

NOTE

**The Impacts of the Non-native Macrophyte *Cabomba caroliniana*
on Littoral Biota of Kashiabog Lake, Ontario**

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ABSTRACT. *An established population of *Cabomba caroliniana* now covers extensive littoral areas in the shallow waters of Kashiabog Lake (Ontario). This is the first known naturalized population of this non-native aquatic macrophyte, commonly called fanwort, on the Canadian side of the Great Lakes basin, despite the fact that it was first reported in the 1930s. High dispersal potentials combined with the ability to adapt and grow in a range of environmental conditions have made *C. caroliniana* a nuisance species in Australia, Japan, and parts of the United States. However, little is known about the broader ecological implications of its introduction and establishment. Using a survey approach, we conducted a preliminary assessment of water chemistry, macrophyte, epiphytic algae, and macroinvertebrate communities found in *C. caroliniana* beds and compared them with native macrophyte beds in Kashiabog Lake. Light penetration was significantly reduced in the *C. caroliniana* beds and was the only sampled physio-chemical parameter that differed between bed types. We also found several notable differences in the structure and composition of biological communities within macrophyte beds. While native macrophytes were present in dense *C. caroliniana* beds, abundance was considerably low and unevenly distributed. Significantly more epiphytic algae was present on *C. caroliniana* plants, however community composition was comparable with epiphytic algae found on native macrophytes. The taxonomic composition of macroinvertebrates was similar between *C. caroliniana* and native beds, while abundance was substantially higher in *C. caroliniana* beds, owing to high densities of coenagrionids and chironomids. These differences suggest that *C. caroliniana* is changing macrophyte community composition in this lake, having an impact on epiphytic algae, and creating a new habitat for some macroinvertebrates. Further studies are required to determine the extent of these ecological impacts.*

INDEX WORDS: *Non-native species, *Cabomba caroliniana*, macrophytes, epiphytic algae, macroinvertebrates, fanwort.*

INTRODUCTION

Cabomba caroliniana was first discovered in the Great Lakes basin in 1935 in the St. Joseph River system in Kalamazoo County, Michigan (Mills *et al.* 1993), and while there have been no confirmed sightings, it is possible that it is currently present in

the Great Lakes. Native to Brazil, Argentina, Paraguay, and Uruguay in South America and the south-eastern United States (Øgaard 1991), this species has readily naturalized lakes in northern temperate areas (e.g., Noel 2005, Lyon and Eastman 2006). Recent invasions and infestations of this species, considered a noxious weed, have been recorded in Australia, Japan, Malaysia, India, and the United States (e.g., Øgaard 1991, Mackey and

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Swarbrick 1997). Little work has been done on this non-native macrophyte in Canada, until a naturalized population was discovered in Kasshabog Lake (Ontario) in 1991 (MacDonald 2002).

As a nuisance species, this competitive, submersed macrophyte, commonly known as fanwort, grows prolifically and forms dense populations, which can displace native macrophyte species and may alter nutrient cycling (Sheldon 1994, Mackey and Swarbrick 1997, Wilson *et al.* in press). Typically monotypic stands of *C. caroliniana* are known to impede water flow, alter navigation patterns, affect water quality, and restrict recreational activities (Mackey and Swarbrick 1997, MacDonald 2002).

C. caroliniana is a submersed, perennial plant of the Nymphaeaceae that grows primarily from vegetative fragments and rhizomes with shallow, fibrous roots in stagnant to slow-flowing water bodies (e.g., ponds, lakes, small rivers) with silty substrates. Finely divided submersed leaves are fan-shaped and typically found in opposite pairs, although are sometimes in whorls of three, while floating leaves are long and slender (1–3 mm wide/ 20 mm long) and alternate on the stem (Øgaard 1991). The stems and leaves range in color from grass to olive green or are sometimes reddish brown. Solitary white emergent flowers are borne on long stalks. *C. caroliniana*, commonly referred to as fanwort, could be confused with native macrophytes, including *Myriophyllum*, *Ceratophyllum*, *Megalodonta beckii*, and *Ranunculus trichophyllus*, due to similar growth forms. However, *C. caroliniana* can be distinguished by the opposite pairs of palmately divided submersed leaves and the alternating floating leaves.

