

SPATIAL ATTACHMENT-SITE PREFERENCES OF MACROECTOPARASITES ON ATLANTIC STURGEONS *ACIPENSER OXYRINCHUS* IN MINAS BASIN, BAY OF FUNDY, CANADA

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ABSTRACT: Although parasite habitat preference is well studied, it is rarely rigorously evaluated statistically because of many zero intensities. Attachment-site preference and intensities of 2 macroectoparasite species (*Caligus elongatus* and *Calliobdella vivida*) of Atlantic sturgeon, *Acipenser oxyrinchus* Mitchill, in Minas Basin, Bay of Fundy, Canada, were characterized with the use of zero-inflated negative binomial statistical models that included a fork-length offset to control for body size. Three other parasites were encountered, sometimes in high numbers on various body sites, but too few counts overall prevented construction of meaningful statistical models. Of 26 sturgeons, prevalence of (1) *C. elongatus* (Copepoda) was 85%, mainly on caudal fins and nonfin body sites; (2) *C. vivida* (Hirudinea) was 81%, mainly on the pelvic and pectoral fins, and dorsal and ventral–lateral body sites; (3) *Dichelesthium oblongum* (Copepoda) was 31% within the gills or burrowed into the musculature at the base of fins; (4) *Argulus stizostethii* (Crustacea: Branchiura) was 8%; and (5) *Nitzschia sturionis* (Monogenea) was 12%. Only *D. oblongum* was associated with visible damage, mainly as lesions on gills and soft tissues. Characterizing parasite prevalences within the Bay of Fundy is important because some parasites affect fish health and population biology.

Parasites can cause hosts to use energy on resistance rather than on growth, survival, or reproduction. Fish populations in Minas Basin, and the Bay of Fundy, Canada, in general, are important economically to local communities. Although sturgeons of these localities have received much attention (Scott and Scott, 1988), their ectoparasites are poorly known (Hogans, 1985; Hogans et al., 1993). Macroectoparasites of Atlantic sturgeon, *Acipenser oxyrinchus* Mitchill, have been examined in the Saint John River, a tributary of the Bay of Fundy (Appy and Dadswell, 1978, 1981), but they are unstudied in marine waters of Canada.

Acipenser oxyrinchus occurs off the east coast of North America, from Labrador to the Gulf of Mexico (Dadswell, 2006). They are the largest anadromous fish, with major spawning populations in the St. Lawrence River, Quebec, and the Saint John River, New Brunswick, Canada (Dadswell, 2006). In the summer, they aggregate in Minas Basin and feed in intertidal and subtidal localities (Wehrell et al., 2008).

Appy and Dadswell (1978, 1981) identified 4 macroectoparasites of *A. oxyrinchus* in the Saint John River estuary; i.e., *Nitzschia sturionis* (Monogenea) and *Dichelesthium oblongum* (Copepoda) within the gill cavity, *Argulus alosa* (Branchiura) on the integument, and *Calliobdella vivida* (Hirudinea) at several body sites. In marine environments near the Hudson River, Fast et al. (2009) found that 30% of *A. oxyrinchus* were infested by *Caligus elongatus* (Copepoda), 70% were infested by *N. sturionis*, and 93% carried *D. oblongum* within the gills or at fin bases. *Dichelesthium oblongum* is found exclusively on sturgeon species, and can decrease osmotic competence and reduce immunocompetence (Fast et al., 2009). Infestations of *D. oblongum* are associated with macroscopic lesions and increased blood serum ion concentrations, similar to what occurs in salmon suffering from severe sea louse infestations (Costello, 2006). A decrease in osmotic competence and lower bicarbonate concentrations, implying metabolic acidosis, indicate that parasitism negatively impacts the health of *A. oxyrinchus*. These changes may reduce fish growth, survival, and fecundity (Bakke and Harris, 2004). Parasites have been responsible for past declines in other sturgeon species. For example, a widespread infestation of *N. sturionis* led

to a steep decline in fringebarbel sturgeon, *Acipenser nudiventris* Lovetsky, populations in the Aral Sea in 1935 (Bauer et al., 2002).

