapper valves may enter the lake. The spillway was 65.5 cm from the top of the control box in 1969 (Emery and Redfield 1969). During this study (1995 - 1997), the spillway was 86.5 cm from the top of the control box. The height of the spillway did not change during this study. However, the clapper valves were not monitored and although certainly nonfunctional, may have varied in their effectiveness at preventing seawater from passing through the spillway. With incoming flow over the spillway on 44% of the visits, it appeared that little restriction was provided by the clapper valves. The average water depth at the weir was 32.53 cm (Range = 9.0-62.0,

SD = 14.466, n = 62). The average depth over the spillway reported by Emery and Redfield (1969), when the spillway was more restrictive than during this study, was 2.54 cm (0.133' or 1").

Water flowing into the lake tended to have a greater salinity than water flowing out (Medians = 26.0‰ and 7.0‰, respectively) (Figures 4 and 5). This is due to seawater flowing through the nonfunctioning tide gate, mixing with less saline lakewater upstream of the weir, and then flowing back through the weir as brackish water. Three observations of high salinity (> 25‰) on outflowing water were all between 2.9 and 3.4 h after Provincetown high tide. Those observations likely represent sampling unmixed seawater from within the channel on a recently turned tide. Similarly, 6 of 7 low (< 15‰) salinities on an incoming tide were within 1.0 h of high tide and likely represent brackish lakewater held in the channel by a rising tide and subsequently pushed back across the weir into the lake. Salinity on outflowing tides did not appear to be strongly correlated with the previous 7 d precipitation, even when the 3 high salinity measurements were removed from consideration because they represented recent turning of the tide and not true lake salinity.

Future Pilgrim Lake monitoring should carefully consider the role of tidal cycles in affecting the salinity measured at the weir. The bi-weekly schedule used for much of this study actually biased the results by sampling on a similar tide stage every two weeks. Future sampling should be more intensive (daily) and over a shorter time period (2 weeks

every quarter), to better describe a full tidal cycle within each season. Additionally, the actual function of the clapper valves should be investigated to aid in interpreting the tidal influence of the incoming tides through the valves.

References

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- Strickland, J. D. H. and T. R. Parsons. 1972. A practical handbook of seawater analysis. Bulletin 167, Fisheries Research Board of Canada, Ottawa, ON. 310pp.

