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Timing of Appearance of *Gyrodactylus colemanensis* (Monogenea) on Young-of-the-Year *Salvelinus fontinalis* in a Nova Scotia Stream and Contribution of These Infections to Total Parasite Standing Crop

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ABSTRACT: Young-of-the-year (YOY) brook trout (*Salvelinus fontinalis*) were collected at 2 wk intervals (15 April to 4 June 2012) after emergence from redds and occurrence of the ectoparasite *Gyrodactylus colemanensis* (Monogenea) recorded. Emergent YOY were not infected. Infected trout (14%) first appeared 15 May, with host age estimated to be 4 wk or less post-emergence. Prevalence and intensity increased over the study period and reached, respectively, 93% and 8.2 ± 6.1 by 4 June. Prevalence and intensity of infection was also determined for older cohorts (1+, >1+) on 6 June, with *G. colemanensis* occurring on representatives of all age groups. The number of hosts in each age group was estimated by mark/recapture electrofishing over a 100 m reach of the stream. Combining estimated host numbers by age group with parasite prevalence and intensity data from those groups allowed calculation of parasite total standing crop. The results indicate that, by late spring, the new host recruits already carried 64% of the parasite population in the stream, serving to illustrate the remarkable efficiency of transmission by this viviparous monogenean in a temperate stream system.

Gyrodactylus colemanensis Mizelle and Kritsky, 1967 (Monogenea) is a common parasite of salmonid fishes in fresh water fish farms throughout North America (Cone et al., 1983). Most information available on this parasite comes from studies of captive fish (Mizelle and Kritsky, 1967; Cusack, 1986; Cone and Cusack, 1988, 1989; Cusack et al., 1988; Cone and Wiles, 1989; Wells and Cone, 1990), although You et al. (2011) describe year-round high prevalence of *G. colemanensis* on juvenile and adults of various species of wild and feral salmonids in northeastern Nova Scotia. You et al. (2011), however, did not include the 0+ trout, and thus we do not know how soon these new recruits become hosts after emergence from the redd. In the present study, we monitor the timing of appearance of *G. colemanensis* on young-of-the-year (YOY) in a stream in southwestern Nova Scotia and assess the importance of these young fish as hosts for the local parasite population.

The study site was a 100 m reach of the Bangor Tributary, a small first order stream running into Meteghan River, Municipality of Clare, Nova Scotia (44°12′55″N, 66°05′34″W). It is located within a lightly urbanized, low-lying mixed forest of alders, softwoods, and hardwoods. It has a mean width of 2.4 m, mean depth of 0.16 m, and a sand/gravel/rocky substrate that varies from riffle areas to small pools, with a limited presence of aquatic plants. Five redds were identified in the reach, all with ground water input. The stream had the following properties from November 2011 to July 2012: pH 6.2 ± 0.2, dissolved oxygen 10.5 ± 1.9 mg/L, and an average temperature 7.8 ± 5.2 C (ground water at 30 cm depth 7.9 C ± 3.5), with a 6 June temperature of 16 C. The reach was electro-fished approximately every 2 wk from 3 April to 4 June 2010. Samples of YOY trout (Table I) were anaesthetized in MS222 (1:2,000) and fixed in 50 ml tube containing 10% formalin; the parasites generally remained attached to the skin surface (mostly the fin margins) and only occasionally dislodged into the fixative. The external surface of the fish was carefully examined with aid of a dissecting microscope. Fish fork length (cm) and wet weight (g) were recorded (Table I). The opercula were removed and the inner surfaces examined, as were the gill arches and filaments. Prevalence and intensity measures were calculated according to Bush et al. (1997). Voucher specimens of *G. colemanensis* from Nova Scotia have been deposited previously under USNPC 104764 (You et al., 2011).

On 4–6 June size of the resident trout population was estimated (Table I) using mark/recapture methods and the Chapman modification of the Petersen equation (as described by Williams et al., 1993): $N = (M+1)(C+1)/(R+1)$, where N is the population size (variance of N is $N^2(C-R)/(C+1)(R+2)$), M is the number of marked fish released, C is the recapture sample size (includes both marked and unmarked), and R is the number of marked fish recaptured. Age cohorts were apparent in length frequency distributions and separate population estimates for YOY (0+), 1-yr-old (1+), and older than 1-yr-old (>1+) fish were conducted to account for the differences in catchability. The oldest age group included 2+-yr-old and 3+-yr-old fish, and these were treated together because of small sample sizes. Upper and lower 95% confidence intervals of the population estimates were calculated using the Poisson approximations in Ricker (1975). The procedure involved marking anaesthetized fish (MS222) through an adipose clip, which was easily recognized during a recapture. A subsample of these older fish was bagged immediately upon capture and placed on ice and the body washings examined for parasites following You et al. (2011).

YOY were not encountered on 3 April. They were caught on 15 April and thus included fish that had emerged sometime during the previous 2 wk. Mean length and weight of YOY caught in subsequent samples increased during the sampling period (Table I), with the presumed post-emergence age reaching up to 10 wk by 4 June. The fact that YOY less than 3 cm in length were present in samples from 15 April to 15 May suggests that emergence from the redds had occurred over approximately a 4 wk period, with each sampling up to 15 May including recently emerged fry.

YOY collected 15 and 30 April were not infected with *G. colemanensis*. Two of 14 fish were infected 15 May, and 13 of 14 on 4 June (Table II). The parasite was also present on 1+ and >1+ fish sampled 6 June (Table II). On 4 and 6 June, prevalence was 75% or higher on all cohorts, but with no significant difference in intensity (Kruskall-Wallis test, $p = 0.26$ $\chi^2 = 1.3$) (Table II).