Count data follow a Poisson error distribution, but many ecological data sets are further complicated by extra-Poisson variation referred to as overdispersion (overdispersion occurs when variance is significantly greater than the mean) that follow a negative binomial distribution, a modification of the Poisson distribution (White and Bennetts, 1996; Long, 1997; Nødtvedt et al., 2002). Poisson-distributed data with more zeros than expected are said to be zero-inflated and generally have additional overdispersion best accounted for by zero-inflated negative binomial (ZINB) models (Long, 1997; Warton, 2005). Zero-inflated models determine (1) the probability that a zero is a true zero (parasites available, but none acquired by the host; or parasites were present, but do not saturate entire habitat) or a false zero (no parasites available during survey period, or parasites not detected); and (2) if it is a true zero, how to model it correctly (Martin et al., 2005). ZINB models properly address the probability of a zero count where both negative binomial and logistic processes are working (Nødtvedt et al., 2002). Because parasite abundances follow negative binomial distributions (e.g., Nødtvedt et al., 2002; Denwood et al., 2008; Ziadinov et al., 2010) and ZINB models have successfully analyzed zero-inflated count data in ecological data sets (Minami et al., 2007; Zuur et al., 2009), we chose Poisson-based modeling over inferior nongeneral linear model approaches (see Wilson and Grenfell, 1997). Analysis of count data requires a stepwise approach to determine first what levels of overdispersion, zero inflation, or both exist, and second, selection of a model that best describes relationships between response and explanatory variables.

We recorded the site and number of visible ectoparasites on *A. oxyrinchus* in Minas Basin to determine parasite attachment site prevalence through statistical modeling. Sturgeons were also evaluated for visible signs of infestation. Characterizing *A. oxyrinchus* macroectoparasites will increase our understanding of sturgeon biology, and potentially aid in management and conservation.

MATERIALS AND METHODS

Study localities

The Bay of Fundy is an embayment of the Atlantic Ocean situated between Maine and the provinces of Nova Scotia and New Brunswick.

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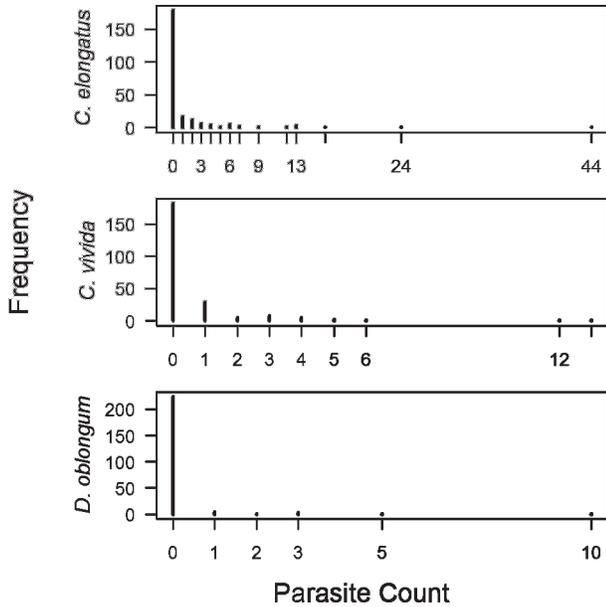


FIGURE 1. Frequency of parasite counts for *Caligus elongatus*, *Calliobdella vivida*, and *Dichelesthium oblongum* from 26 sturgeon × 9 body locations (total n = 234).

Minas Basin is connected to the inner Bay of Fundy by the Minas Channel and penetrates into northwest-central Nova Scotia. Most of the basin is less than 25 m deep with a mean low water depth of 14.6 m and a mean high water depth of 20.9 m (Bousfield and Leim, 1958). At low tide, mud and sand flats can be 1–3 km wide; Atlantic sturgeon and other fishes come to these habitats to forage at high tide (Bleakney and McAllister, 1973). Tidal currents range between 3 and 6 m/sec and are driven by 2 clockwise gyres, one offshore of Five Islands, and a stronger one in the Southern Bight (Rulifson et al., 2008).

Sturgeons (*Acipenser oxyrinchus*) were collected from 2 commercial intertidal fish weirs in Minas Basin in the Bay of Fundy, Canada, i.e., Five Islands (45.394°N, 64.099°W) and Walton (45.232°N, 66.025°W), Nova Scotia. Salinity at each weir locality is historically near 30 ppt (Bousfield and Leim, 1958) but the Walton weir is located near shore and may receive freshwater input from Walton River, additionally lowering salinity during collections that occur at low tide. Fishing weirs were V shaped, with the apex furthest from shore and the wings facing the shore (Gordon, 1993). Notted fencing was stretched between wooden stakes approximately 2–3 m tall, and brush (usually spruce), boulders, and sandbags lined the base of the fence. A pool at the apex of the V of each weir retained water at low tide from which fish were collected and examined.