C. caroliniana is most commonly found in shallow waters (1–3 m), covering extensive areas of lake littoral zones, but can also grow in deeper waters. Warm temperatures (13–27°C), humid climates, and slightly acidic waters (pH 4–6) are considered optimal growing conditions. However *C. caroliniana* can withstand temperatures less than 0°C and can successfully overwinter under ice in northern regions (Riemer and Ilnicki 1968, Noel 2005). This opportunistic species is adapted to seasonal fluctuations in water levels and has shown increased adventitious root development in moderately turbid, light-limited waters (Mackey and Swarbrick 1997). At the end of the growing season, stems become brittle and break apart. These fragments remain green, persist over winter, and resume growth in the spring. Mechanical fragmentation is also common during the growing season, particularly due to human activities (e.g., motor

boating). Without contact with substrate, spontaneous adventitious rooting occurs at the nodes and rhizomes of free floating shoots (Øgaard 1991), facilitating dispersal of the plants. Any fragment, with a single pair of expanded leaves, can produce a mature individual (Gregory 1974). Seed production does not appear to be a viable means of reproduction in northern areas (Noel 2005), but is important for reproduction in this insect pollinated species in southern areas. The morphology and biology of this species have been thoroughly described elsewhere (see Øgaard 1991, Wilson *et al.* in press).

Few studies have been conducted on biological communities found within *C. caroliniana* beds. This information is critical for understanding the broader ecological implications of the introduction and establishment of this non-native macrophyte. For example, reduced dissolved oxygen in the lower layers of dense non-native macrophyte beds (Unmuth *et al.* 2000) or exposure to plant-secreted, allelopathic compounds (Nakai *et al.* 1999, Gross 2003) are known to negatively affect macroinvertebrates or algae. Alternatively, these communities could be positively affected by increased food availability or the creation of refuge from predators (Davork and Best 1982).

The initial introduction of *C. caroliniana* into Kasshabog Lake likely resulted from an inadvertent dumping of an aquarium (MacDonald 2002). Alternatively, it may have been transferred on a boat propeller or trailer from an invaded lake in the United States. This established population provided an opportunity to study the ecological impact of this non-native species on other aquatic communities. Currently, extensive beds of *C. caroliniana* are only found at localized sites which made it possible to compare invaded and non-invaded native macrophyte beds within the lake. Using a survey approach, we conducted a preliminary assessment of the macrophyte, epiphytic algae, and macroinvertebrate communities found in of *C. caroliniana* beds and compared them with native macrophyte beds in Kasshabog Lake. This work will provide the basis for future food web studies.

STUDY SITE

Kasshabog Lake (77°55'N, 44°38'W) is a large (809 ha), relatively shallow lake ($Z_{mean} = 4.5$ m) located in Peterborough County, Ontario. Kasshabog Lake is part of a watershed that ultimately drains into the Trent Severn Waterway and flows into Lake Ontario at the Bay of Quinte. The shoreline is

