Three macroinvertebrate families dominate the macrobenthic community in three bays in the upper St. Lawrence River

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Abstract.– Three macroinvertebrate families, Dreissenidae, Gammaridae, and Chironomidae, accounted for 74% of organisms collected from 1995–1997. Other abundant families were Naididae, Asellidae, and Hydrobiidae. A diverse community of 45 families (69 taxa; 88% of organisms) was collected primarily at water depth of less than 4 m, which included 10 caddisfly families, 9 gastropod families and 3 families of oligochaetes. Two invasive species were collected (excluding Dreissenidae): *Bithynia tentaculata* at all stations and *Potamopyrgus antipodarum* at five stations but primarily in deep water (17 m). Unionid mussels were few in number due to colonization by Dreissenidae and no living unionid mussels were collected after 1996. Seasonal changes in aquatic vegetation corresponded with increases in macroinvertebrate abundance.

Introduction

The shallow aquatic embayments of the Thousand Islands region support a diverse community of aquatic and wetland plants (Geis and Kee 1977; Ruta 1981) and these provide provide multiple seasonal habitat types from an ice-covered surface and sediments that are devoid of living vegetation in winter to open water and profuse vegetation by mid-summer. These physical changes support differing life history strategies that, in total, produce a complex and dynamic community of macroinvertebrates. Littoral areas are more complex in physical and chemical characteristics resulting in greater diversity compared to the more homogeneous deep areas that are subjected to decreased oxygen and increased microbial composition products. Deeper water sediments that are beyond the photic zone are less affected by wind and water level, and being devoid of plants, are less complex in physical structure than the shallower sediments in the bays.

There have been few studies of the macrobenthos in the St. Lawrence River. Kinney (1972) described the benthic community of the St. Lawrence River at Cape Vincent and Clayton, New York, and other sites downriver: oligochaeta dominated the benthos at 5 m depth at Cape Vincent and at 15 m depth at Clayton. Other abundant taxa were *Gammarus faciatus*, *Bithynia tentaculata*, and Chironomidae. Another study conducted at Cape Vincent in 1978–79 (Haynes and Makarewicz 1982) examined the benthos in dredged and undredged areas where *Gammarus* spp., Mollusca, Chironomidae, and Oligochaeta were the more abundant taxa. *Bithynia tentaculata* was quite abundant in undredged areas (>2000/m^2). Mills et al. (1981) described the benthos of the river from Cape Vincent to Lake St. Lawrence in winter: Chironomidae dominated at nearshore areas at Cape Vincent while Amphipoda and Oligochaeta were more abundant in offshore areas. More recently, Farrell et al. (2010) sampled macrobenthos at similar locations as did Mills et al. (1981) with similar results, and Tall et al. (2016) described the benthos in Lake St. Pierre in the lower St. Lawrence River where Gammaridae, Asellidae, Oligochaeta, and Chironomidae were more abundant.

The objective of this study was to assess the condition of the benthic community at shallow and medium depths within three bays and compare it to the community in adjacent deep water areas by using biological indices. Diversity in the benthic community generally declines as depth increases (Johnson and Brinkhurst 1971; Cook and Johnson 1974).

Study sites. Buck, Lindley, and Flynn bays are oriented in a SW to NE direction (Fig.1) that are affected by the prevailing westerly and southwesterly winds. The extreme interior of Buck Bay is sheltered from the full force of the wind by the surrounding granite hills and by Wolfe, Hickory, and Arabella islands. Lindley Bay has been formed by the accumulation of sediment between the NW tip of Club Island and Grindstone Island, perhaps accelerated by controlled water levels (Cooper et al. 2008) and colonization by willow *Salix* and cattails *Typha*. Two small islands, Whiskey and Papoose, to the SW of Lindley Bay provide some protection from SW winds. Lindley Bay and Flynn Bay can be connected by water during sustained SW winds or by high water level. Channels maintained intermittently by beavers, *Castor canadensis*, and muskrats, *Ondatra zibethicus*, also traverse the land and *Typha* between the bays in some years. The sediments in most of Flynn Bay can be stirred up with a SW wind and the SW part of the bay can be affected similarly by a strong NE wind. Water movement within the bays is caused primarily by wind action rather than river current: the tributaries contribute the only measurable water current (<1 cm/s), and this is primarily during spring runoff and rainfall. Lindley Bay is the smallest of the three bays at 10.4 hectares (ha), Buck Bay has a surface area of 18.3 ha, and Flynn Bay is the largest of the three bays with 69 ha.

Methods

A pilot study was initiated in 1994 to sample macroinvertebrates in Buck and Lindley bays at six fixed stations once per month in May, July, and October. Two stations were within each bay and two were in deeper water. Sediment analysis was done for each bay, and in adjacent Flynn Bay, and showed that sediment in Flynn Bay was considerably different than in the other bays, therefore three additional stations for Flynn Bay were added in 1995. Macroinvertebrate sampling frequency was increased to once per month from May through September, 1995 through 1997. Sampling depth (0.6–1.5 m, 1.8–4.6 m, >16 m) was chosen to evaluate potentially different community composition related to sediment type and to account for potential differences in distribution related to depth. Benthic organisms were collected by ponar dredge (0.023 m^2 sample area) in triplicate at each station, washed through a 500µ screen, preserved in 10% buffered formalin, and processed. Organisms were generally identified to family or species and counted with mean density extrapolated to 1 m^2. Shell length (SL), width (SW), and height (SH) of collected unionid mussels were measured with a digital caliper and the range of shell lengths was estimated for dreissenid mussels.

Sediment grain size and organic content. A 120 ml subsample was taken from each of three ponar dredge samples at each fixed station in Buck and Lindley bays in 1994, and at the sampling locations in Flynn Bay in 1995. Each subsample was stored at 3°C until the analyses were performed. Sand, silt, and clay fractions were determined by the dispersal method (Folk 1980) on each subsample. The subsamples for each weight fraction were then averaged for each station and expressed as the percent dry weight of the original sample. Three additional samples were taken with a ponar dredge at each station for organic content. A subsample of 8 g was taken from each sample and refrigerated until processed. Empty crucibles were heated in a muffle furnace for 2 hrs at 470°C, cooled in a dessicator, and weighed. Sediment samples were added to the crucibles and the samples were dried at 105°C for 2 hrs, cooled in a dessicator, and weighed. Dried samples were ashed at 470°C for 19 hrs, cooled in a dessicator, and weighed. The organic content was expressed as the percent loss on ignition.

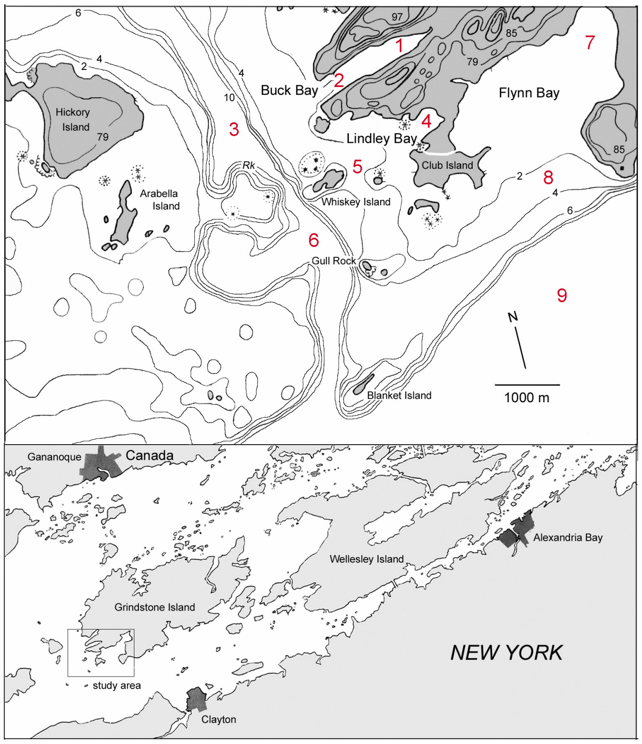

FIGURE 1.–Locations of sampling stations in three bays (red numbers) on Grindstone Island. Depth contours and land elevation contours are in meters.

Aquatic vegetation. Qualitative estimates of the seasonal changes in submerged vegetation were made by visual observation during other sampling activities (approximately once per week), and by direct sampling of the bottom using a small boat anchor that was dragged a short distance behind a boat and then retrieved with the vegetation. Vegetation was identified to genus.

Water chemistry. Water temperature was recorded at 2 h intervals by Onset Optic StowAway recorder suspended 0.5 m above the sediment in each bay from the first week of May to the end of September in 1996 and 1997. Temperature was also recorded at each biological sampling in all years along with secchi depth (m), dissolved oxygen (ppm, YSI model 57 meter), pH (Oakton electronic meter), alkalinity (mg $CaCO_3$, LaMotte test kit), and conductivity (µmhos, Oakton electronic meter).

