PARELAPHOSTRONGYLUS TENUIS IN TERRESTRIAL GASTROPODS FROM WHITE-TAILED DEER WINTER AND SUMMER RANGE IN NORTHERN NEW BRUNSWICK

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ABSTRACT: The prevalence of *Parelaphostrongylus tenuis* infection was compared in terrestrial gastropods from white-tailed deer (*Odocoileus virginianus*) summer range and wintering yards in northern New Brunswick during summer, 1995. Of 10,343 snails and slugs examined, only 4 were infected with 1 to 3 *P. tenuis* third-stage larvae (0.04%); all of these (the snail *Discus cronkhitei* and the slugs *Deroceras laeve* and *Arion* sp.) were collected from the deer yard. The effective frequency of infection in the wintering yard was 0.09% and zero (undetectable) on summer range. Mean gastropod densities on summer and winter range did not differ (8.3/m^2 and 6.2/m^2, respectively). We suggest that the higher frequency of infection in the winter yard results from seasonally increased deer usage of these habitat types, and that moose (*Alces alces*) using such yards during snow-free periods will have increased risk of infection with *P. tenuis*. The relatively low prevalence of infection observed in gastropod intermediate hosts may reflect the effect of an unseasonably dry spring and summer on the transmission of *P. tenuis*.

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The meningeal worm, *Parelaphostrongylus tenuis*, of white-tailed deer (*Odocoileus virginianus*) has been reasonably well studied in New Brunswick. Prevalence in deer has been estimated at 50-60% (Smith and Archibald 1967, Trimper 1984, Upshall *et al* 1987, Beach 1993). Twenty-seven cases of moose sickness have been reported from New Brunswick, dating back as early as 1910 (Whitlaw and Lankester 1994). The prevalence of *P. tenuis* infection in gastropod intermediate hosts in the Maritime Provinces ranged from 1.1 to 2.6% (1.1 and 2.5% in New Brunswick by Beach, 1993 and Upshall *et al.*, 1986, respectively, and 2.6% in Nova Scotia from Parker, 1966). Yet in this province, where white-tailed deer occur at the northern limit of their distribution, the role of winter aggregation areas (deer yards) in the epizootiology of the parasite is unknown.

Lankester and Peterson (1996) demonstrated a greater prevalence of *P. tenuis* in gastropods on deer winter yards than on summer range in Minnesota. Infected gastropods were more dense on the winter range; however, the importance of this focus of infection in perpetuating the parasite in deer herds was questioned. Considerable snow usually covers the ground before deer arrive on winter range during autumn. As well, young deer are most susceptible but many would have become infected in late summer and autumn and be refractory to further infection by the time snow in the yard melts in spring. Yards still, however, represent areas with increased potential for infection of fawns of resident deer, and for moose using them in snow-free seasons. In Minnesota, the prevalence of *P. tenuis* infection in gastropods was low (0.08% overall), even in the wintering yard (0.16%) (Lankester and Peterson 1996). Nonetheless, the high frequency of infection observed in deer (82%) was explained by the high volume of food consumed near the ground by young, susceptible deer during their first summer and autumn.

The objectives of this study were to compare levels of *P. tenuis* infection in gastropods on deer winter and summer ranges in northern New Brunswick, compare these estimates with those previously reported in the province and elsewhere, and to evaluate the possible importance of deer yards in the transmission of *P. tenuis* to deer and moose.

STUDY AREA

The Odell Deer Yard in northcentral New Brunswick (46°N, 67°E) is privately owned by Fraser Papers Inc. Its management does not fall under Provincial guidelines and has had moderate forestry interventions since the 1950's. The yard is 1690 ha in total land area, comprised of a diversity of habitat types, and has an extensive road-trail network. Approximately 60% of the yard is considered critical winter habitat consisting of a dense (60-70%) overstory of white spruce (*Picea glauca*), eastern hemlock (*Tsuga canadensis*), eastern white cedar (*Thuja occidentalis*) and balsam fir (*Abies balsamea*) (Anonymous 1995). The remaining landbase has interspersed small openings (<3ha) and skidder trails as a result of recent logging operations, with a hardwood overstory of balsam poplar (*Populus balsamifera*) and white birch (*Betula papyrifera*). The understory in the critical habitat is sparse compared to the more open hardwood areas, however both consist of regenerating hardwoods such as red maple (*Acer rubrum*), balsam poplar, beaked hazel (*Corylus cornuta*), and white birch, in addition to various ferns and shrubs. The sampled summer range was on the southwest slope of a gradual hardwood ridge, approximately 15 km southeast from the yard. Overstory species included sugar maple (*Acer saccharum*) and american beech (*Fagus grandifolia*), while the understory was comprised primarily of sugar maple.