Parasite collection

The Five Islands weir was visited 39 times during every low tide between 24 May 2009 and 12 June 2009. The Walton weir was visited on 13 May, 20 May, and 78 times (low tides) between 15 June and 5 August 2009. Weirs were visited for 30–120 min during each low tide. Each sturgeon’s posterior was lifted into the air while the sturgeon was still within the pool. Parasites on the sturgeon’s ventral side were viewed and counted prior to the sturgeon’s extraction from the water, because extraction may have caused parasite removal in this site. Large sturgeons were removed from weir pools by tightening a polyester rope lasso around the caudal peduncle and hauling them ashore. The caudal fin, dorsal fin, dorsal side (area above ventral lateral scutes), ventral lateral side (the area below the ventral lateral scutes and above the ventral scutes), ventral side, pelvic fins, pectoral fins, anal fin, and the gills and gill chamber were examined for parasites. Parasites from external body sites and gills were collected with tweezers and preserved in 70% ethanol. The identity and number of parasites from each site for each host were recorded, along with the mass, total length, and fork length of the host. Sturgeons were then released into the catch pool or receding waters. Handling of fish was governed by

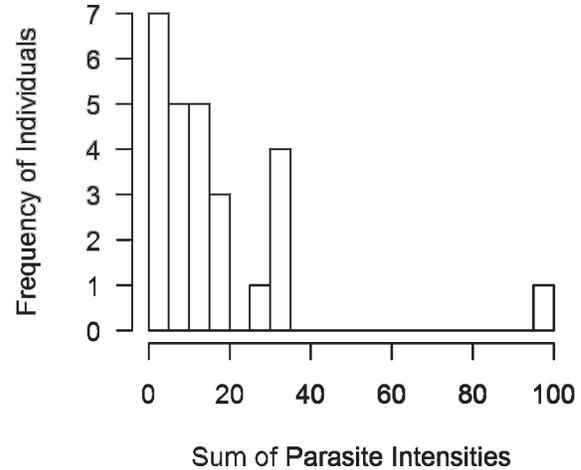


FIGURE 2. Frequency distribution of pooled parasite intensity for *Acipenser oxyrinchus* surveyed from Five Islands and Walton.

protocols approved by the Acadia Animal Care Committee that operates under the guidelines of the Canadian Council on Animal Care.

Model fitting and analysis

Parasite count data followed a Poisson distribution (Fig. 1) with a large number of zeros. Therefore, a ZINB model following Zuur et al. (2009) was used to test for differences among body sites for both *C. elongatus* and *C. vivida*. Observation and fitted count distributions were visualized, and all analyses were completed with the use of R version 2.81 (R Development Core Team, 2008). Model selection was done with likelihood ratio tests in package lmtest (Zeileis and Hothorn, 2002) and Akaike Information Criteria (AIC) values. ZINB models were created with the use of package pscl (Zeileis et al., 2008). Poisson, quasi-Poisson, and zero-inflated Poisson (ZIP) models were overdispersed and had AIC values considerably greater than ZINB models. Fork length was used as a model offset to account for changes in fin and body site surface area. Body site surface areas scale with fork length and, thus, fork length provides a surrogate measure of surface area. Therefore, the fork-length offset is used as a spatial “rate,” just as time is commonly employed to scale counts to counts per unit time, i.e., temporal rates, to account for exposure (Lee et al., 2001; Zuur et al., 2009). In cases where no parasites were found on a particular body site for all sturgeons, those body sites were excluded from modeling because their model estimates and associated standard errors were nonsensical when included. Their exclusion did not change model estimates, standard errors, or P values for remaining body-site comparisons. Differences among body sites were compared with general linear hypothesis tests using glht within package multcomp (Hothorn et al., 2008) with a familywise error rate of 0.05. Catch locality (Walton or Five Islands) was also included as a factor and when not significant, locality data were pooled. Values are reported as means ± standard deviations (SD) unless otherwise noted.

RESULTS

Ten sturgeons were caught at Five Islands and 16 at Walton, with mean fork length of 140 ± 31 cm and mean weight of 17 ± 10 kg. All sturgeons were infested by at least 1 parasite in at least 1 body site with the majority having <20 macroectoparasites (Fig. 2). Overall, 85% of sturgeons were infested by *C. elongatus*, 81% by *C. vivida*, and 65% had both; all of the sturgeons had at least 1 of these species. Three other macroectoparasites were found, but there were fewer of these and they were found on relatively few sturgeons. Prevalence of *D. oblongum* was 31%, with a total of 30 parasites retrieved, and 57% on gills, 27% on pectoral fins, 10% on dorsal fins, and 6% on caudal fins. For *N. sturionis*, prevalence was 12%, with a total of 4 parasites retrieved,

