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DESCRIPTION OF THE MALE FROM STRIPED BASS, MORONE SAXATILIS,
AND IMPLICATIONS FOR RE-INTRODUCTION OF AN EXTIRPATED
POPULATION**

ABSTRACT: *Philometra rubra* (Leidy, 1856) is a pathogenic parasitic nematode infecting striped bass [*Morone saxatilis* (Walbaum, 1792)] in eastern North America. Identification of philometrids is difficult, male *P. rubra* have never been found and transmission is poorly understood. To re-establish the “Extirpated” striped bass population in the St. Lawrence Estuary (SLE), Quebec young-of-the-year (YOY) striped bass from the Miramichi River, New Brunswick were collected and released into the SLE. The present study was undertaken to find *Philometra* in striped bass from the Miramichi River, for identification, description, and examine transmission and lesions. *Philometra rubra* was identified in 100% of 32 YOY (intensity=26 to 125) and 100% of nine 1-year-old (intensity=4 to 25 in five striped bass) striped bass collected in summer 2011. The swim bladder and body cavity were sites of infection in YOY with no tissue response observed histopathologically. Gravid *P. rubra* females occurred in the body cavity and swim bladder with males predominately in the latter site. Males were short-lived being absent in 1-year-old bass. Adult male and adult female *P. rubra* are described. Males of *P. rubra* can be distinguished from other described species based on spicule, gubernaculum and body length measurements. This parasite may have implications for the re-introduction program and conservation of striped bass in the SLE and in other populations.

Keywords: *Philometra rubra*, striped bass, *Morone saxatilis*, re-introduction, conservation

INTRODUCTION

The striped bass [*Morone saxatilis* (Walbaum, 1792)] is native to the east coast of North America, living in fresh, estuarine, and inshore marine coastal waters. They have been introduced to the Pacific coast and elsewhere in the world as they are highly valued in commercial and, especially, recreational fisheries (Scott and Scott 1988). In Canada there were five native populations which spawned in the St. Lawrence Estuary (SLE) in Quebec, the northwest Miramichi and Saint John rivers in New Brunswick and the Shubenacadie and Annapolis rivers in Nova Scotia. Only the striped bass populations spawning in the Miramichi and Shubenacadie rivers remain extant (Robitaille et al. 2011). Striped bass spawning in the Miramichi River are known as the southern Gulf of St. Lawrence (GSL) population. The commercial and recreational catches of the SLE striped bass population collapsed during the 1950's and 1960's which was likely due to overexploitation and habitat destruction (Robitaille 2004). The SLE striped bass population was designated as "Extirpated" in 1996 (COSEWIC 2004).

An action plan to re-establish the striped bass population in the SLE was developed using striped bass from the Miramichi River. Health assessments were performed on less than 200 striped bass from the Miramichi River and the risk of introducing a pathogen or parasite into the SLE was considered low (Robitaille, 2000). Striped bass (young-of-the-year, Age<1) from the Miramichi River were captured in 1999 and in each year from 2002, 2003, 2005 to 2007 and transported to a Quebec fish hatchery. According to Douglas and Chaput (2011a), the majority of young-of-the-year (YOY) striped bass from the Miramichi River were released directly into the SLE from 1999 to 2005. From 2002 to 2005 almost 3,500 striped bass (Age<1 to 6) were released into the SLE (Robitaille et al. 2011). After 2005, only larvae produced in the Quebec fish hatchery from Miramichi River brood stock were released into

the SLE, partly due to the detection of viral hemorrhagic septicemia virus in striped bass from the Miramichi River (Robitaille et al. 2011).

Although unidentified *Philometra* were found in striped bass from the Miramichi River during health assessments (Robitaille 2000), it was not until the winter of 2006 that >60% of YOY striped bass, collected from the Miramichi River died in the Quebec hatchery, due to *Philometra* sp. infection (Séguin et al. 2011). Retrospective analysis of archived museum specimens of striped bass (Age<1) collected from the SLE in October 1944, revealed gravid female *Philometra* sp. in the body cavity but identification to species was not possible as males were not found (L.N. Measures, unpublished data; Séguin et al. 2011). The identification of philometrids is difficult (Moravec and de Buron 2013). Nevertheless, *Philometra rubra* (Leidy, 1856) was considered likely present in SLE striped bass prior to extirpation (Séguin et al. 2011).

