Parasites of spottail shiners (*Notropis hudsonius*) in the St. Lawrence River: effects of municipal effluents and habitat

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Abstract: Parasite communities were examined from spottail shiners (*Notropis hudsonius* (Clinton, 1824)) collected from nine localities in the St. Lawrence River around the Island of Montréal and downstream from its municipal effluents in June and September 1998–2000. A total of 30 taxa were found, the most common being *Diplostomum* spp. Parasite communities were dominated by digeneans, most of which were larval stages that infect birds as definitive hosts. Mean abundance of the most common parasites varied among localities and years. Component community and mean infracommunity species richness fluctuated within and among years at the various localities. Similarity analyses demonstrated that parasite component communities from the different localities could be partitioned according to season, year, and water mass. Canonical correspondence analysis demonstrated that the parasite component communities from the different localities could be distinguished clearly, indicating that the fish in the different localities compose separate populations or stocks. Year, season, and water mass correlated most strongly among the species–environment relationships. The abundance and distribution of parasite species appeared to be subtly influenced by environmental contaminants and urban effluents, leading to slight reductions in parasite diversity. However, the parasite species composition at the various localities more clearly reflected the local food-web structure and biodiversity in terms of the distributions of various invertebrate groups, piscivorous fish, and waterfowl along the St. Lawrence River.

Résumé : On a examiné les communautés de parasites de queue à tache noire (*Notropis hudsonius* (Clinton, 1824)) provenant de neuf sites du fleuve Saint-Laurent autour de l'île de Montréal et en aval de ses effluents municipaux, en juin et en septembre 1998–2000. Un total de 30 taxons ont été trouvés, *Diplostomum* spp. étant le plus commun. Les communautés de parasites étaient dominées par les digènes, dont la plupart sont des stades larvaires qui utilisent les oiseaux piscivores comme hôte final. L'abondance moyenne transformée en rang des parasites les plus communs variait significativement d'un site à l'autre et d'une année à l'autre. La richesse de la communauté de parasites et la richesse de l'infracommunauté fluctuaient selon les années et les saisons. Les analyses de similarité ont montré que les communautés de parasites des différents sites se regroupaient selon la saison, l'année ainsi que le type de masse d'eau. L'analyse canonique des correspondances a démontré que les communautés de parasites des différents sites se distinguaient clairement les unes des autres, suggérant que les queues à tache noire des secteurs échantillonnés formaient des stocks ou des populations distincts. Ce sont l'année, la saison et le type de masse d'eau qui étaient les variables les plus fortement corrélées parmi les relations espèces–environnement examinées. L'abondance et la distribution des espèces de parasites semblaient très subtilement influencées par la contamination du milieu aquatique par les effluents urbains ou d'autres sources, conduisant à de légères réductions de la diversité des parasites. Cependant, la composition de parasites reflétait de manière plus évidente la structure de la chaîne trophique et la biodiversité des milieux échantillonnés en ce qui a trait à la distribution des invertébrés, des poissons piscivores et de la sauvagine le long du fleuve Saint-Laurent.

Introduction

Environmental stress, including pollution, may impact upon both populations and communities of aquatic organisms and their parasites. It is well documented that stress can lead to proliferation of parasites and disease in fish, presumably through reduced resistance in immunocompromised hosts (Khan and Thulin 1991; Overstreet 1993; Mackenzie et al. 1995).

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In this case, disease is typically caused by microparasites (viruses, bacteria, fungi, protozoans) or by macroparasites with direct life cycles (e.g., monogeneans), although immunosuppression also may lead to the proliferation of macroparasites with indirect life cycles.

In contrast, abundance and diversity of macroparasites often decrease after exposure to stressors such as contaminants. Numerous digeneans and cestodes have delicate, short-lived free-living stages that are assumed to be sensitive to water quality (Overstreet 1993; MacKenzie 1999; Pietrock and Marcogliese 2003). Transmission of these parasites may be compromised under polluted conditions, thus effectively reducing their population size in fish hosts. Contaminants and other stressors may impact directly upon free-living organisms, which would, presumably, negatively affect populations of their parasites. Moreover, infected invertebrates and fish have been shown to be more susceptible to the toxic effects of contaminants such as heavy metals than their uninfected counterparts (Boyce and Yamada 1977; Pascoe and Cram 1977; McCahon et al. 1988; Brown and Pascoe 1989). The removal of infected hosts from the ecosystem reduces parasite transmission and leads to the decline of parasite populations. Alternatively, certain host species often flourish under stressful conditions, which in turn should enhance the transmission of their parasites. In addition, toxic effects of contaminants could cause infected organisms to become more susceptible to predation, potentially increasing parasite transmission. Thus, it can be expected that populations of parasites will be affected by environmental stress, as will the communities of which they are a part. Indeed, given that food webs may be altered by environmental perturbations, it is predicted that communities of parasites that rely on trophic interactions for transmission will be similarly affected (Marcogliese and Cone 1996, 1997*a*, 1997*b*; Marcogliese 2004, 2005). A more general prediction that emerges is that environmental stress will lead to outbreaks of disease caused by directly transmitted parasites, but also to a reduction in diversity of indirectly transmitted parasites.

To date, there have been numerous studies of parasite populations and communities in relation to pollution. Some general patterns emerge from an examination of previous work. For example, acidification tends to cause a decrease in parasite species richness and diversity, primarily by eliminating acid-sensitive host species such as molluscs, which are obligate intermediate hosts for digeneans (Cone et al. 1993; Marcogliese and Cone 1996, 1997*b*; Halmetoja et al. 2000). Eutrophication tends to result in a proliferation of parasites that infect oligochaetes during their life cycles, including myxozoans and the nematode *Eustrongylides ignotus* Jägerskiöld, 1909 (Weisberg et al. 1986; Spalding et al. 1993; Marcogliese and Cone 2001; Coyner et al. 2002, 2003). In highly eutrophied systems, species richness tends to decline (Sulgostowska et al. 1987, 1990; Zander 1998; Zander and Reimer 2002).

Many of the world's largest rivers receive effluents from municipal and industrial sewers in addition to other sources. Yet, there are few studies of fish parasites from these ecosystems; most studies involve small rivers, lakes, and coastal waters. The St. Lawrence River, one of North America's largest rivers in terms of outflow, receives effluents from a sewage treatment plant serving 1.8 million people. About 15% of wastes derive from industrial enterprises on the Island of Montréal (Pham et al. 1999; Gagné et al. 2004). By volume, it is the largest primary physico-chemical sewage treatment plant in North America. It has a discharge flow rate of 20–30 $m^3 \cdot s^{-1}$, all exiting via a single discharge outlet. Sewage treatment is basically primary, consisting of coarse filtration, flocculation, and sedimentation (Pham et al. 1999; Gagné et al. 2004). We examined the parasite fauna of fish collected at various localities along the St. Lawrence River to determine whether effluents from the sewage treatment plant on the Island of Montréal had an impact on parasite populations and communities. This study was part of a collaborative effort to elucidate effects of urban wastewater on endocrine disruption (Aravindakshan et al. 2004), immune response, and parasitism in the spottail shiner (*Notropis hudsonius* (Clinton, 1824)).

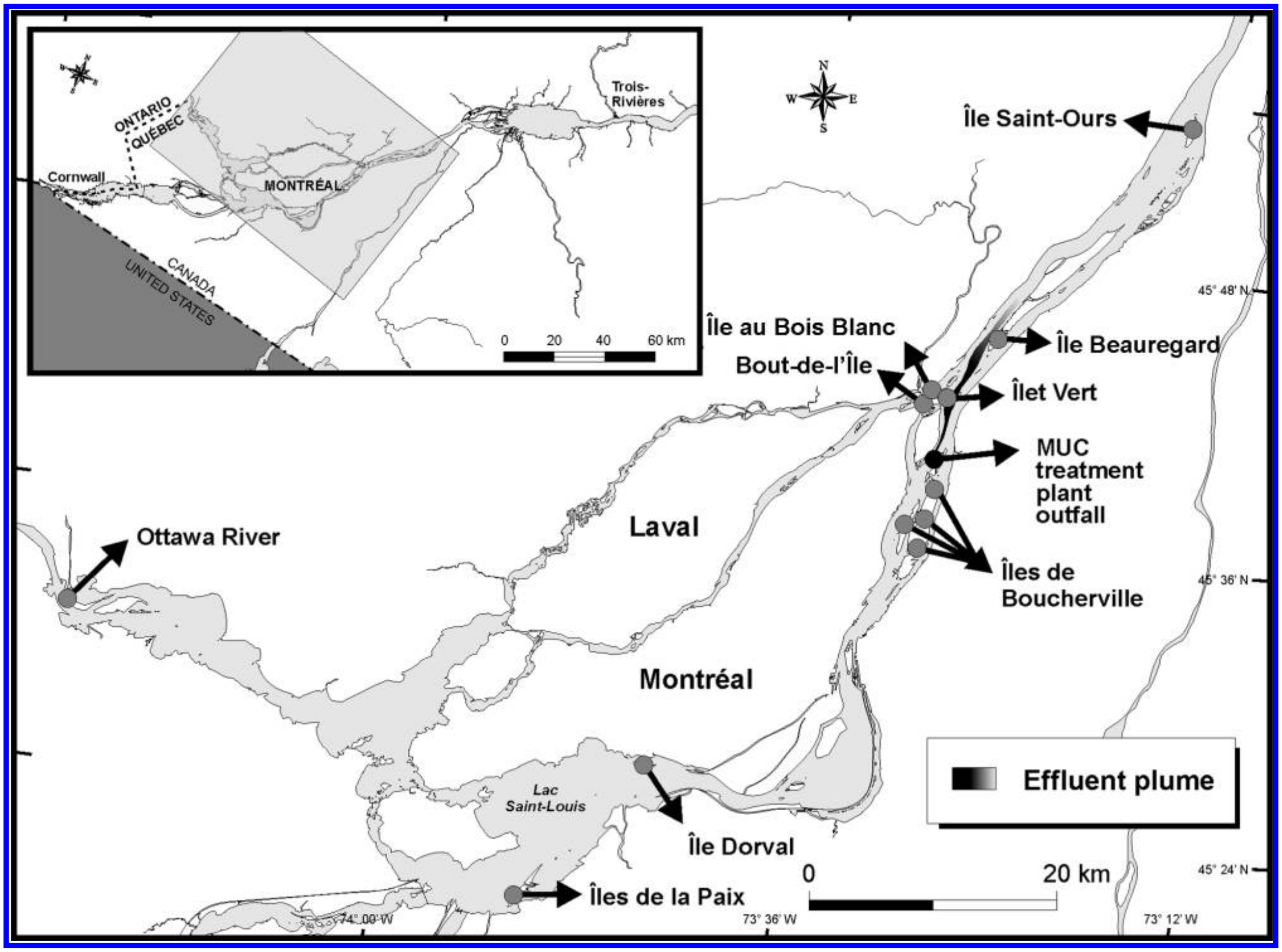
The spottail shiner was chosen as a study organism because these fish are locally abundant in the St. Lawrence River. They are relatively easy to catch and to age with length-frequency histograms. They are not considered migratory and are used as indicator organisms in the Great Lakes for pollution studies (Suns and Rees 1978; Suns et al. 1983, 1993). Previous studies of macroparasites of *N. hudsonius* in the Great Lakes – St. Lawrence River have shown that these fish are infected with 16 parasite species in Lake Erie (Bangham and Hunter 1939; Dechtiar1972), 15 in Lake Huron (Dechtiar et al. 1988), and 15 in Lake Superior (Dechtiar and Lawrie 1988). To our knowledge, this is the first study of macroparasite communities in these fish.

