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PARASITISM OF BROOK TROUT (*SALVELINUS FONTINALIS*) DURING THE FIRST MONTH POST-EMERGENCE IN STREAMS IN SOUTHWEST NOVA SCOTIA

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ABSTRACT

Parasite recruitment of recently emerged fry of brook trout (*Salvelinus fontinalis*) in three streams in southwestern Nova Scotia was documented. In early April, fry appeared to leave the protective gravel redds parasite free but began acquiring parasites within the next 2-4 weeks, with prevalence of infections of any given species reaching 21 to 46% by mid-May. The initial infections involved 1) directly transmitted ectoparasites *Gyrodactylus colemanensis* and *Salmincola edwardsii* and 2) food-borne endoparasites (*Echinorhynchus lateralis* and *Crepidostomum* sp.). Colonizing parasites found in the first month post-emergence varied by locality: at Bangor Creek, it involved *G. colemanensis*, *E. lateralis*, and *Crepidostomum* sp., while at Germaine East, it involved only *G. colemanensis* and at Germaine North, only *S. edwardsii*. In each case, the initial colonizers reflected what was abundant locally and within a regional pool of 10 parasite species. Localized skin thickening and sometimes tissue erosion were evident at sites of attachment of *S. edwardsii*. Minor disruption of fin margins was seen with *G. colemanensis*. No pathology was associated with *E. lateralis* nor *Crepidostomum* sp. The predictable timing of emergence and ease of sampling fry of *S. fontinalis* near redds represents a convenient system with which to assess impact of initial parasitism on fish recruitment at the local level.

Keywords: *Echinorhynchus, Gyrodactylus*, initial parasite colonization, regional parasite pool, *Salmincola*

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INTRODUCTION

Studies on initial parasitism of fishes have included young hosts (larvae, fry, young-of-the-year) in freshwater lakes and streams (Poulin *et al.* 2012, Behrmann-Godel 2013, Markle *et al.* 2014), estuaries (Sirois and Dodson 2000, Bourque *et al.* 2006) and marine seas and reefs (Rybkina *et al.* 2016, Jahnsen-Guzmán *et al.* 2018, Landaeta *et al.* 2020). Metazoan parasites reported in these studies include directly transmitted monogenean and arthropod ectoparasites as well as food-borne digeneans, cestodes and nematodes, some (or closely related species) of which are known to cause mortalities in host fish held in captivity or at fish farms (Schäperclaus 1991, Woo 1995, Hoffman 1999)**.** In a review of the impact of parasites on young, small-bodied fish, Muñoz *et al.* (2015) concluded that there are three general, not mutually exclusive, impacts: 1) alteration of nutritional budgets; 2) energetic cost of tissue repair and immunological response to invasion; and 3) mechanical disruption and overall reduction in physiological efficiency on such fundamental issues as swimming performance.

We documented parasites of brook trout (*Salvelinus fontinalis*) fry within a month post-emergence from gravel redds in three streams in southwestern Nova Scotia and added this host to the study of early parasitism in fish. Brook trout spawn in late October to mid-November, with embryos developing over winter in the protective redd and relying solely on yolk as the energy source (Curry *et al.* 1991). In April, developed alevins emerge from the redd and become active daytime feeders, now called fry, 1-2 days post-emergence (2.0-2.7 cm long), preying on drifting invertebrates made up mostly of invertebrates and aquatic insect larvae (Allen 1981, Williams 1981, McLaughlin *et al.* 1994). The period of highest mortality for fry is during the first months post-emergence (Grant 1990, Curry *et al.* 1995)**.** It is known that by the end of the first summer of life, the young cohort of brook trout are exposed to most species of parasites present in older fish in the same streams (Muzzall 2008). We do not know exactly, however, when fry first start acquiring these parasites after they leave the protection of the redd and whether impacts identified by Muñoz *et al.* (2015) contribute to the period of high fry mortality.