Philometra rubra was inadequately described by Leidy (1856) from a single young female specimen collected from the abdominal cavity of *M. saxatilis* from an unknown locality and its type specimen was subsequently lost (Walton 1928). The female morphology of this species was described only recently by Moravec et al. (2009, 2013) based on specimens newly collected from wild *M. saxatilis* in South Carolina, USA and those from *M. saxatilis* held in the Quebec fish hatchery (YOY originally from the Miramichi River).

Many philometrids are highly pathogenic including those parasitizing the circulatory system, eyes, muscles, skin and subcutaneous tissues, gonads, swim bladder and body cavity of their fish hosts (Moravec 2006; Moravec and de Buron 2013). Lesions due to infection with *Philometra rubra* in striped bass include visceral edema and adhesions, peritonitis and granulomatous encapsulation of degenerate worms in visceral organs (Paperna and Zwerner 1976; Séguin et al. 2011). Extensive granulomatous peritonitis and marked pyogranulomatous inflammation directed to larval and degenerate *Philometra* sp. was reported in massively

infected YOY striped bass that died in the above mentioned Quebec fish hatchery (Séguin et al. 2011). Paperna and Zwerner (1976) suggested that mortality of striped bass may occur in heavily infected fish at 5 to 6 months of age.

Given that *P. rubra* in striped bass is pathogenic, particularly in YOY, and that unidentified *Philometra* in striped bass from the Miramichi River causes mortality of infected YOY under fish hatchery conditions, it is important to identify this parasitic nematode by finding and describing the male. This has potential implications for the success of the re-introduction program and conservation of striped bass in the SLE.

It is hypothesized that striped bass are infected with *Philometra* early in life (spring or early summer) and that males are short-lived. The objectives of the present study are to follow the recruitment of *Philometra* in YOY striped bass from the Miramichi River, and with careful dissection of collected fish, to locate male *Philometra* specimens for specific identification and description so the transmission and pathologic lesions due to this parasitic nematode can be studied.

MATERIALS AND METHODS

Striped bass were collected in 2011 under Fisheries and Oceans Canada Licence No. SG-NBT-11-092 by beach seine or trapnet in the Northwest and Southwest Miramichi rivers, New Brunswick. YOY fish (Age<1) were collected by beach seine from three locations – East Point (47.07474 N, 65.33693 W) ($n=10$) on July 28, 2011 and Bay du Vin ($n=12$) (47.05630 N, 65.13701 W) and Hackett's Beach (46.95890 N, 65.68404 W) ($n=10$) on August 5, 2011. Nine striped bass (Age=1+) were collected from an index trapnet on the Southwest Miramichi River at Millerton (46.90106 N, 65.63359 W) on July 10, 2011. Fish were individually bagged, frozen within 4 to 7 hours and shipped to the Maurice Lamontagne Institute for examination. Fish were thawed at room temperature, total length (TL) (cm) and weight (g) recorded, and fish were dissected in 0.65% saline in a Petri dish using a dissecting microscope

and fine forceps. The body (=coelomic) cavity was opened, examined, and visceral organs separated. The abdominal peritoneum was also removed. The swim bladder and gastrointestinal tract were opened. After examination of tissues in saline, tissues were then pressed between glass plates and examined with a dissecting microscope (x400). Nematodes were transferred by pipette to saline and fixed with hot 10% glycerine alcohol (1 part glycerine, 9 parts 70% alcohol). Number (intensity), mean intensity and prevalence of nematodes in fish were determined. Nematodes were identified by sex and stage of development. Some specimens were fixed in 10% buffered formalin for scanning electron microscopy. Stomach contents of 27 YOY were preserved in 70% alcohol to determine diet. One whole YOY was fixed in 10% buffered formalin for histopathology. Sequential transverse sections, 5 mm in thickness, of the fixed YOY were embedded in paraffin, sectioned at 5 μ m, stained with hematoxylin-phloxine-saffron, and examined by light microscopy.

For light microscopy (LM), nematodes were cleared with glycerine. Drawings were made with the aid of a Zeiss drawing attachment (Carl Zeiss, Jena, Germany). After examination, the specimens were stored in 70% ethanol. Specimens examined via scanning electron microscopy (SEM) were postfixated in 1% osmium tetroxide (in phosphate buffer), dehydrated through a graded acetone series, critical-point-dried and sputter-coated with gold; they were examined using a JEOL JSM-7401F scanning electron microscope (JEOL, Tokyo, Japan) at an accelerating voltage of 4 kV, GB low mode. All measurements are in micrometers unless otherwise indicated.