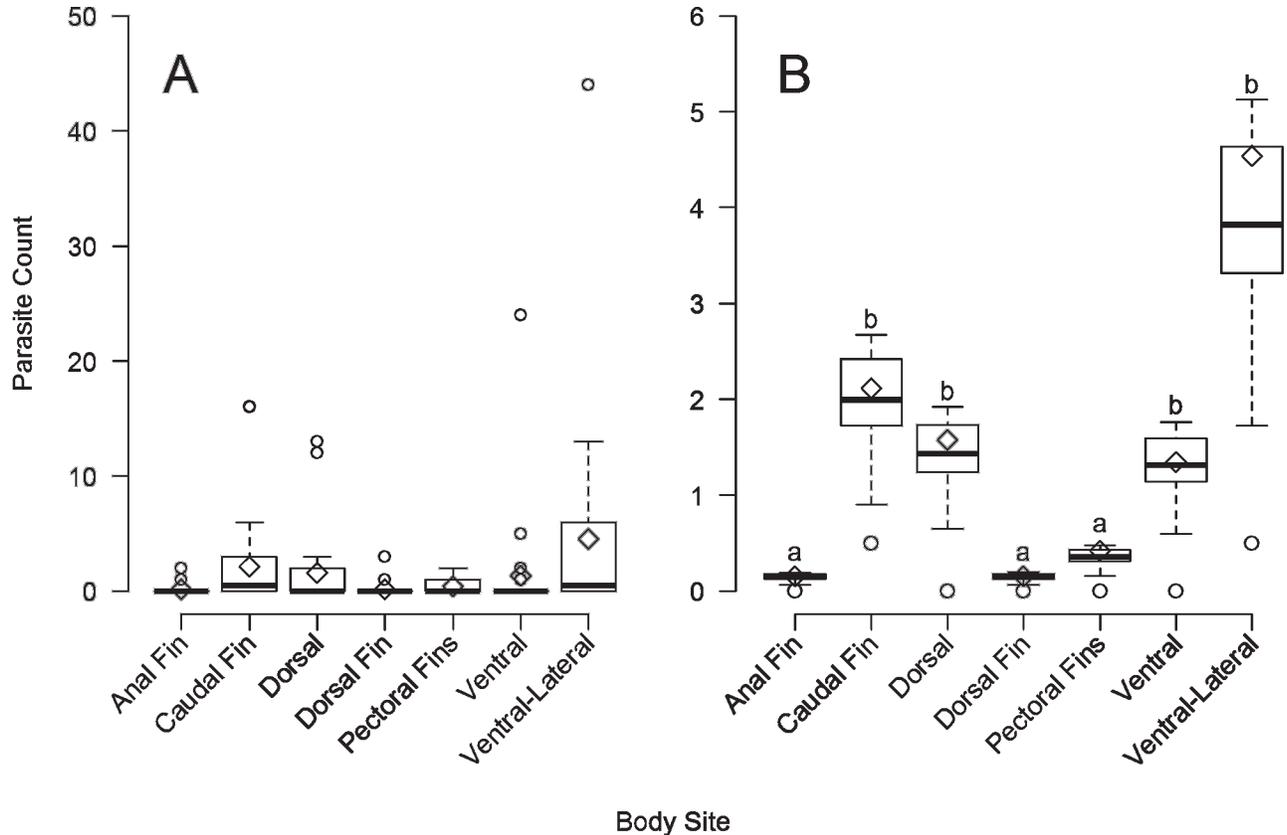


FIGURE 3. Observed (A) and zero-inflated negative binomial model of expected (B) *Caligus elongatus* counts on *Acipenser oxyrinchus*. For expected counts, body sites were pooled across 2 capture localities, and fish size (fork length) was accounted for within the model. In (B), mean counts (diamonds) and median counts (circles) are included from the data (A) for comparison. Circles in (A) are outliers. Body sites in (B) that share letters did not have significantly different parasite counts.

and 75% on ventral-lateral sites, and 25% on gills. For *A. stizostethii*, prevalence was 8%, with a total of 3 parasites retrieved, 33% on caudal fins and 33% on dorsal and 33% on ventral body sites. A total of 429 individual parasites was collected from all sturgeons.

