SHORT COMMUNICATION

Helminth fauna of the Siberian chipmunk, *Tamias sibiricus* Laxmann (Rodentia, Sciuridae) introduced in suburban French forests

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Abstract The spread of an immigrant host species can be influenced both by its specific helminth parasites that come along with it and by newly acquired infections from native fauna. The Siberian chipmunk, *Tamias sibiricus* Laxmann (Rodentia, Sciuridae), a northeastern Eurasiatic ground nesting Sciurid, has been introduced in France for less than three decades. Thirty individuals were collected from three suburban forests in the Ile-de-France Region between 2002 and 2006. Two intestinal nematode species dominated the helminth fauna: *Brevistriata skrjabini* [Prevalence, P, 99% C.I., 87% (64–97%); mean intensity, M.I., 99% C.I., 43 (28–78)] and *Aonchotheca annulosa* [P, 47% (25–69%); M.I., 35 (3–157)]. *B. skrjabini* is a direct life cycle nematode species of North Eurasiatic origin, with a restricted spectrum of phylogenetically related suitable hosts. This result indicates that *B. skrjabini* successfully settled and spread with founder pet chipmunks maintained in captivity and released *in natura*. Chipmunks acquired *A. annulosa*, a nematode species with a large spectrum of phylogenetically unrelated suitable host species, from local Muroid rodent species with similar behavior, life-history traits and habitats. Quantitative studies are needed to evaluate the potential for both *B. skrjabini* and *A. annulosa* to impede the spread of *Tamias* and for *B. skrjabini* to favor chipmunk colonization through detrimental effects upon native co-inhabiting host species.

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Introduction

Parasitism can impede or favor the spread of an immigrant host species into a novel environment (Drake 2003). This effect depend on whether the host is infected by parasites acquired from native fauna (Höfle et al. 2004) or by parasites restricted to the host (Thomas et al. 1997). When abruptly introduced, small rodents can bring along with them a subset of their monoxenous and stenoxenous helminth species (i.e., direct life cycle species and with a restricted range of phylogenetically related suitable host), and generally, loose the more generalist species (Pisanu et al. 2001; Pisanu and Chapuis 2003). Then, helminth fauna can be enriched by the acquisition of oioxenous species (i.e., with a large spectrum of phylogenetically unrelated suitable hosts) present in the native fauna, in the new environment.

The Siberian chipmunk, *Tamias sibiricus* Laxmann (Rodentia, Sciuridae), is a species native from Northeastern regions of Eurasia [Siberia, Mongolia, North and Center China—Nowak (1991)]. Siberian chipmunks were introduced in Western Europe in the early 1970s (Mitchell-Jones et al. 1999). In France, 11 viable populations have recently been identified (Chapuis 2005; J.-L. Chapuis, personal communication). Most of them have originated from the introduction of individuals during the last three decades in the Ile-de-France Region, France (Chapuis 2005). Few studies have investigated the composition of the parasite fauna for this small terrestrial Sciurid (Asakawa 2001; Hasegawa and Asakawa 2003), both for native Northeastern Eurasian and introduced populations in Western Europe.

Here, we present a survey of the helminth fauna found on chipmunks collected in three populations from suburban forests of the Ile-de-France Region. On the basis of

the helminth species recovered, we discuss the potential for helminth species to spread with their hosts and for native helminth species parasitizing the local fauna to be transferred to chipmunks.

Materials and methods

Thirty chipmunks were analyzed: 22 individuals were live-trapped between August 2002 and September 2005 in the Forêt de Sénart (48°39′ N, 02°29′ E; 3,200 ha). Five individuals were trapped in June 2006 in the Henri Sellier urban park (48°46′ N, 2°16′ E; 26 ha). Three individuals were sampled in July 2006 at the Bois de Verneuil-sur-Seine (48°59′ N, 1°56′ E; 400 ha). The complete digestive tract was removed and fixed in ethanol 70–80° within the hour of death for the 22 chipmunks from Sénart. All the eight individuals trapped at H. Sellier and at Verneuil-sur-Seine were frozen at −20°C within the day of trapping. Helminths were searched by dissection of the complete gut walls and lumen and were counted using binocular lenses (×10–60). Species identification for specimens from Family Capillariidae Railliet, 1915 followed the descriptions by Bain and Wertheim (1981) and in subfamily Brevistriatinae Durette-Desset, 1971 by Durette-Desset (1970, 1976). Species identification was done using morphological analysis made from drawings of worms cleared in lactophenol under a microscope equipped with a camera lucida. Prevalence of infection (i.e., the number of hosts infected by a helminth species over the total number of hosts examined, in percent) was compared between sites using the Fisher's exact test. Worm intensity of infection (i. e., the average number of worms per host, excluding uninfected individuals in the samples) was compared between sites by calculating the Mood's median test (Rózsa et al. 2000). The 99% confidence intervals based on the binomial distribution are always following the prevalence and based on 2,000 bootstrapped replications for the mean intensity. All calculations were made using the Quantitative Parasitology 3.0 software (Reiczigel and Rózsa 2005). Significance level was set at $p=0.05$.