Statistical tests. All tests were done on 1995–1997 data since Flynn Bay was not sampled in 1994. The data from 1994 were used only for comparison. All tests were made on non-transformed data using non-parametric tests in SAS version 6.03.

Biological indices: Six indices were calculated for 1995–1997 based on macroinvertebrate families: *Total Families*—the total number of families as a measure of richness; *Percent Chironomidae*—the percentage of chironomid midges out of the total number of individuals collected; *Family Biotic Index*—based on the tolerance values to environmental perturbation (Barbour et al. 1999); *Percent Dominants*— the sum of the percentages of the five more abundant families out of the total number of individuals; *Shannon Diversity Index*—based on the cumulative natural log of the proportion of families for each station (1995–1997 combined); and *Simpson Index* (1–D)—generally using species but in this case it was calculated using the cumulative proportion of families for each station (1995–1997 combined). These indices are primarily used to evaluate the macrobenthic community to assess the degree of organic pollution but they can also give a measure of the suitability of habitat where pollution is not suspected, which was the case for this study. Two additional indices were considered that were developed originally for lakes rather than rivers (Verneaux et al. 2004; Li-Na et al. 2017) with the thought that the bays of the St. Lawrence River are more similar to lakes: affected more by wind than water flow (<1 cm/s) with shallow and deep areas. These two indices did not add to the interpretation of the macrobenthic community characteristics beyond what was available from the other indices and are not presented here.

Results

Physical and chemical parameters

Sediment grain size. The sediment at station 1 in Buck Bay had lower silt and higher clay content (Table 1) than was expected from the preliminary observations. The sediment at station 3 also had unexpected results: a higher percentage of sand than silt, unlike the other deep water stations, which were primarily silt. Station 7 in Flynn Bay was located near an eroding clay bank but the sediment there had much less clay content than sediment at station 1 where there were no visible clay deposits.

Temperature. Water temperature increased gradually from about 10°C in the first week of May to a seasonal high of approximately 27°C in mid-July in 1997 (Cooper 2016). The seasonal peak was delayed until the first week of August in 1996. The general pattern of seasonal changes in temperature was similar among bays and among years. Water temperature could vary as much as 8°C over a 12 h period and extreme short-term fluctuations were detectable on the same dates in each bay within years. Water temperature values from the automatic recorders in each bay were within 2°C of the values measured at similar times with the meter. Water temperature was similar between surface and bottom in the bays to a depth of 1.5 m.

Dissolved oxygen. Seasonal patterns of mean dissolved oxygen were similar in 1996 and 1997 but generally lower in 1997, and oxygen saturation was near or greater than 100% during all sampling periods other than June. Oxygen saturation declined sharply in June with increasing water temperature but remained above 70% in the main bays. This decline occurred prior to the annual increase in vegetative growth and the resultant increase in photosynthesis.

Greater declines in oxygen occurred after periods of heavy rain in each year and may have been due to oxygen uptake by the humic soils in the marshes before the runoff reached the open bay. Oxygen values measured during sampling activities may not have always revealed the extent of low oxygen conditions in the bays. Oxygen saturation was sharply depressed (25% at the surface, 17% on the bottom) after a heavy rainfall on 17 to 19 June, 1996, in the innermost tributary in Flynn Bay. A plume of lower-oxygen water (60 to 70% saturation) was measured along the SW side of the bay out to 600 m from the tributary mouth. Oxygen saturation was over 80% along the NE shore and outside of Flynn Bay. Lower oxygen saturation was found in the tributary in Buck Bay (18 July 1996) where saturation ranged from 42% on the bottom to 59% at the surface. Saturation increased to 82% (surface) and 100% (bottom) at mid-bay. Oxygen saturation was also depressed in the innermost part of Lindley Bay on 18 July, 1996: 83% at the surface and 46% on the bottom compared to 97% (surface) and 104% (bottom) at mid-bay. These conditions were short-lived (less than a week) and other similar conditions may not have been detected.

Organic matter. The percent organic matter was higher at the inner most parts of Buck and Flynn bays, similar at the deep water stations, and quite varied at the mid-depth stations. Station 4 in Lindley Bay had the least organic matter.

Alkalinity. The water in each bay can be classified as well-buffered with alkalinity (as total $CaCO_3$) ranging from 90 to 140 mg/l (phenolphthalein alkalinity was zero). There were no consistent differences among the bays or years. The average alkalinity was 115.3 mg/l and the yearly average for each bay was within 8 mg/l of the overall average.

pH. Water in each bay was basic with pH values ranging from 7.3 to 9.2 (mean=8.1, N=99). The runoff from rainfall during 17 to 19 June, 1996, decreased the pH in the main tributary in Flynn Bay to 7.1 (measured on 20 June) and extended about 700 m out into the bay and along the southwest shore. The pH of water along the northeast shore was 8.1. A similar depression was measured in the other bays on this date but the pH was not as low as in Flynn Bay. A two-day rainfall prior to 18 July 1996 decreased the pH to 6.9 in the tributary to Buck Bay; pH was 7.8 at the bay mouth. A high pH value of 9.1 was measured in the SW part of Flynn Bay in July, 1996, in an area of dense macrophytes and dying algae. The pH of the remainder of the bay ranged from 8.3 to 8.5.

Conductivity. The conductivity of the water in each bay ranged from 240 to 340 µmhos/cm (mean=291.7, N=46). There were no detectable seasonal changes or trends in conductivity among bays (Table 1).

No taxa showed a significant statistical relationship of mean rank density with bottom oxygen saturation, alkalinity, conductivity,or pH.

Secchi disk transparency. The bay bottoms were visible except during periods of strong, sustained winds when suspended sediment reduced secchi transparency to 20 cm or less in Buck and Flynn bays. Turbidity was also increased temporarily in much of inner Buck Bay by the spawning activities of carp *Cyprinus carpio* for about two weeks in July, 1996, which reduced visibility from 35 cm to 15 cm. The increase in turbidity could have contributed to the die-back of vegetation in 1996. Higher water level in

1997 allowed carp to spawn in the *Typha* and the resultant increase in turbidity was restricted to a narrow band along the shore. Water transparency in Lindley Bay was less affected by wind because the sediment was primarily sand. Water transparency was highest in May and early June and declined progressively into August. Deep water secchi transparency (stations 3, 6, and 9) ranged from 12 m in early May to 6.5 m in late August.

Aquatic vegetation. *Potamogeton* stems from the previous year were either scattered on the bottom or arranged in wave-formed clumps in the shallow water areas (1.0 m depth) in May in Buck (Fig. 2) and Flynn (Fig. 3) bays in 1996 but there was only bare substrate in 1997. Dead *Potamogeton* stems were present in deep water areas (2.4–3 m depth) of Buck Bay in 1996 but not in 1997. Wave-formed clumps of *Chara* and *Potamogeton* were present in 3m water areas of Lindley Bay (Fig. 3) in 1994 to 1996 but not in 1997. The seasonal progression of the aquatic vegetation community was similar in all three bays from 1996 to 1997 but began about two weeks earlier in 1997.

TABLE 1. Mean depth, percent sand, silt, and clay, and chemical parameters by station with one standard error in parentheses. pH ranged from 7.8 to 8.1 (SE=0.05–0.1, N=148). Mean secchi depth was 8.2 m (SE=0.15, N=46) at stations 3, 6, and 9.

	Buck Bay			Lindley Bay			Flynn Bay		
Station	1	2	3	4	5	6	7	8	9
Depth (m)	1 (0.04)	3 (0.1)	16 (0.3)	1 (0.06)	4 (0.12)	16 (0.4)	1 (0.2)	3 (0.12)	17 (0.3)
Sand (%)	38 (2)	60 (5)	44 (8.7)	98 (0.4)	86 (1)	13 (0.7)	10 (0.3)	93 (0.5)	12 (0.6)
Silt (%)	15 (1.3)	28 (3.9)	35 (18.3)	1 (0.3)	11 (0.9)	63 (2.8)	65 (3)	5 (0.4)	65 (2.7)
Clay (%)	47 (3.3)	12 (1.9)	21 (9.6)	1 (0.2)	3.4 (0.6)	24 (2.2)	25 (2.8)	2 (0.05)	23 (2.2)
Organic matter (%)	13 (0.3)	5 (0.4)	5 (0.2)	0.4 (0.03)	1.5 (0.07)	6 (0.01)	11 (0.4)	0.8 (0.04)	7 (0.1)
Alkalinity (ppm $CaCO_3$)	110 (6.5)	119 (2.4)	121 (1.1)	116 (2.3)	120 (2.2)	121 (1.9)	107 (4.7)	117 (2.1)	119 (1.6)
Conductivity (µmhos)	274 (9.4)	286 (5.2)	290 (5.4)	283 (8.9)	291 (5.2)	288 (6)	272 (9.1)	286 (6.2)	286 (6.6)