Deer are known to have used the Odell yard near Plaster Rock, NB since the 1950's (D. Woods, Fraser Inc., Plaster Rock NB, pers comm 1996). Generally, deer begin to arrive in the yard in December and stay until mid to late April (Whitlaw *et al.* 1995). Deer densities in the Odell yard during the winter of 1994-95 were estimated at approximately 12/km^2 using the Potvin *et al.*(1992) aerial double count method. Assuming that within the principal range of a deer, yards represent 10-15% of the summer range area (Voigt 1992), with productivity of approximately 1 fawn per adult doe in northern New Brunswick (J. Dempsey, NB Department of Natural Resources and Energy, Fredericton NB, pers comm 1996), we estimate 2-3 deer/km^2 on their summer range. Moose (*Alces alces*) also occur in the area, with a preharvest density estimate of approximately 0.57/km^2 (J. Dempsey, NB Department of Natural Resources and Energy, Fredericton NB, pers comm 1996).

METHODS

Terrestrial gastropods were sampled using the cardboard sheet method (Lankester and Anderson 1968, Hawkins *et al.* 1996). In both winter and summer areas, 100 cardboard sheets (1 m^2) were placed 20 m apart along 10 transects that were 200 m long and 30 m apart. Logs and rocks were placed on the sheets to trap moisture and to prevent them from blowing away. Gastropods were collected once a week from each study area during June 1995, and biweekly from July 6 to October 26, 1995. Individual sheets were moved 1-2 m every 3 to 4 sampling days.

Snails and slugs were placed into separate styrofoam containers. Vegetation was included with slugs, which were kept cool and alive until digestion. Snails were frozen in 3-5 cm of water. Within 2-3 days of collection, gastropods were sent express mail to Lakehead University where snails were refrozen for digestion later; slugs were digested upon arrival. Gastropods were identified with the aid of criteria provided by Nylander (1943), LaRocque (1961), Burch (1962), Clarke *et al.* (1968), Gleich and Gilbert (1976), Gleich *et al.* (1977), Upshall (1985), and Beach (1993).

Live slugs were digested in batches of 30-40 individuals suspended on a piece of vinyl window screening in a large, glass, stoppered funnel (top diameter 14.5 cm) filled with an acidified solution of pepsin (Lankester and Anderson 1968). Snails were thawed and placed in groups of 3-5 in plastic Petri dishes (4 cm diam) filled with 3-4 ml of pepsin digest solution. Preliminary tests indicated a low frequency of infection in gastropods. Hence, if more than one *P. tenuis* larva was recovered from a batch of digested gastropods, they would be assumed to have come from one infected individual. After 24hr in an incubator at 38-40°C, the contents of each dish were examined for nematode larvae following methods described by Lankester and Peterson (1996). The identity of third-stage *P. tenuis* larvae was confirmed by comparing dimensions and morphology to those illustrated by Anderson (1963).

To determine prevalence of infection with *P. tenuis*, deer pellet groups were collected off snow during February and March, 1996 in the Odell Deer Yard. Samples consisting of 20-30 pellets were suspended over cheesecloth in stoppered glass funnels (top diameter 10 cm) filled with tap water. After 24hr at room temperature, 10 ml of water were drained from each funnel into plastic Petri dishes and examined for dorsal-spined, first-stage, elaphostrongyline larvae.

In order to investigate the roles of temperature and precipitation in the transmission of *P. tenuis*, weather data were obtained from Environment Canada's Aroostook weather station, located 25 km west of the Odell Deer Yard.

Prevalence data from deer winter and summer ranges were analyzed in a 2x2 contingency table (Zar 1984). Temperature and rainfall data were analyzed in a 2x7 Chi-square contingency table. Gastropod densities were compared with a Mann-Whitney U test.

RESULTS

A total of 10,343 gastropods, including 4 slug and 18 snail species, was examined for *P. tenuis* larvae (Table 1). Significantly more gastropods collected from the wintering yard contained third-stage larvae of *P. tenuis* (4/4426= 0.09%), than did those collected from deer summer range (0/5917=0%) (X^2=5.34, df=1, p=0.02). All infected snails and slugs were collected from the wintering yard 22 August-23 September, 1995. They included one third-stage larva in an *Arion* spp, three in a *Deroceras laeve*, one in a *D. laeve*, and one in a *Discus cronkhitei*. No infected gastropods were detected from summer range (0/5917). Larvae of *P. tenuis* were 1045-1100 µm long ($\bar{X}$= 1070 µm, SE = 8.9 µm) and resembled those illustrated by Anderson (1963). Those of other nematodes were encountered in snails frequently, but details were not recorded.

