

# GOAT LAKE, A WARM WATER, ESTUARINE REFUGIA FOR MOLLUSCS ON THE SOUTH SHORE OF NOVA SCOTIA

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Goat Lake is a tidal, silled, 11.5 m deep lake-like estuary situated off Mahone Bay on the Atlantic coast of Nova Scotia. The lake is flushed for 2 h and 21 min during an average high tide, and requires between 8 and 32.4 days for complete exchange depending on stratification conditions. Salinity at depths below 3 m average 28 ‰. A 0.5-1 m surface layer of brackish water in combination with the limited flushing led to periods of anoxia in water deeper than 5 m. Maximum surface temperature was 25.1°C during the summer and average summer surface temperature was 2.8°C above adjacent Mahone Bay. Goat Lake has reproducing populations of the ribbed mussel, *Geukensia demissa* and American oyster, *Crassostrea virginica* which rarely occur along the south shore of Nova Scotia. Unique marine ecosystems, such as Goat Lake, should be surveyed and some possibly placed on the list of protected, natural heritage sites in the province of Nova Scotia.

Goat Lake, situé en dehors de MaHone Bay sur la côte atlantique de la Nouvelle-Écosse, est un estuaire sujet à la marée, profond de 11.5 m avec un seuil et avec l'apparence d'un lac. Ce lac est inondé pendant 2 h et 21 min lors d'une moyenne haute marée, et a besoin de 8 à 32.4 jours pour un échange complet, dépendant des conditions de stratification. Au dessous de 3 m, la salinité a une moyenne valeur de 28 ‰. Une couche superficielle d'eau saumâtre de 0.5-1 m, avec un débordement limité, a produit des périodes d'anoxie dans l'eau en dessous de 5 m. La température superficielle maximum pendant l'été était 25.1°C et la température superficielle moyenne pendant l'été était 2.8°C plus élevée que celle de la Mahone Bay avoisinante. Il y a dans Goat Lake des populations reproductrices comme la moule à côtes *Geukensia demissa* et l'huître américain *Crassostrea virginica*, deux espèces que l'on trouve rarement sur la côte sud de la Nouvelle-Écosse. Les écosystèmes uniques, comme ceux de Goat Lake, devraient être surveillés, et, si possible, placés sur la liste des sites naturels protégés en patrimoine dans la province de la Nouvelle-Écosse.

## Introduction

Goat Lake is a marine, tidally influenced, lake-like, silled estuary located in Lunenburg County, Nova Scotia (44°58'16"N, 64°21'05"W). Goat Lake appears to be a freshwater lake with a short outflow creek that runs through a salt marsh emptying into Secret Cove, Mahone Bay. However, water flow reverses to flow into the lake at high tide. The situation is similar to the Saint John River at Reversing Falls gorge where a sill restricts the inflow and outflow, causing a reduction in the tidal range of the estuary in comparison to the Bay of Fundy (Metcalf et al., 1976).

We found populations of ribbed mussels, *Geukensia demissa* (Dillwyn, 1817) and American oysters, *Crassostrea virginica* (Gmelin, 1792) in Goat Lake. *Geukensia demissa* is a mud-dwelling mussel of salt marshes on the Atlantic coast of North America occurring from the Gulf of St. Lawrence to Florida and along the Gulf of Mexico from Florida to Yucatan (Bertness, 1980; Brousseau, 1984; Lin, 1989). It is reported to be very scarce north of northern Massachusetts (Franz, 1995) and is extremely rare in Minas Basin (Bleakney and Meyer, 1979). The American oyster has a range similar to the ribbed mussel, but is rare along the Atlantic shore of Nova Scotia.

Our study examined the hydrographic characteristics of Goat Lake including the amount of tidal flushing. Temperature, salinity, and dissolved oxygen were monitored between May and November during 1995 and 1996. The life history characteristics of the ribbed mussels in Goat Lake were studied including the annual gonadosomatic

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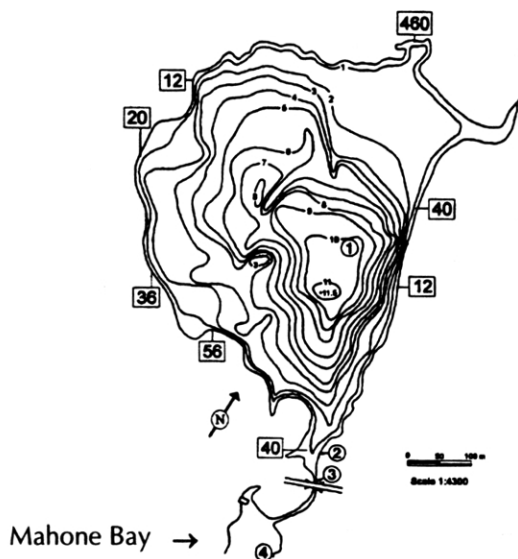
cycle of the adults, spat-settlement, and demographics to determine if this isolated population is self-reproducing.

Our original objective in this research was to locate suitable warm water habitat for use as a nursery for shellfish aquaculture. With the discovery of the unique shellfish species occurring in Goat Lake and its unsuitability for a nursery due to anoxic conditions, we decided to describe the lake and present it as a candidate for inclusion in Nova Scotia's protected, natural heritage areas.

## Materials and Methods

### *Morphometry and Hydrographic Mapping*

An outline of Goat Lake was obtained from a 1:4800 topography map compiled from aerial photographs taken from Hubbards to East Chester. Goat Lake was enlarged from the East River section to 1:3400 using a photocopier. Morphometrics were measured using a centimeter ruler to the nearest millimeter and converted to meters using the map scale (1 mm = 3.4 m; Fig 1). A depth contour map was compiled from depth soundings taken along a series of transects across Goat Lake. A small craft starting at one boat length from shore was run at constant speed along each transect. Soundings were taken at 15-second intervals using a Royal RF-120 depth sounder.