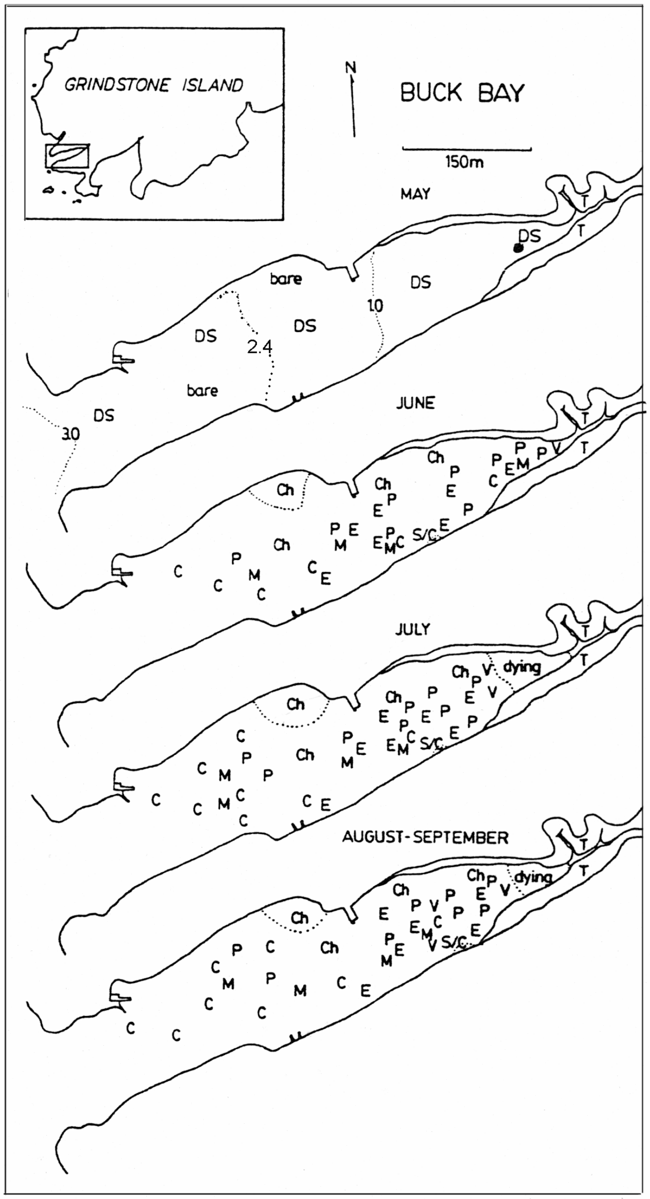

FIGURE 2.–Seasonal progression of submerged aquatic vegetation in Buck Bay in 1996. Key to plants: C–*Ceratophyllum*, Ch–*Chara*, DS–dead stems, E–*Elodea*, M–*Myriophyllum*, P–*Potamogeton*, S/C–*Scirpus/Carex*, T–*Typha*, V–*Vallisneria*. Numbers are water depth in meters. • = temperature recorder.

New growth of *Potamogeton* appeared in the first week of June in Buck and Flynn bays and reached the water surface after three to four weeks of growth. *Chara* was evident in the third week of June and formed extensive beds by the third week of July in shallow water in Buck and Flynn bays and at 3–4 m water depth in Lindley Bay. *Spirogyra* and *Cladophora* covered much of the new growth of *Potamogeton* as well as on most of the sediment in Buck and Flynn bays, but not Lindley Bay, for the first two weeks of June.

Myriophyllum, *Ceratophyllum*, *Vallisneria*, and *Elodea* became abundant during the last two weeks of June. Water lilies (*Nuphar* and *Nymphaea*) emerged along with *Scirpus* and *Carex*. The water lilies and *Scirpus*/*Carex* were always found in distinct areas unlike the more generalized mix of plants in the remainder of the bays. *Chara* was dominant in some areas but was also present throughout the bays except for Lindley Bay, where it was found only at a depth of 3–4 m. Vegetation increased during July and, with a decrease in water level, covered much of the water surface at the inner areas of Buck and Flynn bays by mid-August.

Heteranthera, *Alisma*, *Ranunculus*, and the duckweeds *Lemna* and *Spirodela* were observed in tributaries but were seen less often in the main bays. These plants, other than the duckweeds, were occasionally found under the canopy of the larger plants.

Each bay had areas of thick vegetation that began dying in mid-July, which may have depressed the dissolved oxygen. Algae had covered much of the vegetation at the water surface in Buck Bay, just in front of the tributary and, combined with periphyton on the surface of the leaves, shaded out much of the vegetation.

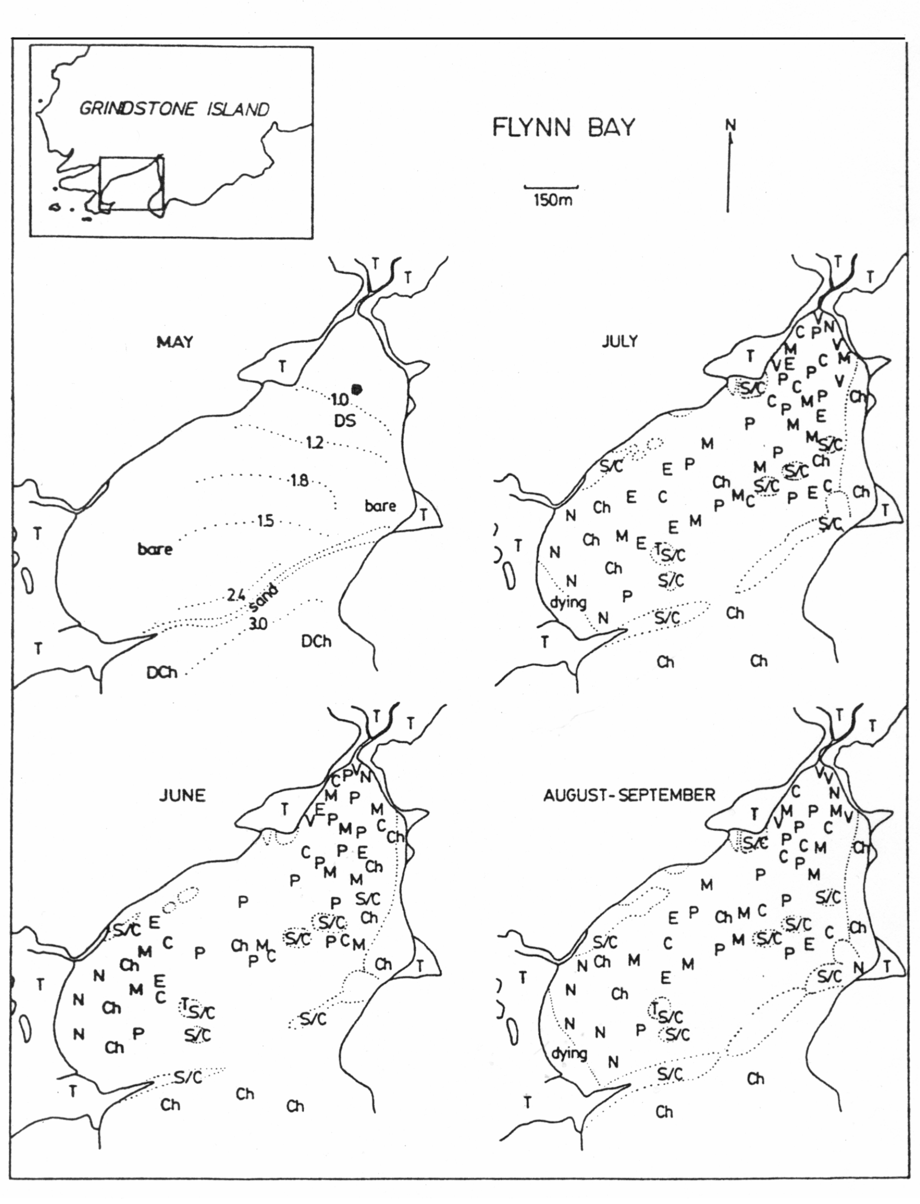

FIGURE 3. Seasonal progression of submerged aquatic vegetation in Flynn Bay in 1996. Key to plants: C–*Ceratophyllum*, Ch–*Chara*, DS–dead stems, DCh–dead *Chara*, E–*Elodea*, M–*Myriophyllum*, N–*Nymphaea* and *Nuphar*, P–*Potamogeton*, S/C–*Scirpus/Carex*, DS/C=dead stems of S/C, T–*Typha*, V–*Vallisneria*. Numbers are water depth in meters. • = temperature recorder.