Materials and methods

Sampling localities

Spottail shiners were collected from four localities in June 1998, five in June 1999, six in September 1999, and nine in June and September 2000 (Fig. 1). As part of a pilot study in June 1998, fish were collected from four localities, two upstream and two downstream of the sewage discharge from the Island of Montréal. The upstream localities were at Îles de la Paix (45°20.022′N, 73°51.362′W) and Île Grosbois, part of Îles de Boucherville (45°58.589′N, 73°27.687′W), and the downstream sites were at Îlet Vert (45°42.230′N, 73°27.143′W) and Île Saint-Ours (45°55.333′N, 73°13.092′W), located 4 and 36 km from the outfall, respectively. In June 1999, we added another locality upstream of the sewage outflow at Île Dorval (45°26.016′N, 73°44.234′W). Further samples were collected in September from all localities, including a new downstream locality at Île Beauregard (45°44.965′N, 73°24.910′W), located 10 km from the sewage discharge. Spottail shiners proved difficult to collect at the Boucherville locality. In June, fish were sampled in a canoe canal (La passe: 45°37.116′N, 73°28.187′W), and in September, from La Grande Rivière (45°36.031′N, 73°28.327′W). In June and September 2000, three more localities were added to account for potential other sources of pollution from the Ottawa River and the des Prairies and des Miles-Îles rivers, which feed into the St. Lawrence River (Aravindakshan et al. 2004). These localities are the Ottawa River (45°31.500′N, 74°20.973′W), Bout-de-l'Île (45°42.165′N, 73°28.728′W), and

Fig. 1. Map of the St. Lawrence River showing the nine sampling localities and the municipal effluent plume from the Island of Montréal. The inset shows the location of the collecting region in the freshwater portion of the St. Lawrence River, Quebec, Canada.



Île au Bois Blanc (45°42.850′N, 73°27.824′W). At Îles de Boucherville, fish were collected at Île Grosbois in June and at Grandes battures Tailhandier (45°37.299′N, 73°29.194′W) in September. Figure 1 depicts all nine sampling localities and the location of the discharge plume. Île Dorval, Îles de la Paix, and the Ottawa River are considered reference sites, unexposed to pollution from sources in the St. Lawrence River.

Sampling

The St. Lawrence River between Montréal and Lake St. Pierre is divided into two water masses. The clear, hard, "green" waters draining from the Great Lakes flow along the south shore of the river and possess a relatively high conductivity. The humic, soft, "brown" waters that drain the Ottawa River and other northern tributaries flow along the north shore and possess low conductivity. The localities added in 2000 are found in brown water, with Île au Bois Blanc being classified as mixed. All the other localities are located in green water, with the exception of Île Dorval, which receives Ottawa River water during the spring runoff and is considered mixed. Sample sizes ranged from 9 to 45 fish at the various localities. In September 1999 only 2 fish were captured at Îles de la Paix and so this sample was excluded from all further analyses. Fish were collected using a beach seine (22.6 m × 1.15 m; 3 mm mesh) held by hand or partially deployed from a boat. Fish were killed by an overdose of tricaine methanesulfonate (0.2 $g \cdot L^{-1}$) and examined fresh, or frozen for subsequent examination, for macroparasites using standard parasitological techniques. Prior to dissection, fork length was measured to the nearest millimetre and each fish was weighed to the nearest 0.1 g. Parasites were identified using the keys in Arai (1989), Moravec (1994), Gibson (1996), and Hoffman (1999).

Water quality variables were measured at each locality during each sampling period. Temperature and conductivity were measured with a hand-held YSI Model 63 conductivity meter. Duplicate water samples were collected from each locality during each sampling period and sent to a commercial laboratory for fecal coliform measurements. Sediment samples were collected on 1–7 June 1999 at Îles de la Paix, Île Dorval, Îles de Boucherville, Îlet Vert, and Île Saint-Ours; 8 October 1999 at Île Beauregard; and 31 May – 7 June 2000 at Bout-de-l'Île, Île au Bois Blanc, and the Ottawa River. Metals, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) were measured using standard methods at Canada's National Laboratory for Environmental Testing, Burlington, Ontario (Environment Canada 1997*a*, 1997*b*). Ten replicate benthic samples were collected from the littoral zone at four localities (Îles de la Paix, Île

Dorval, Îlet Vert, Île Beauregard) using a 15.2 cm × 15.2 cm Ponar grab on 8–12 June 2001. Samples were sorted through a 500 µm sieve on site and fixed in 10% buffered formalin. Animals from a subset of these samples were identified to lowest possible taxon in a commercial laboratory.

Data analysis

A particular size range of fish, based on length frequency distributions, was selected beforehand to obtain comparable samples in terms of fish age and length among years and localities. Fish included in statistical analyses were restricted to 45–85 mm fork length in June, approximating the 1+ cohort, and 30–65 mm in September, reflecting the 0+ cohort. Analyses were restricted to samples with a minimum of nine fish, and differences in mean abundance of the most common parasite species (>10% overall prevalence) were tested nonparametrically (because the data were not normally distributed) by ANOVA on ranked abundances (Conover 1999). The variation among years and localities for each common parasite species was tested with a two-way ANOVA on ranks for those localities that were sampled across more than one year, using a normal score transformation instead of standard ranks (Conover 1999). Subsequent one-way ANOVAs on ranks were performed on the abundance of parasites from all localities sampled during a particular season, followed by multiple comparisons of paired means performed with the Tukey–Kramer method (Sokal and Rohlf 2000).

Component communities of parasites were characterized by mean abundance, prevalence, and intensity of all parasite species. Mean number of taxa per fish from each locality was also included as a community descriptor. Differences in parasite community structure between localities, years, and seasons were tested using the statistical procedure previously described (ANOVA) on the mean number of taxa per fish. Similarity in parasite community structure among samples was examined through two different distance indices: the distance corresponding to the reciprocal of the Jaccard index, based on presence–absence data, and the quantitative Bray–Curtis index, based on parasite intensity (Legendre and Legendre 1998). For each sample, the sum of abundances of each taxon was weighted to account for unequal sample size and standardized to 30 hosts to compute distance indices. Groupings of similar samples were evidenced by a clustering analysis (flexible method; Legendre and Legendre 1998) performed on the distance matrices.

Canonical correspondence analysis was used to investigate how variability in environmental characteristics could be linked to parasite communities. Abundance data were log transformed (log abundance + 1) and rare taxa were downweighted to reduce the extreme influence of rare species and of some particularly high abundance values (Ter Braak and Šmilauer 1998). Environmental variables used in the model were different assemblages of the variables locality, year, season, water mass (green, brown, or mixed), and certain pollutants found in urban effluents: concentration of fecal coliforms (log transformed) and heavy metal concentrations in sediments (Cd, Cr, Hg, Pb, Zn). Canonical correspondence analysis was run based on those parasites that occurred at an overall prevalence of 10% and 2%. SAS® (SAS Institute Inc. 2003) was used for all analyses except correspondence analyses, for which CANOCO software was used (Ter Braak and Šmilauer 1998).

Terminology

Parasitological terms (prevalence, abundance, intensity) are defined according to Bush et al. (1997). Prevalence refers to the proportion of fish in a particular sample infected with a particular parasite, expressed as a percentage. Mean abundance refers to the mean number of parasites of a particular species per host in a sample, including uninfected hosts. Mean intensity refers to the mean number of parasites of a particular species per infected host. Autogenic parasites are those that complete their entire life cycle in an aquatic ecosystem, while allogenic parasites are those that use fish or other aquatic vertebrates as intermediate hosts but mature in birds or mammals (Esch and Fernández 1993). For contaminants, the Minimal Effect Threshold (MET) and the Toxic Effect Threshold (TET) as defined for the St. Lawrence River refer to the pollution level above which harmful effects occur in the most sensitive species, but not most organisms, and the pollution level above which harmful effects occur in 90% of benthic organisms, respectively (Loiselle et al. 1997). We also refer to the Canadian Environmental Quality Guidelines (CEQG) for aquatic life in freshwater and the CEQG Probable Effects Level (PEL) and interim guidelines (ISQG) for exposure of freshwater organisms to sediments (http://www.ccme.ca/publications/ceqg_rcqe.html?category_id=124).

Results

Water and sediment quality

Temperature and conductivity data for each locality at the time of sampling are shown in Table S1[2]. Conductivity is always low at Ottawa River, Bout-de-l'Île, and Île au Bois Blanc, which are considered brown- and mixed-water localities, whereas conductivity is sometimes low in June but usually high in September at Île Dorval, which is considered to have mixed water. The remaining localities always show high conductivity and are considered to have green water. Fecal coliforms were low at localities upstream of the Montréal sewage effluents and much higher downstream, irrespective of time of sampling (Table S1).

Levels of metals measured in the sediments were generally low and indicative of contamination at only a few localities. Cadmium, chromium, copper, lead, mercury, and zinc surpassed the ISQG and the MET at a number of localities (Table 1). Moreover, levels of chromium surpassed the TET and the PEL at Îlet Vert. The sediment concentrations of most PCB and PAH congeners, as well as organochlorines, were below or, when measurable, only slightly above the detection limits (data not shown). There was no evidence of

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[2] Supplementary data for this article are available on the journal Web site (http://cjz.nrc.ca) or may be purchased from the Depository of Unpublished Data, Document Delivery, CISTI, National Research Council Canada, Building M-55, 1200 Montreal Road, Ottawa, ON K1A 0R6, Canada. DUD 5072. For more information on obtaining material refer to http://cisti-icist.nrc-cnrc.gc.ca/irm/unpub_e.shtml.

Table 1. Concentrations of heavy metals in the sediments at different sampling localities in the St. Lawrence River.

Locality	Site code	Water mass	Sampling date	Cadmium (mg/kg)	Lead (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Zinc (mg/kg)	Mercury (µg/kg)
Îles de la Paix	IPA	Green	1 June 1999	0.1	14.2	**78**^{a,b}	15	76	12
Île Dorval	IDO	Mixed	7 June 1999	**1.0**^{a,b}	23.8	**49**^{a}	11	**159**^{a,b}	100
Îles de Boucherville	IBO	Green	2 June 1999	**1.2**^{a,b}	**45.4**^{a,b}	**76**^{a,b}	**49**^{a,b}	**236**^{a,b}	**233**^{a,b}
Îlet Vert	IVT	Green	4 June 1999	0.2	17.8	**129**^{c,d}	**43**^{a,b}	**129**^{a}	6
Île Beauregard	IBE	Green	8 Oct. 1999	0.3	18.0	**40**^{a}	29	84	50
Île Saint-Ours	ISO	Green	3 June 1999	0.2	15.3	**51**^{a}	10	70	25
Île au Bois Blanc	IBB	Mixed	1 June 2000	**0.8**^{a}	**38.9**^{a}	**61**^{a,b}	**70**^{a,b}	**143**^{a}	94
Bout-de-l'Île	BIL	Brown	31 May 2000	0.4	**52.0**^{a,b}	**67**^{a,b}	28	97	**257**^{a,b}
Ottawa River	OR	Brown	6 June 2000	0.5	19.7	**39**^{a}	16	76	58

Note: Concentrations exceeding recommended guidelines are in boldface.

[a] Exceeds Canadian Environmental Quality Guidelines (CEQG) interim guidelines (ISQG): exposure levels for aquatic life in freshwater.

[b] Exceeds St. Lawrence River Minimal Effect Threshold (MET): harmful effects to the most sensitive species, but tolerated by most organisms.

[c] Exceeds CEQG Probable Effects Level (PEL): exposure levels for aquatic life in freshwater.

[d] Exceeds St. Lawrence River Toxic Effect Threshold (TET): harmful effects to 90% of benthic organisms.

excessive contamination and no PCB or PAH concentrations exceeded the MET or the ISQG.

Using the measurements for metals (ISQG = 1; PEL = 2) and fecal coliforms (20–100 = 1; 100–1000 = 2; >1000 = 3), a ranking system was developed to compare pollution levels among localities, leading to the following hierarchy: Îles de Boucherville > Îlet Vert > Île Saint-Ours > Île au Bois Blanc > Bout-de-l'Île > Île Beauregard > Île Dorval > Ottawa River > Îles de la Paix. The localities downstream of the municipal effluents were among the most polluted, while those in Lake St. Louis and the Ottawa River were the least polluted, justifying their use as reference localities. Îles de Boucherville are most likely affected by communities along the south shore of the St. Lawrence, which is densely populated. The overall ranking is similar to that found by Aravindakshan et al. (2004) using measurements of mRNA for vitellogenin as an indicator of endocrine disruption in spottail shiners.