**Fig 1** Bathymetric map of Goat Lake, Lunenburg County, indicating stations 1-4 and density distribution of ribbed mussels, *Geukensia demissa* (mussels/m<sup>2</sup>) at representative stations (in squares). Contour intervals are 1 m.

From the bathymetric map; maximum depth ( $Z_{max}$ ), mean depth ( $Z$ ), relative depth ( $Z_r$ ), volume development ( $Z/Z_{max}$ ), surface area (m<sup>2</sup>), and volume (m<sup>3</sup>) were determined (Cole 1994). The volume of the lake was determined by two methods, integrating a hypsographic curve and adding the volumes calculated by a geometric

formula for each depth interval. The final volume was taken as an average of the results of these two methods.

#### *Water Levels, Tidal Flow, and Flushing Time*

Water levels are expressed with reference to the minimum level in 1995 measured using a self-made tide gauge since no benchmark is easily accessible (Welch, 1948). The tide gauge consisted of a wooden stake marked off in 0.5 cm gradations. Tidal flow for a spring, neap, and two average tidal cycles were recorded at station 3 using a T.S.K. 3725 Tsurumi-Seiki Co. Ltd. Current-meter suspended in the inflow\outflow channel connecting Goat Lake to Mahone Bay. The flushing time (t) in tidal periods was determined using the "tidal prism method" outlined by Bowden (1967) such that

$$t = \frac{V+P}{P}$$

Where: V = total volume of the estuary at low water and,  
P = volume of water entering during flood tide (intertidal volume).

The flushing calculations considered tidal exchange as the main mixing process and used data on the tides and physical dimensions of the lake. Freshwater inflow was ignored since the streams entering the lake were negligible in size most of the year. The "tidal prism method" assumed that all water entering during flood tide becomes completely mixed with the water in the estuary and the ebb flow consists of this mixed water (Bowden, 1967). Salinity data was used to determine whether mixing was vertically complete or not. If it was not complete, the flushing time was corrected to only include the volume of water, which was actively mixed from that vertical depth to the surface (Ketchum, 1951).

#### *Water Analysis*

Water analysis was conducted over the two-year study period with tri-weekly readings from May to November. Temperature and salinity measurements were taken for surface waters, 0.5 m, and from 1-10 m at one meter depth intervals at station 1 in Goat Lake (Fig 1). Comparative measurements were obtained in Secret Cove, Mahone Bay for surface waters, 0.5 m and from 1-3 m at one-meter depth intervals. Temperature (°C) and salinity (‰) readings were measured using a YSI Model 33 S-C-T meter with a probe cord graduated at 1 m intervals, after calibration using a mercury thermometer.

The number of degree days above 10°C was determined for surface waters and at a depth of 3 m at station 1 in Goat Lake to determine if there was any significant shift in the temperatures between 1995 and 1996 (Mann-Whitney, 95%). Comparative temperatures between Mahone Bay and Goat Lake were analysed using degree-days (Mann-Whitney, 95%) for the period from May 8 to November 2, 1996.

Dissolved oxygen samples were obtained using a Nissan water-sampler at station 1 in Goat Lake for surface water, a depth of 0.5 m, and 1-10 m at 1-m intervals. Water samples were also taken at station 4 in Secret Cove, Mahone Bay for surface waters and at a depth of 2 m. The Winkler method was used to determine dissolved oxygen (Welch, 1948).

#### *Biota of Goat Lake*

The fauna of Goat Lake was collected by hand, while wading or by snorkeling. Organisms were visually identified onsite or collected for later identification. Emphasis was placed on species uncommon to marine waters of the Atlantic coast of Nova Scotia

such as the ribbed mussel, *Geukensia demissa* (Bleakney and Meyer, 1979). Distribution of mussels within the lake was observed by wading along shore or by snorkeling. Mussel densities were determined at each location (indicated by numbers in squares in Fig 1) by placing a 0.25 m<sup>2</sup> quadrant on the bottom and counting the number of individuals inside. Demographics of the population were assessed by picking samples of ribbed mussels by hand at various locations within the lake to a maximum depth of 0.5 m. Care was taken to collect all mussels within a given area to prevent bias towards larger sized individuals. Shell length was measured and recorded to the nearest millimeter using a measuring board. Mussels were then returned to the exact locations from which they were removed. Shell length histograms were created by dividing length data into 9 size classes ranging from 0-90 mm.

Samples of 10-12 ribbed mussels were taken on a bi-weekly basis over the sampling period in order to monitor gonadosomatic development. Individual mussels were scrubbed and excess byssus was removed for measurement of total mass (g). The mussels were steamed for approximately 5 minutes at 100°C to remove the body from the shell. The shell mass (g) was measured and subtracted from the total mass (g) to determine the wet body weight. The remaining byssus was removed with dissecting scissors. The body was placed within labelled tin cups and dried for 24 hours at 150°C to find dry body weight. For each year, samples were analyzed by setting a standardized shell length (one-way ANOVA, P=0.05) to determine a size range with no statistical significant difference between mean shell lengths of collected samples. Mean dry body weight (g) and mean wet body weight (g) were determined for standardized mussel samples and statistically analyzed (one-way ANOVA, P=0.05) to determine when significant drops in body weight occurred during the year which was assumed to indicate spawning.

## Results

### *Morphometry and Hydrographic Data*

Goat Lake has a maximum length of 685 m, maximum breadth of 597 m, mean breadth of 296 m, a shoreline length of 2,370 m and an area of 20.2 ha (Table I). Goat Lake is relatively shallow. Mean depth is 4.12 m and relative depth 2.25% (Table I). The maximum depth of 11.5 m, occurs in a central basin (Fig 1). The average volume determined by integration of a hypsographic curve and by geometric formulas is 8.35 x 10<sup>5</sup>m<sup>3</sup> (Table 1).

