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[1] A contribution from Dingell-Johnson Project F-53-R, Michigan.

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Abstract.--Stomach contents were examined from 1,164 yellow perch (*Perca flavescens*) collected from Little Bay de Noc and Big Bay de Noc, Lake Michigan, June through October, 1988. Diet through August consisted of several different taxa considered typical for yellow perch. During September and October, 124 perch (76 to 213 mm total length) contained 1-120 (mean = 16.7) of the exotic cladoceran *Bythotrephes cederstroemi*. Of 39 other fish species examined, only rock bass (*Ambloplites rupestris*) was found to have ingested *Bythotrephes*. Trout-perch (*Percopsis omiscomaycus*) had considerable dietary overlap with yellow perch, but no trout-perch was found to have eaten *B. cederstroemi*. The overall proportion of yellow perch preying on *B. cederstroemi* was higher in Little Bay de Noc (32%) than in Big Bay de Noc (4%). Within individual fall net samples, from 0 to 72% of the yellow perch contained *Bythotrephes*. Yellow perch appeared to prefer *B. cederstroemi* (when available) over other food items that had comprised their diet earlier in the year and continued to be available during the fall. Many age-0 yellow perch were large enough by September to consume *Bythotrephes*, but 1- to 4-year-old fish may have been more efficient in handling the cladoceran. If *B. cederstroemi* become abundant prior to September in subsequent years, age-0 perch may not be of sufficient size to prey on them.

Bythotrephes cederstroemi is a predaceous cladoceran which recently invaded and spread throughout all of the Great Lakes. Previously restricted to a northern and central Palearctic distribution (Lehman 1987), *B. cederstroemi* was reported first in Lake Huron in 1984 (Bur et al. 1986); documentation of its presence in the other Great Lakes was complete within 3 year (Bur et al. 1986, Lange and Cap 1986, Lehman 1987, Cullis and Johnson 1988). *B. cederstroemi* are known to have invaded southern Green Bay, Lake Michigan, at least by 1987 (B. Belonger, personal communication, Wisconsin Department of Natural Resources, Marinette, Wisconsin) but prior to this report were not known to inhabit northern Green Bay. Evans (1988) hypothesized that the apparent ease with which *B. cederstroemi* became established in the Great Lakes may relate in part to reduced predation on the near-surface plankton community as alewife (*Alosa pseudoharengus*) have become relatively less abundant in the 1980s (Jude and Tesar 1985, Hartman 1988).

B. cederstroemi typically hatch in spring and increase parthenogenetically as iteroparous females during the summer. Each female is capable of producing several broods. In the fall *B. cederstroemi* switch to gametogenic reproduction to produce resting eggs, which lay dormant through the winter (Evans 1988, Lehman 1988).

B. cederstroemi are voracious predators. In Lake Michigan, the main prey items during the summer are herbivorous Cladocera, including dominant grazers (Lehman 1987). The potential for *Bythotrephes* to reduce zooplankton assemblages could affect fish communities, because many small and young-of-the-year fish rely on this grazing community for food (Lehman 1987, Barnhisel in review). There is concern that these fish may not be able to switch to eating *B. cederstroemi* because *Bythotrephes* have terminal spines that typically exceed individual body lengths by threefold (Barnhisel in review). Caudal spines may affect *B. cederstroemi* buoyancy (Zozulya and Mordukhai-Boltovskoi 1977) but may also serve as deterrents to potential predators (Evans 1988, Barnhisel in review).

B. cederstroemi are readily ingested by many juvenile and adult fish. In northern Europe, *B. cederstroemi* are important in the diets of several fish species (Lindstrom 1955, Berg and Grimaldi 1966, Nilsson and Pejler 1973, Nilsson 1979). In the Great Lakes, *B. cederstroemi* have been found in the stomachs of yellow perch (*Perca flavescens*), white perch (*Morone americana*), white bass (*M. chrysops*), walleye (*Stizostedion vitreum*) (Bur et al. 1986), deepwater sculpin (*Myoxocephalus thompsoni*) (Evans 1988), chinook salmon (*Oncorhynchus tshawytscha*), pink salmon (*O. gorbuscha*) (Cullis and Johnson 1988), lake trout (*Salvelinus namaycush*) (R. Schorfhaar, personal communication, Michigan Department of Natural Resources, Marquette, Michigan), rock bass (*Ambloplites rupestris*) (this report) and alewife (Schneeberger, unpublished data).