General parasitological results

A total of 30 taxa were found infecting spottail shiners, comprising 15 digeneans, 6 nematodes, 5 cestodes, 1 acanthocephalan, 1 monogenean, 1 crustacean, and 1 leech. Of these, 12 occurred at a prevalence of >10% on at least one occasion (digeneans: *Centrovarium lobotes* (MacCallum, 1895), *Diplostomum* spp., *Ichthyocotylurus platycephalus* (Creplin, 1825), *Neochasmus* spp., *Ornithodiplostomum ptychocheilus* (Faust, 1917), *Plagioporus sinitsini* Mueller, 1934, *Posthodiplostomum minimum* (MacCallum, 1921), *Rhipidocotyle papillosa* (Woodhead, 1929), and *Tylodelphys scheuringi* (Hughes, 1929); nematodes: *Raphidascaris acus* (Bloch, 1779); cestodes: *Pliovitellaria wisconsinensis* Fischthal, 1951 and *Proteocephalus* sp.; acanthocephalans: *Neoechinorhynchus rutili* (O.F. Müller, 1780)). The remaining species were encountered sporadically and never at a prevalence > 10% (Table S2[2]). Only two taxa, *Diplostomum* spp. and *P. sinitsini*, occurred in all the samples, whereas another four digeneans were found in 40% of the samples (*I. platycephalus*, *O. ptychocheilus*, *P. minimum*, and *T. scheuringi*). All of the common digeneans with the exception of *P. sinitsini* are strigeids that use waterfowl as definitive hosts. In terms of frequency of occurrence in fish, the most frequently encountered species were *Diplostomum* spp. (82%), *O. ptychocheilus* (46%), *P. sinitsini* (33%), and *P. minimum* (26%).

Parasite populations

Results of two-way ANOVAs, with locality and year as independent variables, on ranked abundance of each parasite occurring with an overall frequency > 10% are shown in Table 2. The two-way ANOVAs were significant for *C. lobotes*, *Diplostomum* spp., *Neochasmus* spp., *O. ptychocheilus*, *P. minimum*, *N. rutili*, and *R. acus* in June. For September samples, the two-way ANOVAs were significant for *Diplostomum* spp., *I. platycephalus*, *O. ptychocheilus*, *P. sinitsini*, *P. minimum*, *R. papillosa*, and *T. scheuringi*.

Numerous parasites showed significant interannual differences (Table 2). Many species were more common in 2000 than in 1998 and (or) 1999 in the June samples, including *C. lobotes*, *Diplostomum* spp., *I. platycephalus*, *Neochasmus* spp., *O. ptychocheilus*, and *N. rutili*, whereas *P. minimum* and *R. acus* showed the opposite trend. For September samples, species more abundant in 1999 than in 2000 included *Diplostomum* spp., *Neochasmus* spp., and *P. minimum*, whereas *P. sinitsini*, *R. papillosa*, and *T. scheuringi* showed the reverse pattern.

Numerous significant differences in parasite abundance were observed among localities (Tables 2–3). Most notably, *Diplostomum* spp. were most common at localities in Lake St. Louis and least abundant in the Ottawa River. The digenean *T. scheuringi* was also most abundant in Lake St. Louis. Both *O. ptychocheilus* and *P. minimum* were most common in the Ottawa River, fairly abundant at Île Beauregard and other localities east of Montréal, and rarest at Îles de la Paix, a reference locality. The digenean *P. sinitsini* was rare in the Ottawa River but abundant everywhere else. Metacercariae of *Neochasmus* spp. were generally not common except in September 1999, when they were significantly more abundant at localities downstream of Montréal than those upstream, with the highest abundance at Île Beauregard. *Rhipidocotyle papillosa* was significantly more abundant in brown waters of the Ottawa River and Bout-de-l'Île than at the other localities in September 2000, while it was rare or absent in Lake St. Louis. The cestode *Proteocephalus* sp. was present at all localities at one time

Table 2. Results of two-way ANOVAs on ranked abundances of common parasite taxa in spottail shiners (*Notropis hudsonius*) occurring in > 2% of fish overall from various localities in the St. Lawrence River in June and September 1998–2000, with year and locality as independent variables.

Parasite	Season	Analysis	df	SS3	*F*	*P*	Results
Centrovarium lobotes	June	2-way ANOVA	11	9.607	3.31	0.0002	
		Site	3	2.320	2.93	0.0333	ISO > IPA
		Year	2	3.730	7.06	0.0010	2000 = 1998 > 1999
		Site × year	6	3.210	2.03	0.0609	NS
Diplostomum spp.	June	2-way ANOVA	11	130.292	16.78	<0.0001	
		Site	3	112.280	53.02	<0.0001	IPA > IBO = IVT + ISO; IBO > ISO
		Year	2	14.260	10.10	0.0001	2000 > 1998 = 1999
		Site × year	6	1.870	0.44	0.8515	NS
	September	2-way ANOVA	9	138.455	32.07	<0.0001	
		Site	4	42.020	21.90	<0.0001	IBO = IDO > IBE + ISO + IVT; IBE > IVT
		Year	1	91.950	191.68	<0.0001	1999 > 2000
		Site × year	4	0.300	0.16	0.9597	NS
Ichthyocotylurus platycephalus	June	2-way ANOVA	11	2.196	1.30	0.2224	
		Site	3	0.150	0.32	0.8085	NS
		Year	2	1.050	3.42	0.0335	2000 > 1999
		Site × year	6	1.130	1.22	0.2930	NS
	September	2-way ANOVA	9	2.422	1.25	0.2651	NS
		Site	4	1.010	1.17	0.3224	NS
		Year	1	0.430	2.00	0.1584	NS
		Site × year	4	1.020	1.18	0.3208	NS
Neochasmus spp.	June	2-way ANOVA	11	1.739	2.14	0.0165	
		Site	3	0.310	1.39	0.2447	NS
		Year	2	0.600	4.04	0.0183	2000 > 1999 = 1998
		Site × year	6	0.670	1.52	0.1690	NS
	September	2-way ANOVA	9	19.035	9.73	<0.0001	
		Site	4	6.580	7.57	<0.0001	IBE = ISO > IVT = IBO = IDO
		Year	1	6.320	29.09	<0.0001	1999 > 2000
		Site × year	4	6.580	7.57	<0.0001	
Ornithodiplostomum ptychocheilus	June	2-way ANOVA	11	64.474	12.17	<0.0001	
		Site	3	14.940	10.34	<0.0001	ISO = IVT > IPA
		Year	2	38.440	39.91	<0.0001	2000 > 1999 = 1998
		Site × year	6	9.560	3.31	0.0034	
	September	2-way ANOVA	9	89.620	17.14	<0.0001	
		Site	4	82.570	35.53	<0.0001	IBE > IBO = ISO + IVT + IDO; IBO > IVT = IDO; ISO > IDO
		Year	1	0.0001	0.01	0.9270	NS
		Site × year	4	7.070	3.04	0.0176	
Plagioporus sinitsini	June	2-way ANOVA	11	4.775	0.61	0.8242	NS
		Site	3	0.450	0.21	0.8901	NS
		Year	2	2.160	1.51	0.2222	NS
		Site × year	6	1.750	0.41	0.8738	NS
	September	2-way ANOVA	9	43.749	9.44	<0.0001	
		Site	4	32.070	15.57	<0.0001	IDO > ISO = IBO = IBE = IVT
		Year	1	2.410	4.68	0.0314	2000 > 1999
		Site × year	4	9.380	4.56	0.0014	
Posthodiplostomum minimum	June	2-way ANOVA	11	15.898	3.84	<0.0001	
		Site	3	6.180	5.47	0.0011	ISO > IPA = IBO
		Year	2	6.900	9.16	0.0001	1998 = 1999 > 2000
		Site × year	6	3.600	1.60	0.1468	NS
	September	2-way ANOVA	9	28.201	4.88	<0.0001	
		Site	4	12.180	4.74	0.0010	IBE > IVT = ISO
		Year	1	4.820	7.51	0.0065	1999 > 2000
		Site × year	4	10.320	4.02	0.0035	
Rhipidocotyle papillosa	June	2-way ANOVA	11	0.199	0.90	0.5379	NS
		Site	3	0.050	0.81	0.4875	NS
		Year	2	0.030	0.83	0.4377	NS

Table 2 (*concluded*).

Parasite	Season	Analysis	df	SS3	*F*	*P*	Results
		Site × year	6	0.100	0.86	0.5235	NS
	September	2-way ANOVA	9	23.054	8.18	<0.0001	
		Site	4	4.510	3.60	0.0070	ISO > IDO
		Year	1	13.540	43.23	<0.0001	2000 > 1999
		Site × year	4	4.510	3.60	0.0070	
Tylodelphys scheuringi	June	2-way ANOVA	11	0.719	0.86	0.5751	NS
		Site	3	0.050	0.23	0.8721	NS
		Year	2	0.170	1.10	0.3331	NS
		Site × year	6	0.500	1.09	0.3647	NS
	September	2-way ANOVA	9	36.501	16.48	<0.0001	
		Site	4	15.920	16.17	<0.0001	IDO > IBO = IVT = ISO = IBE
		Year	1	6.000	24.36	<0.0001	2000 > 1999
		Site × year	4	15.070	15.30	<0.0001	
Proteocephalus sp.	June	2-way ANOVA	11	0.278	0.69	0.7475	NS
		Site	3	0.044	0.40	0.7536	NS
		Year	2	0.022	0.31	0.7360	NS
		Site × year	6	0.163	0.74	0.6155	NS
	September	2-way ANOVA	9	11.838	4.29	<0.0001	
		Site	4	6.416	5.23	0.0004	IBO > IBE = ISO = IVT
		Year	1	2.064	6.73	0.0100	2000 > 1999
		Site × year	4	3.511	2.86	0.0237	
Neoechinorhynchus rutili	June	2-way ANOVA	11	66.235	20.81	<0.0001	
		Site	3	58.769	67.71	<0.0001	IPA > IBO = ISO = IVT
		Year	2	2.477	4.28	0.0144	2000 > 1998
		Site × year	6	5.360	3.09	0.0057	
Raphidascaris acus	June	2-way ANOVA	11	7.6192	0.69	<0.0001	
		Site	3	2.6063	4.41	0.0046	IPA > IBO = IVT
		Year	2	1.155	2.93	0.0545	1998 > 2000
		Site × year	6	2.3858	2.01	0.0622	NS

Note: The samples are from the following localities: Îles de la Paix (IPA), Île Dorval (IDO), Îles de Boucherville (IBO), Îlet Vert (IVT), Île Beauregard (IBE), and Île Saint-Ours (ISO). NS, not significant.

or another except Îlet Vert. The acanthocephalan *N. rutili* was most abundant at Îles de la Paix and virtually absent outside Lake St. Louis. The nematode *R. acus* was most abundant in Lake St. Louis and Île Saint-Ours and virtually absent elsewhere. Among the rare species, *P. wisconsinensis* was unusually abundant in June 2000 at Île Dorval, where it occurred at a prevalence of 11.4% and a mean abundance (SD) of 4.7 ± 2.9.

Mean total parasite abundance varied among localities within years (Table 3). During most sampling periods, the mean total abundance at the reference localities from Lake St. Louis (Île Dorval, Îles de la Paix) was the highest or among the highest observed. In contrast, the mean total abundance downstream of Montréal at Îlet Vert and Île Saint-Ours was among the lowest recorded among the samples at any one time.