**Table I** Morphometrics, morphometry, and flushing time of Goat Lake determined from 1:3400 hydrographic map.

Maximum length (l)	685 m
Maximum breadth (b)	597 m
Mean breadth (b)	296 m
Shoreline length (L)	2.37 x 10 <sup>3</sup> m
Area (Ao)	20.2 ha
Maximum depth (Zmax)	11.5 m
Mean depth (Z)	4.12 m
Relative depth (Zr)	2.26%
Average volume	834,692 m <sup>3</sup>
Development of volume	0.358
Average tidal range ±max/min.	5.5 ±15.0/1.0 cm
Flushing time with incomplete vertical mixing	15.0 tidal periods
Flushing time with complete vertical mixing	60.7 tidal periods



### *Water Levels, Tidal Flow, and Flushing Time*

The water level in Goat Lake varied with the season and also with the tide on lunar cycle rather than a semi-diurnal cycle. The tidal range measured with the tide gauge indicated an average increase in water level of 5.5 cm during flood tide when water was flowing into Goat Lake.

Flood tides lasted 2 hours and 21 minutes on average. The longest inflow durations of 3 h 9 min and 3 h 2 min occurred during spring and neap tides, respectively (Table II). During 1995, average inflow (flood) and outflow (ebb) velocities were 0.631 m/s and 0.709 m/s, respectively. Maximum velocities recorded during inflow and outflow were 1.03 m/s and 1.01 m/s, respectively. Flushing time, calculated using the "tidal prism method" (Bowden 1967), was 60.7 tidal periods during complete vertical mixing periods such as turnover (Table I). Since a semi-diurnal tidal period is 12.8 hours, the lake required 32.4 days to flush its entire volume during these periods. Incomplete vertical mixing during the summer due to stratification involving the upper mixed layer to a depth of 1 m, reduced flushing time for this layer to 15.0 tidal periods or 8.0 days (Table I).

**Table II** Flushing characteristics for one neap, one spring and two average tides measured at station 3 during 1996 indicating duration of inflow and intertidal volume (P).

Date	Class of Tide	Duration of inflow	Intertidal Volume(m <sup>3</sup> )
June 18	Average	02.31	9.7 × 10 <sup>3</sup>
July 11	Average	01.52	4.9 × 10 <sup>3</sup>
July 24	Neap	03.02	14.2 × 10 <sup>3</sup>
August 2	Spring	03.09	27.1 × 10 <sup>3</sup>

### *Water Analysis*

Weekly temperature recorded during 1995 and 1996 indicated a typical lake profile with a strong thermocline developed by late June at a depth of 3-4 m (Fig 2). The thermocline sunk to greater depth as surface waters cooled during the fall. During 1995, temperature reached 25°C in the upper 0.5 m of water in August and temperature at the bottom rose to 9°C by November. The brackish water floating on top of denser salt water lead to inverse thermal stratification intermittently in the first meter of water during summer and fall (Fig 2). The total number of degree-days above 10°C from June 14 to November 2, 1995 for surface waters was 2,704 and at a depth of 3 m, 2,390 degree-days.

During 1996, a strong thermocline developed in mid-June at a depth of 1-2 m and remained at a depth of 2.5-3.5 m until mid-August (Fig 2). Temperatures of 25°C were recorded at the surface during September and bottom temperatures rose to 8°C by October. Inverse thermal stratification in the upper meter of water was observed during mid-July and in October. The total number of degree-days above 10°C for surface waters and at a depth of 3 m between June 14 to November 2, 1996 was 2,777 and 2,221 degree-days, respectively. Statistical comparisons indicated no significant difference in degree-days between 1995 and 1996 (Mann-Whitney, P=0.05).

Water temperature monitored between May 8 and November 2, 1996 in Secret Cove, Mahone Bay (Fig 1) indicated lower temperatures occurred there than observed in Goat Lake. On May 26, surface temperature was 4.0°C in Secret Cove compared