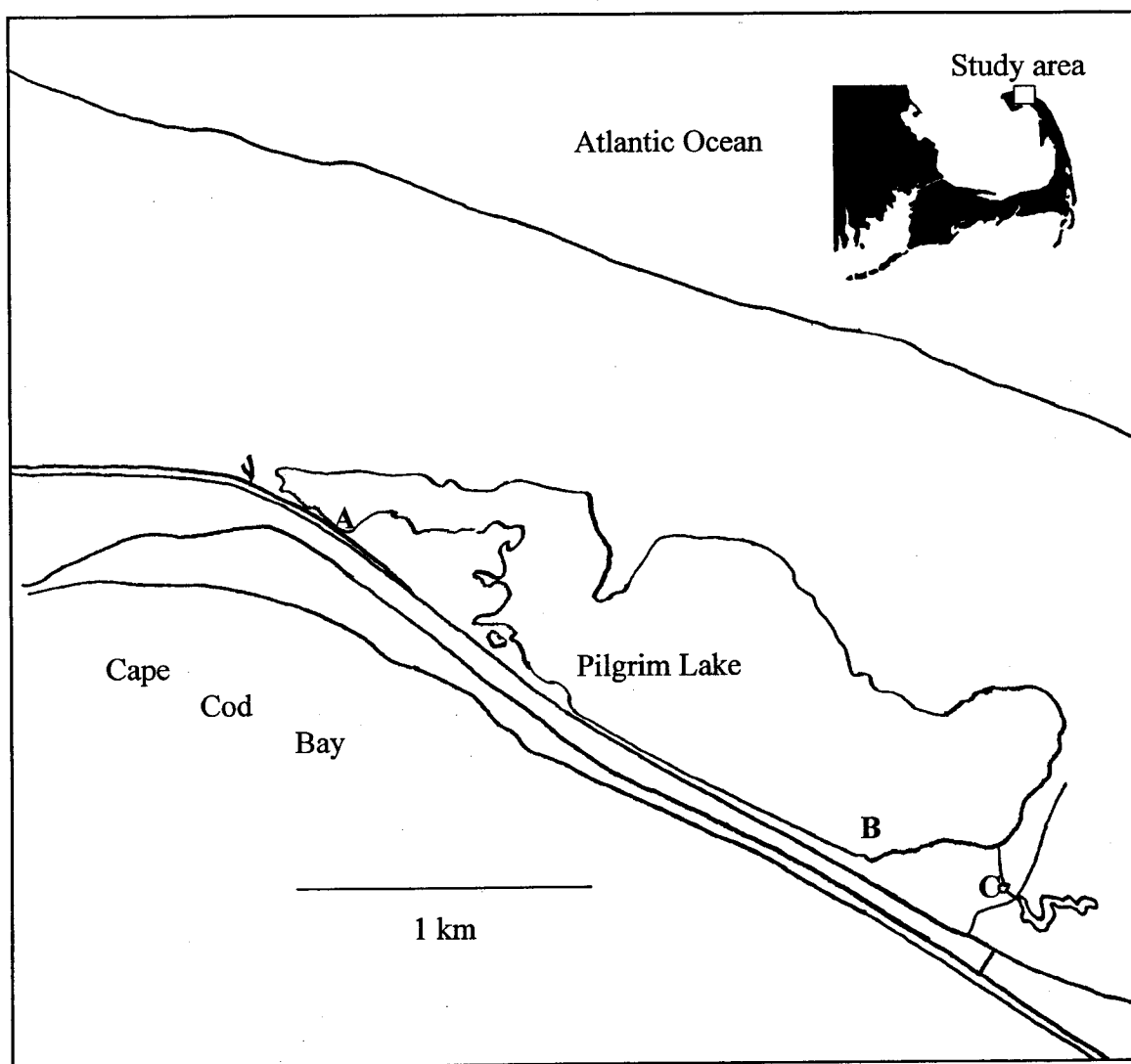


Figure 1. Study area and sampling locations, Pilgrim Lake, Cape Cod National Seashore, Massachusetts. Sampling sites are: A = west end, B = south end, C = weir.

7 pg. notes.