Caligus elongatus were found only on flat and exposed body surfaces. Infestations were not associated with visible signs of damage typical of this species' feeding behavior (Costello, 2006). Abundances ranged from 0 to 85 parasites per sturgeon (mean = 10 ± 17). Because counts of *C. elongatus* for both gills and pelvic fins were zero for all sturgeons examined, these body sites were not included in model fitting. Catch locality (Five Islands or Walton) did not significantly affect the model fit ($P = 0.27$), so locality data were pooled. Median counts of *C. elongatus* were all 0 except for the caudal fin and ventral-lateral body sites, whereas mean counts were higher, indicating that data were highly skewed toward low counts (Fig. 3A). After accounting for body size, predicted numbers of *C. elongatus* were significantly lower on anal, dorsal, and pectoral fins, and higher for caudal fins and for nonfin sites including dorsal, ventral, and ventral-lateral sites (Fig. 3B, Table I). Anal, dorsal, and pectoral fins had no more than 3 parasites on any individual sturgeon, whereas caudal fins and nonfin sites had wider count ranges, with comparatively high counts for some individuals. Ours are the first records of *C. elongatus* on Atlantic sturgeons in the Bay of Fundy region.

Calliobdella vivida were also only found on flat and exposed surfaces of sturgeons, but there were no observable signs of

damage associated with their attachment. Abundances ranged from 0 to 19 parasites per sturgeon (mean = 5 ± 6). Because *C. vivida* counts for gills were 0 for all sturgeons examined, this body site was not included in the model fitting. Catch locality did not significantly affect model fit ($P = 0.26$), so localities were pooled. As was the case for *C. elongatus*, data were skewed toward low counts (Fig. 4A). After accounting for body size, predicted numbers of *C. vivida* were significantly lower for anal and dorsal fins and ventral body sites (these 3 sites were not significantly different from each other), compared with pectoral and pelvic fins, and dorsal and ventral-lateral body sites (these 4 sites were not significantly different from each other) with caudal fins not significantly different from anal and dorsal fins, and dorsal, ventral and ventral-lateral body sites (Fig. 4B, Table II).

TABLE I. Differences (P) between pairs of body sites from a zero-inflated negative binomial model for *Caligus elongatus*; anal fin (AF), caudal fin and peduncle (CF), dorsal body (D), dorsal fin (DF), pectoral fins (PECF), ventral body (V), and ventral-lateral body (VL).

Body site	AF	CF	D	DF	PECF	V
CF	<0.001					
D	<0.01	0.52				
DF	0.98	<0.001	0.002			
PECF	0.23	<0.01	0.02	0.25		
V	<0.01	0.46	0.88	0.003	0.04	
VL	<0.001	0.18	0.05	<0.001	<0.001	0.06