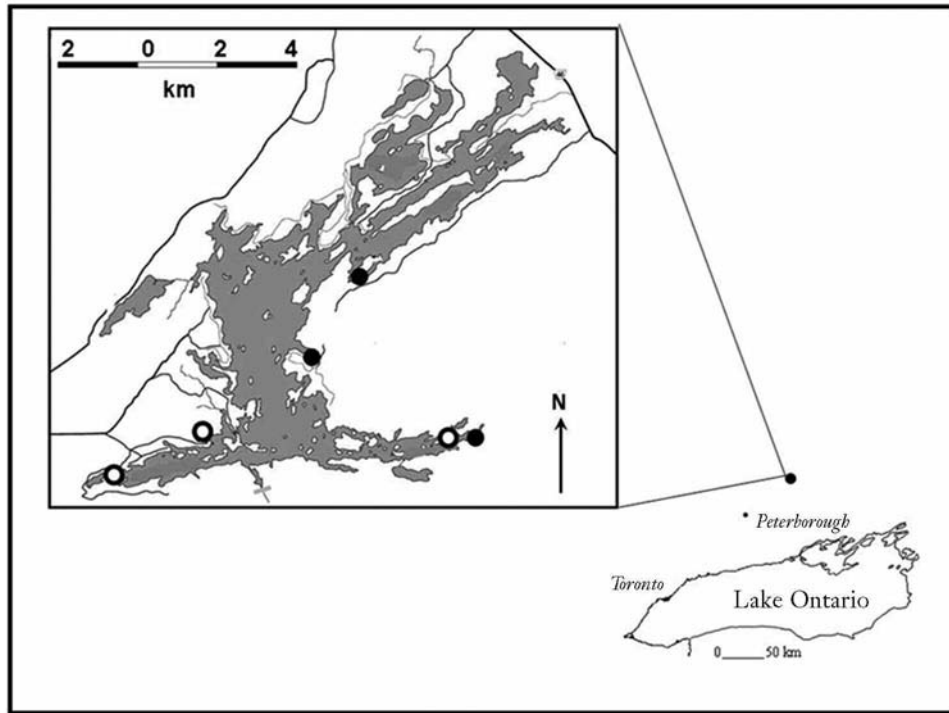


FIG. 1. Location of Kasshabog Lake in Ontario and of sampling sites dominated by *C. caroliniana* (closed circles) and sites dominated by native macrophytes (open circles).

extensively developed with cottages and the lake is highly used for recreational activities including boating and fishing.

Six small bays, three dominated by native species (*Potamogeton robbinsi*, *Najas flexillis*, *Myriophyllum sibiricum*, or *Elodea canadensis*) and three dominated by *C. caroliniana*, were selected within the lake (Fig. 1.). Sampling sites (1 m²) were randomly selected in the littoral zone (~1 m deep) at the end of each bay which provided protection from prevailing winds and had similar shoreline profiles and organic sediment substrate. *C. caroliniana* can be found growing at depths up to 5 m, but is found in greatest abundance in these more protected sites. Three replicate samples were taken in each bay (n = 18). This study was designed to identify changes in the biological communities in *C. caroliniana* beds compared to native beds and as a basis for future food chain impact studies.

METHODS

Water chemistry, submersed macrophyte, epiphytic algae, and macroinvertebrate samples were collected in this order at each site in early September 2005, before macrophyte die-off occurred. Noel

(2005) found that *C. caroliniana* in Kasshabog Lake continues to accumulate biomass well into October. Water samples (1 L) were taken from each site and analyzed in the lab for pH, total phosphorus, and chlorophyll *a*. Total phosphorus samples were digested using potassium persulfate and analyzed on an Ultrospec Biochrom spectrophotometer. Chlorophyll *a* samples were filtered through Whatman GF/C microfibre filters and frozen. Later, chlorophyll *a* was extracted using 90% acetone and analyzed using a spectrophotometer.

All macrophytes found in each 1 m² quadrat were physically removed and collected. Species were separated and identifications were made to the species level, if possible, according to Crow and Hellquist (2000). Samples were dried for 48 hr and weighed for biomass.

Epiphytic algae were collected from the upper shoots (~15 cm) of the dominant macrophyte species at each site by inverting a sampling jar over the plant and cutting the stem, to ensure minimal disturbance of loosely attached epiphytes. The depth at which this sample was taken was dependent on the height of the dominant plant and was not necessarily at the same depth below the surface.

The 100 mL sample jar was vigorously shaken for 30 seconds to remove epiphyton, after which the plant material was removed, dried for 48 hr and weighed. In the lab, the macrophyte-free water was filtered through a GF/C filter for chlorophyll *a* analysis. Epiphytic biomass was reported as $\mu\text{g chl } a \cdot \text{g dry weight}^{-1}$. Taxonomic analysis was conducted on sub-samples fixed in Lugol's solution (Wetzel and Likens 2000). These samples were scanned for species composition on a compound microscope at 100x, until a minimum of 300 viable cells were identified and counted per sample. Taxa were identified to the genus level according to Prescott (1982) and Wehr and Sheath (2003).