Mean gastropod density in the winter yard (6.15 ± 0.99/m^2, range 1.67 - 10.40/m^2), did not differ from that in the summer area (8.25 ± 1.06/m^2, range 2.14 - 11.51/m^2) ($\underline{U}$ = 35.00, $\underline{n}$ = 21, $\underline{P}$ = 0.16). Density estimates were based on 5,535 gastropods from the winter yard and 6,752 from the summer range (total 12,287), some of which died and were unsuitable for digesting. Highest densities ($\geq$7.5/m^2) occurred from July 20 to September 28, 1995 in the winter yard (Figure 1a), and extended to the end of the collection period (October 26, 1995) in the summer area (Figure 1b).

Summer 1995 was relatively dry with significantly less monthly rainfall than the 5-year average (X^2=175.98, df=6, p=0.00) (Figure 2a). Mean monthly temperatures,

Table 1. Terrestrial gastropods with larvae of *Parelaphostrongylus tenuis* collected from winter and summer deer range, northcentral New Brunswick, 6 June to 26 October 1995.

	Winter yard		Summer Range			
	No. examined	No. with *P. tenuis*	No. examined	No. with *P. tenuis*	Total	% with *P. tenuis*
Arion spp.*	1080	1	1297	0	2377	0.04
Derocerus laeve	236	2	202	0	438	0.46
Pallifera dorsalis	17	0	120	0	137	0
Philomycus carolinianus	0	0	1	0	1	0
Discus cronkhitei	1486	1	3185	0	4671	0.02
Helicodiscus parallelus	31	0	61	0	92	0
Anguispira alternata	0	0	6	0	6	0
Zonitoides arboreus	533	0	395	0	928	0
Striatura exigua	450	0	349	0	799	0
Euconulus fulvus	147	0	58	0	205	0
Succinea ovalis	0	0	120	0	120	0
Strobliops labyrinthica	290	0	46	0	336	0
Planogyra sp.	100	0	22	0	122	0
Zoogenetes harpa	1	0	2	0	3	0
Gastrocopta sp.	4	0	0	0	4	0
Vertigo sp.	16	0	1	0	17	0
Columella edentula	12	0	11	0	23	0
Pupisoma sp.	11	0	2	0	13	0
Mesodon sayanus	8	0	19	0	27	0
Tridopsis albolabris	2	0	14	0	16	0
Stenotrema fraternum	1	0	6	0	7	0
Carychium exiguum	1	0	0	0	1	0
TOTAL	4426	4	5917	0	10343	0.04

* includes both *A. circumscriptus* and *A. hortensis*

however, were similar to those of the previous 5 years (X^2=4.41, df=6, p=0.61) (Figure 2b).

The prevalence of dorsal-spined larvae in feces of wintering deer (February-March, 1996) in the Odell yard was 67% (n=25).

DISCUSSION

Overall, 0.04% of all gastropods were infected, but the effective frequency of infection was 0.09% on the wintering ground and zero (undetectable) on summer range. Similar densities and kinds of gastropods indicated that both areas were equally suitable for intermediate hosts. Therefore, the significantly greater frequency of infection in the wintering ground probably reflects the higher deer usage and possibly, differential survivorship of first-stage larvae deposited by deer.

The frequency of infection found on this northern New Brunswick wintering area was similar to that reported in northern Minnesota (0.08%, Lankester and Peterson 1996; 0.8%, Pitt and Jordan 1995), central Ontario (0.11%, Kearney and Gilbert 1978) and northern Maine (0.10%, Gleich *et al.* 1977). However, prevalences previously reported from terrestrial gastropods in the Maritime Provinces (2.6%, Parker 1966, 2.5% Upshall *et al.* 1986, 1.1%, Beach 1993) were noticeably higher than our results. Lankester and