Using mark-recapture information (Table I) standing crop of the parasites was estimated using prevalence and intensity data for each cohort (Table II). The data revealed that 64% (1,599/2,484) of the total parasite population in the reach was on the YOY cohort by early June.

The Bangor tributary of the Meteghan River is a cold water trout stream in southwest Nova Scotia, with warmer ground water influx in the winter and cooler influx in the summer compared to other systems with limited ground water inputs. At the Bangor reach one finds a series of shallow riffles and deeper pools, with the YOY tending to occupy shallow areas with moderate flow, while older cohorts are primarily in the deeper pools, confirming previous reports (Johnson, 2008; Sotiropoulos et al., 2006). Older brook trout tend to be more mobile and have diurnal and

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TABLE I. Summary of mean length (cm) and formalin fixed weight (g) ± SD of young-of-the-year (0+), juveniles (1+), and adults (>1+) and mark/recapture census of numbers of *Salvelinus fontinalis* collected in spring 2012 from the Bangor Tributary of the Meteghan River, southwestern Nova Scotia.

	1 April	15 April	30 April	15 May	4 June		
Age	n/f	0+	0+	0+	0+	1+	>1+
Length (cm)	—	2.3 ± 0.16	2.7 ± 0.31	3.2 ± 0.47	4.4 ± 0.7	13.5 ± 1.9	20.7 ± 3.7
Weight (g)	—	0.15 ± 0.42	0.2 ± 0.08	0.5 ± 0.25	1.4 ± 0.8	28.5 ± 15.1	126.8 ± 97.7
Population size (95% confidence)	—	—	—	—	210 (122–394)	50 (26–105)	28 (10–41)

seasonal migrations based primarily on water levels and temperature (White, 1940).

The absence of *G. colemanensis* 15 and 30 April indicates that fry emerged from the redd without the parasite, and that the new cohort first encountered them within 4 wk of emergence. In small streams in West Virginia, YOY brook trout tend to have limited dispersal from the redd during the first 4 mo post-emergence (Hudy et al., 2010), and, if this is the case in our similar study site, the YOY likely start acquiring infections near the redd of origin. These initial infections must come from the resident older cohorts since the fish emerge infection free. Once the parasite is established on the YOY the subsequent increase in prevalence must at that point involve intra-cohort transmission, given the tendency of the new recruits to aggregate in preferred microhabitats. Unfortunately in this case the exact mode of transmission by the parasite is unclear. It conceivably involves either direct transmission between fish during contact or indirect transmission via drifting of dislodged parasites and/or temporary attachment to substrate such as pebbles and aquatic plants (see Bakke et al., 2007). All of these routes of transmission are possible in the Bangor tributary for the YOY essentially live sympatrically with the older cohorts, all sharing the reach, albeit in different microhabitats. Whatever the route of transmission, *G. colemanensis* reached the new cohort at the latest by wk 4 post-emergence from the redd, with prevalence and intensity increasing up to the 4 June sample, at which time the majority of YOY carried the parasite.

It was unexpected that 64% of estimated parasite standing crop was already on the YOY by late spring. This observation, when coupled with the You et al. (2011) study referred to above, suggests that *G. colemanensis* makes use of all host cohorts year round (You et al., 2011).

Standing crop of trout parasite populations has been reported only occasionally. In a small Newfoundland lake, Cone and Ryan (1984) reported it for 3 parasite species. The nematode *Cystidicoloides ephemeridarum* ((Linstow, 1872) = *tennuisima*), the acanthocephalan *Echinorhynchus lateralis* Leidy, 1851, and a copepod *Ergasilus* sp. were mostly distributed in smaller *S. fontinalis*, while other parasites, the monogenean *Discocotyle sagittata* (Leuckart, 1842), digenean metacercaria (*Apophallus imperator* Lyster, 1940, and *Tetracotyle* sp.), and the copepod *Salmincola edwardsii* (Olsson, 1869), were located in the less abundant, but larger hosts. In Hunt Creek Michigan, Muzzall (2007) reported that prevalence and intensity of infection of parasites of *S. fontinalis* in August were generally higher in the 1+ cohort compared to YOY. However, the standing crops of *Crepidostomum cooperi* Hopkins, 1931, and *C. ephemeridarum* were aggregated in 1+ fish, and that of *Acanthocephalus dirus* VanCleave, 1931, was distributed comparably in YOY and 1+ cohorts, while that of *S. edwardsii* was aggregated in 0+ fish. These studies and the present one suggest that, in the case of *S. fontinalis*, the distribution of parasite standing crop can vary significantly among host cohorts, but the significance of this patchiness to both the parasite and host populations remains unexplored.

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TABLE II. Summary of prevalence and intensity of infection in each cohort of *Salvelinus fontinalis* sampled in the Bangor Tributary of the Meteghan River system in western Nova Scotia, and estimate of standing crop of *Gyrodactylus colemanensis* (calculated by multiplying prevalence, intensity, and standing crop of trout in each cohort estimated from mark/recapture data presented in Table I) for spring 2012.

Sample date	Host cohort	Prevalence	Intensity	Host standing crop	Parasite standing crop
1 April	0+	—	—	—	—
15 April	0+	0/18	—	—	—
30 April	0+	0/18	—	—	—
15 May	0+	2/14	1.5 ± 0.7	—	—
4 June	0+	13/14	8.2 ± 6.1	210	1,599
6 June	1+	6/8	18 ± 15.9	50	675
6 June	>1+	7/8	8.6 ± 11.9	28	210

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