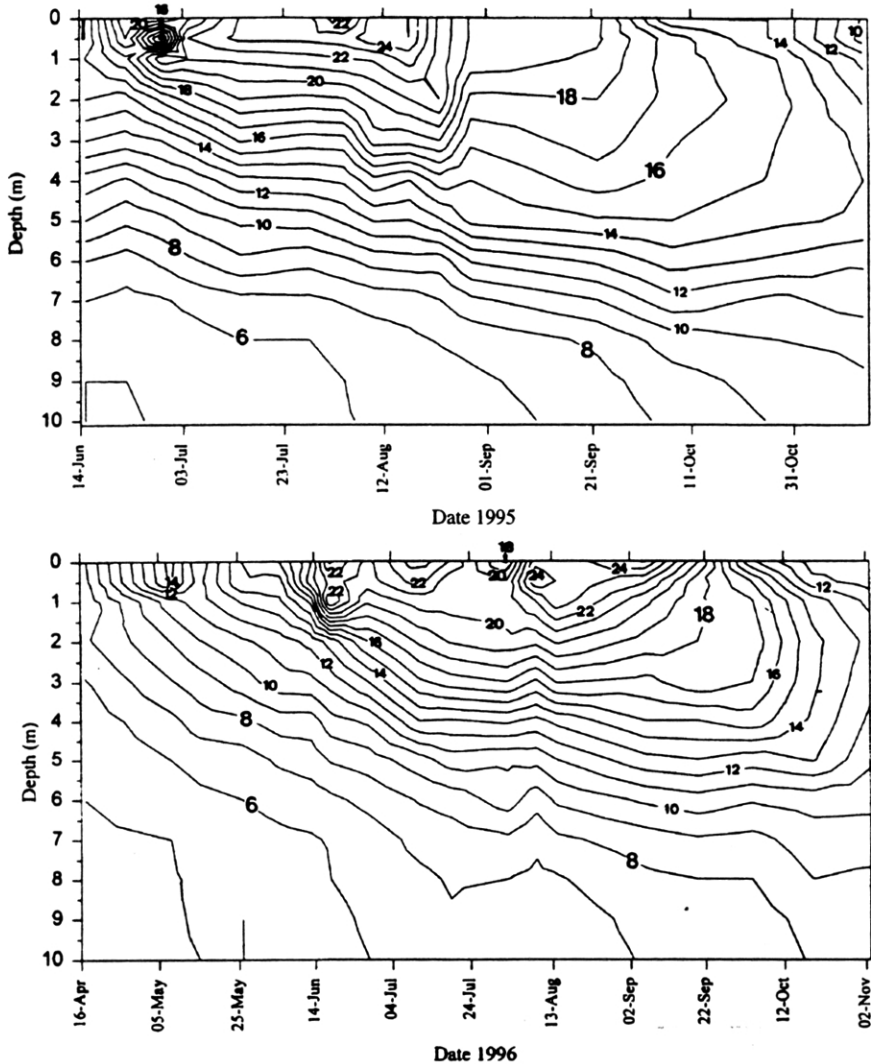


Fig 2 Temperature ( $^{\circ}\text{C}$ ) isopleths at station 1 in Goat Lake during 1995 and 1996.

to surface temperature of  $15.0^{\circ}\text{C}$  in Goat Lake. A maximum surface temperature of  $23.5^{\circ}\text{C}$  was observed in Secret Cove on August 9 when the comparable temperature was  $23.7^{\circ}\text{C}$  in Goat Lake. The maximum surface temperature of  $25.1^{\circ}\text{C}$  observed in Goat Lake was on September 6 when Mahone Bay was  $18.0^{\circ}\text{C}$  on the surface. On certain occasions, the ocean was warmer than Goat Lake, but on average, the surface temperature of Goat Lake was  $2.8^{\circ}\text{C}$  above adjacent Mahone Bay. The number of degree-days above  $10^{\circ}\text{C}$  in Goat Lake compared to Secret Cove were 3,301 versus 2,832 for surface waters and 2,574 versus 2,294 at a depth of 3 m. Statistical analysis indicated there was a significant difference in water temperatures at the surface and at a depth of 3 m between Goat Lake and Mahone Bay from May 8 to May 26, 1996 (Mann-Whitney,  $P=0.05$ ). Goat Lake warms much faster than Mahone Bay. Goat Lake also remained warmer in early fall, but surface waters rapidly cooled with the onset of

cold weather during November. Water temperatures at the surface and a depth of 3 m at stations 1 and 4 from September 6 to November 2, 1996 showed no significant difference between Goat Lake and Mahone Bay (Mann-Whitney,  $P=0.05$ ).

Salinity measurements in Goat Lake during 1995 and 1996 indicated the formation of various pycnoclines and meiohaline conditions. A maximum salinity of 30.9‰ was recorded at a depth of 7 m on June 29, 1995 and a minimum of 0.2‰ at the surface on July 19, 1996. A halocline occurred within the first meter throughout most of the study period where salinity ranged between 4‰ and 24‰ (Fig 3). Salinity deeper than 1 m remained isohaline throughout the study period at an average salinity of 28.5‰.

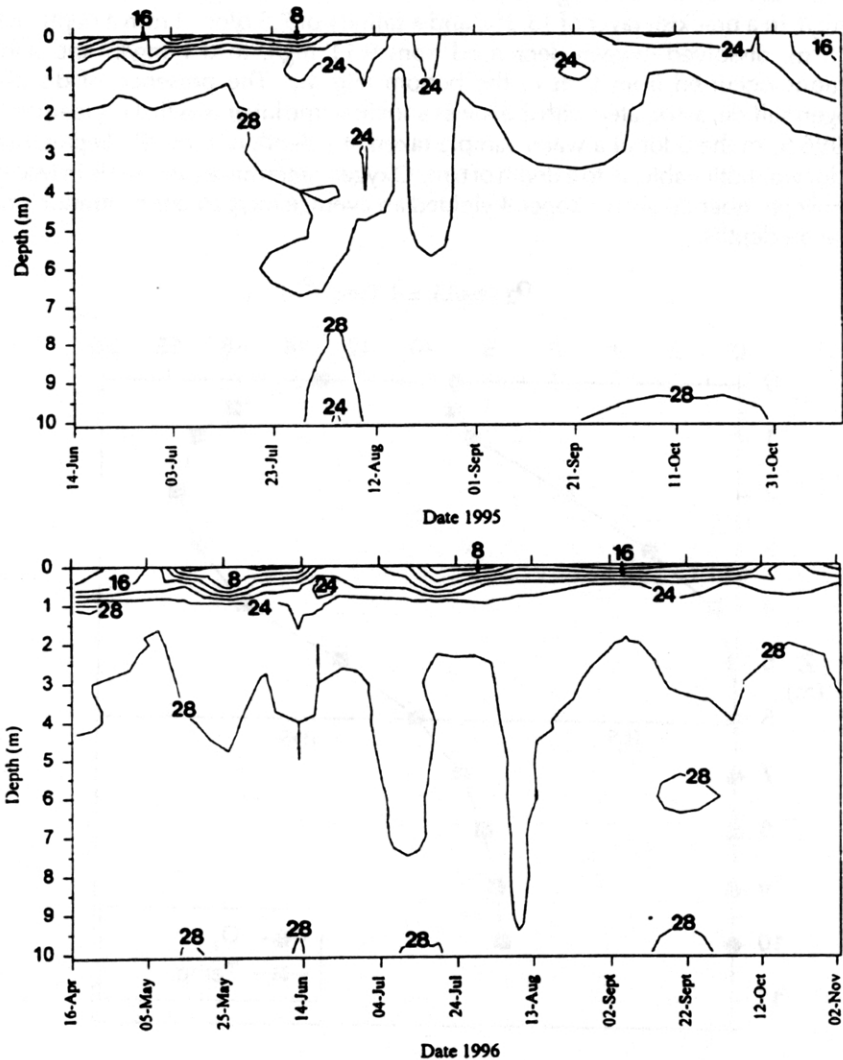


Fig 3 Salinity isopleths (‰) at station 1 in Goat Lake during 1995 and 1996.