METHODS

Trout fry were sampled by electrofishing in early spring of 2012 at spawning beds in three shallow streams within two river drainages in southwest Nova Scotia: 1) Germaine watershed (Germaine North 44°14.356'N, 66°7.611'W; Germaine East 44°14.039'N, 66°7.256'W, and 2) the Meteghan River watershed (Bangor Creek 44°12.899'N, 66°5.565'W) (Fig 1). The streams are alike in drainage area: the Bangor tributary is 1.7 km^2, Germaine East Branch 1.6 km^2 and Germaine North Branch 1.3 km^2. Both watersheds are situated on shallow Goldenville group bedrock formations with low potential to generate acid rock drainage (White *et al.* 2014). This is seen in the Bangor tributary, Germaine East Branch and North Branch having a mean pH of 6.2, 6.3 and 6.8, respectively (R. LeBlanc, unpublished).

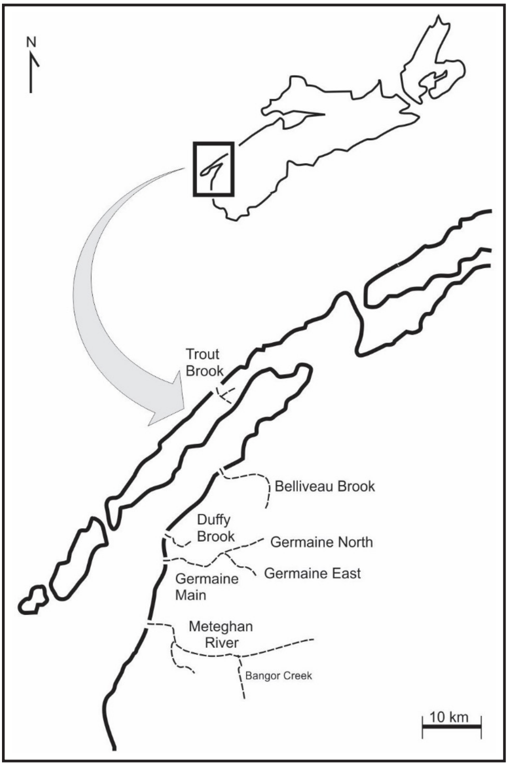

Fig 1 Map showing localities in southwestern Nova Scotia from which brook trout (*Salvelinus fontinalis*) were sampled.

The watersheds can be categorized as Class A systems where the mean summer temperature is ≤ 16.5 °C due to ground-water influx (MacMillan *et al.* 2008). Brook trout spawning in such streams (Fig 2) typically occurs in late October to mid-November and emergence in early April (Scott and Crossman 1973).

A total of 106 recently emerged fry were sampled by electrofishing along a 50 m stretch at each study site from April 14 to May 15, 2012. Shocked fish were euthanized in MS222 (about 250 mg/L) and fixed individually with 5% formalin in Falcon tubes. At necropsy, total length (cm) and weight (g) were recorded for each fish. All organs, along with the vial contents, were examined microscopically for parasites. Representative samples of parasites were examined in glycerine wet mounts to confirm identification using relevant taxonomic keys (Beverley-Burton 1984, Kabata 1988, Arai 1989, Gibson 1996). The data set includes prevalence and intensity data on gyrodactylids previously reported by Leblanc *et al.* (2013) in a study estimating standing crop of gyrodactylids on all ages of trout in Bangor Creek. Use of terms prevalence (number of fish infected/number of fish examined expressed as percent) and mean intensity (mean number of parasites/infected fish) follow Bush *et al.* (1997) and considered recommendations of Rózsa *et al.* (2000) on descriptive statistics for parasite populations.

The regional parasite species pool was determined from necropsy of an additional 537 brook trout of all ages (0+ and >1+) sampled

Fig 2 **Bangor Creek in the fall of 2020 showing a young adult brook trout (*Salvelinus fontinalis*) on a spawning bed. The gravel redd is in the upper right corner. The trout was approximately 10 cm long.**

throughout the late spring and summer of 2011-2014 by electrofishing and angling at the sampling sites and three additional watersheds nearby; Duffy Brook (44°14.972'N, 66°7.611'W), Belliveau Brook (44°22.430'N; 66°3.715'W) and Trout Brook (44°32.726'N, 66°1.480'W (Fig 1). Fish were placed immediately in Ziploc bags, iced and frozen later in the day. Thawed fish were processed as described above for recently emerged fry. The regional pool includes the parasites of the 106 recently emerged fry. All samples were obtained under a Department of Fisheries and Oceans Collecting Permit (Fir 7-000140-07) for 2011 with annual renewal.