Aside from the report that 9 of 10 deepwater sculpin (24 to 153 mm total length) sampled from Lake Michigan in October 1986 had an average of 3.7 (range 1-15) *B. cederstroemi* in their stomachs (Evans 1988), quantitative ingestion rates of *B. cederstroemi* by fish either in Europe or the Great Lakes are lacking. This study gives seasonal, quantitative, and size-related information on yellow perch predation on *B. cederstroemi* in northern Green Bay.

Methods

Field work was performed in the Michigan waters of Green Bay in Little Bay de Noc and Big Bay de Noc (Figure 1). Fish were collected each month from June through October, 1988. Trawls, experimental gill nets, and seines were used in water 0.3- to 16.7 m deep in an attempt to capture all species and sizes of fish. Trawl haul duration was 10 min; gill net sets were 24 hours; seine haul distance was 20 to 30 m. Fish were measured and examined in the field or whole specimens were preserved in 10% formalin for examination in the lab.

Stomachs from 1,164 yellow perch (64 to 297 mm total length) and 606 stomachs from 39 other species were examined. Twenty-five fairly general stomach content categories were differentiated and empty stomachs were also recorded. Food items were enumerated for each stomach and summaries were generated to allow examination of diet by species, season, bay, and size of fish. Other summaries listed combinations of multiple food items in individual stomachs.

Results

Most (66%) of the yellow perch examined in this study were captured by trawl (Table 1). Of the others, approximately 21% were caught in gill nets and 12% in seines. Trawls and seines tended to catch smaller perch while gill nets caught the largest specimens.

Yellow perch consumed several taxa, most of which were eaten throughout the study period by a wide size range of fish (Table 2). *B. cederstroemi* was a new food item, which appeared in perch stomachs in September and October. *B. cederstroemi* were numerically more abundant in yellow perch stomachs than any other food item even though *Bythotrephes* were consumed only during the last 2 months of sampling while other top food items were ingested throughout the study period (Table 2). Yellow perch between 76 and 213 mm total length were found to have ingested *B. cederstroemi*. Individual fish consumed from 1 to 120 (mean = 16.7) *Bythotrephes* (Table 2).

Overall, 28% of the yellow perch that ate *B. cederstroemi* were under 100 mm and 89% were smaller than 140 mm (Table 3). A regression of fish length on the number of *Bythotrephes* consumed was not significant (r^2 = 0.06), but the mean number of *Bythotrephes* ingested by perch larger than 99 mm total length (20.8) was significantly larger ($P<0.05$) than the mean for smaller fish (6.4). Of the fish that had eaten *B. cederstroemi*, most (79%) contained no other food item in their stomachs while 21% had eaten one or two other food types along with *Bythotrephes*. Seven yellow perch which had eaten *B. cederstroemi* were found to have considerable masses of tangled spines in their intestines. Intestinal perforations were not observed.

Although 39 species besides yellow perch were caught during the course of this study, only 15 were collected during the September-October period. Of these, rock bass was the only other species found to have eaten *B. cederstroemi* (two of four specimens contained five *B. cederstroemi* apiece). Trout-perch (*Percopsis omiscomaycus*) had the greatest dietary overlap with yellow perch in Little Bay de Noc (few trout-perch were caught in Big Bay de Noc). However, when many yellow perch switched to eating *B. cederstroemi* in the fall, trout-perch continued to consume several of the same shared food items that both species had been preying upon earlier in the year (Table 4). No trout-perch (N = 295; mean TL = 87 mm; length range = 30-137 mm) was found containing *B. cederstroemi*.

Consumption of *B. cederstroemi* occurred in both bays during September and October, but the overall percentage of yellow perch preying on *Bythotrephes* was much higher in Little Bay de Noc (32%) than in Big Bay de Noc (4%). Frequencies of occurrence of food items other than *B. cederstroemi* were also different for yellow perch in each bay (Table 5), but perch length-at-age was not significantly different between bays (Table 6). Within individual net samples collected during September and October, the proportion of yellow perch eating *B. cederstroemi* ranged from 18 to 72% in Little Bay de Noc and from 0 to 19% in Big Bay de Noc.

Discussion

Diet information collected in this study was coherent despite the combining of data from three different types of sampling gear. Hayward et al. (1989) demonstrated that point estimates of food consumption by yellow perch were biased when fish were caught in gill nets because passive gear tended to collect the most active fish that were more likely to have been feeding; trawls were better at collecting the full spectrum of active and quiescent fish. Diet studies of fish caught in gill nets are also confounded because digestion of food progresses during the time of capture (Eggers 1977). Seventy-nine percent of the yellow perch stomach data in the present study came from trawl or seine samples, but data from active and passive gear were combined to increase the size range of fish examined. Since diet items were enumerated rather than weighed or measured, the problem of food digestion in stomachs of fish caught in gill nets was minimized.