RESULTS

Examination of fish

Philometra rubra was identified in 100% of 32 YOY and nine 1-year-old striped bass from all four sampled locations in the Miramichi River in 2011. Intensity of infection in five

1-year-old bass [mean TL (range) 18.5 (16.9-19.5) cm, mean weight (range) 61.4 (43.7-73.4) g] from Millerton ranged from 4 to 25. Mean length (range) of eight adult *P. rubra* females was 6.9 (3.1-11.9) cm, some were gravid, spent or degenerate. Intensity was not determined in the four other 1-year-old bass as many worms were degenerate and fragmented.

Overall mean intensity $\pm$ SD (range) of infection in 32 YOY [mean TL 4.7 (3.5-6.4) cm, mean weight 1.1 (0.4-2.7) g] was 63.8 $\pm$ 27.7 (26-125), intensity of infection in 2 YOY was not determined as specimens were fragmented. There was no significant difference in mean intensity of *P. rubra* in YOY from Hackett's Beach (average salinity=0.42 ppt), East Point (average salinity=12.8 ppt) or Bay du Vin (average salinity=20.2 ppt) [intensity data was normal (Shapiro-Wilk), with equal variance ($p=0.859$), one-way ANOVA at $\alpha=0.05$, $P=0.065$]. All specimens of *P. rubra* were fifth-stage adults. Male *P. rubra* were present in all YOY but absent in 1-year-old bass. Overall, the sex ratio of adult male to adult female *P. rubra* in 30 YOY was 1:1.5 with a higher ratio (1:2.2) in YOY from East Point collected on July 28 compared to YOY from Bay du Vin (1:1.1) and Hackett's Beach (1:1.2) collected on August 5th.

Philometra rubra (males and females) were found in the body cavity (often dorsally clustered near the vent) and in the swim bladder (often caudally, free in the lumen, sometimes associated with abundant mucoid material) and particularly in or under the serosa of the swim bladder. Large female specimens were more often found in the body cavity, a few degenerate worms were on the mesentery or in the body cavity. Some unfixed large adult females in the body cavity were red in colour. In most 1-year-old bass, *P. rubra*, many degenerate, were found in the body cavity and appeared surrounded by a host tissue reaction with numerous adhesions on abdominal organs.

Upon histopathologic examination of one YOY, up to 10 cross-sections of small nematodes were observed per transverse section. Large nematode cross-sections were free in

the coelomic cavity, and small nematode cross-sections were present in the coelomic cavity, the lumen of the swim bladder, and in the lateral musculature. These parasites were not associated with any visible host tissue reaction.

Stomach contents of 27 YOY striped bass included copepods (*Acartia* spp., 5/27 or 18%), *Mysis* spp. (6/27 or 22%), *Crangon septemspinosa* Say, 1818 (9/27 or 33%), gammaridean amphipods (9/27 or 33%), unidentified aquatic insects (2/27 or 7%) and polychaetes (1/27 or 4%). Copepods were found in YOY from Bay du Vin with an average salinity of 20.2 ppt, *Mysis* spp. and *Crangon septemspinosa* in YOY from East Point and Bay du Vin with average salinities of 12.8 and 20.2 ppt, respectively, and aquatic insects and amphipods in Hackett's Beach with an average salinity of 0.42 ppt.

Description

***Philometra rubra* (Leidy, 1856) Yamaguti, 1961** Figs. 1, 2

Syn.: *Filaria rubra* Leidy, 1856.

Adult Male (12 specimens; measurements of neotype in parentheses): Body filiform, whitish, 2.72–4.42 (3.43) mm long, maximum width at middle 42–54 (42); anterior part of body somewhat narrower than posterior part. Cuticle smooth. Cephalic extremity rounded. Maximum width/body length 1:60–98 (1:82); width of cephalic extremity 24–30 (27), that of posterior extremity 24–27 (27). Oral aperture small, circular, surrounded by 14 cephalic papillae arranged in 2 circles: external circle formed by 4 submedian pairs of papillae; internal circle by 4 submedian and 2 lateral papillae (Figs. 1B, 2A, 2B). Small lateral amphids just posterior to lateral papillae of internal circle (Figs. 1B, 2A, 2B). Esophagus 438–546 (546) long, maximum width 15–18 (15), forming 11–16 (16)% of body length, slightly inflated at anterior extremity; posterior part of muscular esophagus overlapped by well developed esophageal gland with large cell nucleus situated somewhat posterior to its middle (Fig. 1A); anterior esophageal inflation 21–27 (24) long, 12–15 (15) wide. Small ventriculus 6 (6) long,