Parasite communities

The species richness of component communities varied between 3 and 18, with the minimum at Îles de Boucherville in June 1998 and the maximum in the Ottawa River in June 2000. Patterns fluctuated within and among years, with ranges as follows: 7–11 at Îles de la Paix, 5–15 at Île Dorval, 11–18 in the Ottawa River, 3–12 at Îles de Boucherville, 5–10 at Îlet Vert, 4–8 at Bout-de-l'Île, 9–11 at Île au Bois Blanc, 10–16 at Île Beauregard and 8–13 at Île Saint-Ours. No clear patterns in species richness or diversity were evident. Minimum measures of species richness occurred at Île Dorval, Îles de Boucherville, Îlet Vert, and Bout-de-l'Île, whereas maximum values were observed at Îles de la Paix, the Ottawa River, Île au Bois Blanc, Île Beauregard, and Île Saint-Ours. Minima and maxima could be observed both upstream and downstream of the municipal effluents. However, it should be noted that the lowest species richness occurred at Îlet Vert, immediately downstream of Montréal, on three separate occasions, and richness there never exceeded 10 species. There were annual variations in component species richness, being highest in 2000 at all localities where interannual comparisons were possible during June (Fig. 2).

Mean infracommunity species richness varied between 1.2 and 3.7. For the June samples, the only significant difference was between Îles de Boucherville and Îles de la Paix in 1998 (Fig. 2, $P = 0.0064$), with no siginificant differences in 1999 ($P = 0.05$) or 2000 ($P = 0.1709$). Significant differences ($P < 0.0001$) in mean infracommunity species richness occurred more often in the September samples (Fig. 2). Mean infracommunity species richness at Îlet Vert, downstream of the effluent outflow, almost always ranked among the two lowest.

The distance index based on presence–absence of parasites revealed that component communities were similar, based largely on the season and year of sampling (Fig. 3). The September 1999 and 2000 samples formed a higher cluster based on the presence of *Diplostomum* spp., *P. mini-*

Table 3. Summary statistics of infections of the common parasite taxa in spottail shiners (*Notropis hudsonius*) occurring in > 2% of fish

(*a*) June samples: number of fish.

Year	Îles de la Paix	Île Dorval	Îles de Boucherville	Îlet Vert
1998	57	—	19	51
1999	37	9	26	25
2000	41	35	38	43

(*b*) June samples: parasites.

		Îles de la Paix		Île Dorval		Îles de Boucherville		Îlet Vert	
	Year	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)
Trematoda									
Centrovarium lobotes	1998	0.02 ± 0.1b	2	—	—	0b	0	0.3 ± 1.4ab	8
	1999	0b	0	0.2 ± 0.7a	11	0b	0	0b	0
	2000	0.1 ± 0.2ab	5	0.2 ± 0.7ab	11	0.2 ± 0.5ab	18	0.1 ± 0.3ab	9
Diplostomum spp.	1998	11.5 ± 7.4a	96	—	—	5.5 ± 2.8b	95	4.2 ± 2.8b	92
	1999	9.8 ± 4.8a	100	18.0 ± 10.9a	89	4.7 ± 3.4b	88	4.7 ± 4.0b	80
	2000	12.5 ± 6.1a	98	16.1 ± 11.2a	100	6.6 ± 4.3b	100	6.5 ± 4.2b	100
Ichthyocotylurus platycephalus	1998	0.6 ± 0.6	4	—	—	0	0	0.02 ± 0.02	2
	1999	0	0	0	0	0	0	0	0
	2000	0	0	0.1 ± 0.1	6	0.2 ± 0.1	8	0.1 ± 0.04	7
Neochasmus spp.	1998	0	0	—	—	0	0	0	0
	1999	0	0	0	0	0	0	0	0
	2000	0	0	0.03 ± 0.2	3	0	0	0.1 ± 0.4	7
Ornithodiplostomum ptychocheilus	1998	0.2 ± 0.8	7	—	—	0.2 ± 0.5	11	0.1 ± 0.4	14
	1999	0.1 ± 0.3	11	0.4 ± 0.7	33	0.1 ± 0.3	8	0.3 ± 0.6	20
	2000	0.2 ± 0.5d	20	0.4 ± 0.9cd	26	1.1 ± 1.3bc	61	0.9 ± 1.2bcd	53
Plagioporus sinitsini	1998	8.1 ± 18.4	37	—	—	6.0 ± 13.9	37	7.4 ± 19.4	29
	1999	3.0 ± 7.3	27	0.7 ± 2.0	11	5.1 ± 12.5	31	4.3 ± 10.4	28
	2000	4.0 ± 7.1a	46	9.1 ± 19.0a	37	4.6 ± 8.1a	45	5.0 ± 10.3ab	35
Posthodiplostomum minimum	1998	0.1 ± 0.5	9	—	—	0	0	0.1 ± 0.3	8
	1999	0.03 ± 0.2	3	0	0	0	0	0.2 ± 0.8	4
	2000	0.1 ± 0.5b	5	0.2 ± 0.4ab	17	0.3 ± 0.8ab	18	0.5 ± 1.2ab	26
Rhipidicotyle papillosa	1998	0	0	—	—	0	0	0	0
	1999	0	0	0	0	0	0	0	0
	2000	0	0	0	0	0	0	0	0
Tylodelphys scheuringi	1998	0.02 ± 0.1	2	—	—	0	0	0.02 ± 0.1	2
	1999	0	0	0	0	0	0	0	0
	2000	0	0	0.2 ± 0.6	11	0.03 ± 0.2	3	0	0
Acanthocephala									
Neoechinorhynchus rutili	1998	1.1 ± 3.7a	33	—	—	0b	0	0b	0
	1999	0.9 ± 1.5a	38	0b	0	0b	0	0.04 ± 0.2b	4
	2000	1.9 ± 2.6a	61	0.2 ± 0.6b	17	0.1 ± 0.2b	5	0.05 ± 0.3b	2
Cestoda									
Proteocephalus sp.	1998	0.04 ± 0.3	2	—	—	0	0	0	0
	1999	0	0	0	0	0	0	0	0
	2000	0	0	0	0	0.03 ± 0.2	3	0	0
Nematoda									
Raphidascaris acus	1998	0.2 ± 0.5a	19	—	—	0b	0	0.02 ± 0.1b	2
	1999	0.2 ± 0.6	8	0	0	0	0	0	0
	2000	0	0	0.2 ± 0.7	11	0.03 ± 0.2	3	0	0
Total parasites	1998	25.8 ± 3.1a	100	—	—	11.6 ± 3.3b	94.7	12.3 ± 2.8b	92.3
	1999	14.0 ± 1.4ab	100	19.6 ± 3.9a	100	10.0 ± 2.5bc	100	9.6 ± 2.4c	89.2
	2000	19.0 ± 1.5ab	100	31.6 ± 4.6a	100	13.2 ± 1.6bc	100	13.3 ± 1.7bc	100

overall from various localities in the St. Lawrence River in June and September 1998–2000.

Île Beauregard	Île Saint-Ours	Île au Bois Blanc	Bout-de-l'Île	Ottawa River
—	37	—	—	—
—	34	—	—	—
40	41	33	12	47

Île Beauregard		Île Saint-Ours		Île au Bois Blanc		Bout-de-l'Île		Ottawa River	
Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)
—	—	0.9 ± 3.8a	19	—	—	—	—	—	—
—	—	0b	0	—	—	—	—	—	—
0.03 ± 0.2b	3	0.2 ± 0.4ab	15	0.1 ± 0.3ab	9	0b	0	0.5 ± 0.8a	28
—	—	4.4 ± 4.4b	84	—	—	—	—	—	—
—	—	3.1 ± 3.5b	79	—	—	—	—	—	—
6.1 ± 3.5b	100	6.2 ± 6.9b	88	6.8 ± 4.7b	100	7.8 ± 5.2b	100	1.3 ± 2.6c	34
—	—	0	0	—	—	—	—	—	—
—	—	0.03 ± 0.03	0	—	—	—	—	—	—
0.2 ± 0.1	23	0.1 ± 0.1	7	0.2 ± 0.1	12	0	0	0.1 ± 0.1	13
—	—	0	0	—	—	—	—	—	—
—	—	0	0	—	—	—	—	—	—
0.1 ± 0.4	5	0.1 ± 0.2	5	0	0	0	0	0.2 ± 0.6	13
—	—	0.4 ± 1.2	16	—	—	—	—	—	
—	—	0.7 ± 1.5	32	—	—	—	—	—	
3.4 ±4.9ab	63	1.8 ± 3.5ab	66	1.3 ± 2.2bc	61	0.9 ± 1bcd	58	9.8 ± 15.2a	47
—	—	8.0 ± 14.9	49	—	—	—	—	—	—
—	—	3.9 ± 8.7	35	—	—	—	—	—	—
4.1 ± 10.1ab	30	3.9 ± 7.8ab	32	2.9 ± 6.9ab	42	5.6 ± 7.9a	42	0.3 ± 1.3b	4
—	—	0.2 ± 0.9	11	—	—	—	—	—	—
—	—	0.2 ± 0.1	21	—	—	—	—	—	—
0.8 ± 1.5a	40	0.5 ± 0.8ab	34	1.6 ± 3.9a	45	0.2 ± 0.4ab	17	3.2 ± 6.7a	38
—	—	0	0	—	—	—	—	—	—
—	—	0	0	—	—	—	—	—	—
0.3 ± 1.0	10	0.1 ± 0.3	2	0.2 ± 0.9	6	0	0	0.2 ± 0.4	15
—	—	0	0	—	—	—	—	—	—
—	—	0	0	—	—	—	—	—	—
0.03 ± 0.2	3	0.1 ± 0.2	5	0	0	0	0	0	0
—	—	0b	0	—	—	—	—	—	—
—	—	0b	0	—	—	—	—	—	—
0.03 ± 0.2b	3	0b	0	0b	0	0b	0	0.1 ± 0.6b	2
—	—	0	0	—	—	—	—	—	—
—	—	0	0	—	—	—	—	—	—
0	0	0	0	0	0	0	0	0.04 ± 0.2	4
—	—	0.2 ± 0.7ab	5	—	—	—	—	—	—
—	—	0.03 ± 0.2	3	—	—	—	—	—	—
0	0	0.02 ± 0.2	2	0	0	0	0	0.1 ± 0.4	6
—	—	14.3 ± 2.5b	98.2	—	—	—	—	—	—
—	—	8.6 ± 1.7c	91.7	—	—	—	—	—	—
15.7 ± 2.0abc	100	13.0 ± 2.0c	100	13.0 ± 1.7bc	100	14.5 ± 3.0bc	100	16.2 ± 3.0c	97.9

Table 3 (*concluded*).

(*c*) September samples: number of fish.

Year	Îles de la Paix	Île Dorval	Îles de Boucherville	Îlet Vert
1999	26	30	32	30
2000		29	30	30

(*d*) September samples: parasites.