Yellow perch diet through August (Table 2) was typical for the species. Earlier studies in Little Bay de Noc (Dodge 1968) and Green Bay (Reinhard 1979) included descriptions of similar food habits for yellow perch. In 1988, yellow perch predation on *B. cederstroemi* occurred only in the fall presumably because numerical abundance of *B. cederstroemi* was low or nonexistent earlier in the year. Previously, Dodge (1968) found that there was no seasonal shift in consumption of different food items by yellow perch. The September-October distribution of *B. cederstroemi* in both bays may have been patchy based on the observation that from 0 to 72% of the yellow perch in any given fall sample had eaten *Bythotrephes*. However, once abundances of *B. cederstroemi* reached some critical level, yellow perch appeared to have eaten the cladoceran preferentially over other food items. This apparent preference was not compelled from a lack of availability of other food items because several items common to both yellow perch and trout-perch diets occurred with equal or increased frequency in trout-perch stomachs during September and October compared with earlier in the year (Table 4).

Age-0 yellow perch caught during September and October in Little Bay de Noc had grown to lengths of 60-99 mm and many were evidently large enough to consume *B. cederstroemi* (Table 3). However, both the proportion of fish containing *Bythotrephes* and the mean number of *Bythotrephes* per stomach were smaller for young-of-the-year perch than for 1- to 4-year-old fish. Compared with older fish, age-0 perch either did not demonstrate as strong a preference for *B. cederstroemi* over other food items, or they were less efficient at catching/consuming the large cladoceran. If *B. cederstroemi* should subsequently occur in northern Green Bay in high densities during July and August (as they have in other areas of the Great Lakes after initial colonization), age-0 perch may not be large enough to take advantage of this food source. Cullis and Johnson (1988) noted that larval fishes may be incapable of utilizing *B. cederstroemi* as food, and Guma'a (1978) found that juvenile *Perca fluviatilis* avoided *Bythotrephes* spp. Also, rainbow trout (*Oncorhynchus mykiss* formerly *Salmo gairdneri*) (40 to 80 mm total length) were eight times less efficient (in terms of time) at handling spined versus de-spined *B. cederstroemi* (Barnhisel in review).

The cost-benefit for yellow perch eating *B. cederstroemi* is somewhat unclear. Although *Bythotrephes* are prime food items for many fish in Europe, their spines are not digestible, and are in fact so durable they are considered suitable as a biological marker in Great Lakes sediments (Keilty 1988). Only seven yellow perch were noted to have had intestines packed with *B. cederstroemi* spines but this condition was not systematically enumerated and therefore may be under-represented by these data. The ultimate effect of spine masses in the intestine is not known, but they could conceivably affect digestion and passing of food.

It is not known why fish species other than yellow perch and rock bass did not prey upon *B. cederstroemi* in Little Bay de Noc and Big Bay de Noc. Perhaps in future years *B. cederstroemi* will become abundant throughout a larger portion of the year and will be seen in stomachs of a variety of fish species as they are in other areas of the Great Lakes and in Europe.

A higher percentage of yellow perch ate *B. cederstroemi* in Little Bay de Noc than in Big Bay de Noc. It may be that compared to Little Bay de Noc, the habitat in Big Bay de Noc is less suitable for *B. cederstroemi*. The two bays are physically quite different. Big Bay de Noc (total area about 388 square km) is relatively shallow with a maximum depth of 20 m and over half the water less than 8-m deep. Little Bay de Noc (total area approximately 129 square km) is deeper with a 12- to 30-m channel running the length of the bay. *B. cederstroemi* preference for deep, cool water is well documented (Nilsson 1979, Lehman 1987, Berg and Garton 1988). Another possible explanation is that the relatively more dense yellow perch population in Big Bay de Noc, as determined from my gill net catches and supported by creel census data (Rakoczy and Rogers 1988), has created a barrier of predation that inhibits the establishment of *Bythotrephes*. This type of situation has been documented by Stenson (1972) and also appears to be occurring in Saginaw Bay, Lake Huron (R. Haas, personal communication, Michigan Department of Natural Resources, Mt. Clemens). Finally, the apparent difference in *B. cederstroemi* abundance in Little Bay de Noc and Big Bay de Noc during 1988 may have been caused by chance. Other biological invaders have established themselves within non-coincident time frames in Little Bay de Noc, Big Bay de Noc, and Green Bay. For example, white perch were established in southern Green Bay in the late 1980s (B. Belonger, personal communication, Wisconsin Department of Natural Resources, Marinette) but have not yet been reported in northern Green Bay. Also, three-spine stickleback (*Gasterosteus aculeatus*) have been collected from southern Lake Michigan (Richard Hess, personal communication, Illinois Department of Conservation, Chicago) and north to Big Bay de Noc (Schneeberger, unpublished data), but have not been found to occur in Little Bay de Noc. In any case, if *B. cederstroemi* continues to occur in greater densities in Little Bay de Noc than in Big Bay de Noc, the effects of yellow perch predation on *B. cederstroemi* could be monitored by comparing perch growth, condition, and survival of year classes in each bay during future years.