9 (9) wide, present. Esophageal nucleus, nerve ring and excretory pore 282–384 (384), 132–168 (162) and 165–207 (195), respectively, from anterior extremity. Intestine narrow, straight. Testis extending anteriorly to extremity of esophagus, sometimes overlapping its base (Fig. 1A). Posterior extremity of body blunt, provided with broad U-shaped mound situated laterally and dorsally to cloacal aperture (Figs. 1G, 1H, 1J, 2C–E). Genital papillae, all located on caudal mound: 4 pairs of distinct adanal papillae (3 subventral and 1 lateral pairs; latter at level of last pair of subventrals) and 1 pair of subdorsal postanal papillae; small phasmids situated more laterally somewhat anterior to postanal papillae (Figs. 1J, 2C–E). Papillae indistinct by LM. Spicules short, slightly subequal, distinctly extended ventrally at posterior halves, with somewhat expanded proximal and sharply pointed distal tips (Figs. 1G, 1H, 1L, 2C–F); length of left spicule 66–78 (75), representing 1.6–2.2 (2.2)% of body length, of right spicule 63–75 (72). Length ratio of spicules 1:1.04–1.08 (1:1.04). Gubernaculum narrow, 60–75 (75) long, with anterior portion somewhat dorsally bent; length of anterior bent part 9–12 (12), representing 15–17 (16)% of entire gubernaculum length; distal tip of gubernaculum pointed, smooth, with distinct dorsal reflexed barb (Figs. 1G,K, 2C–F). Length ratio of gubernaculum and larger spicule 1:0.96–1.30 (1:1.00). Spicules and gubernaculum well sclerotized; spicules and gubernaculum yellow in color, anterior part of gubernaculum colourless. Tail 3–6 (3) long.

Adult gravid female (4 larvigerous specimens): Body of fixed specimens yellowish to brownish, with rounded anterior and somewhat bluntly conical posterior extremity. Posterior part of body somewhat narrower than anterior part. Cuticle slightly transversely striated. Body length 29.00–68.00 mm, maximum width 272–381, maximum width/body length ratio 1:107–178. Width of cephalic extremity 109–163, that of posterior extremity 122–150. Cephalic papillae small, indistinct when viewed laterally (Fig. 1F). Oral aperture small, dorsoventrally elongate, surrounded by 4 pairs of submedian cephalic papillae of external circle and 6 single

papillae (2 lateral and 4 submedian) of internal circle; amphids indistinct. Four dorso-lateral and ventro-lateral papillae of external circle distinctly larger than 4 dorso-dorsal and ventro-ventral external papillae. Esophagus including anterior bulbous inflation 1.46–1.99 mm long, representing 2–7% of body length; anterior bulbous inflation 66–109 long and 66–109 wide; maximum width of esophagus including esophageal gland 109–122. Esophageal gland large, opening into esophagus short distance posterior to nerve ring, with large cell nucleus situated somewhat posterior to its middle (Fig. 1F). Nerve ring and esophageal nucleus 231–299 and 884–1,061, respectively, from anterior extremity. Small ventriculus 24–33 long and 66–78 wide. Intestine ending blindly, its distal extremity narrow, attached by short ligament to body wall near caudal extremity; ligament 272–408 long. Vulva and anus atrophied. Ovaries narrow, long, forming coils near body extremities (Fig. 1F,1M). Uterus occupying most space of body, filled with numerous larvae 408–438 long and 15–18 wide, and developing embryos; uterus extending anteriorly nearly to level of nerve ring and posteriorly to level of intestinal ligament (Fig. 1F,M). Posterior extremity of female rounded in lateral view and rectangular in dorsoventral view, bearing 2 large lateral papilla-like caudal projections 12–24 high (Fig. 1M).