		Îles de la Paix		Île Dorval		Îles de Boucherville		Îlet Vert	
	Year	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)
Trematoda									
Centrovarium lobotes	1999	—	—	0	0	0.03 ± 0.2	3	0	0
	2000	0	0	0	0	0	0	0	0
Diplostomum spp.	1999	—	—	6.8 ± 2.9a	97	8.6 ± 5.2a	97	3.3 ± 3.2b	87
	2000	1.4 ± 1.6bcd	58	2.3 ± 2.0ab	83	2.4 ± 2.1a	97	0.5 ± 0.9d	30
Ichthyocotylurus platycephalus	1999	—	—	0	0	0.03 ± 0.1	3	0.1 ± 0.1	3
	2000	0	0	0.1 ± 0.1	14	0.1 ± 0.1	7	0	0
Neochasmus spp.	1999	—	—	0c	0	0c	0	0.2 ± 0.9bc	10
	2000	0	0	0	0	0	0	0	0
Ornithodiplostomum ptychocheilus	1999	—	—	0.3 ± 0.6c	30	1.7 ± 1.8b	75	0.9 ± 1.3bc	50
	2000	0f	0	0.8 ± 1.0de	55	2.4 ± 2.5bc	77	0.6 ± 1.2ef	27
Plagioporus sinitsini	1999	—	—	6.7 ± 12.5a	43	2.6 ± 6.2ab	22	0.1 ± 0.6b	3
	2000	3.0 ± 8.5cd	35	24.6 ± 40.1a	83	2.9 ± 6.5cd	27	4.2 ± 12.6cd	17
Posthodiplostomum minimum	1999	—	—	0.4 ± 0.6b	23	1.9 ± 2.4a	63	0.7 ± 0.8ab	47
	2000	0.1 ± 0.3b	8	0.7 ± 1.0a	45	0.4 ± 0.9ab	27	0.3 ± 0.8ab	20
Rhipidicotyle papillosa	1999	—	—	0	0	0	0	0	0
	2000	0.2 ± 0.5bc	15	0c	0	0.3 ± 0.5bc	30	0.2 ± 0.4bc	20
Tylodelphys scheuringi	1999	—	—	0.1 ± 0.4	3	0.1 ± 0.3	6	0.03 ± 0.2	3
	2000	1.0 ± 2.0ab	42	1.2 ± 1.3a	62	0.2 ± 0.6d	10	0.03 ± 0.2d	3
Acanthocephala									
Neoechinorhynchus rutili	1999	—	—	0	0	0	0	0	0
	2000	0	0	0	0	0	0	0	0
Cestoda									
Proteocephalus sp.	1999	—	—	0b	0	0.3 ± 0.5a	25	0b	0
	2000	0.3 ± 0.9	12	0.3 ± 0.5	28	0.2 ± 0.6	17	0	0
Nematoda									
Raphidascaris acus	1999	—	—	0	0	0	0	0	0
	2000	0	0	0	0	0	0	0	0
Total parasites	1999	—	—	14.3±2.3ab	100	15.9±1.6a	100	5.5±0.9c	100
	2000	6.1±2.1cd	100	30.3±7.5ab	100	9.7±1.3bc	100	6.0±2.5d	60

Note: Ab, abundance per fish; Prev, prevalence. Localities are ordered from upstream to downstream (except the brown- and mixed-water sites sampled (one-way ANOVA on ranks).

mum, and *P. sinitsini*. This group was further partitioned into two clusters that could be separated by year. The parasites that characterize these groups are listed in Figs. 3A and 3B. A second major cluster was defined by the presence of *Diplostomum* spp., *O. ptychocheilus*, *P. minimum*, and *P. sinitsini*. This cluster was further subdivided into two principal groups based primarily on samples from June 1998 and June 1999 and those from June 2000. The parasites that characterize these groups are listed in Figs. 3C and 3D. The remaining major cluster, defined by the presence of *Diplostomum* spp., *O. ptychocheilus*, and *P. sinitsini*, mainly consisted of samples from June 1998 and June samples from other years (Fig. 3E).

The distance index based on intensity of parasite taxa revealed two higher groups of communities. In the first, *P. sinitsini*, *O. ptychocheilus*, and *P. minimum* occurred at relatively high abundances and *Diplostomum* spp. occurred at relatively low abundance. Most of these samples were collected in September 2000. Further partitioning of this group revealed similarities based on water mass and locality (Figs. 4A and 4B). The second major cluster, containing the remaining samples, was characterized by the occurrence of both *Diplostomum* spp. and *P. sinitsini* at high abundances. Further partitioning of this group showed similarities based on season, year, and locality. This second main cluster was divided into three groups, one from June 2000 (Fig. 4C), another from September 2000 (Fig. 4D), and the last containing samples from Lake St. Louis (Fig. 4E). The parasites that characterize all the different groups are listed in Figs. 4A–4E.

Parasite communities could be distinguished further based on canonical correspondence analysis. When restricted to taxa with 10% overall occurrence and using the variables locality, year, season, water mass, log coliforms, mercury, zinc, lead, chromium, and copper, the model was significant for the first canonical axis ($P = 0.005$) and for all four axes

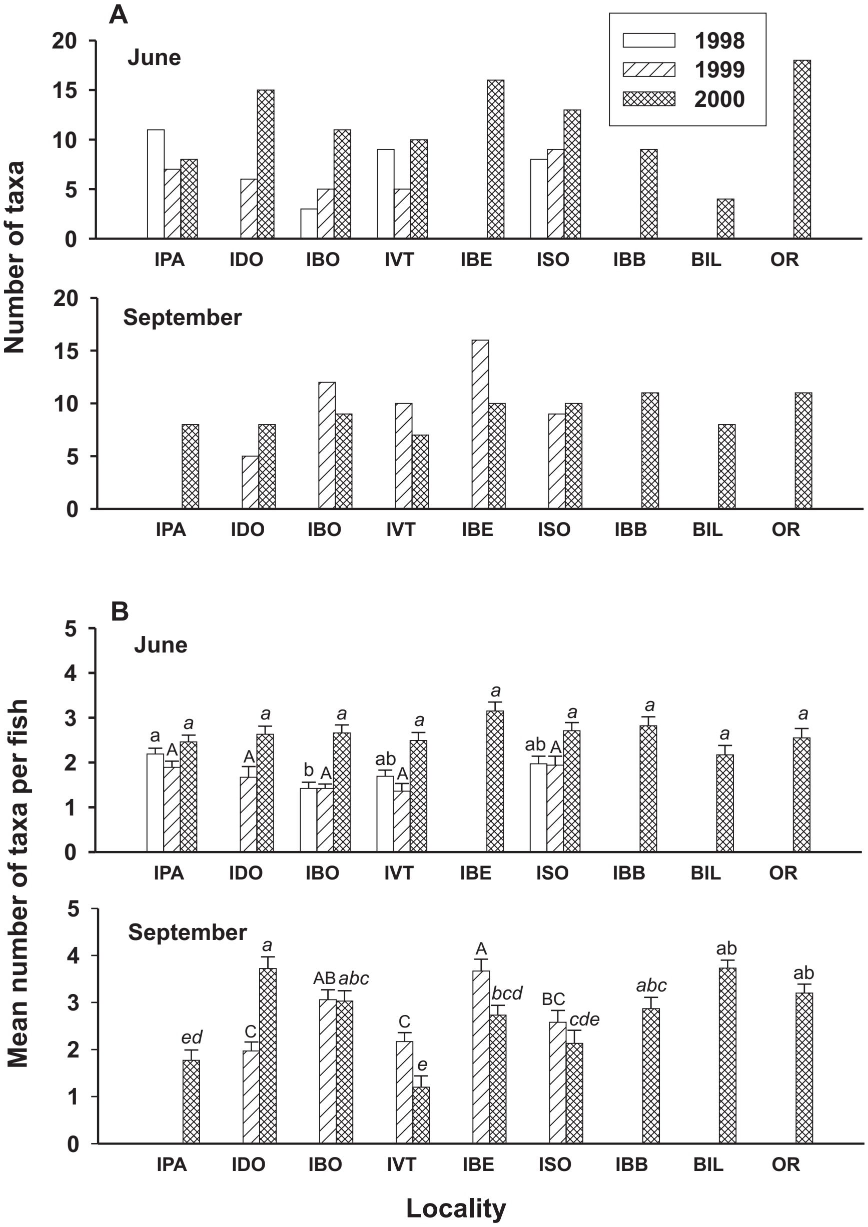
Île Beauregard	Île Saint-Ours	Île au Bois Blanc	Bout-de-l'Île	Ottawa River
30	24	—	—	—
30	30	30	30	30

Île Beauregard		Île Saint-Ours		Île au Bois Blanc		Bout-de-l'Île		Ottawa River	
Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)	Mean Ab ± SD	Prev (%)
0	0	0	0	—	—	—	—	—	—
0	0	0	0	0	0	0	0	0	0
4.7 ± 3.9b	93	4.6 ± 6.6b	92	—	—	—	—	—	—
1.1 ± 1.2cd	57	0.9 ± 1.3cd	43	0.9 ± 1.0cd	60	1.5 ± 1.4abc	70	0.8 ± 1.4 cd	33
0.1 ± 0.1	7	0	0	—	—	—	—	—	—
0.2 ± 0.1	10	0.03 ± 0.1	3	0.1 ± 0.1	13	0.03 ± 0.1	3	0.03 ± 0.1	3
0.7 ± 1.4a	37	0.3 ± 0.6ab	25	—	—	—	—	—	—
0	0	0	0	0.1 ± 0.4	3	0	0	0.1 ± 0.4	3
5.8 ± 4.1a	93	1.2 ± 1.4bc	54	—	—	—	—	—	—
4.2 ± 4.3ab	87	2.0 ± 2.5bcd	60	1.3 ± 1.8cde	57	2.1 ± 2.4bcd	60	5.2 ± 5.2a	97
1.7 ± 4.6ab	20	2.9 ± 4.1a	42	—	—	—	—	—	—
2.0 ± 3.6cd	27	1.3 ± 2.9cd	20	8.6 ± 18.0bc	47	14.0 ±25.2ab	63	0.1 ± 0.3d	10
1.2 ± 1.5a	67	0.4 ± 0.7b	29	—	—	—	—	—	—
1.2 ± 2.6ab	40	0.4 ± 1.0ab	20	0.6 ± 1.4ab	33	0.8 ± 0.9a	53	1.2 ± 1.8a	50
0	0	0	0	—	—	—	—	—	—
0.4 ± 0.7bc	27	0.7 ± 1.3b	37	1.1 ± 3.0b	37	4.4 ± 5.6a	67	4.6 ± 4.8a	90
0	0	0.04 ± 0.2	4	—	—	—	—	—	—
0.1 ± 0.3d	7	0.1 ± 0.3d	7	0.2 ± 0.4cd	17	0.6 ± 0.8bc	37	0d	0
0	0	0	0	—	—	—	—	—	—
0	0	0	0	0	0	0	0	0	0
0b	0	0b	0	—	—	—	—	—	—
0.1 ± 0.4	13	0.1 ± 0.4	10	0.1 ± 0.4	13	0.2 ± 0.5	20	0.2 ± 0.5	20
0	0	0	0	—	—	—	—	—	—
0	0	0	0	0	0	0	0	0.03 ± 0.2	3
15.3±1.5a	100	9.7±1.7bc	96.7	—	—	—	—	—	—
10.2±1.8bc	96.7	6.5±1.2cd	83.3	13.2±3.3bc	100	23.7±5.0a	100	13.7±1.4ab	100

in 2000: Île au Bois Blanc, Bout-de-l'Île, and the Ottawa River). Different letters indicate significant differences among localities within months and years

($P = 0.005$) and explained 28% of the total variance in parasite species occurrence. Axis 1 explained 75.4% of the variability in parasite species – environment relationships and axis 2 accounted for a further 18.6%. Water mass (green and brown), season (June and September), year (1998 and 2000), contaminants (chromium), and certain localities (Îles de la Paix and the Ottawa River) were the variables that were associated most strongly ($r > 0.30$) with the first canonical axis, while no variables were associated strongly with the second axis. Differences were indicated by the separation of samples on an annual basis, with the centroid for 1998 negative along axis 1 and positive along axis 2, that for 1999 negative along both axes, and the centroid for 2000 positive along both axes (Fig. 5). Seasons of collection were clearly separated, with the centroid for June samples falling in the lower left quadrant and that for September falling in the upper right (Fig. 5). In addition, samples clearly separated out when classified according to water mass (green, brown, mixed), with the centroid for green waters negatively associated with axis 1 and that for brown waters positively associated with axis 1. Parasite communities clearly were partitioned by locality. The centroids for Îles de la Paix and Île Dorval, both reference localities in Lake St. Louis, occurred in the upper left; those for Îles de Boucherville, Îlet Vert, and Île Saint-Ours, all green-water localities, fell in the lower left; those for Bout-de-l'Île and Île au Bois Blanc, brown- and mixed-water sites, respectively, east of the Island of Montréal, appeared in the upper right; and those for the Ottawa River (the brown-water reference locality) and Île Beauregard occurred in the lower right (Fig. 5). Among the different contaminants, chromium appeared in the upper left, zinc in the lower left, mercury and lead in the upper right, and copper and fecal coliforms in the lower right (Fig. 5). The relationships between the most common parasites (>10% frequency of occurrence) and the two principal axes also are illustrated (Fig. 5). *Diplostomum* spp. were found in the lower left, *P. sinitsini*