Comparative salinity measurements were taken in Mahone Bay during 1996 from May 8 to November 2. A maximum salinity of 29.6 o/oo was recorded at a depth of 0.5 on May 26 and a minimum of 11.3 o/oo at the surface on June 13. During periods of brackish water within the surface meter of water, salinity ranged from less than 12 o/oo to 24 o/oo. The salinity of water below 1 m remained relatively isohaline at an average salinity of 28.2 o/oo.

Dissolved oxygen was determined during the fall of 1996 in Goat Lake and comparative data was collected in Mahone Bay. At the surface, the lowest oxygen concentration of 6.5 mg/L was related to a brackish layer of water of 20.2°C and a salinity of 7.0o/oo on September 20. Between the depths of 0.5 m and 5 m, dissolved oxygen decreased from 7.6 mg/L to 0.2 mg/L. At a depth of 6 m to the bottom at 11.5 m, there was no dissolved oxygen present. On October 4, oxygen at the surface was 9.01 mg/L in a brackish layer of 13.2°C and a salinity of 7.5 o/oo. From a depth of 0.5 m to 5 m, dissolved oxygen decreased from 9.11 mg/L to 0.1 mg/L, and anoxic conditions occurred from 6 m to the bottom (Fig 4). The presence of dissolved hydrogen sulfide, associated with the lower anoxic saline layer was first noticed on July 19, 1996 from the odor of a water sample taken at a depth of 8 m. By September 6, this odor was noticeable up to a depth of 6 m. Oxygen determinations made in Mahone Bay on September 20 and October 4 yielded an average oxygen concentration of 8.0 mg/L at all depths.

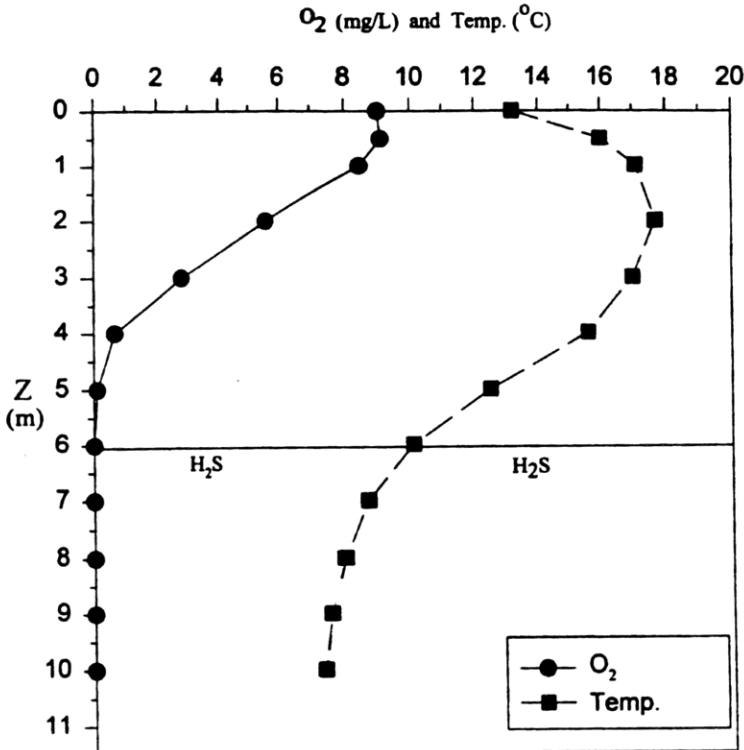


Fig 4 Dissolved oxygen (mg/L) and temperature (°C) in relation to depth (m) on October 4, 1996 at station 1 in Goat Lake.

### Biota of Goat Lake

The biotic survey in shallow water less than 3 m deep yielded 36 species of animals and 10 species of plants (Sparcs 1997). Of the 8 species of molluscs found, 4 are bivalves: the mussels, *Geukensia demissa* and *Mytilus edulis* [L., 1758]; the false quahog, *Pitar morrhuana* [Gould, 1848]; and the American oyster, *Crassostrea virginica*.

Ribbed mussels occurred mainly in the subtidal zone at depths of less than 1.5 m. Ribbed mussels were infrequently found intertidally semi-buried among the roots of *Spartina* sp., but commonly occurred anchored under the undercut ledges of the southern saltmarsh. Subtidally, ribbed mussels occurred as half-buried individuals in sand intermixed with coarse gravel and detritus or aggregated in dense clumps on submerged rocks. Ribbed mussels were found in Goat Lake in waters ranging from 13.8°C to 27°C with salinities ranging from 10.0 o/oo to 28.2 o/oo. Distribution of the ribbed mussels was around the entire shoreline with densities ranging from 12 mussels/m<sup>2</sup> to 460 mussels/m<sup>2</sup> (Fig 1).