Results

Only nematodes were recorded from the digestive tract of the 30 individuals examined. Six taxa were found of which two species dominated (Table 1). Brevistriata skrjabini (Schulz and Lubimov 1932; Durette-Desset 1976) was found in the duodenum of the host in the three localities. Prevalence was 87% (64–97%), and mean intensity of 43 (28–78) worms per host. We could not find any significant difference in mean worm burden between the localities

(Table 1). Aonchotheca annulosa (Dujardin, 1845) Bain et Wertheim, 1981 was recovered in the duodenum of the host in each locality, with a prevalence of 47% (25–69%) and mean intensity of 35 (3–157) worms per chipmunk. Chipmunks from H. Sellier Park were significantly more frequently infected by A. annulosa than chipmunks at Sénart, where 8 out off 22 individuals were infected (Fisher's exact test: $p=0.019$). Furthermore, chipmunks from H. Sellier Park hosted more nematodes than chipmunks at Sénart and at Verneuil-sur-Seine (Table 1). Overall, 1,599 worms were counted of which seven specimens from seven different hosts could not be identified at the species level: at Sénart, four chipmunks hosted a Trichuroid female in their cecum, and one chipmunk hosted an Oxyurid male in the cecum. One chipmunk harbored a Trichostrongyloid female and another Tamia, an Ascaroid male, in their duodenum, at Verneuil-sur-Seine.

Discussion

Schulz and Lubimov (1932) described B. skrjabini which was first recovered from T. sibiricus and red squirrels, Sciurus vulgaris s.l., in the Soviet Far East (Durette-Desset 1970). According to Durette-Desset (1976), the two species that form the genus Brevistriata Travassos, 1937 are restricted to palearctic Sciurids in a very specific biogeographic area covering Eastern China and Korea. Asakawa and Ohbayashi (1986) first recorded B. skrjabini from two specimens chipmunks in Otaru (Hokkaido, Northern Japan), and no helminths were recorded from a single individual analyzed from Akkeshi-cho, Hokkaido (Asakawa 2001). Brevistriatiinae belong to the Family Heligmonellidae Durette-Desset et Chabaud, 1977, which is characterized by monoxenous species, i.e., with a direct life cycle (Anderson 1992). Given its distribution, B. skrjabini was probably carried on by the Siberian chipmunks that founded the French populations. Such a process is common for many introduced wild and domestic vertebrates (Dobson and May 1986; Kennedy 1993; Barton 1997; Font 2003; Pisanu and Chapuis 2003; Taraschewski 2006) and for introduced pet species (Ide et al. 2000; Suzuki and Asakawa 2000; Yokoyama et al. 2003). B. skrjabini was maintained in all the feral host populations prospected, including the small "insular" population of H. Sellier Park surrounded by a densely urbanized area. This occurred despite the fact that chipmunks of the different populations probably originated from different pet shops and were kept in captivity by different owners. The first record of B. skrjabini in France was made 36 years ago from two chipmunks imported from Korea (Durette-Desset 1970). This nematode has, therefore, been introduced with its hosts

Table 1 Helminth species found in 30 Siberian chipmunks *T. sibiricus*, in three suburban forests of the Ile-de-France Region, France

Site	Sénart (N=22)		Henri Sellier (N=5)		Verneuil-sur-Seine (N=3)		P_M
Brevistriata skrjabini	n=20	44 (26–77) [1–225]	n=3	29 (20–38) [30–87]	n=3	29 (20–35) [20–38]	1.000
Aonchotheca annulosa	n=8	2 (1–4) [1–7]	n=4	116 (6–327) [3–431]	n=2	[1; 2] –	0.024
Other taxa	n=5	[1; 1; 1; 1; 1]	n=0	–	n=2	[1; 1]	–

Number of hosts analyzed (*N*), number of infected hosts (*n*) and mean intensity of infection followed by the 99% confidence intervals between brackets and range in worm counts below, are shown for each host population. Chipmunks have been collected between August 2002 and July 2006. P_M indicate the exact probability from median comparison calculated by the Mood's test.

very early and has been successfully maintained in chipmunks leaving in both captivity and natural conditions. This observation highlights the role of animal translocations in the risk of introducing zoonose into a novel environment (Taraschewski 2006), more specifically, stenoxenous and monoxenous helminth species.