Pilgrim Lake salinity August, 1995 - October, 1997

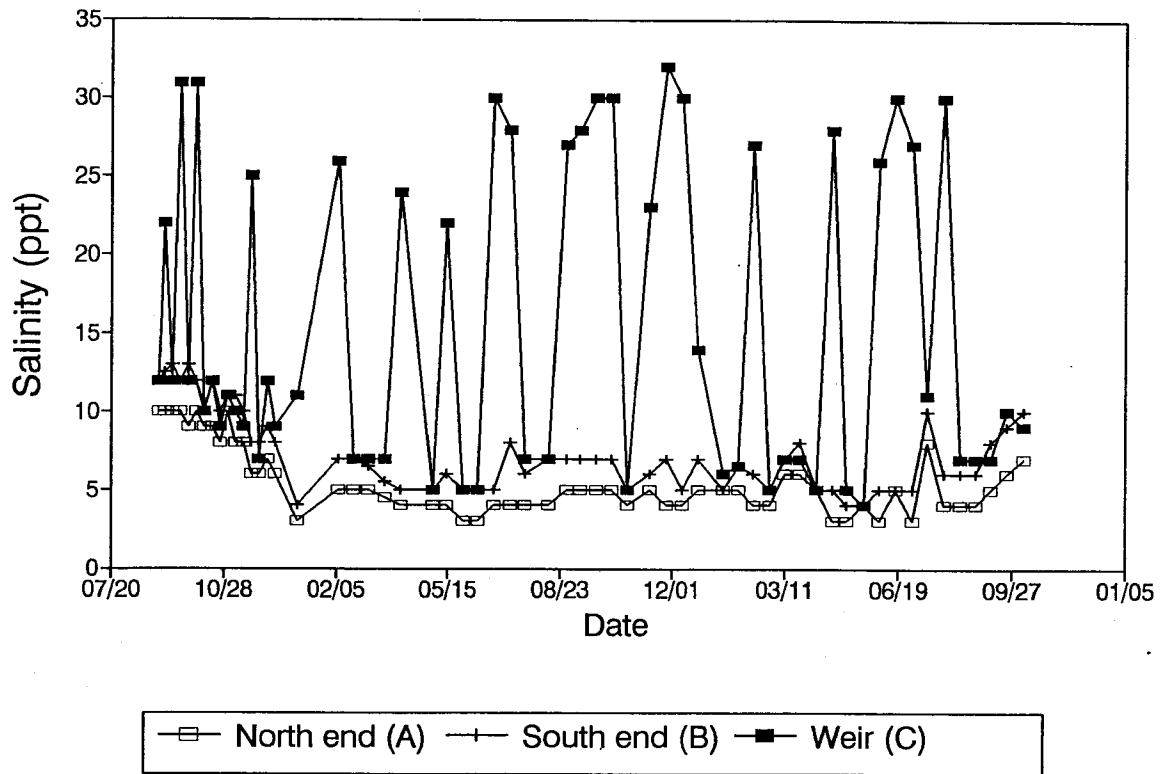


Figure 2. Salinity (ppt) from three sampling locations in Pilgrim Lake, 1995 - 1997.

of bottom water, ~2 cm off bottom.

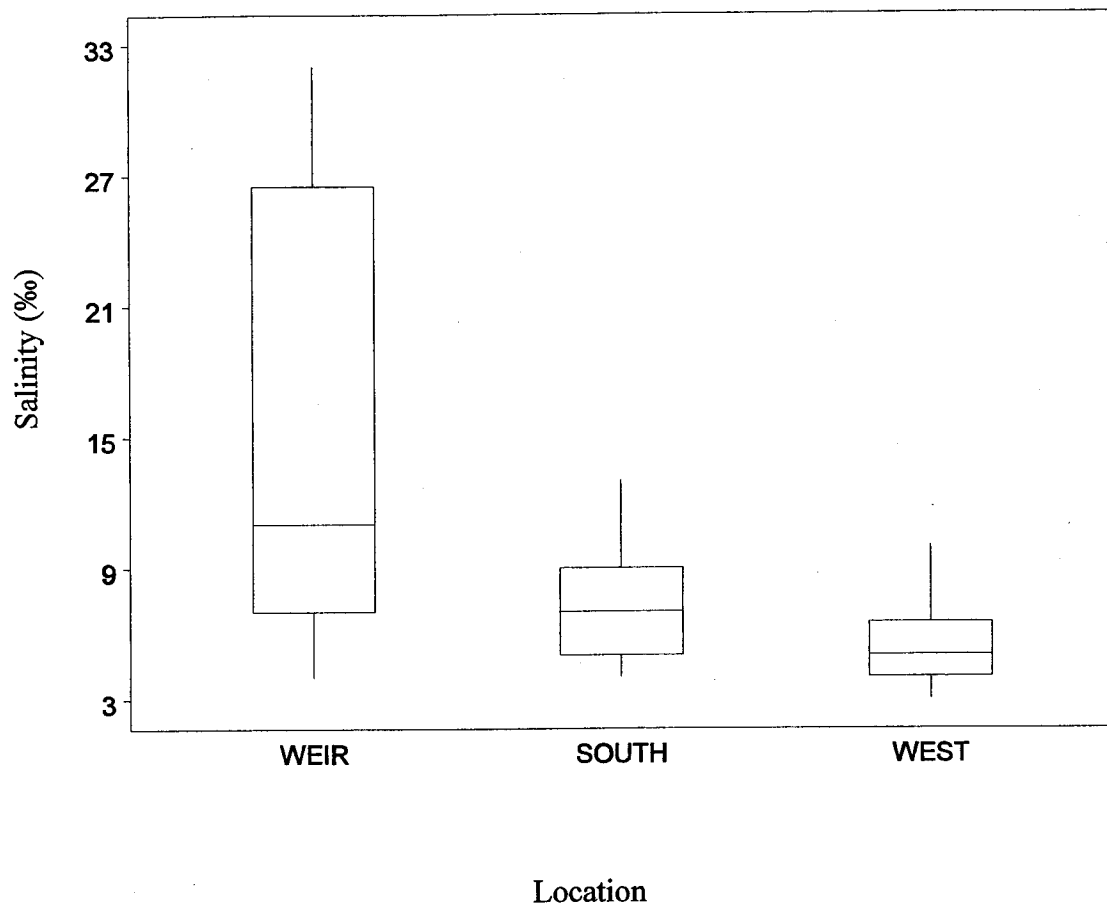


Figure 3. Box and whisker plots of salinity (‰) measured at three sites in Pilgrim Lake, 1995 - 1997 (59 observations). Median observations are represented by the horizontal line inside each box, the boxes represent the first and third quartiles, and the distal ends of the whiskers represent the full range of data.