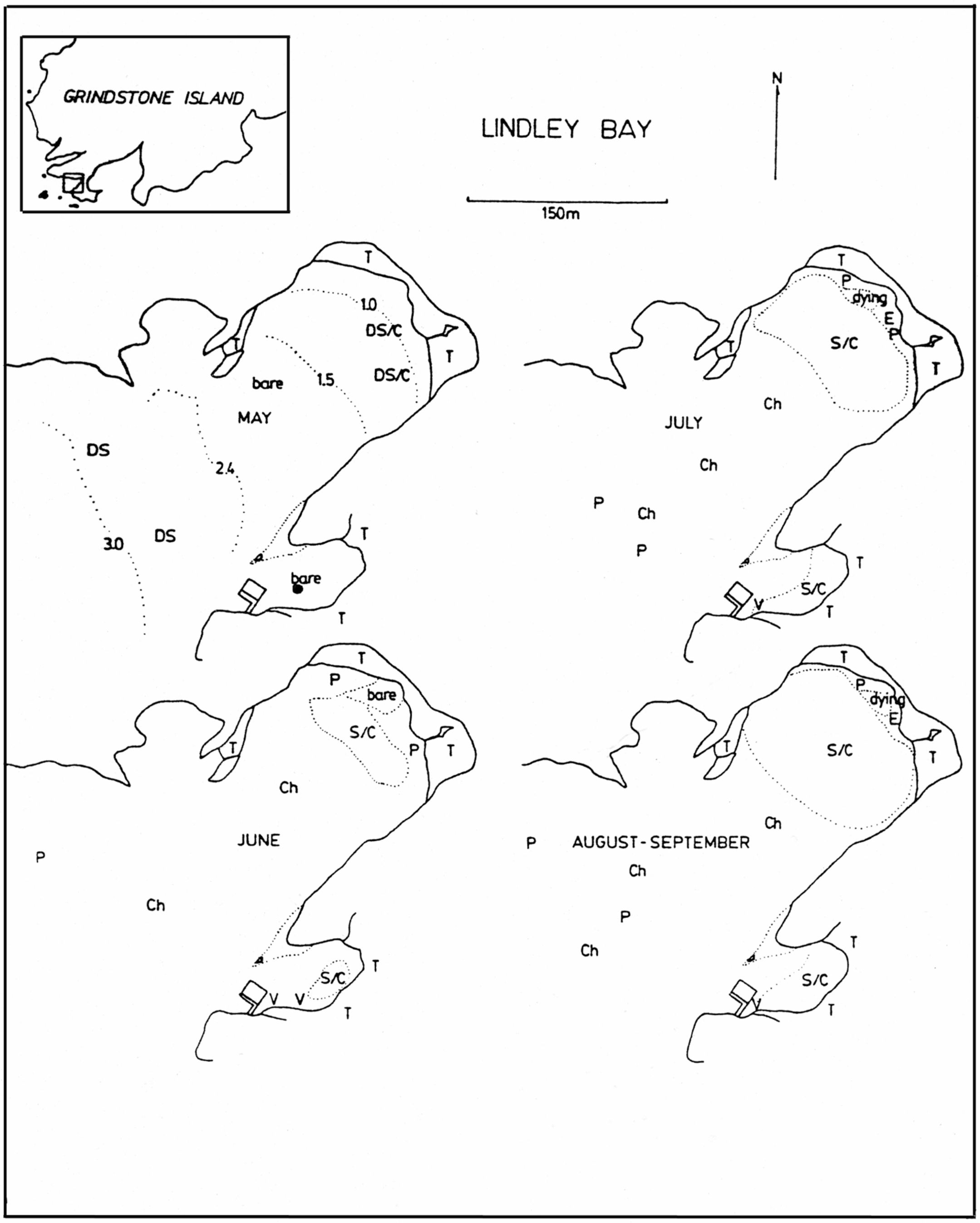

FIGURE 4. Seasonal progression of submerged aquatic vegetation in Lindley Bay in 1996. Key to plants: C–*Ceratophyllum*, Ch–*Chara*, DS–dead stems, DCh–dead *Chara*, E–*Elodea*, M–*Myriophyllum*, N–*Nymphaea* and *Nuphar*, P–*Potamogeton*, S/C–*Scirpus/Carex*, DS/C=dead stems of S/C, T–*Typha*, V–*Vallisneria*. Numbers are water depth in meters. • = temperature recorder.

There was a small, central area near the shore in Lindley Bay which had a silt/clay bottom composition, unlike the remainder of the bay which was primarily sand. There was thick *Potamageton* and *Elodea* growth in this area and these plants became covered with algae in mid-July. Oxygen saturation in this area was lower on the bottom (46%) than at mid-bay (83%) but only slightly less at the surface: 97% compared to 104% at mid-bay. This area was also used by spawning carp in 1996 and 1997, which increased turbidity and may have contributed to the decrease in dissolved oxygen by a reduction in photosynthesis.

The SW part of Flynn Bay, where it borders Lindley Bay, also experienced a die-back during mid- to late July and August. Vegetation was extremely dense and was covered by a thick layer of dying algae. Photosynthesis at the surface led to supersaturated conditions (137% oxygen saturation measured on 21 July 1996) while decomposition of the dead plants on the bottom created low oxygen saturation (30%).

Biological parameters

Macroinvertebrates.–Dreissenidae dominated the macroinvertebrates in 1994 (54% by number) and in 1995–1997 (32% by number). There were 34 families in 51 taxa in 1994 and 45 families in 69 taxa in 1995–1997 (Table 2). Six families accounted for 87% of the total organisms collected (Fig. 5): Dreissenidae, Gammaridae, Chironomidae, Naididae, Asellidae, and Hydrobiidae. Zebra mussels (*Dreissena polymorpha*) accounted for 97% of dreissenid mussels. Zebra mussels occurred in all samples and mean ranks of density were significantly greater at stations 2 and 5 (primarily sand substrate) and least at station 6 (primarily silt substrate ($F_{8,126}$=8.83; P<0.0001). There was a weak but significant correlation between mean ranked density and sand substrate (Pearson=0.37, P<0.0001). Mean zebra mussel density at station 2 was 3012/m^2, 6242/m^2 at station 5, and 632/m^2 at station 6. Mean zebra mussel density was 6781/m^2 in 1994 and declined significantly from 4976/m^2 in 1995 to 1831/m^2 in 1997 ($F_{2,132}$=8.68, P=0.0003; Fig. 4). Colonization by dreissenids was seen on unionid mussels (22–25mm) and several species of snails including *Potamopyrgus antipodarum* at 4.5mm.

Quagga mussel (*Dreissena rostriformis bugensis*) mean density was greatest at station 8 (368/m^2; primarily sand substrate) and least at station 1 (7/m^2; clay/sand substrate) but with only a weak correlation between mean ranked density and substrate (sand, Pearson=0.35, P<0.0001; clay, Pearson=–0.37, P<0.0001). Mean density increased significantly in each year: 13/m^2 in 1994, 54/m^2 in 1995, 99.6/m^2 in 1996, 161/m^2 in 1997 (Fig. 5; $F_{2,132}$=33.1, P<0.0001). There were no significant differences in quagga mussel mean ranks of density by station. A subsample of 757 zebra mussels ranged from 2–17 mm SL (mode=7mm) and a subsample of 131 quagga mussels ranged from 2–35 mm SL (mode=5mm).

Two amphipod species were collected: *Gammarus fasciatus* (22% by number) and *Hyalella azteca* (0.3%). *G. fasciatus* was collected in all samples at a mean density of 2064/m^2. Mean ranks of density were significantly greatest at station 4 and least at deep water stations 3, 6, and 9 ($F_{8,126}$=28.5; P<0.0001) with a significant but weak correlation between mean ranked density and depth (Pearson=–0.49, P<0.0001). *H. azteca* was collected only in Flynn Bay at station 7 at a mean density of 343/m^2.

Members of Chironomidae represented 17% of all organisms collected and occurred at all stations but had significantly greater mean ranks of density at stations 4, 5, 7, and 8 (mean density=1572/m^2) compared to the deep stations where mean density was 788/m^2 ($F_{8,126}$=6.0; P<0.0001). Mean ranked density was weakly correlated with depth (Pearson=–0.34, P<0.0001). Mean ranks of density were least in June and greatest in July ($F_{4,130}$=3.75; P<0.0001), which might be due to emergence of Chironomidae in June: clouds of adults could be seen against the sky from up to 3700 m distance.

TABLE 2.–Living macroinvertebrate taxa collected in bays in the upper St. Lawrence River in 1994 and 1995–1997. Invasive species are in bold lettering. Taxa italicized at the bottom of this table were not identified to family and were not used in analyses.