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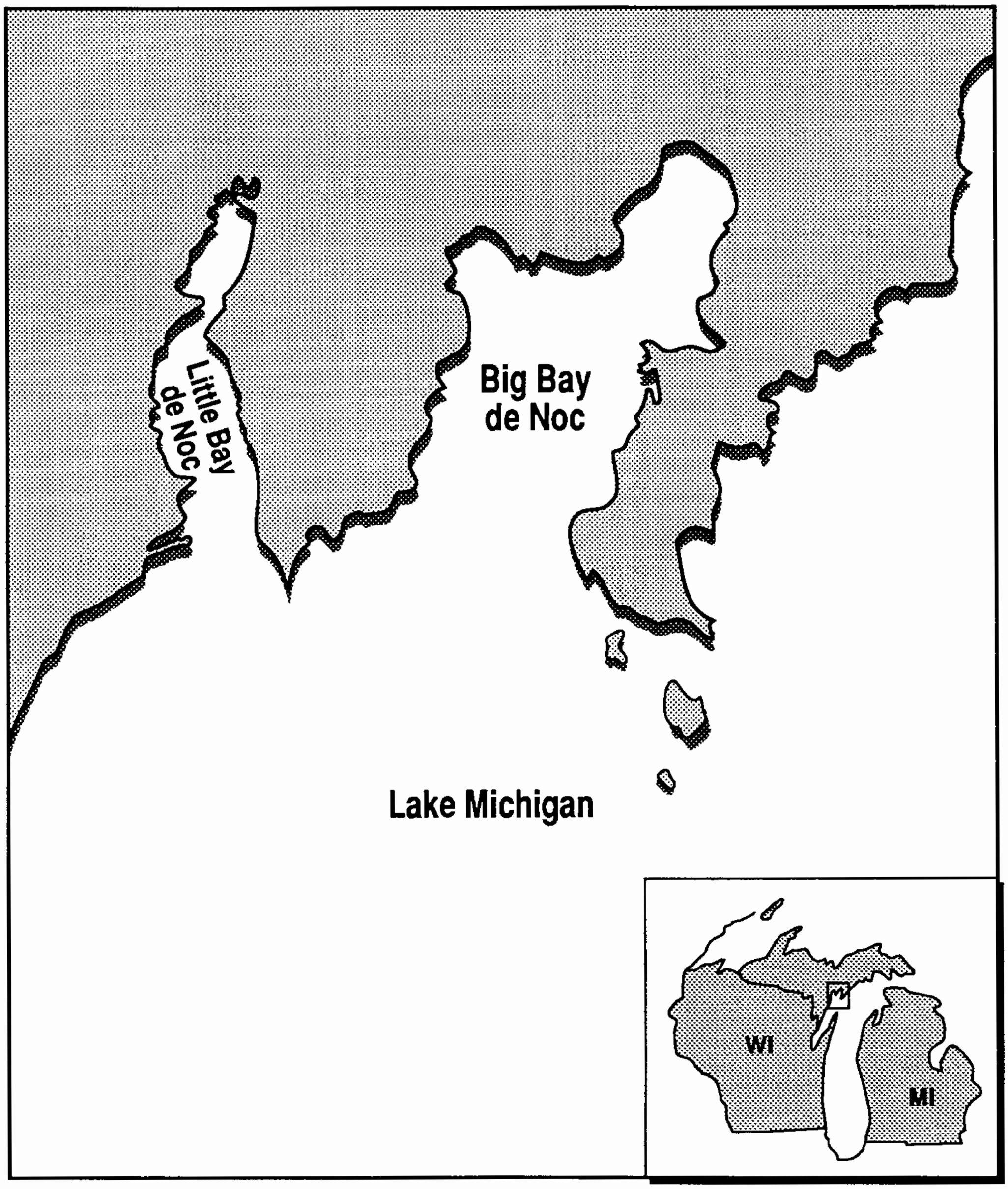

Figure 1. Location of study area.