Adult subgravid female (2 larger ovigerous specimens; measurements of 1 additional specimen still with vulva and containing few immature embryos in parentheses): Body length 25.00–32.00 (14.10) mm, maximum width 272–299 (109); maximum width/length ratio 1:84–118 (1:129). Width of cephalic extremity 122 (95), that of posterior extremity 136–150 (95). Entire esophagus 1.93–2.12 (1.97) mm long and 95–109 (68) wide, representing 6–8 (14)% of body length. Anterior esophageal inflation 84–109 × 90–95 (82 × 68), ventriculus 24–27 × 60–69 (30 × 54). Nerve ring and esophageal nucleus 204–245 (204) and 898–1,210 (911), respectively, from anterior extremity. Intestinal ligament 231–313 (219) long. Anus atrophied. Vulva still present only in smallest specimen with small number of developing embryos, at

(9.59) mm from anterior extremity (i.e. at 68% of body length); in larger specimens vulva absent. Uterus of larger specimens filled with many developing embryos. Caudal projections 9–12 (12) high.

Adult non-gravid female (3 specimens): Body length 3.18–4.05 mm, maximum width 51–78; maximum width/length ratio 1:52–62. Width of anterior extremity 39–54, that of posterior extremity 39–57. Entire esophagus 857–952 long and 24–30 wide. Anterior esophageal inflation 30–36 × 24–30; ventriculus 6–12 × 21–27. Nerve ring and esophageal nucleus 102–144 and 503–558, respectively, from anterior extremity (Fig. 1E). Intestinal ligament 99–105 long. Anus atrophied. Vulva and reduced vagina present (Fig. 1C), former situated 2.14–2.79 from anterior extremity (at 67–70% of body length). Uterus empty. Caudal extremity rounded, with 2 lateral caudal projections 6 high (Fig. 1D, I).

Host: Striped bass *Morone saxatilis* (Walbaum, 1792) (type host) (Moronidae, Perciformes), of 3.5–6.4 cm TL. Reported also from the white bass *Morone americana* (Gmelin, 1788) by Walton (1928).

Site of infection: Body cavity, swim bladder and under the serosa of the latter.

Type locality: Millerton, Southwest Miramichi River and Bay du Vin, Miramichi River, New Brunswick, Canada. (see above for co-ordinates)

Deposition of specimens and description: Male neotype and one adult gravid female voucher specimen in the Canadian Museum of Nature Parasite Collection, Ottawa, Ontario, Canada (Catalogue Nos. CMNPA 2014-0041 and CMNPA 2014-0042, respectively); voucher specimens (14 adult males, 3 small adult and 4 large adult females) in the US National Parasite Collection, Beltsville, Maryland, USA (Catalogue No. USNPC 107912.00, Storage No. MT2051-D) and Helminthological Collection of the Institute of Parasitology, Biology Centre of the Czech Academy of Sciences, České Budějovice, Czech Republic (Catalogue No. N-920). Male neotype was from a striped bass of 4.5 cm TL; female voucher specimens

were from a 1-year-old striped bass of 19.2 cm TL. Description of above specimens registered in Zoobank <http://www.zoobank.org> (No. 4B959A30-66CC-4BBB-B547-EDD71784D979).

Remarks

Although the gravid *Philometra* females of the present material are substantially smaller than those of *P. rubra* described by Moravec et al. (2013), their general morphology, including a unique feature of this species (the different sizes of external cephalic papillae and their distribution), is identical and there is no doubt that they belong to this species. It is also supported by the fact that they were collected from the same locality (Miramichi River) from which the *M. saxatilis* YOY were captured for raising in captivity in the Quebec fish hatchery, and from where large *P. rubra* females were recorded in striped bass (5.4 – 5.6 cm TL) (Séguin et al. 2011; Moravec et al. 2013).

The males and mature females of *P. rubra* are described in this paper for the first time. They belong to this species as they occurred in *M. saxatilis* in large numbers along with conspecific adult subgravid and gravid females from the same locality (Moravec et al. 2013). Their frequent localization under the serosa of the host's swim bladder is typical of the species of *Philometra* whose gravid females are parasitic in the abdominal cavity (Moravec 2006).