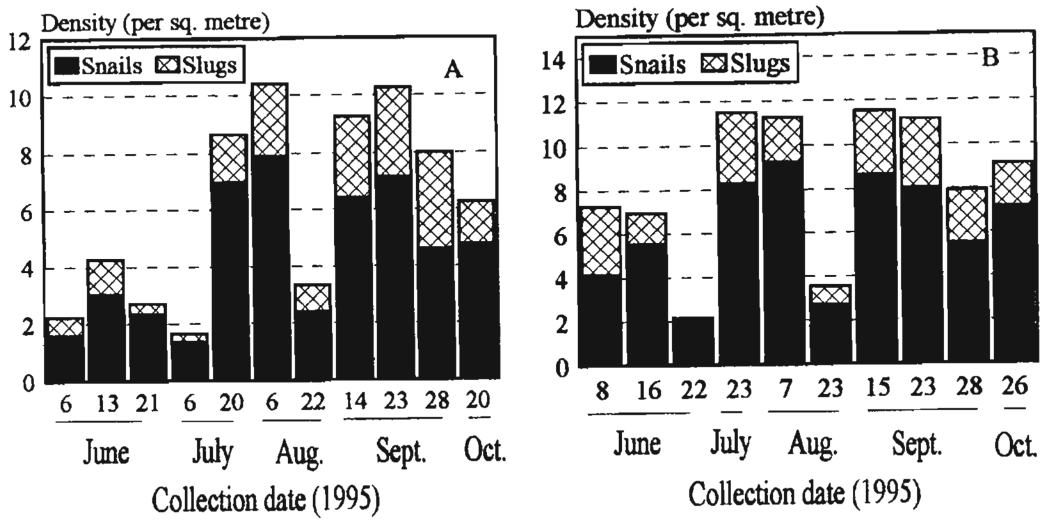

Fig 1. Density of terrestrial gastropods collected from white-tailed deer winter (A) and summer (B) range in northern New Brunswick, 6 June through 26 October, 1995.

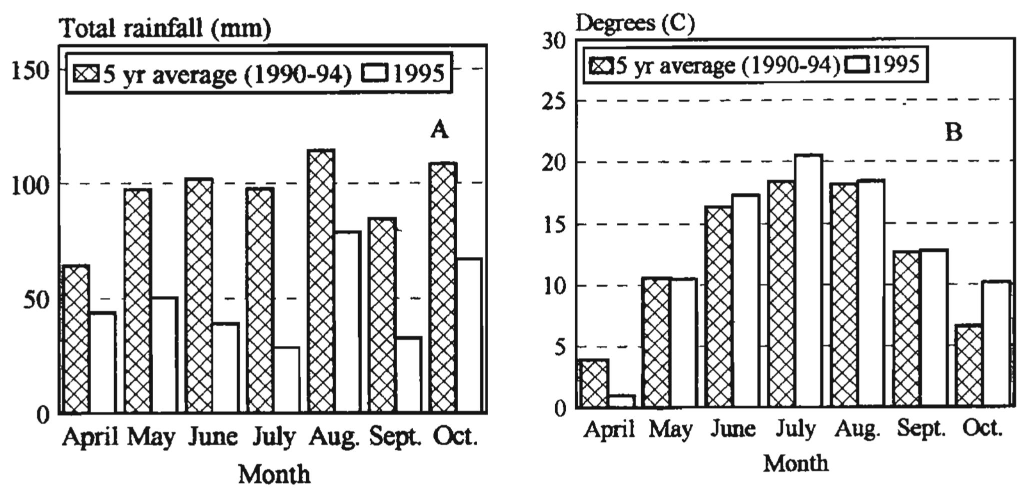

Fig 2. Total monthly rainfall (A) and average monthly temperature (B), 1990-94 five year average and 1995, collected at the Environment Canada Aroostook Weather Station in northern New Brunswick, April through October.

Peterson (1996) suggested that high prevalences of infection in gastropods from southern jurisdictions (reported range from 2.2-16.2%) (Lankester and Anderson 1968, Maze and Johnstone 1986, Raskevitz *et al.* 1991, Rowley *et al.* 1987, Platt 1989), where deer do not migrate between summer and winter ranges, were probably influenced by high deer densities,warmer climate, and a longer season of gastropod activity. Differences between our results and those previously reported for the Maritime Regions are more difficult to resolve.

Temperatures were seasonal during our collection period, but it was unusually dry. Several authors describe a positive correlation between summer precipitation and the prevalence of *P. tenuis* in deer (Gilbert 1973, Thomas and Dodds 1988, Peterson and Lankester 1991, Bogaczyk *et al.* 1993). Generally, climatic factors can affect both the movements of gastropods and the development of *P. tenuis* larvae in snails and slugs (Lankester and Anderson 1968). When microclimate is dry, movements of gastropods are reduced and they remain in the soil below the forest floor (Hawkins *et al.* 1996). Potential impacts of this type of climate are twofold; reduced contact with first-stage larvae and reduced chance of being eaten by a grazing cervid. In addition, when conditions are unfavourable, snails will aestivate. Development of larvae in aestivating snails and slugs is retarded, potentially affecting the timing of transmission during snow-free periods (Lankester and Anderson 1968). Our relatively low prevalence of infection in terrestrial gastropods may be a reflection of the effects of dry microclimate on the epizootiology of *P. tenuis*.