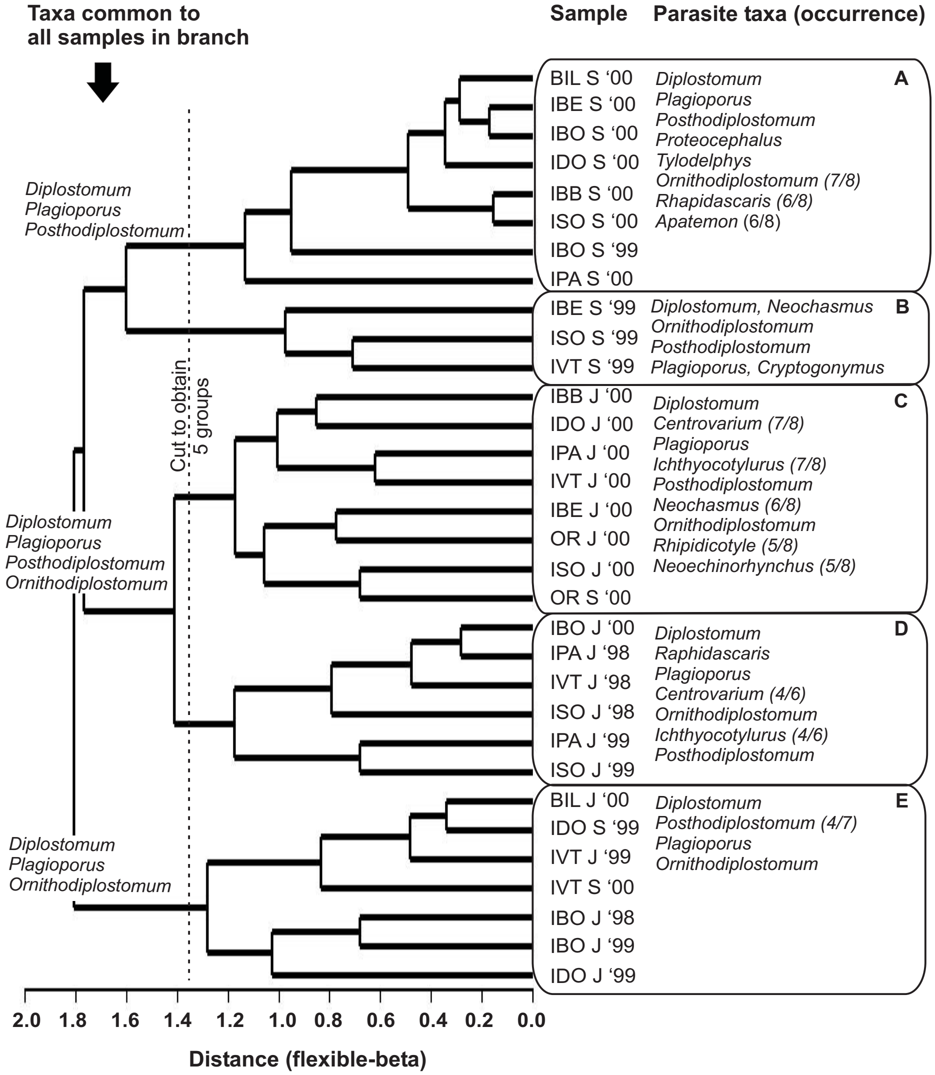
Fig. 2. Species richness of the parasite communities of spottail shiners (*Notropis hudsonius*) at various localities in the St. Lawrence River in June and September 1998–2000. (A) Component community richness; (B) infracommunity species richness. In (B), significant differences among localities within years are indicated by different letters. For all graphs, the localities are Îles de la Paix (IPA), Île Dorval (IDO), Îles de Boucherville (IBO), Îlet Vert (IVT), Île Beauregard (IBE), Île Saint-Ours (ISO), Île au Bois Blanc (IBB), Bout-de-l'Île (BIL), and the Ottawa River (OR).



was found in the upper left, *R. papillosa* appeared in the upper right, and *P. minimum* and *O. ptychocheilus* were found in the lower right. When analyses included all parasites with ≥ 2% overall prevalence, the model was significant for the first canonical axis ($P = 0.005$) and for all four canonical axes ($P = 0.005$) and explained 19% of the total variance in parasite occurrence. Axis 1 accounted for 53.8% of the variance in the parasite–environment relationships and axis 2 accounted for 19.3%. In addition to the parasites mentioned above, *N. rutili* and *R. acus* were found in the upper left, *T. scheuringi* and *Proteocephalus* sp. in the upper right, and *I. platycephalus* and *Neochasmus* spp. in the lower right, while *C. lobotes* was situated negatively and directly on axis 2 (graph not shown).

The proportion of allogenic parasites at any one site varied between 17% and 95%, with no clear patterns evident (Table 4). In general, a high proportion of autogenic parasites was due to the high abundance of *P. sinitsini*. Another way to partition the parasites based on life-history characteristics is to calculate the proportion of autogenic larval stages that belong to parasites that use piscivorous fish as definitive hosts. Given the clear predominance of larval trematodes that infect birds (allogenic parasites), the proportion of autogenic larvae, expressed as a percentage, is always low, and usually

Fig. 3. Clustergram based on the distance matrices (reciprocal of the Jaccard index) for parasite communities of spottail shiners (*Notropis hudsonius*) collected from various localities in the St. Lawrence River in June and September 1998–2000. The parasites that characterize the three main groupings as well as the clusters of individual samples are indicated. The samples are from the following localities: Îles de la Paix (IPA), Île Dorval (IDO), Îles de Boucherville (IBO), Îlet Vert (IVT), Île Beauregard (IBE), Île Saint-Ours (ISO), Île au Bois Blanc (IBB), Bout-de-l'Île (BIL), and the Ottawa River (OR).

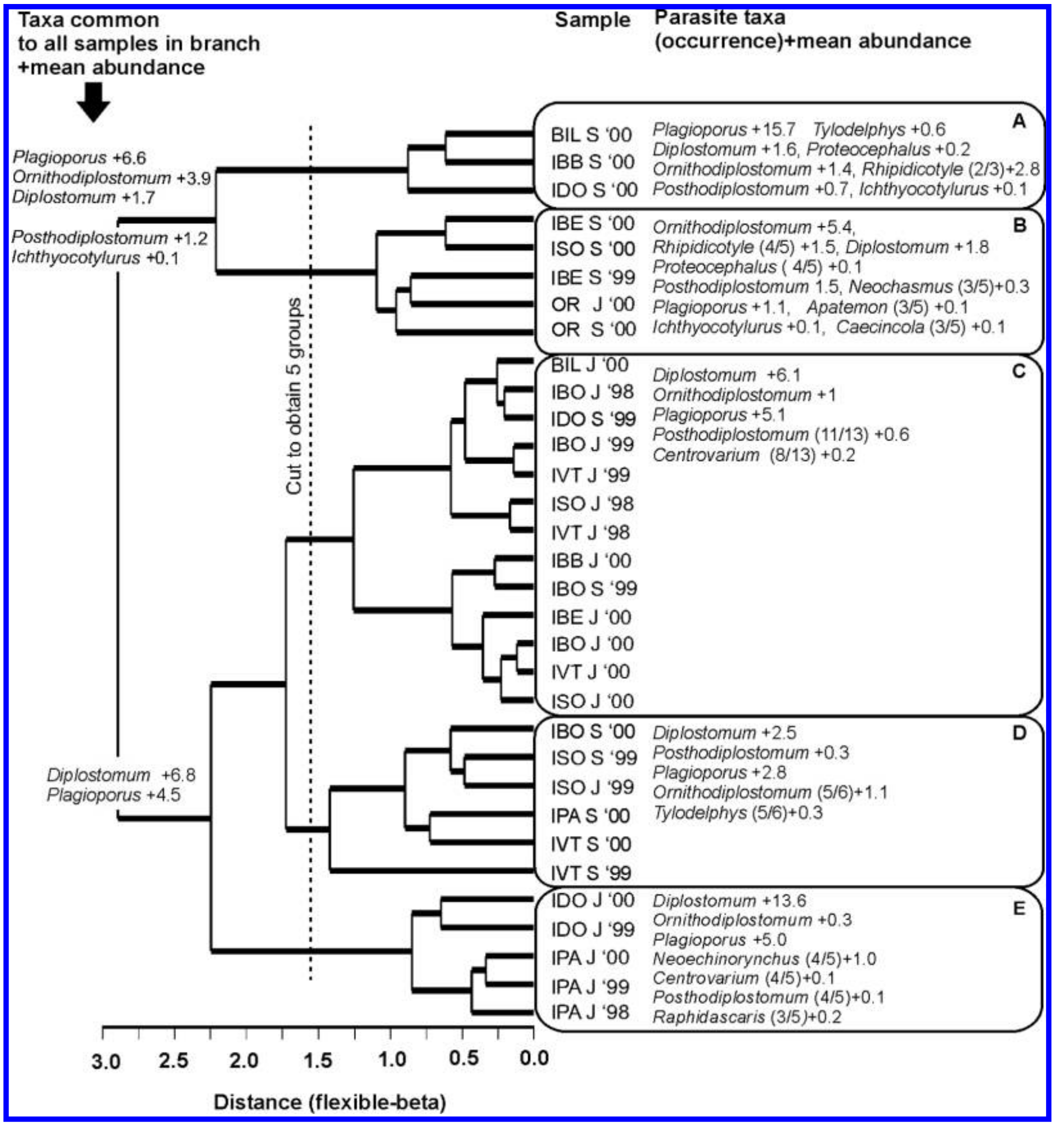


less than 4% (Table 4). However, in June 1998 and June 1999, it was 6.5%–7.4% at Île Saint-Ours. This was due to the presence of *C. lobotes* and *R. acus* in 1998 and the nematodes *Philometra cylindracea* (Ward and Magath, 1917) and *Hysterothylacium* sp. in 1999. The proportion of autogenic larvae was 4.9% in the Ottawa River in June 2000 as a result of the occurrence of *R. papillosa* and *C. lobotes*. In September 2000, the proportion of autogenic larval stages was high at Île Saint-Ours (11.3%) and in the brown and mixed waters at Bout-de-l'Île (18.7%), Île au Bois Blanc (8.6%), and the Ottawa River (34.4%) owing to the abundance of *R. papillosa* at all sites. Waters at Île Saint-Ours, located farthest downstream, were quite turbid, with low visibility. The proportion of parasites transmitted via zooplanktonic intermediate hosts was always low, and usually less than 2%, with the following exceptions. In June 1999, the proportion was 4.8% at Île Saint-Ours owing to the presence of *P. cylindracea*. In September 2000, the proportion was higher at Îles de la Paix (4.4%), Îles de Boucherville (2.4%), and the Ottawa River (2.2%) principally because of the presence of *Proteocephalus* sp. at those sites. Planktivorous transmission is absent or rare at Îlet Vert. Both *P. cylindracea* and *Proteocephalus* sp. use copepods as intermediate hosts.