According to Moravec et al. (2008), the following nine species of *Philometra* Costa, 1845 are known to parasitize fresh and brackish water fishes in North America: *P. carolinensis* Moravec, de Buron and Roumillat, 2006 in spotted weakfish [*Cynoscion nebulosus* (Cuvier in Cuvier and Valenciennes, 1830)], *P. cylindracea* (Ward and Magath, 1918) in mainly yellow perch [*Perca flavescens* (Mitchill, 1814)] but also in several other fish species, *P. cynoscionis* Moravec, de Buron and Roumillat, 2006 in spotted weakfish, *P. kobuleji* Molnár and Fernando, 1975b in white sucker [*Catostomus commersoni* (Lacépède, 1803)], *P. ophisterni* Moravec, Salgado-Maldonado and Aguillar-Aguillar, 2002 in swamp-eel

(*Ophisternon aenigmaticum* Rosen and Greenwood, 1976), *P. orbitalensis* Moravec, Crosby, de Buron, González-Solís and Roumillat, 2008 in largemouth bass [*Micropterus salmoides* (Lacépède, 1802)], *P. overstreeti* Moravec and de Buron, 2006 in southern flounder (*Paralichthys lethostigma* Jordan and Gilbert in Jordan and Meek, 1884), *P. rubra* (Leidy, 1856) in striped bass and white bass, and *P. translucida* Walton, 1928 [*species inquirenda*] in northern pike [*Esox lucius* (Linnaeus, 1758)]. Of these, conspecific males were described only for *P. carolinensis*, *P. cylindracea* and *P. kobuleji* (see Ashmead and Crites 1975; Molnár and Fernando 1975a, 1975b; Moravec et al. 2006; Moravec and de Buron 2009), whereas the remaining species are known solely by females.

Although the male morphology was studied by SEM only for *P. carolinensis* (see Moravec and de Buron 2009), the present study shows that the males of *P. rubra* can be distinguished from the above-mentioned three species on the basis of spicule, gubernaculum, and body length measurements. The spicules of *P. kobuleji* are distinctly longer (106–134 vs. 63–78 μm); spicules of *P. cylindracea* are reported to be of a similar length (49–75 μm) but the gubernaculum is distinctly shorter (34–43 μm vs. 60–75 μm); and spicules of *P. carolinensis* are longer (78–87 μm), whereas the body is shorter (1.59–2.71 vs. 2.72–4.42 mm), and the structure of the caudal extremity of this gonad-infecting species is different. The presence of a dorsal barb on the smooth distal tip of the gubernaculum, as present in *P. rubra*, is typical of most *Philometra* spp. parasitizing Holarctic freshwater fishes (Moravec 2006; Moravec and de Buron 2013).

Since the type specimen of *P. rubra* was lost and the original locality is unknown (see above), we consider it reasonable to establish a male neotype of this species in accordance with the International Code of Zoological Nomenclature. The male is identified as a neotype, because taxonomically more important features are generally found in male nematodes than in females including *Philometra* (see Moravec and de Buron 2013).

DISCUSSION

The presence of unusually small gravid (larvigerous) females of *P. rubra* found in this study may be due to fish host size (i.e. YOY of 3.5 to 6.4 cm TL), in which the parasites have a very limited space for further development and growth, resulting in attaining sexual maturity and gravidity at a small size. This phenomenon is well known in helminths as a so called “space factor”. For example, a similar case was reported by Moravec et al. (1994) in *Anguillicoloides crassus* (Kuwahara et al., 1974), a swim bladder nematode of eels (*Anguilla* spp.): gravid females of this parasite in large (ca. 50-100 cm long) European eels may attain a body length up to about 5 cm, those obtained from experimentally infected small eels (8–16 cm long) were only 7–17 mm long.

Alternatively, as male *P. rubra* are short-lived (male:female sex ratio declining in YOY collected 10 days apart and males absent in striped bass of 1-year and older), fertilization of females likely occurs as soon as males are mature, females persist and continue to grow. An adult gravid 11.9 cm long female *P. rubra* was found in a 1-year-old striped bass of 16.9 cm TL and specimens up to 18.4 cm long were reported in striped bass from previous collections from South Carolina and Quebec (Moravec et al. 2013). Rapid maturation and growth of *P. rubra* may be an adaptation to the biology of striped bass in eastern Canada (see below). We observed no immune response to *P. rubra* in one infected YOY examined histopathologically. In some YOY with high intensities (>80 worms) the swim bladder wall appeared thickened with abundant mucus in the lumen and a few worms were encapsulated, darkly pigmented or opaque, hard and degenerate in appearance.