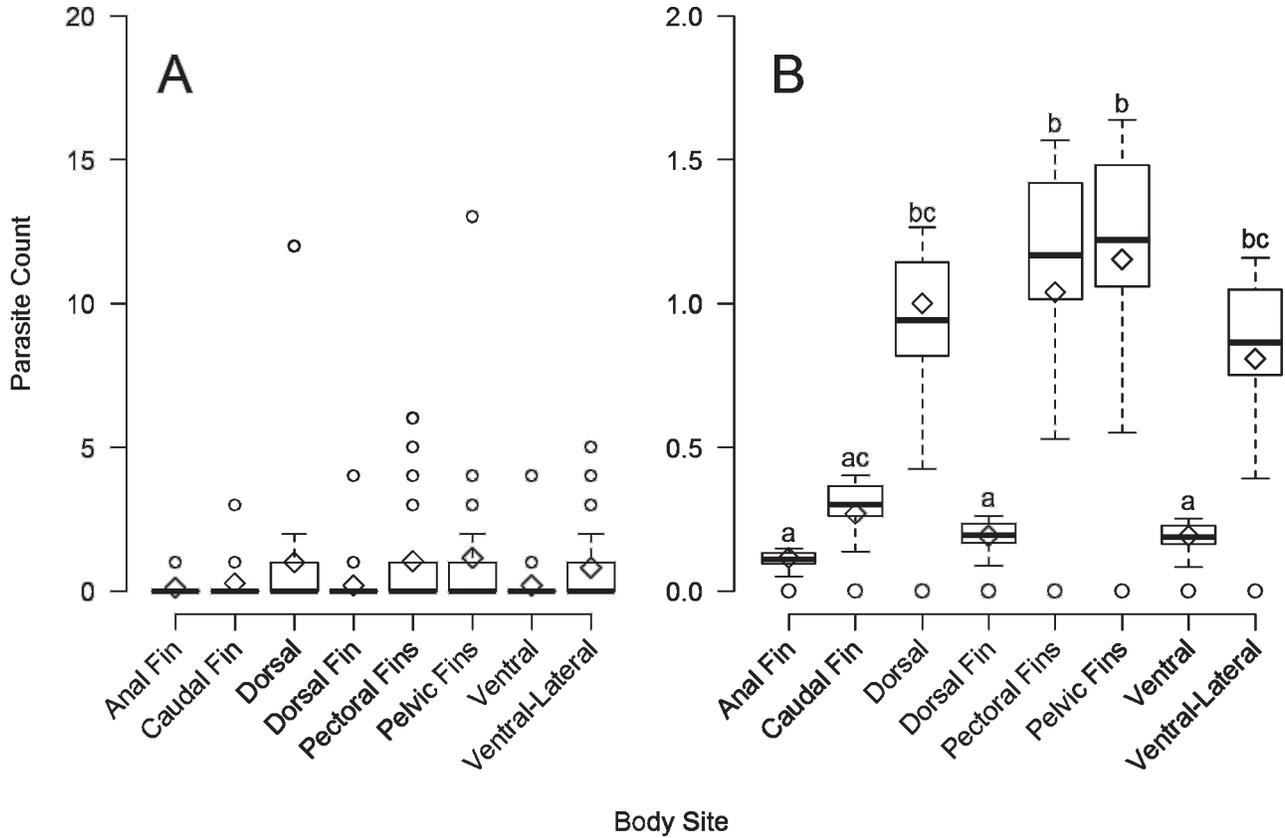


FIGURE 4. Observed (A) and zero-inflated negative binomial model of expected (B) *Calliobdella vivida* counts on *Acipenser oxyrinchus*. For expected counts, body sites were pooled across 2 capture localities and fish size (fork length) was accounted for within the model. In (B), mean counts (diamonds) and median counts (circles) are included from the data (A) for comparison. Circles in (A) are outliers. Body sites in (B) that share letters did not have significantly different parasite counts.

Remaining parasite intensities were too low on individual sturgeon body sites to make statistical comparisons meaningful or to fit models. All *D. oblongum* were found on gills, or burrowed into soft tissue connecting dorsal, anal, and pectoral fins to the trunk of the body (Fig. 5). Overall, 77% of *D. oblongum* parasites in soft tissue and gills were male. Females, all of which were gravid, were only observed in gills, but the majority (58.5%) of parasites in gills was male. Attachment sites were associated with hemorrhaging lesions, which often extended through the underlying musculature, or were associated with loss of epithelium and with reduced pigmentation of tissue surrounding damaged sites.

TABLE II. Differences (*P*) between pairs of body sites from a zero-inflated negative binomial model for *Calliobdella vivida*; anal fin (AF), caudal fin and peduncle (CF), dorsal body (D), dorsal fin (DF), pectoral fins (PECF), pelvic fins (PELF), ventral body (V), and ventral-lateral body (VL).

Body site	AF	CF	D	DF	PECF	PELF	V
CF	0.24						
D	0.01	0.09					
DF	0.53	0.58	0.03				
PECF	<0.01	0.04	0.71	0.01			
PELF	<0.01	0.04	0.66	0.01	0.94		
V	0.55	0.55	0.02	0.97	0.01	0.01	
VL	0.01	0.12	0.89	0.04	0.61	0.56	0.03

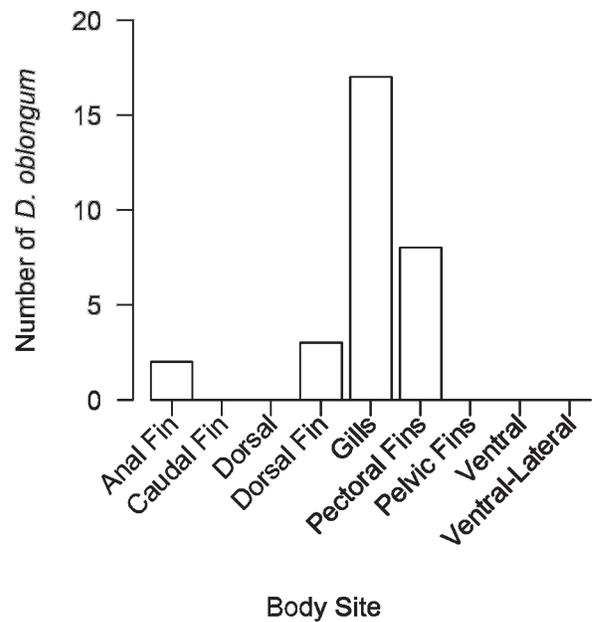


FIGURE 5. Distribution of *Dichelesthium oblongum* on *Acipenser oxyrinchus* across 9 body sites: anal fin, caudal fin and peduncle, dorsal body, dorsal fin, gills, pectoral fins, pelvic fins, ventral body, and ventral-lateral body.

Abundances ranged from 0 to 18 individuals per sturgeon, with 60% ($n = 18$) of parasites on a single sturgeon (no more than 3 parasites were found on any other sturgeon).