It should also be emphasized that there is some risk of over-estimating infection rates of *P. tenuis* in intermediate hosts. Gastropods are hosts to a large variety of nematodes, some of which closely resemble the larvae of *P. tenuis*. Lankester and Peterson (1996) found such larvae in 3.7% of gastropods examined in northeastern Minnesota. Gleich *et al.* (1977) reported that 6.8% of gastropods examined were infected with larvae similar to *P. tenuis*. The morphology and dimensions of all suspect *P. tenuis* larvae should be compared to published data or identifications should be verified by experienced workers.

The present research supports the hypothesis that deer yards present a greater risk of infection to cervids using these habitats during snow-free periods, than does deer summer range. Lankester and Peterson (1996) predicted that the potential for a moose or deer to become infected was twice as great in a deer yard as on summer range in northeastern Minnesota. Although they discounted deer yards as being of major importance in transmission to deer over winter, yards might represent important foci of infection for moose using the area during snow-free periods and for fawns resident in the summer. Moose use the Odell Deer Yard in New Brunswick on a year-round basis, potentially exposing them to increased risk of infection. We are aware of two unverified public reports of moose exhibiting uncharacteristic behaviour in this area within the last five years (Whitlaw, unpubl. data). Of 25 radio-collared does caught in the Odell Deer Yard during the winters of 1994 and 1995, none have fawned within the yard (Whitlaw, unpubl. data). This suggests that although there is increased risk of infection on the deer winter range, few fawns may acquire their initial infection within this habitat.

The existence of foci with increased risk of *P. tenuis* transmission has been suggested by several authors. Lankester and Anderson (1968) suggested that wet forested habitat where gastropods were abundant, commonly infected, and active from May to October was probably important for transmission. Maze and Johnstone (1986) and Platt (1989) investigated the possibility of foci being related to vegetation cover, soil pH and replaceable calcium, whereas Kearney and Gilbert (1978) and Raskevitz *et al.* (1991) proposed that foci were related to forest type and dominant overstory species. The concept of "refugia", or areas of reduced risk due to lowered availability of terrestrial gastropods has been suggested by Rowley *et al.* (1987), Raskevitz *et al.* (1991), and Beach (1993). A consistent feature of all of these studies was finding reduced numbers of gastropods in open pastures, meadows and fields.

In northern New Brunswick, white-tailed deer move from their forested winter range to adjacent fields in the spring (late March through April) (Ballard, pers. obs.). During this period snow melts in the exposed areas, before it melts in the yard, and many deer can be observed feeding in open areas with bare ground. Although deer pass more larvae at this time of the year (Slomke *et al.* 1995), gastropods may be in low numbers in the open fields. Such areas may, therefore, be of little consequence in transmission.

The management implications of deer yards as potential foci of transmission for *P. tenuis* are significant for New Brunswick and elsewhere. Mature coniferous forest habitat (MCFH) is preserved by the New Brunswick Department of Natural Resources and Energy (DNRE) to protect deer yards and pine marten (*Martes americana*) habitat (Anonymous 1995). Approximately 900 deer wintering areas are recognized on Crown land in the Province, covering 268,000 ha (9% of Crown land). Presuming that moose in New Brunswick utilize some component of MCFH during snow-free periods as has been documented in New Hampshire (Pruss and Pekins 1992), the potential exists for moose to be forced into deer yards to obtain the benefits of this habitat type.

Moose using deer yards during snow-free periods may have an increased risk of infection with *P. tenuis*. However, factors that influence the risk of infection presented to deer and moose by gastropods are not clear. For example, in a model developed by Schmitz and Nudds (1994), sensitivity analyses indicated the rate of transmission of first-stage larvae to intermediate hosts and the instantaneous rate of ingestion of intermediate hosts by definitive hosts were important variables in predicting changes in moose populations. At present, we are unable to quantify these variables, and research in directions such as these would improve our understanding of how variations in frequency and density of infected intermediate hosts and their availability affect the transmission of *P. tenuis* to cervids.

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