RESULTS

The regional pool of brook trout parasites in southwestern Nova Scotia consisted of 10 species, including two monogeneans, two digeneans, one cestode, two nematodes, one acanthocephalan, one copepod, and mixed infections of the ciliates *Apiosoma/Trichodina* (Table 1). One species, *Gyrodactylus colemanensis* (Monogenea), occurred at all five sampling watersheds, with *Echinorhynchus lateralis* (Acanthocephala) occurring at four of five, and *S. edwardsii* (Copepoda) and *Crepidostomum* sp. (Digenea) occurring at three (Table 1).

Necropsy of the 106 trout fry at Bangor Creek, Germaine East, and Germaine North within an estimated first month post-emergence revealed four of the 10 regional species: the directly transmitted ectoparasites *G. colemanensis* and *S. edwardsii* and the food-borne endoparasites *E. lateralis* and *Crepidostomum* sp. (Table 2).

Fry were not encountered at the sites on April 1, 2012. They were first collected on April 14 and 15, having emerged sometime during the previous two weeks. Initially sampled fry rarely had parasites (1 of 32), compared to 24 of 56 sampled on May 7 and 15 (Table 2). Twenty-eight of the 30 infected fish had single species infections; two had mixed infections of *E. lateralis* and *Crepidostomum* sp.

At Bangor Creek on April 15, two weeks or less post-emergence, a single fry had an immature *E. lateralis* (Table 2). On April 30, immature specimens of *Crepidostomum* sp. were found and on May 15, *G. colemanensis* was present (Table 2). At Germaine North on May 7, the initial parasite was *S. edwardsii,* while at Germaine East it was *G. colemanensis* (Table 2).

Table 1 **Summary statistics of parasite infections in brook trout (*Salvelinus fontinalis*) from the Bangor, Germaine, Duffy, Belliveau, and Trout Brook watersheds in southwestern Nova Scotia collected spring, summer and fall of 2011-2014 to establish makeup of the regional pool of trout parasites. Prevalence, mean intensity, and intensity range in parentheses are presented for 0+ and ≥1 year old cohorts as well as regional totals (SW Nova Scotia).**

Parasite	Site in Host	Bangor		Germaine		Duffy	Belliveau		Trout Brook		SW Nova
Age of fish cohort		0+	≥1+	0+	≥1+	0+	0+	≥1+	0+	≥1+	
Sample size (N)		148	37	77	22	37	58	9	123	132	643
Protozoa *Apiosoma/Trichodina*	gills, skin	2	0	0	0	0	0	0	0	0	0.4
Monogenea *Gyrodactylus colemanensis* Mizelle and Kritsky, 1967	fins	39.8 8.5 (1-44)	54 9.8 (1-35)	7.8 2.0 (1-3)	4.5 4 (4)	21.6 2 (1-7)	12.0 6.4 (1-17)	55 6.4 (3-13)	5.6 1.5 (1-3)	19.6 3.6 (1-4)	84.7 6.5 (1-44)
Gyrodactylus salmonis Yin and Sproston, 1948	Body surface	0	0	0	0	0	0	0	0	3.7 1.2 (1-2)	0.7 1.2 (1-2)
Digenea *Crepidostomum* sp.	intestine	4.7 1.5 (1-3)	0	0	0	0	0	11.1 1 (1)	3.2 1 (1)	5.3 2 (1-3)	2.9 1.5 (1-3)
Apophallus imperator Lyster, 1940	skin	0	0	0	0	0	0	0	0	1 hundreds	
Cestoda *Eubothrium salvelini* Schrank, 1790	intestine	0	0	0	0	0	0	0	0.8 1 (1)	0.7 1 (1)	0.3 1 (1)

Table 1 cont'd

Parasite	**Site in Host**	**Bangor**		**Germaine**		**Duffy**	**Belliveau**		**Trout Brook**		**SW Nova**
Nematoda *Salmonema ephemeridarum* (von Linstow, 1872)	intestine	0	0	0	0	0	0	0	0	24.2 5.5 (1-32)	4.9 5.5 (1-32)
Raphidascaris sp.	mesentery	1.3 2 (1-3)	2.7 1(1)								0.4 1.7 (1-3)
Acanthocephala *Echinorhynchus lateralis* Leidy, 1851	intestine	37.8 2.2 (1-17)	64.8 6.2 (1-23)	0	4.5 1 (1)	0	3.4 1.5 (1-2)	33.3 3 (1-5)	0.8 1 (1-5)	13.6 3.2 (1-18)	16.3 3.3 (1-23)
Copepoda *Salmincola edwards* (Olsson, 1869)	Body, head fins, gills	0	2.7 6 (6)	23.3 2 (1-6)	54.5 7.3 (1-54)	0	0	0	20.3 2 (1-6)	43.9 10 (1-77)	17.7 6.4 (1-77)