Only 3 *N. sturionis* were found on 2 sturgeons in mouth furrows and, on 1 occasion, on a gill lamella; all 3 sturgeons were caught at Five Islands. In contrast, only 1 *A. stizostethii* was found on a caudal fin, 1 on a ventral side, and 1 on a dorsal body site, and only at Walton. To our knowledge *A. stizostethii* is a new host record for *A. oxyrinchus* (Kabata, 1988). Attachment site was not associated with any visible signs of damage for either parasite species.

DISCUSSION

Caligus elongatus on the caudal fin and *C. vivida* on the pectoral and pelvic fins had higher mean densities than on all other body sites, but parasite densities based on abundance skew the actual relationship due to many zeros and overdispersion. Zeros can be generated from at least 4 sources: (1) sturgeons were not in contact with parasites, and therefore acquired none; (2) there were no parasites to acquire within the habitats occupied by sturgeons; (3) parasites dropped off or were eliminated by the host before or following arrival in the weir; or (4) parasites were not detected by our sampling (see Martin et al., 2005, for a discussion). Many zeros skew data distributions and create room for misinterpretation of results. The zero-inflated Poisson-based models account for zeros and aggregated data, and attempt to form reasonable distributions upon which interpretation can be made with increased confidence. The benefits of this method outweigh other methods, such as normalizing data with log transformations that are prone to Type I errors (Wilson et al., 1996; Wilson and Grenfell, 1997). Interpreting measures of parasite infestations such as abundance or parasite density appear logical and representative, but these measures do not adequately account for zeros. In this case, parasite-density analysis does not reveal that dorsal, ventral, or ventral-lateral body sites are not significantly different than caudal fins for *C. elongatus*, nor does it reveal that dorsal and ventral-lateral areas may be just as important when interpreting *C. vivida* attachment sites. Zero-inflated negative binomial models improve insights and robustness of our interpretation of results.

Although parasites identified in this study are common to marine and estuarine fishes, 2 records are firsts for the Bay of Fundy. *Caligus elongatus* is a parasite of at least 80 species of fishes (McDonald and Margolis, 1995; Johnson et al., 1996; Costello, 2006; Oines et al., 2006) and has been previously reported on American shad in the Saint John River (Hogans et al., 1993). This parasite has rasping mouthparts best adapted to graze host flesh and remove mucus, skin, and underlying tissues. Host blood is not an important part of their diet, although blood loss may result from high-intensity infestations. The parasite's streamlined shape allows water to flow easily over its body, likely reducing the energy required to remain attached (Tucker et al., 2002; Costello, 2006). This parasite's distribution on *A. oxyrinchus* may be a result of the feeding mode of *C. elongatus*. Their higher densities on flat, exposed body surfaces and caudal fins may reflect their preference for fleshier tissues that are somewhat protected from currents. The distribution pattern of *C. elongatus* on *A. oxyrinchus* was similar to that of *Lepeophtheirus salmonis* (Copepoda), a parasite with a similar body type to *C.*

elongatus, on Atlantic salmon *Salmo salar* (Hogans and Trudeau, 1989; Tucker et al., 2002). *Lepeophtheirus salmonis* was found mostly on the fins, particularly on caudal and dorsal fins. Tucker et al. (2002) suggested that their distribution may be due to hydrodynamic microhabitat selection. Fast et al. (2009) observed no external signs of damage associated with *C. elongatus* feeding and, similarly, were always found on lateral and partially protected surfaces. No osmotic imbalances were detected associated with *C. elongatus* feeding (Fast et al., 2009); however, *C. elongatus* intensities on *A. oxyrinchus* in Minas Basin were greater than those observed on Hudson River fishes.

The fish leech *C. vivida* has a wide range of host species, although it appears to prefer pleuronectiform and clupeid fishes (Sawyer and Hammond, 1973; Appy and Dadswell, 1978; Burreson, 2006). These highly mobile blood feeders were attached to the ventral-lateral and dorsal body sites, and pelvic and pectoral fins on *A. oxyrinchus*. The pectoral and pelvic fins are covered in thinner skin than that on the majority of the body and, unlike the caudal fin, these fins have a richer blood supply (M. J. Dadswell, pers. obs.). Leeches may have more success feeding in these sites. However, high densities of *C. vivida* on the trunk suggest that hydrodynamics may be a better explanation for its distribution pattern (see Tucker et al., 2002). It is interesting that *C. vivida* was not found associated with the rich blood supply in the gills of *A. oxyrinchus*, especially given that these parasites are often found within the gills of other fish species (Sawyer and Hammond, 1973). Given the low gill intensities of *N. sturionis* and *D. oblongum*, it is unlikely that the leech was outcompeted for gill space. It is possible that *C. vivida* enters the gills via the mouth of other hosts, but a sturgeon's ventral mouth may be more difficult to enter and navigate to reach the gills. It is also possible that *A. oxyrinchus* were newly infested and that the leeches had not yet had an opportunity to attach to the gills, or that because sturgeons exhaust large amounts of sediment through their gills when feeding, the unprotected skin of leeches is subjected to substantial abrasion.