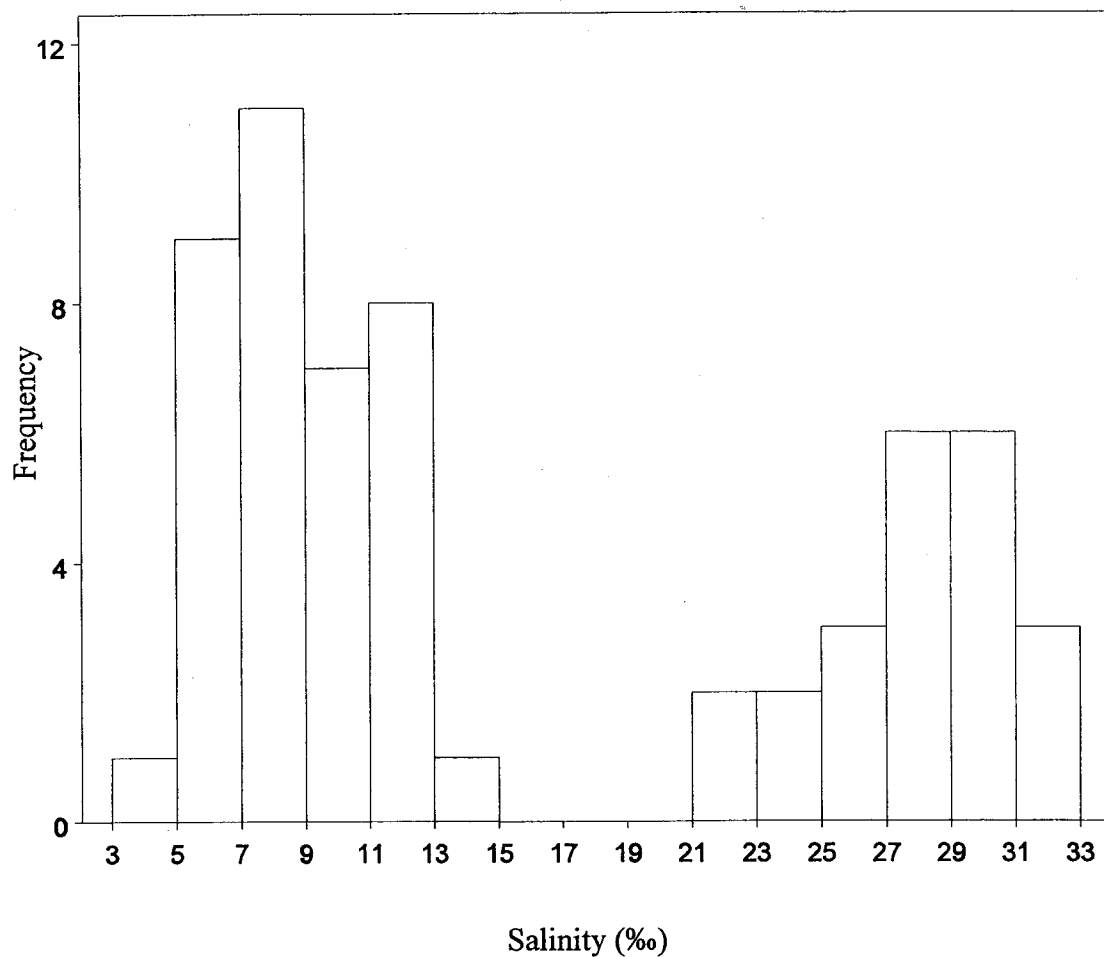


Figure 4. Histogram of salinity (‰) at the Pilgrim Lake weir, 1995 - 1997 (59 observations). Note the bi-modal distribution of salinity which is largely correlated with direction of flow (incoming seawater flow is more saline than outgoing brackish lake flow, except just after a turning tide).