A. annulosa is an oioxenous intestinal nematode mainly encountered in the wood mouse, *Apodemus sylvaticus*, its type-host, and the bank vole, *Clethrionomys glareolus*, in Northern Africa (Tunisia: Bernard 1987), Western Europe (Italy: Milazzo et al. 2003, 2005; Spain: Feliu et al. 1997; France: Roman 1951; Belgium: Bernard 1961) and Eastern Europe (Czech and Slovak republics: Moravec 2000; World distribution: see Gibson 2005). World distribution of the main host species for *A. annulosa* indicates that this parasite is restricted to the Western Palearctic forest belt (Mitchell-Jones et al. 1999; Nowak 1991). It is absent in the Northwestern part of China (i.e., the Xinjiang Uygur Region, see Asakawa et al. 2001) and Japan (Hasegawa and Asakawa 2003). As the chipmunks that founded the French populations were coming from the most Eastern parts of *T. sibiricus* native area (Korea, Japan: Chapuis 2005), *A. annulosa* was probably acquired by chipmunks after their introduction. Wood mice and bank voles are common at Sénart and in the H. Sellier Park (J.-L. Chapuis, personal communication). Given that both the introduced chipmunks and the native rodents are ground nesting species and terrestrial foragers, it is not surprising to encounter *A. annulosa* in *T. sibiricus*; similar behaviors, life histories, and habitat use may facilitate the infection by local helminth species (Combes 1995). Infections by *A. annulosa* were significantly more frequent and intense in the H. Sellier Park than at Sénart. This pattern of infection is characteristic of the helminth fauna of insular vertebrates (Thomas et al. 1997; Combes 1995). Such a high level of infection suggests a higher rate of transmission of *A. annulosa* in an isolated insular type of host population (i.e., H. Sellier Park) than in a larger population (i.e., Sénart). This could either be due to a change in the behavior of chipmunks or to a higher rate of dissemina-

tion in the native host populations. This result also suggests that chipmunks in H. Sellier Park may be less resistant against infection than other populations, as found for inbred populations of small rodents on small islands (Meagher 1999).

The other unique Sciurid that lives with introduced chipmunks in French forests is the red squirrel. The helminth species of native red squirrels in Western Europe was investigated in Belgium (Bernard 1961), Spain (Feliu et al. 1994), and in Bielorussian Polesie (Shimalov and Shimalov 2002). Considering only intestinal nematode species, six taxa were recorded of which only two species are restricted to Sciurids: *Trypanoxyuris* (*Rodentoxyuris*) *sciuri* (Cameron, 1932) Hugot, 1984, parasitizing *Sciurus* spp. in all Western Europe (Hugot 1984), and *Syphabulea mascomai* Hugot et Feliu, 1990, which have only been found in Iberian populations. Thus, according to our results, introduced chipmunks in French forest did not acquire the stenoxenous species found in western squirrels (Hugot 1984) named *T. (R.) sciuri*, although this parasite has been found in two red squirrels from H. Sellier Park and from Sénart (B. Pisanu, personal communication). Except those species restricted to western Sciurids, five generalist species were found in western *S. vulgaris*, of which four are known to primarily infect small ground-nesting mammals, including *A. annulosa* in Bielorussian Polesie (Shimalov and Shimalov 2002). This result provides evidence that some aspects of red squirrel behavior that forage on the ground, like introduced chipmunks, favors the transmission of ground-related infective stages of parasitic nematode that are disseminated by co-inhabiting terrestrial small mammals and that Sciurid are suitable hosts for *A. annulosa*.

The helminth fauna of introduced chipmunks in France confirms that introduced animals can bring with them direct life cycle helminth species with reduced spectrum of phylogenetically related suitable host species. According to Hugot and Feliu (1990), the highly restricted area for the Oxyurid *S. mascomai* indicates a long-term biogeographic isolation of southwestern populations of Iberian red squirrels. This situation can lead to both behaviorally and

physiologically less defensive hosts toward new parasitic infections (Taraschewski 2006). After establishment, the helminth fauna of the immigrant is enriched by native species, providing that similar behavior, life histories, and habitat use may facilitate the infection, and that the new host is suitable for generalist helminth species. More quantitative data on helminth infection are needed to precisely investigate the balanced influence of direct detrimental effect of both introduced and native helminth infections on the spread of the immigrant host and the indirect advantage to it of introducing novel helminth that may be detrimental to potentially competitive native hosts.

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