A D-net sweep was done in each 1 m² quadrat for 30 seconds to collect zoobenthos found in the macrophyte bed and the sediments below. The collection was made by stirring the sediments and sweeping throughout the bed. Macroinvertebrates were identified to the family level (Merritt and Cummings 1984) and the relative abundance and biomass were determined for each site.

Untransformed data were combined into native and *Cabomba* groups for statistical analyses and a Student's T-test was conducted between these groups. Species diversity and equitability were calculated using the Shannon Wiener Diversity Index (Equation 1) and Shannon's equitability (Equation 2). Equitability ranges from 0 to 1, with 1 representing complete evenness within a community.

$$H = -\sum_{i=1}^S \ln p_i \quad (1)$$

$$E_H = H / H_{\max} = H / \ln S \quad (2)$$

RESULTS AND DISCUSSION

Our findings show that the structure and composition of biological communities in dense beds of *Cabomba caroliniana* differ from those found in native macrophyte beds in Kasshabog Lake. We have documented significant differences between *C. caroliniana* and native beds for underwater light conditions, macrophyte equitability, epiphytic algae biomass, and macroinvertebrate biomass and abundance.

Lake water at all sites was slightly alkaline and oligotrophic (TP < 10 $\mu\text{g}\cdot\text{L}^{-1}$). Biological productivity ranged from low (< 3 $\mu\text{g}\cdot\text{L}^{-1}$ chl *a*) in water collected from native beds to moderate (2.5–9 $\mu\text{g}\cdot\text{L}^{-1}$ chl *a*) in water collected at *C. caroliniana* sites. Notable differences were observed in both measures of light conditions in the macrophyte beds (Table 1). Both I_0 and K_{PAR} were significantly reduced in the *C. caroliniana* beds ($P < 0.001$). At two study sites, Golden Pond and Portage Bay, the percentage of surface light reaching the sediments (I_0) were reduced to zero in *C. caroliniana* beds. The dense beds of *C. caroliniana* also produced steep light extinction curve coefficients (K_{PAR}). Otherwise, no significant differences were recorded between physical and chemical characteristics of the macrophyte beds.

No differences were detected in macrophyte biomass and diversity between plots dominated by native plants and *Cabomba* ($p = 0.65$ and $p = 0.32$; Table 2, respectively), although biomass was slightly higher and diversity lower in *C. caroliniana* beds. Aside from the four native species (*Potamogeton robbinsi*, *Najas flexilis*, *Myriophyllum het-*

TABLE 1. Physical and chemical characteristics of surveyed sites in Kasshabog Lake (DO = dissolved oxygen; I_0 = percent light reaching sediment relative to light at surface; K_{PAR} = light extinction coefficient; TP = total phosphorus; Chl *a* = chlorophyll *a*).

	Site	Temp (°C)	DO (mg · L ⁻¹)	% I_0	K_{PAR}	pH	Conductivity ($\mu\text{S} \cdot \text{cm}^{-1}$)	TP ($\mu\text{g} \cdot \text{L}^{-1}$)	Chl <i>a</i> ($\mu\text{g} \cdot \text{L}^{-1}$)
Cabomba	Aquarium Bay	22.41	11.93	1.00	6.77	7.19	70.76	11.68	2.49
	Golden Pond	21.54	12.06	0.00	14.02	7.20	102.78	6.26	4.58
	Portage Bay	21.42	14.79	0.00	8.53	7.11	75.00	7.11	8.35
	Mean	21.79	12.93	0.33	9.77	7.16	82.84	8.35	5.14
	S.E.	0.31	0.93	0.33	2.18	0.03	10.05	1.69	2.11
Native	Helga's Bay	22.18	12.22	19.00	3.32	7.15	77.00	11.45	3.68
	Marina Bay	21.78	9.73	17.00	2.35	7.17	76.64	8.74	2.42
	Stony Lake Bay	22.03	12.92	16.00	2.56	7.21	77.02	6.26	2.11
	Mean	22.00	11.62	17.33	2.74	7.18	76.89	8.81	2.74
	S.E.	0.11	0.97	0.88	0.29	0.02	0.12	1.50	0.48

TABLE 2. Mean biomass, diversity, and equitability for macrophytes, macroinvertebrates, and epiphytic algae in *Cabomba caroliniana* beds and native macrophyte beds. Values represent mean (\pm S. E. (standard error); $n = 9$). * indicates significant difference ($p < 0.05$) as determined by Student's T-test.