Table 2 **Summary statistics of parasite infections in fry of brook trout (*Salvelinus fontinalis*) collected early spring of 2012 at spawning sites in three streams in southwestern Nova Scotia, near the town of Meteghan River, Nova Scotia. Data summarized includes sampling date, surface water temperature (°C), sample size (N), host fork length (cm) and weight (gm) (mean ± SD), prevalence, mean intensity, and range of intensity in parentheses.**

Spawning site	**Bangor Creek**			**Germaine East**		**Germaine North**	
Sample date Surface water temp (°C)	Apr 15 4.9	Apr 30 5.1	May 15 15.6	Apr 14 4.8	May 7 14.9 C	May 7 15.1	May 15 14.5
Sample size (N)	18	18	14	14	13	16	13
Host length (cm)	2.3 ± 0.15	2.6 ± 0.37	3.4 ± 0.51	2.7 ± 0.05	3.8 ± 0.08	3.7 ± 0.01	4.1 ± 0.02
Host weight (gm)	0.15 ± 0.04	0.2 ± 0.01	0.6 ± 0.28	0.2 ± 0.5	0.7 ± 0.7	0.7 ± 0.21	0.9 ± 0.37
Echinorhynchus lateralis	5.5 1 (1)	16.6 1.3 (1-2)	21.4 1.3 (1-2)	0	0	0	0
Crepidostomum sp.	0	11.1 1 (1)	7.1 1 (1)	0	0	0	0
Gyrodactylus colemanensis	0	0	14.2 1.5 (1-2)	0	38.4 2.2 (1-3)	0	0
Salmincola edwardsii	0	0	0	0	0	43.7 1.3 (1-3)	46.1 2 (1-6)

With *S. edwardsii*, juveniles were firmly embedded in host connective tissue by means of the frontal filament. There was localized epithelial thickening around the site of attachment and, in two fry from Germaine North, the base of a pectoral fin was noticeably eroded but not hemorrhagic. Infection with *G. colemanensis* caused slight disruption to the normally smooth fin margin near the site of attachment and presumed grazing. There was no pathology observed with *E. lateralis* and *Crepidostomum* sp., which were free in the lumen of the intestine. There was no significant difference in length or weight of infected versus non-infected fry tested separately for date and locality (t-test, $p>0.05$).

Diet items included a wide variety of aquatic invertebrates, noticeably copepods, ostracods, and larval insects. One fry (3.4 cm, 0.7 gm) from Germaine East collected on May 7 had the recognizable carapace of the amphipod *Hyalella azteca* in its stomach. Fry typically had a stomach full of invertebrates. However, one fry (5.8 cm long; 3.5 gm) from Bangor Creek on July 19, 2012 had no food items in its stomach and 17 well-developed adult *E. lateralis* (5 females, 12 males; fixed weight 0.07 gm) essentially blocking the intestinal lumen. Also noteworthy, a fry in Belliveau Brook on June 8, 2012, had a well-developed adult *E. lateralis* with the proboscis embedded in the posterior intestinal wall and with its body protruding from the anus (Fig 3), with slight abrasion of the ventral lobe of the caudal fin being evident.

DISCUSSION

All parasite species found in the present study are common in *S. fontinalis* inhabiting freshwater lakes and streams in northeastern North America (Frimeth 1987, You *et al.* 2011; White *et al.* 2020) and most have been reported from other salmonid hosts in Atlantic Canada (Margolis and Arthur 1979, McDonald and Margolis 1995).

Our goal was to determine when emergent fry start acquiring local parasites and which ones. We did not collect pre-emerged alevins to determine whether fish are parasitized in the redd. However, they appear to begin acquiring infections after emergence since parasites were initially rare with prevalence increasing substantially in subsequent samples. This is expected because, within the redd, young trout are removed from the infective stages of local parasites.