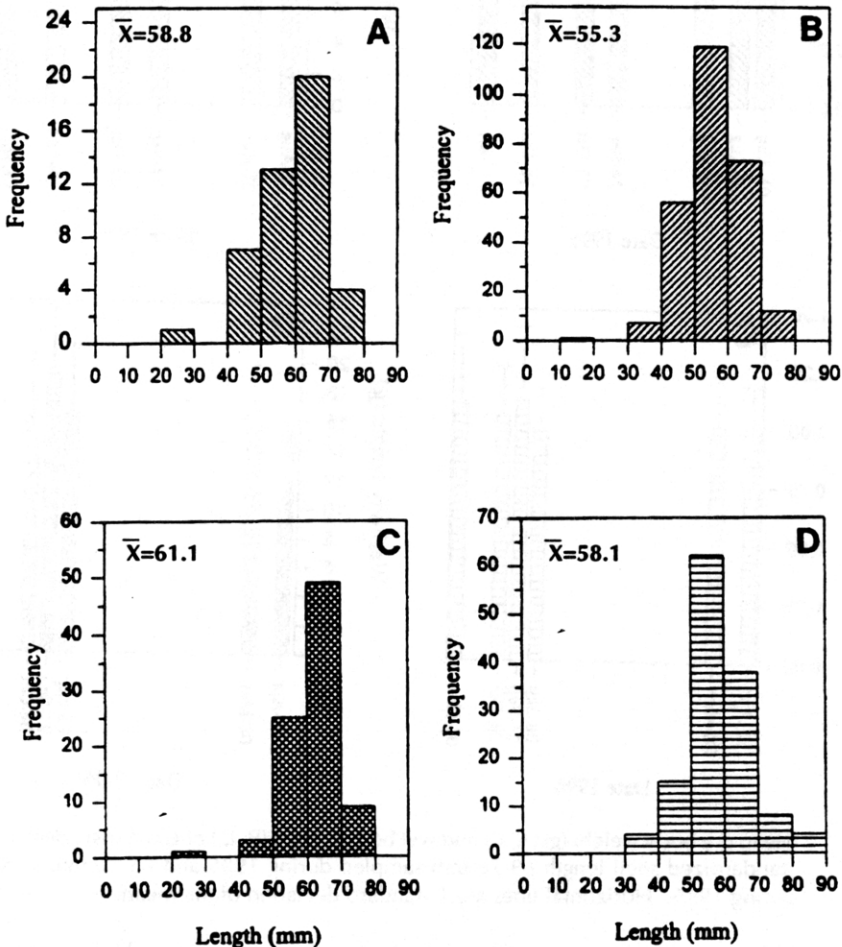
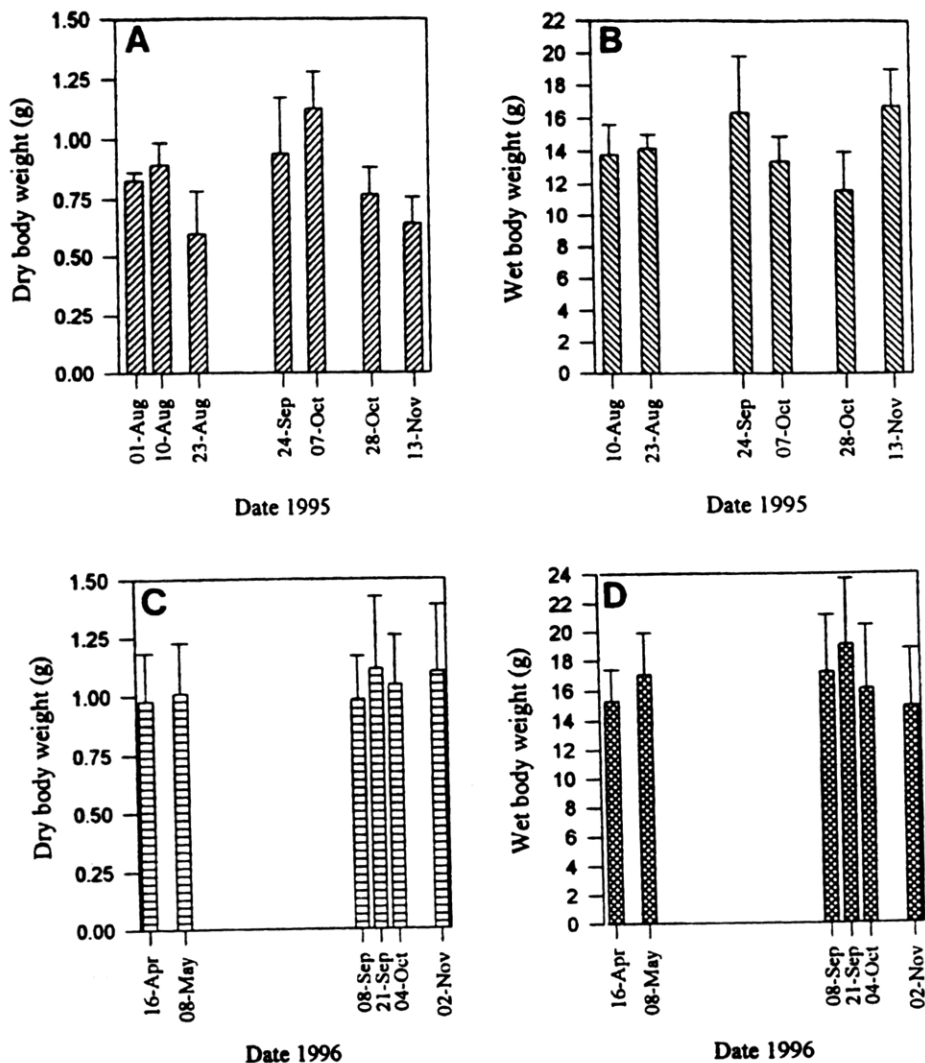


Fig 5 Size histograms of *Geukensia demissa* sampled in Goat Lake during July, 95 (A), August, 95 (B), October, 95 (C), and May, 96 (D).

Shell length of ribbed mussels ranged from 12 to 93 mm. Juvenile ribbed mussels (<30 mm) were rare and were found byssally attached within mussel clumps or as individuals almost completely buried among sand and gravel in the intertidal zone. Individuals half-buried in the subtidal zone tended to be greater than 30 mm. Size histograms determined from samples of mussels displayed a normal distribution centered around a mean shell length of 58 mm with juveniles disjunct from the normal distribution (Fig 5).



**Fig 6** Mean dry body weight (g) (A, C) and wet body weight (B, D) of *Geukensia demissa* for standardized shell length 69-76 mm sampled during 1995 and 65-80 mm sampled during 1996. Horizontal lines are 1 standard deviation of the mean.