This study showed that YOY striped bass are infected in spring and that males are short-lived. Striped bass of the southern GSL are anadromous, spawning just above the salt wedge in the Northwest Miramichi during late May and early June when daily average surface water temperatures are near 15.0°C (Robichaud-Leblanc et al. 1996). Once

metamorphosed, YOY move downstream into estuarine and marine coastal areas of the southern GSL in July and August and return to estuaries in the fall to overwinter (Robichaud-LeBlanc et al. 1998; Robinson et al. 2004). Philometrids are known to use copepods (shown experimentally and in natural infections for some *Philometra* species) as intermediate hosts in which first-stage larvae develop to the third infective stage (Moravec 2006; Moravec and de Buron 2013). The stomachs of YOY examined in the present study contained copepods (albeit marine copepods, *Acartia* sp.) and in 18% of examined YOY and only in YOY from Bay du Vin, a sample site with the highest average salinity. YOY may be infected by consuming infected fresh-water copepods but none was found in examined YOY stomachs. All examined YOY from estuarine waters were already infected and thus stomach analyses indicated prey items recently ingested in those collection sites. However, stomach contents of 33% of examined YOY contained amphipods and only in YOY from Hackett's Beach, which had the lowest average salinity. Scott and Scott (1988) report that larval striped bass feed on zooplankton and that juveniles consume small *Gammarus*, *Crangon*, other crustaceans, annelids and insects. Thus copepod and non-copepod invertebrates in fresh water or in estuarine waters should be investigated experimentally as potential intermediate hosts. Fertilized female *P. rubra* grow in the body cavity and overwinter in striped bass, releasing first-stage larvae via the host's genital pore in the spring and early summer when copepod populations are abundant. While the life cycle of *P. rubra* appears to be annual in the Miramichi with YOY having a prevalence of infection of 100%, the presence of large gravid females in striped bass (Age=1+) in the present study, in Age=2 to 6 striped bass from the Kouchibouguac River, New Brunswick (Hogans 1984) and in Age=1 to 3+ striped bass from the Chesapeake Bay area, U.S.A. (Paperna and Zwerner 1976) may suggest that some female *P. rubra* live longer or that some striped bass are not infected in their first year of life.

Paperna and Zwerner (1976) suggest that release of first-stage larvae can continue for several years but this remains to be verified.

Seguin et al. (2011) reported distended abdomens in infected YOY striped bass with female *Philometra* expelled through the vent, releasing numerous larvae. Water temperatures in the fish hatchery when this occurred in February were 17 to 19°C which do not occur in the Miramichi until late May (Douglas and Chaput 2011a). It was suggested that these temperatures induced rapid development and that high worm burdens caused physical obstruction near the vent. Moravec and de Buron (2013) stated that these YOY likely died as they were not yet ready to spawn (physiologically). Some gravid philometrids in the body cavity exit or release larvae with fish reproductive products via the swollen and enlarged genital pore during spawning. Survival of *P. rubra* first-stage larvae, development in copepods with subsequent transmission and development in YOY is likely affected by water temperatures, as seen with the Quebec fish hatchery mortalities and may threaten survival and recovery of populations at risk [i.e. “Endangered” SLE population (status was changed from “Extirpated” to “Endangered” in 2012) or southern GSL population (status designated as “Special Concern”) (COSEWIC 2012)]. Striped bass survival is dependent on water temperature with cold temperatures apparently being fatal (Bradford et al. 1995). Fish immune response is reduced at low temperatures and heavily infected fish may die over winter.

In our study all YOY examined were infected. Paperna and Zwerner (1976) reported gravid female *P. rubra* in the body cavity and mesenteries of striped bass from lower Chesapeake Bay with description of parasitic lesions including reporting encapsulated larvae in the liver and spleen and dead immature females in the mesenteries. Prevalence of *P. rubra* in YOY was 39%, 64% in Age=1+, 77% in Age=2+ and 100% in Age=3+ striped bass, with the greatest intensity being 14 in YOY and 11 in Age=1+. They also reported that prevalence