Fig 3 Brook trout (*Salvelinus fontinalis*) fry collected from Belliveau Brook on June 8, 2011 with an adult *Echinorhynchus lateralis* attached to the hind gut and protruding from the anus (arrow). Note that the lower lobe of the caudal fin appears shortened, possible because of abrasion on the substrate. Scale bar 4 mm.

The redd, while allowing protective development and growth, serves to delay initial parasitism within the stream. Similarly, open water dispersal of larvae of reef fishes is believed to reduce exposure of young hosts to parasites cycling on reefs (Cribb *et al.* 2000, Grutter *et al.* 2010, Peyruse *et al.* 2012), while larval migration of certain galaxiid salmonids, observed in coastal New Zealand, postpones early parasitism (Poulin *et al.* 2012). In contrast, hatchlings of the threespine stickleback (*Gasterosteus aculeatus*) pick up directly transmitted parasites, likely because they are associated with the male parents that guard the nest (Rybkina *et al.* 2016). King and Cone (2008) suspected newborn fry of brook stickleback (*Culaea inconstans*) acquired infections of the directly transmitted monogenean *Dactylogyrus eucalius* in the protective nest which males guard.

In southwestern Nova Scotia, emerging brook trout fry (as a cohort) acquired parasites within the first month post-emergence either through: 1) free swimming infective copepodids of *S. edwardsii* (see White *et al.* 2020); 2) adult *G. colemanensis* transferring directly between fish (see Cone and Cusack 1988, 1989); or 3) food-borne infective stages of *E. lateralis* (cystacanths) and *Crepidostomum* sp. (metacercariae) using amphipod/mayfly larva as intermediate hosts (Baggs and Cowan 1989, Caira 1989, Shaw *et al.* 2020). This early acquisition of parasites should be expected given that fry live sympatrically with older cohorts in these streams and are essentially proximal to parasites cycling through older cohorts. This initial colonization of young trout fry by food-borne endoparasites and directly transmitted ectoparasites contrasts a proposed general rule (Dogiel *et al.* 1961) that the initial parasites to infect freshwater fishes are those with simple life cycles, i.e., those without intermediate hosts. The present study shows that at the local level the first colonizing parasites involve the most common local parasites irrespective of the mode of transmission. This was particularly evident in the Germaine watershed, where in Gemaine East *G. colemanensis* was abundant and the first to colonize the new cohort, while in adjacent Germaine North it was *S. edwardsii* that was abundant locally and similarly the initial colonizing parasite species. At Bangor Creek, *G. colemanensis* and *E. lateralis* were colonizers and again abundant locally.

Fry emerge from the redd as active predators feeding on stream invertebrates (Allen 1981, Williams 1981, McLaughlin *et al.* 1994) and therefore are exposed to infective stages of *E. lateralis* and *Crepidostomum* sp. cycling through the local food web. Baggs and Cowan (1989) reported *E. lateralis* from brook trout fry in Newfoundland and suggested that, through coprophagy, young fish acquired infective cystacanths shed by local adult trout and not through an amphipod host, which were thought to be too large for young fry because of gape limitation (Baggs and Cowan 1989). Leblanc (unpublished) offered locally obtained live amphipods (*Hyalella azteca*) to schools of hatchery-reared fry (total length 4.8-5.3 cm; total weight 1-1.8 gm) in a large recirculating tank – fry converged almost immediately on the amphipods, tearing them apart within minutes and consuming the pieces. This presumably could take place in the wild, given that fry tend to aggregate in preferred microhabitats (Grant and Noakes 1987, Grant 1990), with cystacanths of *E. lateralis* and possibly metacercariae of *Crepidostomum* sp. being consumed by fish during the feeding frenzy. In the present study, we found a recognizable carapace of an amphipod in the stomach contents of one brook trout fry, which must have consumed it shortly after emergence, given the fish still had fin folds. This suggests that brook trout fry can acquire infections of *E. lateralis* and *Crepidostomum* sp. directly from amphipod hosts and not necessarily through coprophagy of shed cystacanths.