Taxa	Family		1994		1995-1997	
			total collected	mean density (#/m^2)	total collected	mean density (#/m^2)
Turbellaria	Planariidae		99	91.7	1877	201.5
Oligochaeta	Naididae		531	491.7	6016	645.8
	Lumbriculidae		43	39.8	327	35.1
	Aeolosomatidae		62	57.4	260	27.9
Isopoda	Asellidae		82	75.9	3637	390.4
Amphipoda	Gammaridae	*Gammarus fasciatus*	2046	1894.4	19225	2063.9
	Hyalellidae	*Hyalella azteca*	0	0	309	33.2
Ephemeroptera	Caenidae		2	1.9	272	29.2
	Ephemeridae		3	2.8	132	14.2
	Baetidae		0	0	1	0.1
Odonata	Coenagrionidae		0	0	103	11.1
	Cordulidae		0	0	1	0.1
Neuroptera	Sisyridae		0	0	3	0.3
Trichoptera	Leptoceridae		40	37.0	584	62.7
	Helicopsychidae		9	8.3	586	62.9
	Odontoceridae		11	10.2	259	27.8
	Limnephilidae		7	6.5	237	25.4
	Polycentropodidae		37	34.3	143	15.4
	Hydroptilidae		4	3.7	92	9.9
	Molannidae		13	12.0	67	7.2
	Phyrganeidae		9	8.3	37	4.0
	Brachycentridae		1	0.9	26	2.8
	Lepidostomatidae		0	0	15	1.6
Lepidoptera	Pyralidae		13	12.0	68	7.3
Coleoptera	Elmidae		3	2.8	43	4.6
	Dytiscidae		0	0	11	1.2
	Psephenidae		0	0	1	0.1
Diptera	Chironomidae		2040	1888.9	14356	1541.2
	Ceratopogonidae		7	6.5	92	9.9
	Empididae		0	0	5	0.5
	Chaoboridae		0	0	2	0.2
Gastropoda	Hydrobiidae	various hydrobids	289	267.6	2465	264.6
		Gillia altilis	1	0.9	1	0.1
	Pleuroceridae	*Pleurocera virginica*	2	1.9	18	1.9
	Bithyniidae	***Bithynia tentaculata***	115	106.5	524	56.3
	Planorbidae	*Gyraulus circumstriatus*	43	39.8	527	56.6
		Gyraulus deflectus	40	37.0	475	51.0
		Promenetus exacuous	29	26.9	212	22.8
		Gyraulus crista	0	0	35	3.8
		Helisoma campanulatum	3	2.8	34	3.7
		Helisoma trivolvis	4	3.7	15	1.6
		Helisoma anceps	0	0	6	0.6
		Gyraulus parvus	5	4.6	1	0.1

TABLE 2. *continued.*

			1994		1995-1997	
Taxa	Family		total collected	mean density (#/m^2)	total collected	mean density (#/m^2)
	Valvatidae	*Valvata tricarinata*	12	11.1	372	39.9
		Valvata sincera	19	17.6	131	14.1
		Valvata lewisi	4	3.7	23	2.5
		Valvata piscinalis (introduced)	0	0	15	1.6
	Lymnaeidae	*Acella haldemani*	1	0.9	21	2.3
		Lymnaea stagnalis	8	7.4	15	1.6
		Stagnicola elodes	3	2.8	15	1.6
		Lymnaea obrussa	0	0	4	0.4
	Tateidae	***Potamopyrgus antipodarum***	0	0	29	3.1
	Ancylidae	*Ferrissia parallela*	27	25.0	63	6.8
		Laevapex fuscus	1	0.9	14	1.5
		Ferrissia californica	3	2.8	1	0.1
	Physidae	*Physa* spp.	88	81.5	291	31.2
Bivalvia	Unionidae	*Elliptio complanata*	6	12.0	14	1.5
		Lampsilis radiata	5	2.8	3	0.3
	Sphaeriidae	*Sphaerium* spp.	311	288.0	655	70.3
	Pisidiidae	*Pisidium* spp.	128	118.5	595	63.9
	Dreissenidae	***Dreissena polymorpha***	7324	6781.5	26071	2798.8
		Dreissena r. bugensis	15	13.9	851	91.4
Porifera	Spongillidae	*Spongilla lacustris* colonies	1	0.9	6	0.6
		Eunapius fragilis colonies	0	0	1	0.1
Nematoda	*nematode*		11	10.2	156	16.7
Hydracarina	*water mite*		0	0	4	0.4
Nematomorpha	*nematomorpha*		8	7.4	58	6.2
Hirudinea	*leech*		54	50.0	494	53.0
Coelenterata	*hydra*		0	0	2	0.2
Total collected			13622		83004	

Three families of annelids were collected: Naididae, Lumbriculidae, and Aeolosomatidae. Naididae (90% of all annelids) accounted for 7% of all organisms collected and were collected at all stations. Stations 4, 5, 7, and 8 had significantly greater mean ranks of Naididae density and deep stations had lower mean ranks of density ($F_{8,126}$=13.5; P<0.0001) with a corresponding correlation with depth (Pearson=–0.42, P<0.0001). Mean Naididae density at stations 4, 5, 7, and 8 was 486/m^2 compared to 246/m^2 at deep water stations. Naididae mean density was significantly less in 1997 (Fig. 5; $F_{2,132}$=6.73, P<0.0016). Mean ranks of Lumbriculidae density were similar at stations 1, 2, and 5 and were significantly greater than mean ranks at stations 4, 7, and 8 ($F_{8,126}$=39.02; P<0.0001). Lumbriculidae did not occur at deep water stations. Mean ranks of Aeolosomatidae density were similar at stations 1, 2, 4, 7, and 8 (mean density range 48.9–74.7m^2), lower at station 5 (mean=32.5/m^2) and none was collected at the deep water stations.

Asellidae was collected at all stations but stations 7 and 8 accounted for 72%. Stations 1 and 2 accounted for 27%. Mean density was 2240/m^2 at station 7 and 659/m^2 at station 8. Mean ranks of Asellidae density were significantly greatest at station 7, followed by station 8, similar at stations 1, 2, 4, and 5, and less at deep water stations ($F_{8,126}$=21.0; P<0.0001). Mean ranked density was weakly correlated with depth (Pearson=–0.32, P=0.0001). Mean density at deep water stations was 18–41/m^2.

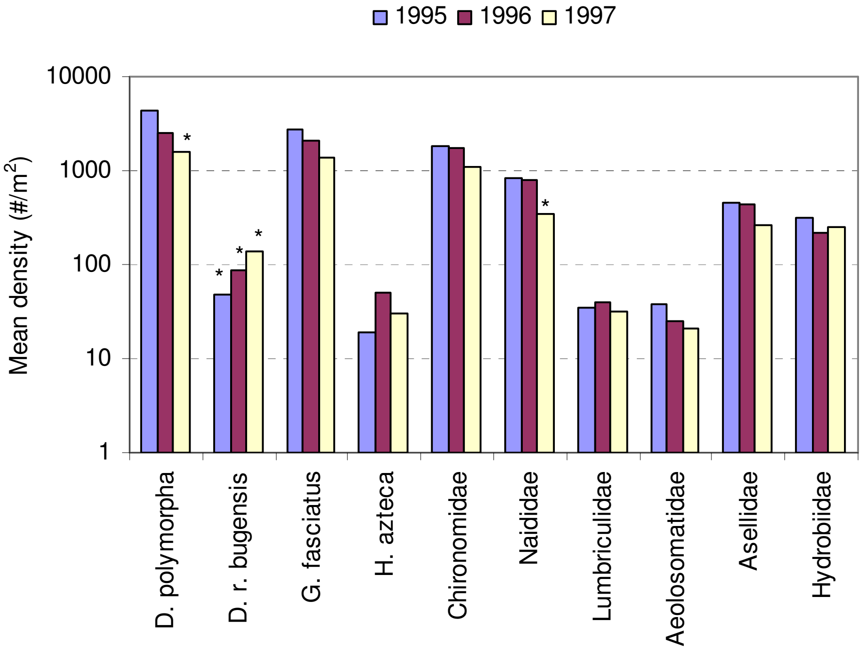

FIGURE 5.–Mean density (#/m^2, all stations combined) of dreissenids (*Dreissena polymorpha* and *D. rostriformis bugensis*), amphipods (*Gammarus fasciatus* and *Hyalella azteca*), Chironomidae, oligochaetes (Naididae, Lumbriculidae, and Aeolosomatidae), Asellidae, and Hydrobiidae. An asterisk denotes a significant difference for *D. polymorpha* ($F_{2,132}$=8.73, P=0.003), for *D. r. bugensis* ($F_{2,132}$=5.6, P=0.005) and for Naididae ($F_{2,132}$=6.73, P=0.0016).