Dichelesthium oblongum feeds on blood by burrowing into its fish host, and it lacks a streamlined body (Fast et al., 2009). Its shape facilitates burrowing into flesh. Similarly, *D. oblongum* are found on gills and tissues beneath the epidermal layers of sturgeon which are sites with a richer blood supply in comparison to other external surfaces. Tissues connecting fins to the body, and the gill filaments themselves, are also considerably thinner and more accessible than the skin surrounding the trunk of the body, and easier to penetrate by this parasite. The distribution pattern of *D. oblongum* on *A. oxyrinchus* in Minas Basin was similar to that reported on sturgeons from other localities. This parasite also infests gills of European acipenserids (Bauer et al., 2002; Fast et al., 2009). *Dichelesthium oblongum* on *A. oxyrinchus* captured near the Hudson River were most often attached to the gills and less often attached to the mouth and the base of the fins, and prevalence was 3.4 times greater than what we observed in Minas Basin (Fast et al., 2009). Similar to Fast et al. (2009), the majority (67%) of copepods in the gills were gravid females, whereas none was observed at other sites. Fast et al. (2009) attributed the sex-biased density of females on the gills to greater accessibility to blood nutrients required by females to produce eggs.

Nitzschia sturionis were not associated with visible gill damage, but were at lower intensities than previously described on other

sturgeon species. Bauer et al. (2002) concluded that 300–400 *N. sturionis* per *A. nudiventris* consumed 150–200 ml of blood in 1 day and intensities of 600 parasites have been found. Fast et al. (2009) found 70% of *A. oxyrinchus* were infested with *N. sturionis* and, in some cases, the infestation caused sloughing of skin and hemorrhaging on the mouth and in the gills.

Argulus stizostethii has been recorded on a number of freshwater fish species in eastern Canada, including lake sturgeon, *Acipenser fulvescens* Rafinesque (Kabata, 1988). It is possible that *A. oxyrinchus* carrying *A. stizostethii* recently traveled from a nearby river, and parasites remained attached in the Walton weir because of reduced salinity in this locality, or parasites may have been carried by another host species and transferred. It may also be that this parasite has greater tolerance for estuarine conditions than is currently suspected.

Many stocks of *A. oxyrinchus* in the United States have failed to recover substantially following years of unregulated harvesting, water pollution, damming of spawning rivers, and degradation of habitat, and the fishery in the United States is now closed (Smith and Clugston, 1997; Grunwald et al., 2008). Canadian sturgeons do not appear to be endangered or threatened, although some populations may become extirpated because they are no longer able to access spawning rivers (Dadswell, 2006). For example, in Nova Scotia, a causeway continues to impede spawning in the Avon River, and the tidal power generating station in the Annapolis River may significantly increase mortality of migrating adults, potentially contributing to population declines (Dadswell and Rulifson, 1994).

Differences in parasite assemblages of *A. oxyrinchus* between Hudson River localities and Minas Basin may be explained by differences in salinity. Salinity in Minas Basin is reduced compared to the open sea because of high freshwater inflow (about 20 rivers) and a long distance from the open Atlantic Ocean (about 200 km). Fast et al. (2009) surveyed open ocean habitat, which probably had a salinity of 33 to 35 ppt. The estuarine condition of Minas Basin may also explain significantly lower intensities of *N. sturionis* and *D. oblongum*, which are marine parasites and would be expected to be more abundant in higher salinity (Beverley-Burton, 1984; Kabata, 1988).

The future of sturgeon parasite research would be advanced by determining if there is a link between the health of Canadian sturgeon populations and parasite intensities. Fast et al. (2009) determined that *D. oblongum* infestations could be associated with decreased osmotic competence in sturgeon as a result of the combined impact of elevated cortisol levels due to stress, large lesions, breached epithelia, and decreased Na^+/K^+ -ATPase function. Fast et al. (2009) found that the parasite impact may increase in regions with higher levels of water pollution, or where changes in salinity increase parasite densities. Moreover, *A. oxyrinchus* are highly migratory, and these factors will likely be important in future studies.

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