	<i>C. caroliniana</i> beds	Native macrophyte beds
Biomass		
Macrophyte (g dry wt · m ⁻²)	202 (30)	165 (35)
Macroinvertebrate (g wet wt · m ⁻²)	1.02 (0.12)	5.95 (1.32)*
Algal (μ g chl <i>a</i> · g dry wt ⁻¹)	1535 (231)*	821 (109)
Shannon Wiener Diversity Index		
Macrophyte (H)	0.28 (0.05)	0.36 (0.08)
Macroinvertebrate (H)	1.48 (0.09)	1.54 (0.05)
Algal (H)	2.57 (0.04)	2.70 (0.20)
Shannon's Equitability		
Macrophyte (E)	0.25 (0.04)	0.35 (0.07)
Macroinvertebrate (E)	0.76 (0.05)	0.83 (0.03)
Algal (E)	0.76 (0.00)	0.80 (0.04)

erophyllum, and *Elodea canadensis*) which were selected for in native beds, the biomass of species found in both bed types (e.g., *Vallisneria americana*, *Utricularia gibba*) was 50% greater in native beds. Equitability was significantly lower in *C. caroliniana* beds ($p = 0.001$; Table 2). Lower equitability in *C. caroliniana* beds, despite selection of sites dominated by one species, suggests that other species are less evenly distributed within these dense stands and may forecast future losses of macrophyte diversity, particularly for low-growing native species such as *Najas flexilis* (Table 3). Ten species were found within *C. caroliniana* beds, but in very low proportions, including *Potamogeton tenuifolius*, *P. strictifolius*, *P. zosteriformis*, *P. pusillus*, *Utricularia gibba*, *U. vulgaris*, *Vallisneria americana*, *Elodea canadensis*, *Najas flexilis*, and *Myriophyllum heterophyllum* (Table 3). Noel (2005) found low densities of only five species established in *C. caroliniana* beds in Kasshabog Lake.

The biomass of epiphytic algae (estimated by chl *a*) was significantly greater on the upper shoots of *C. caroliniana* plants when compared to the upper shoots of native plants ($p = 0.04$; Table 2). Mean biomass was 44% higher on *C. caroliniana* plants. This difference likely can be attributed to the growth morphology (i.e., highly divided leaves; growing just below the surface of the water where light levels are greatest and competition from other

TABLE 3. Proportion of above-ground biomass (dry weight · m⁻²) for the different macrophyte species found at Kasshabog Lake sampling sites.

	Portage Bay	Golden Pond	Aquarium Bay
<i>C. caroliniana</i> beds			
<i>Cabomba caroliniana</i>	0.83	0.89	0.82
<i>Elodea canadensis</i>	0.02	0.02	
<i>Najas flexilis</i>		0.07	0.04
<i>Myriophyllum heterophyllum</i>	0.05		0.04
<i>Potamogeton pusillus</i>	0.01	0.02	
<i>Potamogeton strictifolius</i>			0.04
<i>Potamogeton tenuifolius</i>	0.01		
<i>Potamogeton zosteriformis</i>			0.04
<i>Utricularia vulgaris</i>	0.07		
<i>Utricularia gibba</i>			0.04
<i>Vallisneria americana</i>	0.01		
Native beds			
	Helga's Bay	Marina Bay	Stoney Lake Bay
<i>Elodea canadensis</i>	0.52		
<i>Megalodonta beckii</i>	0.01		
<i>Myriophyllum heterophyllum</i>	0.87	0.76	
<i>Najas flexilis</i>	0.07		
<i>Pontederia chordata</i>	0.01		
<i>Potamogeton robbinsi</i>	0.35		0.14
<i>Sparganium angustifolium</i>		0.05	0.02
<i>Utricularia gibba</i>		0.08	0.05
<i>Utricularia vulgaris</i>	0.01		
<i>Vallisneria americana</i>	0.03		0.02

TABLE 4. List of epiphytic algae taxa present (X) on *C. caroliniana* and native macrophytes.