Three families of Ephemeroptera, Ephemeridae (*Ephemera* spp., *Hexagenia* spp.), Caenidae, and Baetidae were collected with Caenidae being most abundant (66% of all mayflies). Caenidae was more abundant at stations 4 (64%) and 7 (23%) and was not collected at deep water stations. *Ephemera* spp. was most abundant at station 4 (99%) with 1% at station 8. None was collected at other stations. *Hexagenia* spp. was collected at deep water stations (87% of total *Hexagenia*) with 73% at station 3. One Baetidae was collected at station 1.

Ten families of caddisflies (Trichoptera) were collected dominated by Leptoceridae at 29% of all caddisflies. Leptoceridae was collected at all stations (Fig. 6) but was significantly lower in mean rank density at the deep water stations ($F_{8,126}$=14.4**,** P<0.0001). Helicopsychidae, second in abundance at 27%, was more abundant at stations 4, 5, and 8 (mean rank density $F_{8,126}$=61.5, P<0.0001)**,** and was not collected at stations 3, 6, 7, or 9. Odontoceridae had significantly greater mean ranks of density at stations 4 and 5 than at stations 2, 3, or 8 ($F_{8,126}$=5.72**,** P<0.0001). Odontoceridae was not collected at stations 1, 6, 7, or 9.

Limnephilidae mean ranks of density at station 4 was greater than at stations 6 and 9 ($F_{8,126}$=3.1**,** P<0.003) but similar at remaining stations. There were no significant differences in mean rank of density by month or year for Leptoceridae, Helicopsychidae, Odontoceridae, or Limnephilidae. The six other families were not analysed for differences as they were not collected in 84% of the samples**.** Mean ranks of density for all caddisfly families was significantly less at deep water stations and greatest at station 5 ($F_{8,126}$=30.17**,** P<0.0001).

Twenty-five taxa of gastropods were collected (N=6005, Fig. 7). Hydrobiidae was the most abundant of the gastropods collected at 46% of the total. Hydrobiidae was collected at all stations with greater mean density at station 7 ($230/m^2$) and station 1 ($211/m^2$) but there was no significant difference in mean ranks among stations 1, 2, 5, 7, and 8. Hydrobiidae mean density at deep water stations, and station 4, ranged from $4–19/m^2$ and was significantly less ($F_{8,126}=27.83$; $P<0.0001$) than at other stations. Mean ranked density was correlated with depth (Pearson=–0.44, $P<0.0001$) but not with substrate. Eight species of Planorbidae accounted for 24% of the total gastropods collected. Two species, *G. circumstriatus* and *G. deflectus*, were more abundant at 9.4% (mean density $20.4/m^2$) and 8.6% (mean density $18/m^2$) of all gastropods collected. Mean ranked density of these two species was greater at stations 2, 5, and 7 and least at deep water stations (*G. circumstriatus* $F_{8,126}=20.7$, $P<0.0001$; *G. deflectus* $F_{8,126}=22.04$, $P<0.0001$).

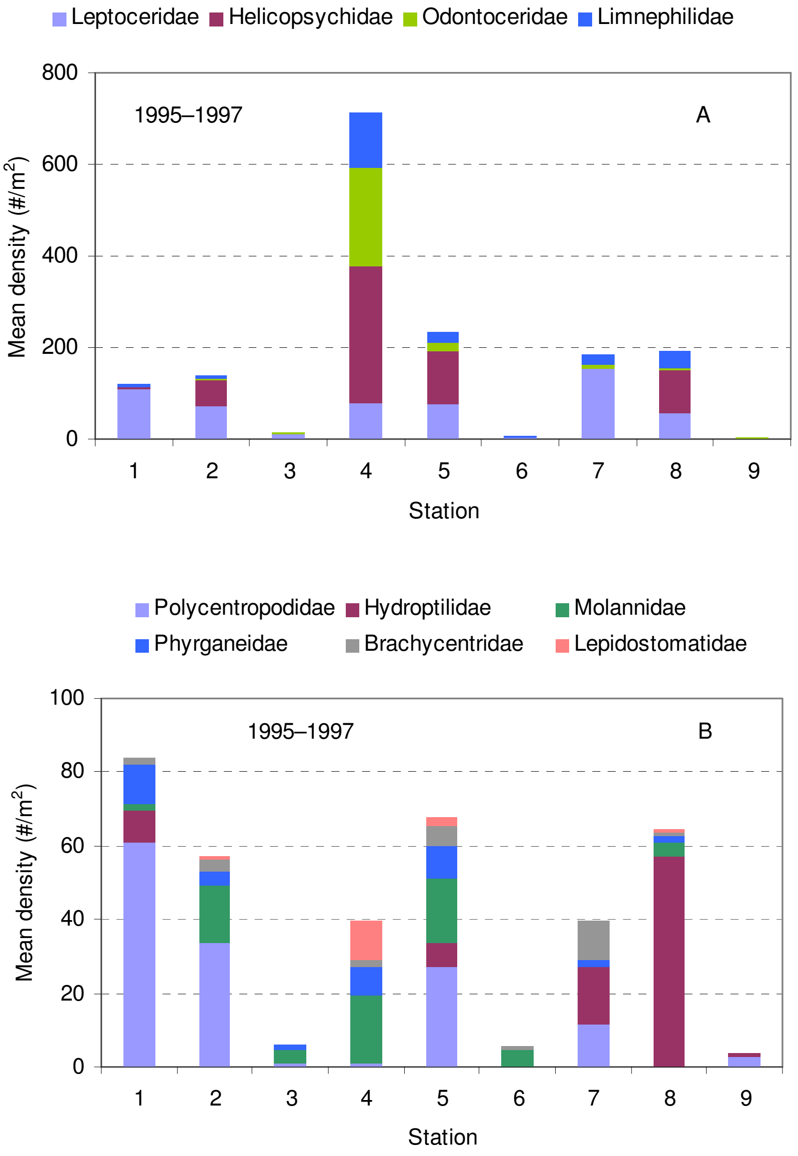

FIGURE 6.–Mean density of caddisfly families collected by station. One Limnephilidae was collected at station 9 (panel A). The four more abundant families are shown in panel A and the remaining six families are in panel B.

The invasive snail *Bithynia tentaculata* accounted for 11% of all gastropods and was collected at all stations. Mean *Bithynia* density was greater at station 8 ($60/m^2$), station 5 ($51/m^2$), and station 2 ($49/m^2$) and least at deep water stations as were mean ranks of density ($F_{8,126}$=25.9, P<0.0001).

Of the four species of Valvatidae, *V. tricarinata* was most abundant (Table 2) and mean ranks of density were significantly greater at stations 5 and 8 ($F_{8,126}$=11.32, P<0.0001) with similar mean ranks of density at the other stations. The introduced gastropod *Valvata piscinalis* was not abundant but had a wide distribution (all stations except 5, 6, and 8) over various sediment types and aquatic plants. *Acella haldemani* was the most abundant of the four Lymnaeidae species at 38% and occurred at stations 1, 2, 5, and 7 with the greatest percentage at station 7 (68%). Ancylidae was represented by three species with *Ferrissia paralella* being the most abundant (81%) but this species was collected only at stations 1, 2, 5, and 7. Physidae was collected at all stations other than station 3: deep water stations had significanly lower mean ranks for Physidae density ($F_{8,126}$=10.52, P<0.0001) with no significant differences among the other stations.