Table 1. Number and size of yellow perch caught by various gear in Little Bay de Noc and Big Bay de Noc, Lake Michigan, June-October, 1988.

Gear	N	Total length (mm)		
		Mean	SD	Range
Gill net	248	150	55	89-325
Seine	143	100	27	69-170
Trawl	773	97	22	64-213

Table 2. Food items consumed by yellow perch caught in Little Bay de Noc and Big Bay de Noc, Lake Michigan, June-October, 1988. Min = minimum; Max = maximum.

Food item	Total number	Mean number per stomach	Number of fish	Fish total length (mm)			Months of occurrence in diet
				Mean	Min	Max	
Bythotrephes	2,072	16.7	124	112	76	213	Sep-Oct
Zooplankton[1]	1,640	15.0	109	89	64	147	Jun, Aug-Oct
Amphipods[2]	1,233	7.2	171	94	66	201	Jun-Oct
Midge larvae	1,119	6.4	175	99	68	213	Jun-Oct
Midge pupae	623	9.3	67	99	76	165	Jun-Sep
Mayfly nymphs	443	9.0	49	119	76	274	Jun, Aug-Sep
Eggs	103	14.7	7	119	81	155	Jun
Fish larvae	75	5.0	15	96	79	175	Jun
Hexagenia	73	1.3	56	132	81	213	Jun-Oct
Tricoptera	53	4.4	12	124	76	162	Jun-Sep
Fish	48	1.1	45	201	84	297	Jun-Oct
All other taxa	311	1.7	186	107	64	239	Jun-Oct

[1]Mostly *Hydrachna*.

[2]*Hyallela*, *Gammarus*, and *Pontoporeia*.

Table 3. Yellow perch predation on *Bythotrephes cederstroemi* (BC) in Little Bay de Noc and Big Bay de Noc, Lake Michigan, September-October, 1988, by age and size.

			Yellow perch stomach contents					
			Stomachs with BC		Stomachs without BC		Empty	
Age[1]	Length range (mm)	N	Number	Percent	Number	Percent	Number	Percent
0	60-99	157	35	22	56	36	66	42
1	100-139	200	75	38	51	25	74	37
2	140-169	22	9	41	2	9	11	50
3	170-189	6	3	50	2	33	1	17
4	190-229	4	2	50	1	25	1	25
5	230-269	1	0	0	1	100	0	0

[1]Estimated from length-at-age data. See Table 6.

Table 4. Seasonal percentages of yellow perch and trout-perch from Little Bay de Noc, Lake Michigan, 1988, containing selected food items.

	Yellow perch		Trout-perch	
Food category	Jun-Aug	Sep-Oct	Jun-Aug	Sep-Oct
Empty	27.5	40.0	39.0	27.9
Amphipods	11.5	0.7	2.7	2.9
Bythotrephes	0	31.8	0	0
Hexagenia	7.7	3.4	8.1	8.8
Midge larvae	23.4	9.7	18.8	44.1
Midge pupae	11.5	0.8	5.8	1.5
Zooplankton	8.4	13.1	2.7	4.4

Table 5. Percentages of yellow perch from Little Bay de Noc and Big Bay de Noc, September-October, 1988, containing various food items.

Food category	Little Bay de Noc	Big Bay de Noc
Empty	40.0	38.2
Amphipods	0.3	40.2
Bythotrephes	30.4	3.6
Fish	0.8	0.4
Hexagenia	3.4	0.4
Mayfly nymph	1.0	0.4
Midge larvae	9.7	4.1
Midge pupae	0.8	0.4
Zooplankton	13.1	4.1

Table 6. Length-at-age for yellow perch collected from Little Bay de Noc and Big Bay de Noc, Lake Michigan, June-October, 1988. CI=95% confidence interval.

	Total length (mm)					
	Little Bay de Noc			Big Bay de Noc		
Age	N	Mean	CI	N	Mean	CI
0	134	85	3	38	88	2
1	67	114	4	15	109	15
2	46	152	7	8	172	15
3	32	169	8	7	179	20
4	30	205	12	3	234	89
5	13	251	25	0	---	---
6	4	278	60	1	267	---

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