Gonadosomatic development of the ribbed mussels was monitored by determining wet and dry body weights of samples standardized by shell length. A standardized shell length of 69-76 mm was chosen (One-way ANOVA,  $P=0.05$ ) for which there was no

statistical significant difference ( $P=0.480$ ) between the mean shell lengths of each collection during 1995. A significant weight decrease from 0.894 g to 0.295 g (ANOVA/Student-Newman-Keuls,  $P=0.05$ ) in mean dry body weight (g) occurred between August 10 and August 23, 1995 (Fig 6). Another significant decrease in mean dry body weight from 1.13 g to 0.767 g (ANOVA/Student-Newman-Keuls Method;  $P=0.05$ ) occurred between October 7 and October 28, 1995. Wet body weight decreased significantly (one-way ANOVA,  $P=0.05$ ) between September 14 and October 28, 1995 (Fig 6). There was no significant decreased (one-way ANOVA,  $P=0.05$ ) in wet body weight between August 10 and August 23 or between October 7 and October 28 indicating the mussels probably took in water as gametes were released.

American oysters were found in the south cove of Goat Lake during 1995 cemented onto submerged granite rocks. By 1996, oysters were commonly encountered in shallow water around the periphery of the lake. These oysters were smaller (mean 47 mm) compared to the larger specimens (mean 90 mm) encountered in the south cove suggesting a successful spawning event during 1995.

### Discussion

Environmental conditions in Goat Lake are due to a complex combination of factors including its size, inflow characteristics, flushing time, and stratification. Relative depth ( $Z_r$ ) of Goat Lake is 2.26% and volume development ( $D_v$ ) is 0.358. Since  $D_v < 1.0$  ( $1.0 =$  a lake with a volume equal to the hypothetical cone) and  $Z_r$  is 2.26%; Goat Lake is dominated by the shallows around its periphery.

Water level fluctuation due to tides is minimal, only 5.5 cm on average. The sill in the connecting channel to Mahone Bay restricts inflow and outflow. Seasonal conditions account for the greatest changes in water levels. Highest water levels were recorded during spring runoff and fall rains and lowest during high evaporation and low precipitation in summer. Tidal range was greatest for spring tides, but duration of inflow was longest for spring and neap tides. Neap tides have long duration of inflow due to the fact that the rising tide had a shorter height to surmount the sill. Flushing time (Tully, 1949) ranged from 15.0 days during stratification to 32.4 days during decreased stratification caused by turnovers.

Temperature patterns in Goat Lake show classical summer stratification of a stratified estuary with a thermocline at 3-4 m and the periodic occurrence of mesothermy within the upper 1 m (Fig 2). Since Goat Lake seems to follow the characteristic profile of a dimictic lake, it is inferred that it does undergo two turnovers. Although no direct data was collected to justify this, the water does appear to become more loosely stratified in November and was nearly isothermal in mid-April (Fig 2) indicating possible turnover events in late December and early April. Ice forms over the lake during the winter months indicating possible inverse stratification. If so, one would expect anoxic conditions in the lower saline layer during the winter period also.

Waters with unusual salt stratification sometimes exhibit a vertical temperature profile with the greatest temperature at some depth, suggesting inverse stratification (Fig 4). The layer of salt water underneath the freshwater layer often exhibited warmer temperatures that were sandwiched between colder upper and lower layers. The mesothermal profile was a result of the solar radiation penetrating the upper clear layer to be rapidly absorbed by the upper part of the saline stratum (Cole, 1994). Comparative data between Goat Lake and Mahone Bay provide convincing evidence that Goat Lake is warmer at most times during the year, especially during the spring. Salinity



profiles indicated a highly stratified system with a surface layer of brackish water and a lower saline layer trapped by a sill at the connecting channel to Mahone Bay. Goat Lake could be almost classified as a fjord type estuary with a two-layer flow with entrainment estuarine circulation type (Bowden, 1967). The salinity of the lower layer ( $Z > 1$  m) remains relatively unchanged with a small proportion of low-salinity water from the upper layer ( $z = 0-1$  m) entering the layer below. This interface between fresh and saline water is then replaced with an intermediate mixing layer of steep salinity gradient. The deeper saline layer acted as a reservoir of seawater in which circulation was restricted, with the majority of seaward horizontal movement occurring above the halocline.

The odor of hydrogen sulfide in water samples brought up from a depth of 8 m in July 19, 1996 prompted water samples to be analysed for dissolved oxygen. High concentrations of dissolved oxygen, an average of 8.35 mg/L at a depth of 0.5 m, within the upper 3 m of water suggest higher primary productivity compared to Mahone Bay with an average concentration of 8.0 mg/L in the first 2 m of water.

Layers of reduced oxygen generally occur in the ocean at depths below sills in enclosed basins or at depths with minimal horizontal movement. These layers may be accompanied by the production of hydrogen sulfide as in the Black Sea (Cushing and Walsh, 1976). Goat Lake exhibits these characteristics with oxygen depletion occurring in water deeper than 4 m from mid-summer to late fall. The anoxic region correlates with the presence of the thermocline at a depth of 3-5 m (Fig 4).

The anoxic conditions of the deeper layer have resulted from stratification of upper waters, poor tidal flushing, and destruction of one of two connecting channels to adjacent Mahone Bay. Poor tidal flushing is partially related to only one channel connecting the lake to the ocean.

The biota of Goat Lake largely occurs in the shallow waters less than 3 m deep due to the anoxic conditions present in the lower saline layer. Of all the large species identified, molluscs were the most prevalent organisms found (Spares, 1997), but the American oyster and the ribbed mussel were notable since they do not commonly occur within the coastal waters of south and east Nova Scotia (Gosner 1978).

Ribbed mussels are a dominant component of the *Spartina* zone of salt marsh communities along the east coast of North America south of Canada (Bertness 1980; Brousseau 1984; Lin 1989). North of northern Massachusetts, *Geukensia* is very scarce and mainly occurs subtidally (Franz, 1995). There are records of populations occurring in Minas Basin and Malpeque Bay, P.E.I. (Brousseau, 1982; Bromley and Bleakney, 1985). Goat Lake is the only recorded population of ribbed mussels occurring along the east and south coast of Nova Scotia.