The colonizing parasites, or close relatives, have documented disease potential in salmonids (Pippy and Sandeman 1967, Cusack and Cone 1986, Bakke *et al.* 2007) with *Gyrodactylus* spp. being considered a major selective force in the wild (Zueva *et al.* 2014). *Salmincola edwardsii* is notorious in this regard with reported epidemics in wild brook trout (Mitro 2016, White *et al.* 2020) and disease outbreaks at fish farms (Dustun and Cusack 2002). Poulin *et al.* (1991) showed experimentally that brook trout infected with *S. edwardsii* were more likely to acquire additional infections than uninfected controls, suggesting that the parasite alters host behaviour or immunity in a way that facilitates subsequent infection. White *et al.* (2020) described pronounced, multiple hyperplastic growths at sites of attachment in wild brook trout from northwestern New Brunswick but did not see wounds that could be attributed to feeding. The tissue damage at points of attachment that we report was minor compared to extensive hyperplasia reported with older brook trout (White *et al.* 2020). Erosion at the base of pectoral fins, however, was significant in two cases and these wounds could have been caused by current-driven abrasion by the parasite's body on the fin base or possibly feeding. Previous studies have reported *S. edwardsii* from age 0+ brook trout fry collected in fall (Mitro 2016, White *et al.* 2020) and expressed concerns over increased gill ventilation rates, stunting, delayed sexual maturation and the overall impact of infections on trout recruitment. The present study indicates this concern should be extended to early spring, given that in a locality like Germaine North, nearly half of the new recruits start acquiring infections within the first month post-emergence, a period of significant fry mortality (Grant 1990, Curry *et al.* 1991). Our survey suggests that at Germaine North, a local epidemic of *S. edwardsii* is taking place and under such conditions young fry are a vulnerable part of the epidemic, essentially from time of emergence.

Infections of *G. colemanensis* were limited to few worms with only minor evidence of grazing and fraying on infected fin margins, which is expected given the nature of attachment and feeding (Cone and Wiles 1989). Leblanc *et al.* (2013) reported that, at the Bangor site, prevalence and intensity of infection of *G. colemanensis* increased during summer and by fall, the majority of the parasite standing crop was on 0+ fish, with no evidence of disease.

The immature *Crepidostomum* sp. and *E. lateralis* were free in the hind gut and not yet attached to the wall. The observation of *E. lateralis* protruding from the anus of one fry later in the summer has been seen occasionally in fry during annual assessments of brook trout in other parts of Nova Scotia (MacMillan, unpubl.). Pippy and Sandeman (1967) described infections of *E. lateralis* in adult brook trout from a lake in Newfoundland (200 adult worms per fish) in which groups of parasites had their posterior end protruded through the body wall and, in some fish, from the anus, as was seen in the present study. Pippy and Sandeman (1967) suspected that a bacterial infection may have contributed to the disease condition of the brook trout, many of which were still alive after capture in gill nets. It appears that *E. lateralis* has disease potential in trout in southwestern Nova Scotia and for fry may be important later in the summer. Thilakaratne *et al.* (2007) showed that in freshwater spottail shiner (*Notropis hudsonius*), infections of the gut dwelling acanthocephalan *Neoechinorhynchus rutili* were negatively correlated with condition factor in 1+ but not 2+ fish and concluded that young fish may be more sensitive to pathological effects than older fish. Similarly, size-selective mortality of rainbow smelt *(Osmerus mordax*) larvae due to infections with the cestode, *Proteocephalus tetrastomus,* resulted from predation on or starvation of smaller infected fish (Bourque *et al.* 2006). Indeed, parasitized larvae had less food in their guts (Sirois and Dodson 2000). Prevalence ranged from 43 to 96% during different years in the St. Lawrence estuary, and this cestode may be important in regulating recruitment to the adult smelt population (Bourque *et al.* 2006). In our samples, the only fry with a completely empty stomach had 17 adult *E. lateralis,* essentially blocking the gut lumen and suggesting a similar impact on feeding.

CONCLUSIONS

Brook trout fry acquire metazoan parasites within weeks of emerging from the protective gravel redd, directly through free-living infective stages or indirectly through food-borne parasites carried by aquatic invertebrates. Given their relatively small body size, fry may be affected much more than by such infections in larger, older hosts. The predictability of emergence and ease of sampling brook trout fry in gravel redds is a convenient system with which to study impact of the initial infections on survival of young hosts and subsequent recruitment into the local fish population.

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