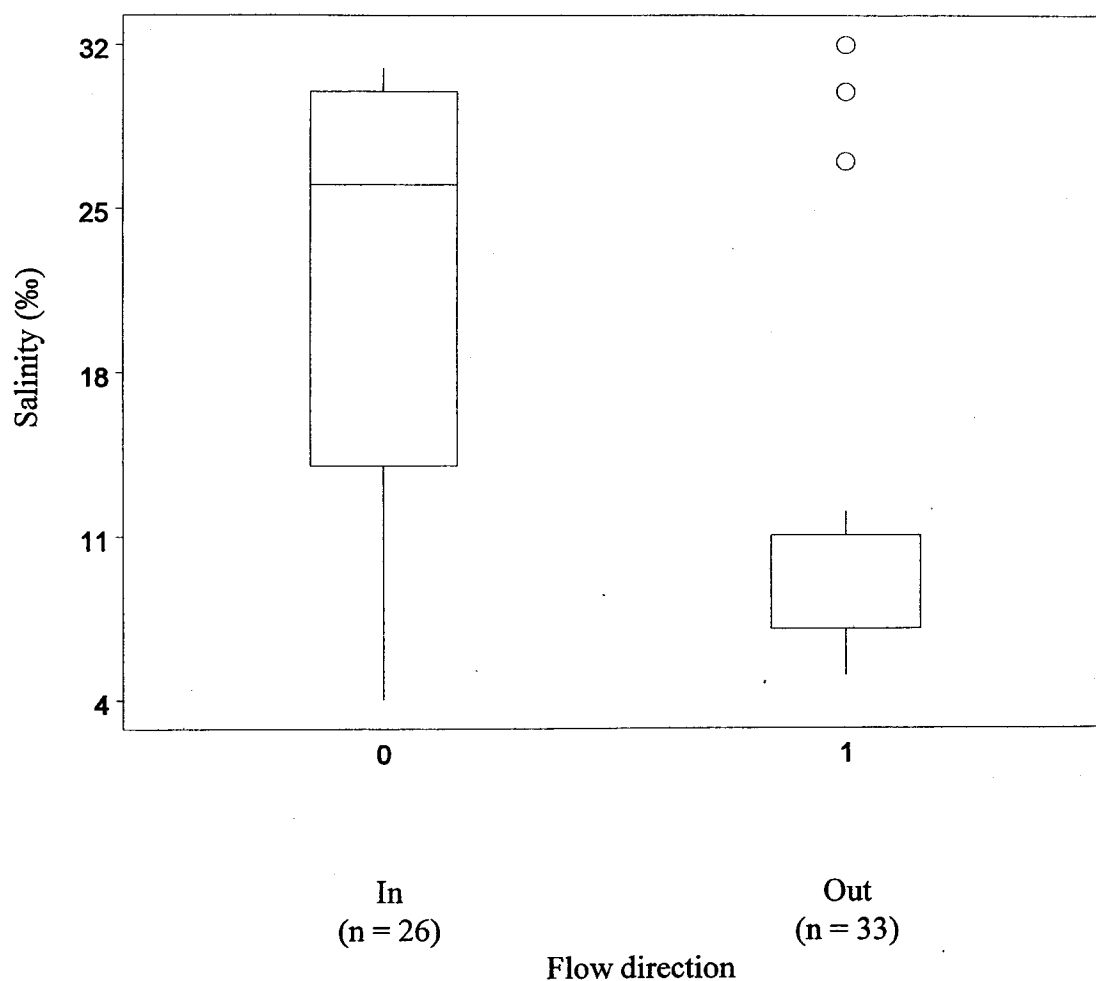


Figure 5. Box and whisker plots of salinity (‰) versus tidal flow direction measured at the weir in Pilgrim Lake, 1995 - 1997 (59 observations). Median observations are represented by the horizontal line inside each box, the boxes represent the first and third quartiles, and the distal ends of the whiskers and outlying circles represent the full range of data. Median (7 ‰) and first quartile (6.75 ‰) are nearly identical for outflowing water; therefore, the median is not discernable in this plot.

Table 1. Salinity (‰) measured at three sites in Pilgrim Lake, 1995 - 1997 (59 observations).