		Cabomba	Native	
Cyanobacteria	<i>Anabaena</i>	X	X	
	<i>Aphansocapsa</i>	X	X	
	<i>Chroococcus</i>	X	X	
	<i>Merismopedia</i>	X	X	
	<i>Oscillatoria</i>	X	X	
	<i>Rhaboderma</i>	X	X	
	<i>Spirulina</i>	—	X	
Chrysophytes	<i>Dinobryon</i>	X	X	
Desmids	<i>Closterium</i>	X	X	
	<i>Cosmarium</i>	X	X	
	<i>Bambusina</i>	X	—	
	<i>Desmidiium</i>	X	X	
	<i>Euastrum</i>	X	X	
	<i>Gonazygton</i>	X	X	
	<i>Micrasterias</i>	X	X	
	<i>Netrium</i>	—	X	
	<i>Pleurotaneium</i>	X	X	
	<i>Spondylosium</i>	X	X	
	<i>Staurastrum</i>	X	X	
	Diatoms	<i>Achnanthes</i>	X	X
		<i>Cymbella</i>	X	X
		<i>Eunotia</i>	—	X
<i>Fragilaria</i>		X	X	
<i>Gomphonema</i>		X	X	
<i>Gyrosigma</i>		X	X	
<i>Navicula</i>		X	X	
<i>Nedium</i>		X	X	
<i>Pinnularia</i>		X	X	
<i>Synedra</i>		X	X	
<i>Tabellaria</i>		X	X	
Green algae		<i>Ankistrodesmus</i>	X	X
		<i>Pediastrum</i>	X	X
		<i>Scenedesmus</i>	X	X
	<i>Selenastrum</i>	X	X	
FGA	<i>Bulbochaete</i>	X	X	
	<i>Mougeotia</i>	X	X	
	<i>Oedogonium</i>	X	X	
	<i>Spirogyra</i>	X	X	
	<i>Zygnema</i>	X	X	
Dinoflagellate	<i>Peridinium</i>	X	—	

plants is minimized). A total of 40 algal taxa were identified and richness was comparable between *C. caroliniana* and native beds (Table 4; 37 taxa vs. 36 taxa). Species of *Mougeotia*, *Anabaena*, *Cosmarium*, *Tabellaria*, *Navicula*, and *Achnanthes* were most common to community assemblages in both bed types, occurring in over 80% of enumerated samples. The proportion of epiphytic algae, divided into major taxonomic groups, did not differ significantly between *C. caroliniana* and native macrophytes (Fig. 2). Algal diversity ($p = 0.53$; Table 2)

and equitability ($p = 0.45$; Table 2) were not significantly different between the macrophyte bed types. The lack of difference in epiphytes found on *C. caroliniana* and native plants may suggest that species composition was more related to the lake water chemistry than the host macrophyte (Cattaneo *et al.* 1998).

Macroinvertebrate biomass was significantly higher in natives beds ($p = 0.008$; Table 2), while species diversity ($p = 0.55$; Table 2) and equitability ($p = 0.23$; Table 2) did not differ between macrophyte beds. Community composition was similar between *C. caroliniana* and native beds. Of the eleven families identified, all were found in both macrophyte bed types, except *Gammarus*, which was only found on native plants. Total abundance was substantially higher in *C. caroliniana* beds, owing to high densities of coenagrionids and chironomids ($p = 0.023$; Table 5). In fact, mean overall abundance and the abundance of chironomids, coenagrionids, and hepatgeniid mayflies were all significantly higher in *C. caroliniana* beds ($p < 0.05$). The increased abundance of some predators (e.g., odonates, chironomids) in *C. caroliniana* beds contributed to significantly more invertebrates being found, despite greater biomass being recorded in native beds. This could suggest that *C. caroliniana* beds are providing new habitats for some predacious macroinvertebrates. Finely dissected leaves and complex architectures are known to provide superior habitats for invertebrates (Dvorak and Best 1982)