Benthic invertebrates

Benthic invertebrates were collected from two reference localities in Lake St. Louis (Îles de la Paix and Île Dorval) and two localities downstream of the urban effluents (Îlet Vert and Île Beauregard) in June 2001. Density of amphipods was slightly higher at Îlet Vert and Île Beauregard than at localities in Lake St. Louis (ANOVA, $P = 0.3316$) (Fig. 6A). Amphipods serve as intermediate hosts for some of the rarer nematodes (Table S2). Density of ostracods, which act as intermediate hosts for *N. rutili*, was significantly higher at Île Beauregard than at Îles de la Paix (ANOVA, $P = 0.0459$), but no other differences were signifi-

Fig. 4. Clustergram based on the distance matrices (Bray–Curtis Index) for parasite communities of spottail shiners (*Notropis hudsonius*) collected from various localities in the St. Lawrence River in June and September 1998–2000. The parasites that characterize the three main groupings as well as the clusters of individual samples are indicated. The samples are from the following localities: Îles de la Paix (IPA), Île Dorval (IDO), Îles de Boucherville (IBO), Îlet Vert (IVT), Île Beauregard (IBE), Île Saint-Ours (ISO), Île au Bois Blanc (IBB), Bout-de-l'Île (BIL), and the Ottawa River (OR).



cant (Fig. 6A). At all localities amphipods consisted of *Gammarus fasciatus* Say, 1818 and ostracods consisted of *Candona* spp. Chironomids were more abundant downstream of Montréal than in Lake St. Louis (data not shown) (ANOVA, P = 0.0011). In contrast, density of gastropods was significantly higher at Îles de la Paix and Île Dorval than at the two localities downstream of the Montréal effluents (ANOVA, $P < 0.0001$) (Fig. 6B). Molluscs were particularly rare at Îlet Vert. Bivalves, especially *Pisidium* sp., were relatively common at all sites, but more so in Lake St. Louis. *Bithynia tentaculata* (L., 1767) dominated the gastropods in Lake St. Louis but was absent from the two downstream sites. Diversity of gastropods was markedly higher in Lake St. Louis, with six and eight taxa collected from Îles de la Paix and Île Dorval, respectively, and one and five taxa collected from Îlet Vert and Île Beauregard. Lymnaeids were most abundant at Île Dorval (ANOVA, P = 0.0003), while physids occurred in limited numbers at all localites except Îlet Vert (ANOVA, P = 0.1495) (Fig. 6B). Lymnaeids and physids are intermediate hosts for *Diplostomum* spp. and for *P. minimum* and *O. ptychocheilus*, respectively.

Discussion

Parasite community structure

There were no clear differences in parasite community structure between spottail shiners collected from localities receiving municipal effluents and those not exposed to the effluents. However, component community species richness was often low at Îlet Vert, a locality directly downstream of the municipal outflow. The component parasite community was also relatively impoverished at all localities close to the Island of Montréal. Similarly, infracommunity species rich-

Fig. 5. Results from the canonical correspondence analysis showing variables plotted against the first two canonical axes. Variables include year, month (J, June; S, September), water mass (G, green; B, brown; M, mixed), contaminants (Cd, cadmium; Cu, copper; Cr, chromium; Pb, lead; Hg, mercury; Zn, zinc), and sampling localities (IPA, Îles de la Paix; IDO, Île Dorval; IBO, Îles de Boucherville; IVT, Îlet Vert; IBE, Île Beauregard; ISO, Île Saint-Ours; IBB, Île au Bois Blanc; BIL, Bout-de-l'Île; and OR, the Ottawa River).

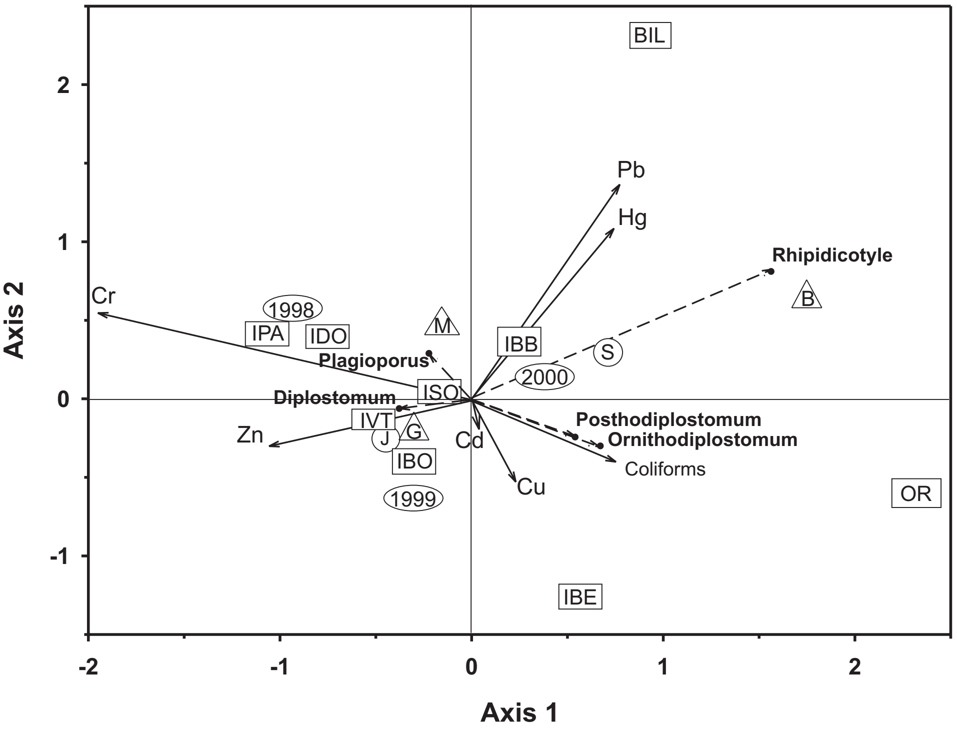


Table 4. Characteristics of parasite communities of spottail shiners (*Notropis hudsonius*) collected in June (J) or September (S) 1998–2000 in the St. Lawrence River.

	% allogenic					% planktonic transmission					% larval autogenic parasites				
	1998	1999		2000		1998	1999		2000		1998	1999		2000	
Site	J	J	S	J	S	J	J	S	J	S	J	J	S	J	S
Îles de la Paix	57	71	—	68	41	0.1	0	—	0	4.4	1.0	1.4	—	0.3	3.8
Île Dorval	—	95	53	54	17	—	0	0	0.2	0.9	—	1.1	0	1.4	0
Îles de Boucherville	49	49	81	63	62	0	0	1.8	0.2	2.4	0	0	0.2	1.8	3.1
Îlet Vert	38	54	93	60	26	0	0	1.2	0.2	0	2.2	0	1.2	0.9	3.4
Île Beauregard	—	—	82	70	73	—	—	0.6	0	1.3	—	—	2.3	2.7	3.9
Île Saint-Ours	36	48	65	66	62	0	4.8	0	1.5	0	7.4	6.5	1.7	2.8	11.3
Bout-de-l'Île	—	—	—	91	59	—	—	—	0	1.0	—	—	0	0	18.7
Île au Bois Blanc	—	—	—	61	21	—	—	—	0	1.0	—	—	2.1	2.1	8.6
Ottawa River	—	—	—	75	24	—	—	—	1.4	2.2	—	—	4.9	4.9	34.4

ness did not vary a great deal among localities; however, it tended to be lowest or among the lowest at Îlet Vert during most sampling periods, especially in September. Total parasite abundance was also consistently low at this locality.

Other studies have documented changes in parasite communities associated with urban and industrial effluents. Most often these changes are manifested as decreases in species richness, as observed in winter flounder (*Pseudopleuronectes americanus* (Walbaum, 1792)), European flounder (*Platichthys flesus* (L., 1758)), eelpout (*Zoarces viviparus* (L., 1758)), chub (*Leuciscus cephalus* (L., 1758)), white croaker (*Genyonemus lineatus* (Ayres, 1855)), silver perch (*Bairdiella chrysoura* (Lacepède, 1802)), and barbel (*Barbus barbus* (L., 1758)) (Burn 1980; Sulgostowska et al. 1987, 1990; Gelnar et al. 1997; Landsberg et al. 1998; Hogue and Peng 2003; Schludermann et al. 2003). Landsberg et al. (1998) also found a decrease in the mean number of parasites per fish at the most heavily affected locality. However, parasite communities may not always be suitable indicators of pollution, as in the case herein. Populations of certain parasite species may increase in response to anthropogenic impacts, while others may decrease, yet these changes may not be detectable using measurements of community structure (Kennedy 1997; Lafferty 1997; Overstreet 1997; Marcogliese 2005). In ecosystems where the contaminant levels are low or the environmental impacts are limited, parasite communities may not be greatly affected. In the St. Lawrence River, the concentrations of PCBs and PAHs are relatively low compared with those in other polluted systems that have been studied, and concentrations in river water reach background levels 13 km and 6 km from the sewage outflow for PCBs and PAHs, respectively (Pham and Proulx 1997). Using the composition of PCBs and PAHs to determine water masses, the effluent plume from the Island of Montréal was no longer detectable at a distance of 11 km from the outflow (Pham et al. 1999). Dissolved trace metal concentrations reach a maximum 1 km downstream from the effluent outflow, decreasing to a minimum 5 km away (Gagnon and Saulnier 2003). In contrast, particulate trace metal content in surface waters suggests that metals decrease between 500 m and 1 km from the outflow and then increase to reach a maximum 5 km downstream from the source (Gagnon and Saulnier 2003). However, these metals remain bioavailable downstream of the effluent source (Gagnon and Saulnier 2003). For stations downstream of the effluents, measurements in sediments indicate significant amounts of chromium at Îlet Vert, the locality closest to the effluent source, 4 km away. Other metals occur below toxic levels but above the MET and the ISQG at different localities in Lake St. Louis, and in both green and brown waters of the river, indicating different sources of contamination (Great Lakes, tributaries, surface runoff, other municipalities) in addition to the effluents from the Montréal sewage treatment plant, which may further confound the interpretation of parasitological results.

Further analyses indicate that parasite community structure varies considerably both spatially and temporally in the St. Lawrence River. The distance index based on presence–absence data demonstrated that similarities among the parasite component communities of spottail shiners were largely based on year and season. The differences among these major clusters appeared to be due to the high prevalence of *P. minimum* in one group, *P. minimum* and *O. ptychocheilus* in a second group, and *O. ptychocheilus* in a third group. The first two groups were further partitioned into smaller groups separated by year, based on the differential prevalence of certain species. Thus, there are clear annual variations in community structure based on the occurrence of parasites. Moreover, there are distinct seasonal differences in community structure between June and September, also based on parasite occurrence. These differences may in part be due to the use of different age classes, with 1+ fish being collected in June and 0+ fish in September. Seasonal and annual variations of this type in the St. Lawrence River render the application of parasite communities as indicators of impacts of municipal effluents problematic (see Kennedy 1997). However, using the same age class consistently at the same time of year avoids this problem, though seasonally variable species may be missed. Cluster analysis based on intensity data reinforced the interpretation that there are clear seasonal and annual fluctuations in the occurrence and abundance of parasites. Moreover, parasite communities were also partitioned based on green and brown water masses and location (e.g., Lake St. Louis), suggesting that they are good indicators of habitat structure. These patterns may be affected somewhat by the small sample sizes of certain collections. Nevertheless, the patterns appear to result from the distribution and abundance of the most common parasites, which will be less affected by limited numbers of hosts.

The patterns exhibited in the cluster analyses were reinforced by the results of the canonical correspondence analysis. June samples were separated from September samples, and the three years were partitioned differentially along the major axes, a reflection of the seasonal and annual variations in parasite community structure. The seasonal and annual variations in parasite occurrence and abundance may be partly explained by variations in water levels. Certain types of parasites proliferate under conditions of reduced water levels and flow (Marcogliese 2001). Janovy et al. (1997) found that populations of larval digeneans in fish increased in the year following reduced flow rates in the Platt River, a fact they attributed to an augmentation of snail intermediate hosts during years with low flow. Water levels in the St. Lawrence River were near record lows in the spring and summer of 1999 and also in May 2000 (Environment Canada archived hydrometric data, Varennes station, http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=graph.cfm). The annual patterns of abundance were not consistent across species, but numerous parasites including *Diplostomum* spp., *P. minimum*, and *Proteocephalus* sp. were most abundant in September 1999 and June 2000. The digenean *O. ptychocheilus* was more abundant in June 2000 than in the same month in other years. Component species richness also was highest in June 2000 compared with the same month in other years. Low flow rates promote development of suitable habitat for gastropod intermediate hosts and retention of free-living larval stages (e.g., digenean miracidia and cercariae) and zooplanktonic intermediate hosts (e.g., copepods), thus enhancing transmission of certain parasites, including digeneans and cestodes (Marcogliese 2001), and providing a possible explanation for the variations in abundance of the parasites mentioned above.