in YOY increased from July (30%) to September (53%) and declined in October (26%) which may indicate mortality. Mass mortality of striped bass due to *P. rubra* was considered unlikely but heavily infected YOY may die when 5- to 6-months-old (Paperna and Zwerner 1976). Hogans (1984) reported 82% of 17 striped bass (Age= 2 to 6, 36.5 – 50.1 cm fork length) infected with *P. rubra* (mean intensity=21.8, range 13 – 36) in the body cavity and peritoneum. Hogans (1984) deposited female specimens of *P. rubra* in the Canadian Museum of Nature (Catalogue Nos. CMNPA 1983-0379), no males were deposited or reported, and the fish were too old for males to be present. These striped bass were collected in September and October from the Kouchibouguac River, which is 50 km south of the Miramichi River in New Brunswick. No histopathology was conducted. In eastern Canadian waters, heavily infected striped bass may die prior to recruitment or be more susceptible to predation. Natural mortality is likely high during early larval development of striped bass but considered low for adult striped bass after they attain an age of 2 or 3 years (Douglas and Chaput 2011b; Robitaille et al. 2011).

Re-introduction is defined as the intentional movement of an organism into part of its historic range where it has been extirpated or become extinct. Conservation translocation is the deliberate and human-mediated movement of living organisms from one area for release in another with the required intention to yield measurable conservation benefit. Post-release health monitoring of re-introduced organisms is seldom conducted but advisable (Woodford and Rossiter 1993). The IUCN/SSC (2013) provides detailed guidelines for conservation translocations that yield quantifiable conservation benefit to species, populations, or ecosystems and advise post-release health and mortality monitoring which can reveal if diseases are affecting the success of translocated species. Historical evidence suggests that the SLE and Miramichi River striped bass populations are reproductively isolated (COSEWIC

2004; Robitaille et al. 2011). Animals used to re-introduce a population should be free of any harmful pathogens or parasites that might threaten the new population (IUCN/SSC 2013).

Archival data suggests that *P. rubra* was likely present in SLE striped bass prior to extirpation. This parasite may already be re-introduced with striped bass translocated from the Miramichi. Some juvenile striped bass from the Miramichi River, held in the Quebec fish hatchery and released into the SLE were captured in eel traps at Rivière Ouelle, in the SLE in October 2005 – numerous gravid female *Philometra* sp. were found in the body cavity, no males were found (L.N. Measures, unpublished data). On-going monitoring of the re-introduced striped bass population in the SLE indicates that striped bass are reproducing in the SLE as of 2008 and appear to be occupying every part of their historic range (Robitaille et al. 2011; Guy Verreault, QMFFPQ personal communication, 2016.). However, abundance of YOY is low. No systematic health assessments have been conducted on re-introduced striped bass to determine if parasites or other pathogens are present and whether disease may be having an effect on recruitment and recovery of this population. Health assessments on the southern GSL striped bass population may also be informative and aid in the recovery of this population at risk. In this regard examination of a cohort of larval, juvenile and adult striped bass from the SLE, Miramichi and other rivers in eastern Canada using careful dissections, morphologic and molecular methods to identify infections of philometrids, other parasites and pathogens as well as complementary histopathologic analyses should be undertaken to determine the role of disease in mortality of striped bass populations, particularly during early larval development.

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FIGURE 1. *Philometra rubra* (Leidy, 1856). (A) Anterior extremity of adult male, lateral view. (B) Cephalic extremity of adult male, apical view. (C) Vulva region of mature adult female, lateral view. (D–E) Posterior and anterior extremities of mature adult female, lateral views. (F) Anterior extremity of adult gravid female, lateral view. (G–H) Caudal extremity of adult male, lateral and ventral views. (I) Caudal extremity of mature adult females, dorsoventral view. (J) Caudal extremity of adult male, apical view. (K–L) Gubernaculum and spicule, respectively, lateral views. (M) Posterior extremity of adult gravid female, dorsoventral view.

FIGURE 2. *Philometra rubra* (Leidy, 1856), scanning electron micrographs of adult male. (A–B) Cephalic extremity, subapical views from dorsoventral and lateral sides, respectively (arrow indicates amphid). (C–D) Caudal extremity, lateral and apical views. (E) Enlarged caudal extremity, apical view (arrows indicate phasmids). (F) Detail of protruding distal extremities of spicules and gubernaculum provided with distinct dorsal barb, lateral view. a = submedian pair of cephalic papillae of external circle; b = submedian cephalic papilla of internal circle; c = lateral cephalic papilla of internal circle; e = caudal papilla; g = gubernaculum; o = oral aperture; s = spicule.

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