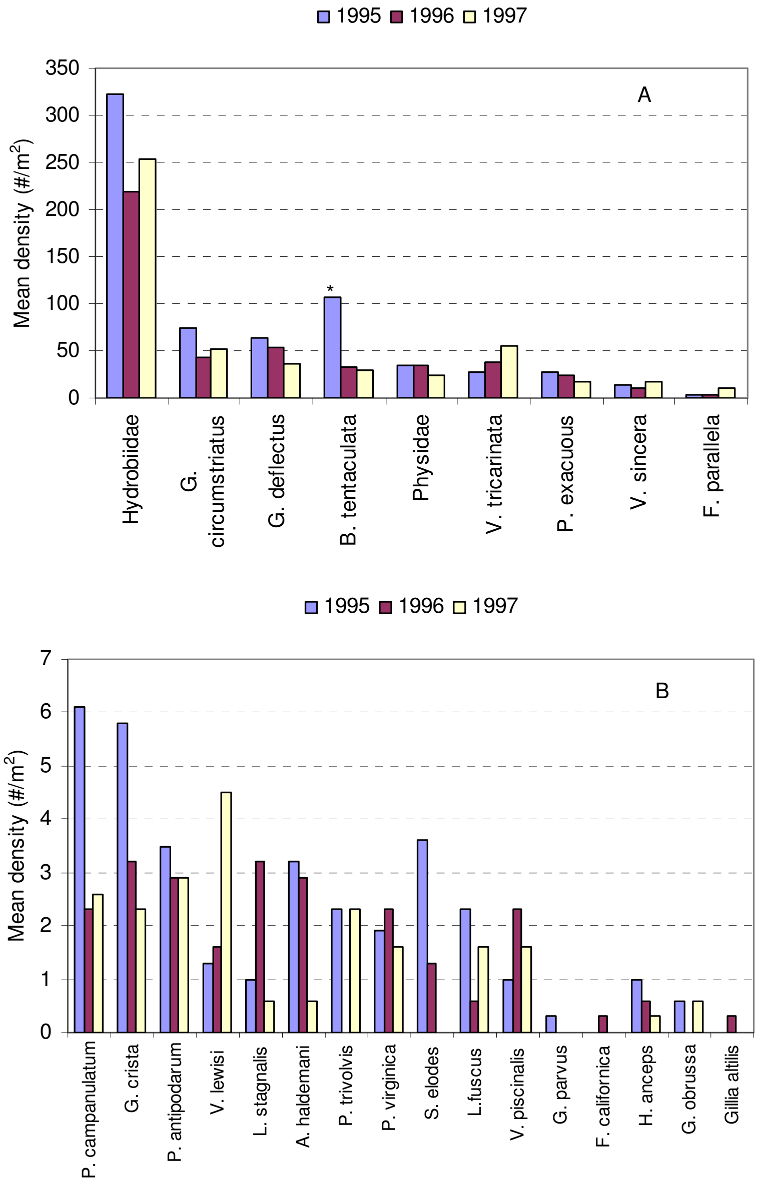

FIGURE 7.–Mean density of gastropod taxa by year, all stations combined. Those taxa that occurred at greater than 7/m^2 density are in panel A where the only statistical difference by year was for *B. tentaculata* ($F_{2,132}$=4.30, P=0.015). Taxa for which mean density was less than 7/m^2 are in panel B. No statistical tests were run on taxa in panel B due to their low abundance.

The invasive New Zealand mud snail *Potamopyrgus antipodarum* was collected in 1995, 1996, and 1997 (none in 1994) at similar densities by year (Fig. 7). It was collected at stations 2, 3, 7, 8, and 9 with the greatest mean density at station 9 (37/m^2) in 1995. The ornamented snail, *Gyraulus crista* (Star Gyro) was collected at stations 1, 2, 5, 7, and 8, was most abundant at station 7 (57% of those collected) with the majority (51%) being collected in 1995. These two species are shown in Figure 8.

FIGURE 8.–*Potamopyrgus antipodarum* from station 9 (left, range 4–5.5 mm SL) and *Gyraulus crista* from station 7 (right, 2 mm diameter).The pink color is from stain used in sample collection.

Two unionid species were collected alive from 1994 to 1996: *Elliptio complanata* and *Lampsilis radiata*. Adult *E. complanata* was more abundant (N=10; mean SL =63.2 mm; SE=3.3; range 44.2–78.2 mm) than *L. radiata* (N=5; mean SL=64.4 mm; SE=3.2; range 56.5–73.9 mm). Adult *E. complanata* was collected at all stations other than 6 and 7, and adult *L. radiata* was collected at stations 2, 4, 6, and 8. Living juvenile *E. complanata* (N=10; mean SL=13.7; SE=3.8; range 1.5–32.5 mm) was more abundant than juvenile *L. radiata* (N=3; mean SL=20.8; SE=4.2; range 12.5–25.5 mm). The mean shell length of empty adult unionid shells was: *E. complanata* 64.7 mm (N=75; SE=1.1; range 40.1–86.2 mm); *L. radiata* 65.1 mm (N=60; SE=1.2; range 43.3–84.9 mm), and *Pyganodon cataracta* 75.7 mm (N=1). The mean shell length of empty juvenile unionids was: *E. complanata* 19.0 mm (N=18; SE=2.3; range 7–37.2 mm) and *L. radiata* 31.8 mm (N=5; SE=3.2; range 23.8–37.8 mm). Evidence of dreissenid colonization (byssal threads) on unionid mussels was seen on most shells and occurred in mussels as small as 22 mm SL in *E. complanata* and 25 mm in *L. radiata*. Tracks of unionid mussel movement were visible in Lindley and Flynn bays until 1996. The last living unionid mussel collected was *L. radiata* (12.5 mm SL) in September 1996.

Sphaerium spp. was collected at all stations but the greater percentage and density came from stations 1 (18%, 132/m^2), 2 (20%, 148/m^2), and 7 (20%, 145/m^2); the other stations contributed less than 10%. Mean ranks of density were significantly greater at stations 1, 2, and 7 ($F_{8,126}$=8.26, P<0.0001) than at other stations. Mean density of *Sphaerium* spp. at deep water stations ranged from 15/m^2 at station 3 to 71/m^2 at station 6.

Pisidium spp. was collected at all stations but the greater percentage and density came from stations 2 (34%, 67/m^2), 4 (20%, 38/m^2), and 7 (14%, 27/m^2); the other stations contributed 1% at station 3 (mean density=3/m^2) to 8% at station 6 (mean density=16/m^2). Mean ranks of density were greater at stations 2, 4, and 7 ($F_{8,126}$=8.69, P<0.0001). *Sphaerium* and *Pisidium* mean ranked density was weakly correlated with depth

(*Sphaerium*, Pearson=–0.34, $P<0.0001$; *Pisidium*, Pearson=–0.27, $P=0.001$) but there was no correlation with substrate.

Deeper water stations had significantly fewer macroinvertebrate families (mean=16 families) compared to other stations (mean=27 families; $F_{8,126}=13.5$, $P<0.0001$), less Percent Chironomidae (less than 1% compared to greater than 1.5% at other stations; $F_{8,126}=5.19$, $P<0.0001$), a greater Family Biotic Index at stations 3 and 9 ($F_{8,18}=5.26$, $P=0.002$), station 6 was statistically different only from stations 3 and 9, and greater Percent Dominants although deep water stations did not differ statisically from stations 4, 5, and 8 ($F_{8,18}=5.38$, $P=0.001$; Fig 9).

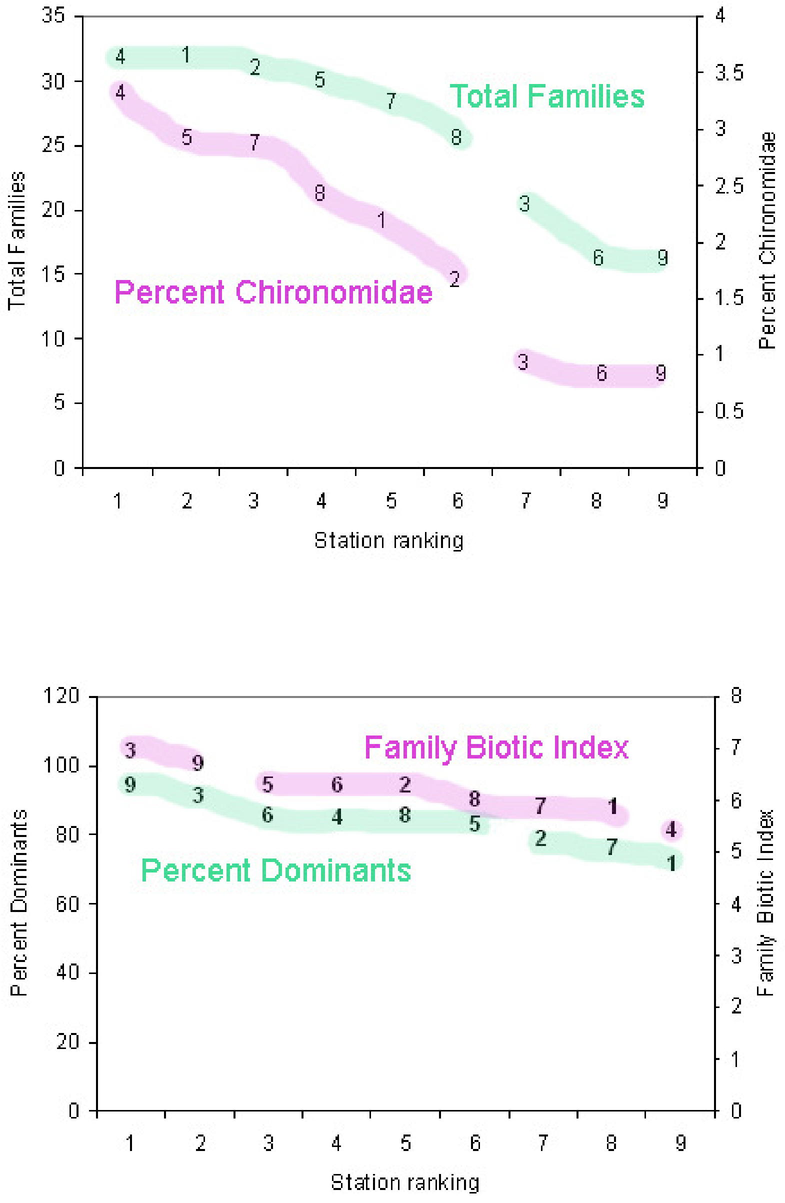

FIGURE 9. Comparison of station ranking for Total Families and Percent Chironomidae (upper panel), and Family Biotic Index and Percent Dominants (lower panel). Stations connected by a common color are not statistically different in ranking.