Based on its extensive distribution and rapid spread within this central Ontario lake, we expect this non-native species will invade other lakes linked by the Trent-Severn Waterway, which ultimately flows in Lake Ontario. By the summer of 2005, *C. caroliniana* was documented in the North River and two other lakes connected to Kasshabog Lake (H. Smith, pers. comm.). The expansion of dense monotypic stands of *C. caroliniana* will likely have implications for littoral zone food web interactions in lakes or wetlands within the Great Lakes basin. For example, the displacement of structurally diverse native macrophyte beds can alter resource and habitat availability for macroinvertebrates, affecting both primary and secondary productivity rates. Or, dense beds of invasive exotic macrophytes have been linked with reduced foraging efficiency and success of fish (Keast 1984, Engle 1995).

This preliminary survey has identified several differences in light conditions, macrophyte, epi-

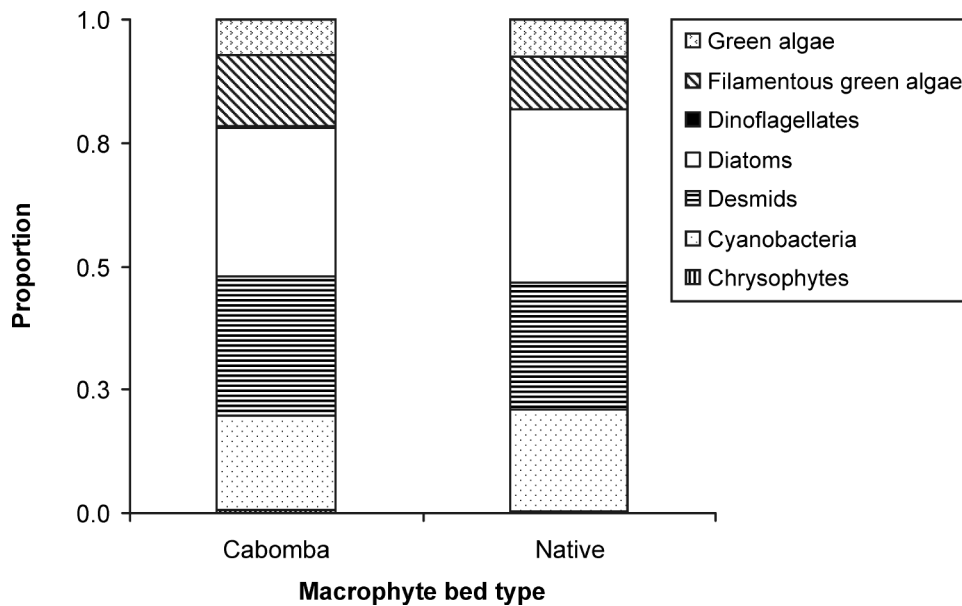


FIG. 2. Proportion of epiphytic algae, divided into major taxonomic groups, found on *C. caroliniana* and native macrophytes.

TABLE 5. Mean abundance (+ SE) of macroinvertebrates in Kasshabog Lake in Cabomba and native plant beds.

Order	Family	Cabomba	Native
Amphipoda	Gammaridae	0 (0)	0.2 (0.1)
	Hyallidae	11.8 (2.7)	6.9 (1.6)
Diptera	Chironomidae	9.2 (1.2)	4.9 (1.1)
	Ephemeroptera	Baetiscidae	1.4 (0.6)
Hemiptera	Heptageniidae	6.6 (2.0)	3.1 (0.7)
	Corixidae	0.2 (0.2)	0.3 (0.3)
Hydrachrinda	Notonectidae	0.1 (0.1)	0 (0)
	unknown	4.6 (1.5)	1.7 (0.8)
Odonata	Coenagrionidae	34.3 (8.1)	16.1 (3.4)
	Libellulidae	3.0 (0.9)	4.4 (1.2)
Trichoptera	Limnephilidae	1.1 (0.4)	3.8 (2.0)
Total		78.3 (11.3)	49.4 (6.0)

phytic algal, and macroinvertebrate communities in *C. caroliniana* beds compared to existing beds of native macrophytes. These results merit further studies which should include more extensive sampling and be designed to determine potential impacts of *C. caroliniana* on food web dynamics.

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