Site	Min	Med	Max	Mean (SD)
Weir	4	11	32	15.40 (9.876)
South	4	7	13	7.41 (2.547)
West	3	5	10	5.57 (2.170)

APPENDIX

PILGRIM

PILGRIM LAKE MONITORING

DATE	TIME(DST)	OBS	SALINITY (ppt)			WEIR	FLOW
			WEIR	S.END	W.END	DEPTH(cm)	DIRECTION
31-Aug-95	8:46	LKJ	12	12	10	10	OUT
5-Sep-95	9:30	JSW	22	12.5	10	31.5	IN
12-Sep-95	8:10	LKJ	12	13	10	9.5	OUT
19-Sep-95	8:20	LKJ	31	12	10	23	IN
26-Sep-95	10:55	LKJ	12	13	9	20.5	OUT
3-Oct-95	9:27	JSW	31	12	10	34.5	IN
10-Oct-95	10:14	JSW	10	10	9	23.5	OUT
17-Oct-95	10:05	LKJ	12	12	9	29	OUT
24-Oct-95	8:48	JSW	9	10	8	20	OUT
31-Oct-95	9:25	JSW	11	11	10	18.4	OUT
7-Nov-95	9:45	LKJ	10	11	8	35.5	IN
14-Nov-95	10:42	JSW	9	10	8	13	OUT
21-Nov-95	8:55	LKJ	25	8	6	48	IN
28-Nov-95	11:55	JSW	7	8	6	28	OUT
5-Dec-95	8:40	LKJ	12	9	7	44	IN
12-Dec-95	8:45	LKJ	9	8	6	17.5	OUT
1-Jan-96	10:50	JSW	11	4	3	49.7	IN
7-Feb-96	13:15	LKJ	26	7	5	43.5	IN
20-Feb-96	9:30	LKJ	7	7	5	36	OUT
5-Mar-96	9:40	LKJ	7	6.5	5	22	OUT
19-Mar-96	10:00	LKJ	7	5.5	4.5	47	IN
2-Apr-96	9:20	LKJ	24	5	4	47	IN
1-May-96	8:20	LKJ	5	5	4	30	OUT
14-May-96	9:20	LKJ	22	6	4	38.5	IN
28-May-96	14:30	LKJ	5	5	3	13	OUT
11-Jun-96	8:00	TAS	5	5	3	29	OUT
25-Jun-96	8:00	TAS	30	5	4	36	IN
9-Jul-96	8:00	TAS	28	8	4	36	IN
23-Jul-96	10:00	TAS	7	6	4	10	OUT
13-Aug-96	9:30	LKJ	7	7	4	9	OUT
28-Aug-96	11:00	LKJ	27	7	5	22	IN
10-Sep-96	11:40	LKJ	28	7	5	47	IN
24-Sep-96	11:20	LKJ	30	7	5	54.5	IN
8-Oct-96	10:20	LKJ	30	7	5	54.5	IN
22-Oct-96	12:35	JSW	5	5	4	54.6	OUT
11-Nov-96	8:30	JSW/KDL	23	6	5	48.2	IN
26-Nov-96	14:40	LKJ	32	7	4	47	OUT
10-Dec-96	14:10	LKJ	30	5	4	52	OUT

PILGRIM

24-Dec-96	10:45	KDL	14	7	5	44.1	IN
16-Jan-97	9:10	LKJ	6	5	5	35	OUT
29-Jan-97	11:50	LKJ	6.5	6.5	5	36	OUT
11-Feb-97	13:35	LKJ	27	6	4	42.5	IN
26-Feb-97	9:10	LKJ	5	5	4	17	OUT
11-Mar-97	10:45	KDL	7	7	6	42	OUT
24-Mar-97	9:30	LKJ	7	8	6	18	OUT
8-Apr-97	11:20	LKJ	5	5	5	62	OUT
22-Apr-97	13:50	LKJ	28	5	3	56	IN
5-May-97	11:02	JSW	5	4	3	44.5	IN
20-May-97	10:08	LKJ	4	4	4	44	IN
3-Jun-97	11:00	LKJ	26	5	3	37.5	IN
17-Jun-97	11:30	LKJ	30	5	5	35.6	IN
1-Jul-97	12:30	LKJ	27	5	3	30.5	OUT
15-Jul-97	15:00	KDL	11	10	8	11	OUT
29-Jul-97	10:30	LKJ	30	6	4	36	IN
13-Aug-97	14:45	LKJ	7	6	4	9.5	OUT
26-Aug-97	11:20	LKJ	7	6	4	19.5	OUT
9-Sep-97	11:30	LKJ	7	8	5	12.5	OUT
23-Sep-97	10:40	LKJ	10	9	6	15.5	OUT
7-Oct-97	11:10	LKJ	9	10	7	15	OUT
21-Oct-97	15:36	LKJ	31	10	8	36	IN