The Shannon Diversity index showed stations 3 and 9 having lower scores than all other stations with station 6 being intermediate between stations 8 and 4 (Fig. 10). Scores for the Simpson Index were similar to those of the Shannon Index with the deeper stations having lower scores.

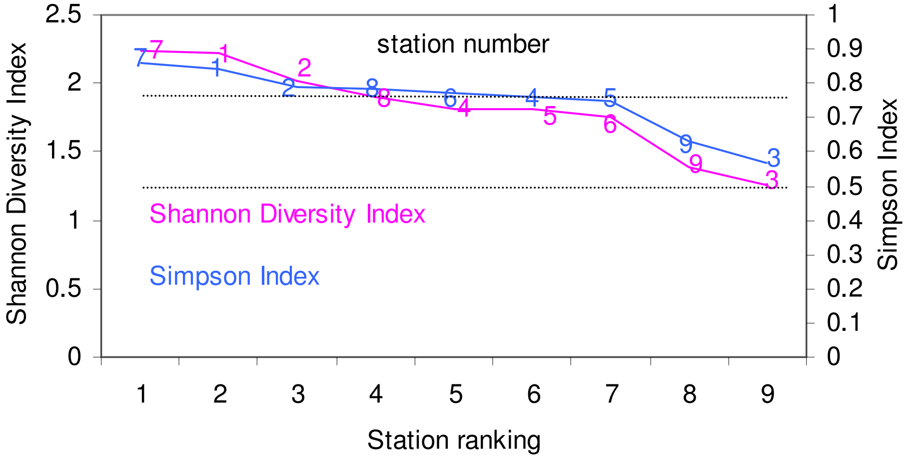

Figure 10. Comparison of the Shannon Diversity Index to the Simpson Index by station, all years combined. Dotted lines indicate the Simpson Index level above which no pollution occurs (0.75) and below which greater organic pollution occurs (0.5).

Discussion

The sediment composition of the bays resulted from the exposure of the bays to the prevailing wind and its effect on the differing grain sizes, and from the composition of the land surrounding each bay. Buck Bay was partially protected from the wind by islands and by the narrow bay mouth, which together reduced direct wave effects at the interior of the bay and allowed silty sediments to accumulate. Sand eroded from the surrounding granite hills was deposited directly into the bay and through the small tributary. Flynn Bay was also protected from erosional effects to some extent by Club Island and *Typha* that had become established between Club and Grindstone islands (Cooper et al. 2008). The wave-breaking nature of *Typha* (Geis 1979), which would reduce water exchange, may have exacerbated the low oxygen levels in the SW part of Flynn Bay brought about by the decomposition of organic matter in late summer. The higher silt component at the interior of the bay was a result of the greater inflow from the tributaries that drained farm fields and the lack of extensive granitic headlands around the bay. Lindley Bay was exposed directly to strong westerly and south-westerly winds, which prevented the accumulation of silt. The resulting sandy substrate restricted vegetative growth to the emergents *Carex* and *Scirpus* in the shallow areas and *Chara* and *Potamogeton* in deeper water where wave action is minimal. Submerged macrophytes have less extensive root systems than emergent plants (Wetzel 1983) and are more susceptible to washout by wind and wave action. The sandy sediment was derived from erosion of the surrounding upland and forms part of a large sand deposit extending from the sand bar that crosses the mouth of Flynn Bay, encompasses all of Lindley Bay, the outer part (station 2) of Buck Bay and along much of the western shoreline of Grindstone Island. The sand extends out into the deeper sediments at station 3, which had a greater proportion of sand than either of the other deep water stations.

The accumulation of silt and clay sediments in Buck and Flynn bays has resulted in a more diverse vegetative community than that found in Lindley Bay. Buck and Flynn bays were more similar to each other than either was to Lindley Bay. The interiors of Buck and Flynn bays have seasonally-flooded meadows and an extensive shallow water area that supports submerged vegetation. Buck Bay has a more limited vegetative area than Flynn Bay due to its narrow configuration and greater depth.

The significant correlations among taxa and physical environmental features were weak, which suggests that these relationships do not determine the community structure on their own but work in concert with each other. Water depth was the strongest factor for determining macroinvertebrate distribution and density.

Macroinvertebrate diversity among the three bays was similar but declined in deeper water. This was reflected in the index values: fewer Total Families, greater values for Percent Dominants, lower Percent Chironomidae, and a greater Family Biotic Index. The Shannon Diversity Index and the Simpson Index also showed similar results in that diversity declined in deeper water. The latter two indices are used more often to estimate the effect of organic pollution but can also estimate the suitability of habitat: in this case the deeper water habitat being suitable for fewer macroinvertebrate taxa. The deeper water stations were beyond the photic zone so there were no plants to provide a food source or structural refuge. The indices therefore reflect which macroinvertebrate taxa can tolerate these conditions.

The invasive Dreissenidae dominated the macroinvertebrate community by number and altered the community structure by eliminating the unionid mussel population. These actions have the effect of changing the complexity of the bottom substrate (Strayer et al. 1999). Another invasive, the New Zealand Mud snail *Potamopyrgus antipodarum*, was collected in the St. Lawrence River near Kingston in 1994 (Zaranko et al. 1997) and in Four-mile Creek, a tributary of Lake Ontario in western New York in 2007 (Levri and Jacoby 2008). The distribution of mud snail was summarized in Levri et al. 2008. This snail was not reported by Farrell et al. (2010) or by Tall et al. (2016) but their sampling did not include deep water stations. This species now occurs in all the Great Lakes (USGS 2021).

The European faucet snail *Bithynia tentaculata* appeared in Lake Ontario around 1880 (Beauchamp 1888) and was abundant in the St. Lawrence River near Clayton in 1970 (Kinney 1972) and Cape Vincent in 1978–1979 (Haynes and Makarewicz 1982) and in the present study. It was not as abundant in Lake St. Pierre (lower St. Lawrence River; Tall et al. 2016). The European stream valvata *Valvata piscinalis* was introduced into Lake Ontario at the mouth of the Genesee River in 1897 where it became abundant (Baker 1898, 1900). This snail is known for rapid growth and high fecundity and has the potential to become invasive (Grigorovich et al. 2005) although it was the least abundant of the Valvatidae in the present study and in Farrell et al. 2010.

The invasive amphipod *Echinogammarus ischnus* was not collected in the present study but no samples were taken along shorelines where they would be more abundant (van Overdijk et al. 2003; Cooper et al. 2012). This amphipod has been collected in Lake Ontario (Haynes et al. 2005) and in the St. Lawrence River at Montreal (Kestrup et al. 2011).

Some taxa that have what appears to be a limited distribution in the present study may be more widespread but in low abundance: *Hyalella azteca* was limited to one station in the present study but was collected at Cape Vincent, French Bay, and Chippewa Bay from 2004 to 2007 (unpublished data); *Gyraulus crista* was also collected in French Bay in 2006 in low abundance; and the polychaete *Manayunkia* was collected at Cape Vincent by Kinney (1972) and Mills et al. (1981); at Morristown (Kinney 1972) and Lake St. Pierre (Tall et al. 2016) but not by Haynes and Makarewicz (1982) or in the present study or in Farrell et al. (2010).

Previous studies of the inshore taxa of the Great Lakes showed that macroinvertebrates were represented primarily by Chironomidae, Sphaeriidae, Oligochaeta (especially Naididae) and Amphipoda due to the extensive range of microhabitats (Cook and Johnson 1974) with deeper water dominated by Oligochaeta (Johnson and Brinkhurst 1971). Gammaridae, *Hyalella*, and Chironomidae were more abundant in Great Lakes marshes that were protected from wave energy and mixing (Cooper et al. 2007) but this was not the case in the present study: the most exposed area (Lindley Bay) had greater densities of *Gammarus* and Chironomidae in each year than did protected stations.

Three taxa, (other than Dreissenidae), Gammaridae, Oligochaeta, and Chironomidae, were among the more abundant taxa by number, density, and distribution in six studies of the St. Lawrence River from 1972 to 2016. Other abundant taxa were Gastropoda and Asellidae depending on river location.

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