Despite the broad annual and seasonal differences, however, the sampling localities partitioned into distinct groups. The brown waters were positively correlated with the first canonical axis, but Île au Bois Blanc and Bout-de-l'Île were positively correlated, and the Ottawa River was negatively correlated, with the second canonical axis. The samples from the green waters were negatively correlated with axis 1. Within them, those from Lake St. Louis were positively correlated with axis 2, while those from the fluvial corridor south and east of the Island of Montréal correlated negatively with axis 2. Thus, the parasite component communities of spottail shiners clearly separated into distinct assemblages that tended to be associated with habitat characteristics, despite the occurrence of seasonal and annual variations. The clear separation of parasite component communities by locality provides empirical support for the use of spottail shiners as an indicator species in the St. Lawrence River. Analogous to the use of parasites as biological tags in commercial fish species (Williams et al. 1992; MacKenzie and Abaunza 1998), the parasite communities can be used to partition spottail shiners in the St. Lawrence River into distinct ecological stocks, at least for 0+ and 1+ fish. This is most apparent with the clear separation of fish from Îlet Vert and Île au Bois Blanc, two islands separated by only 500 m of water.

Parasite species distribution, habitat quality, and biodiversity

Among the parasites found (see Table S2), the digeneans *Apatemon gracilis* (Rudolphi, 1819), *I. platycephalus*, *Neo-*

chasmus spp., *O. ptychocheilus*, *R. papillosa*, and *T. scheuringi* and the nematodes *Hysterothylacium* sp., *P. cylindracea*, and *R. acus* have not been reported previously in spottail shiners (Margolis and Arthur 1979; McDonald and Margolis 1995; Hoffman 1999). This is also the first report of the digenean *Caecincola* sp. and the cestode *P. wisconsinensis* in spottail shiners in Canada (Margolis and Arthur 1979; McDonald and Margolis 1995).

Diplostomum spp. are usually the most common parasites in spottail shiners collected from the St. Lawrence River. Typically they were more abundant at localities in Lake St. Louis than elsewhere. Other studies of different fish and amphibian species also demonstrate that *Diplostomum* spp. are extremely common in Lake St. Louis (Marcogliese et al. 2000, 2001*a*). While previous studies suggest that the distribution of the definitive hosts (gulls) is important, habitat characteristics also influence the distribution of *Diplostomum* spp. in the St. Lawrence River (Marcogliese et al. 2001*b*). Lake St. Louis is within foraging distance of some major gull colonies (Marcogliese et al. 2001*a*) and also contains extensive macrophyte development and wetlands, thus providing good habitat for the first intermediate hosts, lymnaeid snails, as indicated by our benthic data. Curiously, mean abundance of *Diplostomum* spp. at Îlet Vert and other localities in the fluvial corridor downstream of Montréal was consistently among the lowest observed in this study, yet this island is located only 500 m from Île Deslauriers, the largest gull colony on the St. Lawrence River (Marcogliese et al. 2001*a*, 2001*b*). Another potentially confounding influence may be the levels of trace metals in the water column close to the source of the effluents. Concentrations of particulate trace metals are highest 5 km from the effluent outfall (Gagnon and Saulnier 2003), and toxic levels of chromium were measured in the sediments at Îlet Vert. Certain trace metals, including chromium, at high concentrations have been shown to negatively affect cercarial survival and activity of *Diplostomum* spp. (Morley et al. 2001, 2003*a*, 2003*b*; Pietrock et al. 2002*a*, 2002*b*). Other diplostomatid parasites experience reduced cercarial infectivity when exposed to low levels of cadmium (Pietrock and Goater 2005). In addition, lymnaeid snails infected with *Diplostomum spathaceum* (Rudolphi, 1819) experience reduced survival when exposed to cadmium (Morley et al. 2003*c*). Alternatively, the low mean abundance of *Diplostomum* spp. at localities downstream from Montréal may be due to the rarity of gastropod intermediate hosts. However, the presence of large numbers of definitive-host birds may mask the negative effects of pollutants and the low density of gastropod hosts at a locality, maintaining prevalence at a certain level (Morley et al. 2003*d*). Nevertheless, the abundance of *Diplostomum* spp. is consistently low at Îlet Vert, and this may be related to the contaminants from the municipal effluents, the low density of snail hosts, or both.

The strigeids *P. minimum* and *O. ptychocheilus* tended to have similar patterns of distribution. These parasites were most abundant at Île Beauregard, Île Saint-Ours, and the Ottawa River. The similar distributions of the two parasites are best explained by the distribution of their shared first intermediate hosts, snails of the genus *Physa* (Schell 1985), given that their definitive hosts are different. Herons are the final host for *P. minimum*, while ducks, especially mergansers, are final hosts for *O. ptychocheilus*. Indeed, physid snails were among the most common gastropods at Île Beauregard.

Tylodelphys scheuringi tended to be most abundant at localities in Lake St. Louis. The life cycle of this species is not known, but its distribution may also be related to the distribution of its gastropod first intermediate host. This parasite was more common in September than in June, most likely because it has an annual life span in the fish host and does not overwinter (Marcogliese et al. 2001*b*).

The digenean *P. sinitsini* is noteworthy because it is among the most common parasites of spottail shiners in the St. Lawrence River but, unlike the others, it occurs as an adult in fish. The snail *Goniobasis* sp. is the first intermediate host, and sporocysts released by the snail are consumed directly by the fish host (Olsen 1986). The snail host is undoubtedly widely distributed and abundant. This is the only autogenic parasite that occurs with high abundance and prevalence in the river.

The digeneans *C. lobotes* and *R. papillosa*, along with the nematode *R. acus*, share common life-history patterns in that they also mature in piscivorous fish. These parasites are most abundant in Lake St. Louis, in the brown waters (*C. lobotes*, *R. papillosa*), and at Île Saint-Ours (*R. acus*, *C. lobotes*). The occurrence of these parasites reflects the presence of piscivorous fish in the vicinity of the sampling locality. For example, Johnson et al. (2004) demonstrated that the distribution of *R. acus* among lakes in yellow perch (*Perca flavescens* (Mitchill, 1814)) reflects the distribution of its main definitive host, the northern pike (*Esox lucius* L., 1758), although it can also mature in walleye (*Sander vitreus* (Mitchill, 1818)). In our sampling, we frequently encountered young walleye at Île Saint-Ours, and Lake St. Louis is known for its recreational sport fishery. In addition, the diversity of fishes in the St. Lawrence River is higher in Lake St. Louis than in most other sectors (LaViolette 2004). Thus, the parasite fauna of a forage fish provides information on the food-web structure and biodiversity of the local ecosystem. Note that the distribution of *Neochasmus* spp. does not follow the same pattern, even though these species are reported as adults in certain piscivorous fishes (Margolis and Arthur 1979; McDonald and Margolis 1995; Hoffman 1999). There are at least two species in the St. Lawrence River, and they exhibit progenesis as metacercariae, thus eliminating the need for a piscivorous final host (McLaughlin et al. 2006). These parasites are most abundant downstream of the Island of Montréal in the green waters and in the Ottawa River. Their distribution most likely is related to the relative abundance of their gastropod intermediate hosts.

The prevalence of larval autogenic parasites was higher in September than in June, suggesting that the recruitment of these parasites occurs over the summer months. Furthermore, these parasites were more common in 2000 than in other years, suggesting that the low water levels and volume observed throughout 1999 and in spring 2000 (Environment Canada archived hydrometric data, Varennes station, http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=graph.cfm) may have led to enhanced transmission, possibly by promoting contact between the forage fish that function as intermediate hosts and their piscine predators.

The high abundance of *R. papillosa* in brown waters is also noteworthy. This parasite uses bivalves as its first intermediate host (Schell 1985). Its limited distribution in the green waters of the St. Lawrence River is most likely the indirect result of invasion by the zebra mussel (*Dreissena polymorpha* (Pallas, 1771)), which led to a severe reduction in the density of unionid mussels (Mellina and Rasmussen 1994; Ricciardi et al. 1996). However, zebra mussels are restricted to the green waters because they cannot tolerate the low calcium levels of the brown waters along the north shore of the St. Lawrence River (Mellina and Rasmussen 1994). Thus, the distribution of the digenean *R. papillosa* likely reflects the restricted distribution of unionid mussels and other native bivalves in the St. Lawrence River.

In 1998 and 1999, plerocercoids of the cestode *Proteocephalus* sp. were found in spottail shiners only from Îles de la Paix and Îles de Boucherville. This is one of the only parasites encountered that is transmitted by copepods. A restricted distribution in the St. Lawrence River likely reflects the relatively unimportant role of zooplankton in this ecosystem (Basu et al. 2000). However, in September 2000, the parasite was found at almost all sites, with the exception of Îlet Vert. Why this parasite should experience a clear expansion of its distribution is puzzling, but it may be related to low water levels in 1999 that led to the retention and proliferation of zooplankton and the subsequent population expansion in its piscine definitive host. Other studies have linked changes in the population biology of cestodes in fish to alterations in the species composition and abundance of copepod intermediate hosts (Marcogliese and Esch 1989; Hanzelová 1992). Spottail shiners are known to feed on zooplankton when available (Scott and Crossman 1973).

The cestode *P. wisconsinensis* was remarkably abundant at Île Dorval in June 2000. This parasite requires an oligochaete intermediate host. The explanation for the population increase at this locality remains unknown, but it may be related to local increases in other definitive fish hosts at this time.

The restricted distribution of the acanthocephalan *N. rutili* is noteworthy. The parasite is abundant in Lake St. Louis, especially at Îles de la Paix, but rare elsewhere. This parasite or its intermediate host may be negatively influenced by pollution, as it has been suggested that acanthocephalans may be good indicators of heavy metal contamination and other environmental disturbances (reviewed in Lafferty 1997). However, we have since discovered this parasite in spottail shiners from other contaminated areas (Thilakaratne 2006), and we cannot attribute the distribution observed in the St. Lawrence River to pollution. The differential distribution may be attributed to the absence of intermediate hosts downstream. However, *N. rutili* is transmitted by ostracods (Walkey 1967), including *Candona* spp., which were more abundant downstream of the Montréal effluents than in Lake St. Louis. The cause of the restricted distribution of *N. rutili* remains unknown.

The low parasite species richness, the low total parasite abundance, and the lack of autogenic parasites at Îlet Vert, immediately downstream of the effluent outflow, may be consequences of a simplified food web in that vicinity. The absence of autogenic larval stages signifies reduced predation by piscivores and a shorter food chain. The absence of *Proteocephalus* sp. and the low prevalence of plankton-transmitted parasites implies that copepods may not be an important constituent of the local food web. Studies in the St. Lawrence River using stable isotope analysis showed an increase in benthic secondary production in the effluent plume within 10 km from the source, but this was mainly due to enhanced production of chironomids (deBruyn et al. 2003). Furthermore, enhanced productivity among different trophic levels was principally due to white sucker (*Catostomus commersonii* (Lacepède, 1803)), whereas productivity at downstream reference sites was attributed to a diverse array of taxa. Macroinvertebrates and fish in the effluents fed closer to the base of the food chain, as indicated by the lower δ^{15}N values. Thus, the food web in the sewage outflow was characterized by higher productivity but fewer predominant species and a compression of the food chain towards sewage-derived resources. The relatively impoverished parasite species richness in spottail shiners at the component and infracommunity levels at Îlet Vert, where the biota is directly exposed to the sewage effluents, together with the absence of certain parasite species, is a result of the relatively poor invertebrate and fish diversity plus alterations in food-chain dynamics. Thus, the parasite community structure reflects local ecosystem conditions, food-web structure, and biodiversity. Indeed, bearing in mind that the conclusions may be affected by small sample sizes in a few cases, the Ottawa River, Lake St. Louis, the brown waters east of Montréal, and the green waters south and east of Montréal are habitats that can be distinguished based on the parasite fauna, even though they are interconnected. In contrast, while the subtle changes observed at Îlet Vert appear to be biologically meaningful, the lack of profound changes in parasite species composition and abundance in the Montréal effluents suggests that parasite communities of spottail shiners may not be clear-cut indicators of moderately polluted conditions in the St. Lawrence River.

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