The ribbed mussel is highly eurytopic tolerating temperatures of  $-22^{\circ}\text{C}$  to  $40^{\circ}\text{C}$  and salinities of 5 o/oo to 75 o/oo (Bertness, 1980). The conditions experienced by the mussels in Goat Lake falls well within these extremes. Ribbed mussel distribution of northern U.S.A. populations is in dense aggregations at and near the marsh edge (Nielsen and Franz, 1995). In the Branford marsh in Connecticut, mussel densities of 1,500 mussels/m<sup>2</sup> and upwards were recorded (Fell et al., 1982). In Goat Lake, the mussel population is predominantly subtidal clumps due to the low tide range with densities ranging from 12 to 460 mussels/m<sup>2</sup>.

The propensity to form dense aggregations on hard and soft substrata is the ribbed mussel's key for success against physical disturbance and predation, particularly in the case of juvenile mussels (Bertness and Grosholz, 1985). In Goat Lake, clumping on rocks decreases predation by the population of green crabs *Carcinus maenas* [L., 1758], suffocation from sediment deposits, and disturbance from winter ice cover.

Major predators of ribbed mussels farther south include the blue crab, *Callinectes sapidus* [Rathbun, 1896] and the mud crab, *Panopeus herbstii* [Milne-Edwards, 1834] which both show a preference to feed on smaller mussels (10-30 mm). *Geukensia*, once it reaches a size of 30-40 mm has increasing immunity to predation due to a thicker shell and firm anchorage in a vertical half-buried position to protect the venerable umbo (Seed 1980). The presence of empty shells littering the lake bottom and the absence of small numbers of mussels ranging in size from 0-40 mm suggests heavy predation. Sampling indicated that immunity to predation is achieved and there is high survivorship in the 50-70 mm length classes (Fig 5).

The juvenile mussels (<30 mm) found within the crevices of clumps and almost completely buried in the intertidal zone suggests both "selective settlement" and "secondary settlement" may occur (Bertness and Grosholz, 1985). "Selective settlement" deals with active settlement around adult conspecifics due to chemical and tactile cues. "Secondary settlement" occurs during the year after metamorphosis involving mobile juveniles (5-10 mm) which can move on average 2.1 cm/day in order to concentrate among adult conspecifics (Bertness and Grosholz, 1985). The advantages of settling among adults involve escaping predation, reducing risk of desiccation and thermal stress, and avoiding sediment burial (Nielsen and Franz, 1995).

*Geukensia demissa* is a dioecious bivalve that reproduces by broadcast spawning. Monitoring of wet and dry body weight was used to determine gonad development. The ripe stage occurred when dry body weight reached a maximum, and the spent stage was after a sudden decrease in dry body weight. The population of Goat Lake was determined to be self-reproducing as evident by the gonadosomatic monitoring and subsequent occurrence of small juveniles (12 mm). *Geukensia* from New England and Connecticut exhibit a single spawning period from June through September (Borrero, 1987). In Malpeque Bay, P.E.I. during mid-July to August, larvae were reported within the plankton indicating spawning in June to July since the larvae stage lasts approximately one month (Brousseau, 1982). Our results from 1995 indicated the possibility of two separate spawning events, one occurring in mid-August and one in mid-October (Fig 6). These results do not agree with the current literature and sources of error or misinterpretation may be because of the small sample sizes ( $n = 9-12$ ) collected for gonadosomatic monitoring and the subsequent standardizing which decreased sample sizes still further ( $n = 6-12$ ). The collecting of small samples was taken as a precautionary measure not to seriously decrease the small population of ribbed mussels in Goat Lake.

Occurrence of temporal variation across the intertidal zone as an approximate two-month delay in reproductive activity caused by diminished nutritional status brought on by reduced feeding time has been established by Borrero (1987). Site-to-site differences in food quantity and quality were identified as the major determinants of gametogenesis and spawning in ribbed mussels (Borrero, 1987). The appearance of two spawning events could be explained by this temporal variation across the population since the samples were taken from different locations within the lake. Perhaps a group of ribbed mussels sampled from a certain part of the lake were experiencing diminished nutritional status which resulted in a two-month delayed spawning period. Oysters, mussels, and other animals may remain closed or cease feeding when adverse conditions are present resulting in poor growth and gonad ripening (Moore, 1958). Ribbed mussels within Goat Lake have been observed to be closed at times when fully submerged, which suggests that nutritional deprivation could be the reason for these two spawning events.

The presence of American oysters was predictable in Goat Lake. Although American oysters do not commonly occur on the east and south shore of Nova Scotia, their range extends as far north as southern Maine with disjunct populations in the Gulf of St. Lawrence and Bras d'Or Lake, Cape Breton Island (Gosner, 1978). This population of adult-sized animals was thought to occur solely in the south cove connected to Mahone Bay, but smaller specimens observed around the periphery of Goat Lake while snorkeling in 1996 indicated that oysters reproduced in Goat Lake. The salinities in Goat Lake fell well within the oyster's tolerance of 5 o/oo to 30 o/oo (Gosner, 1978). The question of how the oysters may have reached Goat Lake was answered by a conversation with a local resident of Goat Lake. Apparently, the oysters were introduced approximately 12 years ago by a person who had some leftover live oysters that would have died. Whether this population is really a result of this introduction or the survival of a natural population like the ribbed mussels will require further study.

There are presumably more marine situations, such as Goat Lake, along the south shore of Nova Scotia where unique environmental conditions enable the survival of these molluscs and/or other warm water species. Because of the uniqueness of each site, a concerted effort should be made to survey them. Many may deserve being placed on the list of protected, natural heritage sites for the province. Unfortunately, the discovery and description of these unique ecosystems has lagged behind comparable terrestrial ones.

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