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Arthropod parasites of the red-bellied squirrel *Callosciurus erythraeus* introduced into Argentina

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Abstract. The introduction of an exotic species usually modifies parasite–host dynamics by the import of new parasites or the exotic species' acquiral of local parasites. The loss of parasites may determine the outcome of an invasion if the introduced species is liberated from co-evolved parasites in its range of invasion. In addition, an introduced species may pose sanitary risks to humans and other mammals if it serves as a reservoir of pathogens or carries arthropod vectors. The red-bellied squirrel, *Callosciurus erythraeus* (Pallas) (Rodentia: Sciuridae), was introduced into Argentina in 1970, since when several foci of invasion have been closely associated with humans. Investigation of the parasitological fauna of *C. erythraeus* in Argentina will generate new information about novel parasite–host dynamics and may provide new insight into the reasons for the successful invasion of this species. The objective of this study was to describe the arthropod parasites of *C. erythraeus* in Argentina in comparison with previous studies of parasites of this species in its native habitat and in the ranges of its invasion. Occasional host–parasite associations with local arthropod parasites not previously described for *C. erythraeus* are reported; these include the mites *Androlaelaps fahrenholzi* (Ewing) (Mesostigmata: Laelapidae) and *Ornithonyssus* cf. *bacoti* (Mesostigmata: Macronyssidae), the flea *Polygenis (Polygenis) rimatus* Jordan (Siphonaptera: Rhopalopsyllidae) and the botfly *Cuterebra* Clark (Diptera: Oestridae: Cuterebrinae). *Cheyletus* sp. mites (Trombidiformes: Cheyletidae) were also found. The low prevalence and mean intensity of ectoparasite species may influence invasion dynamics.

Key words. *Callosciurus erythraeus*, botfly, fleas, invasive species, mites, parasite–host dynamics.

Introduction

The introduction of an exotic species usually modifies existing parasite–host dynamics because new parasites are imported from their native range into the recipient community and because the exotic host may acquire new parasites from native hosts, especially if a parasite is able to expand its host range (Tompkins & Poulin, 2006). Parasites may also play an important role in the outcome of the invasion process, as has been reported for several introduced species that have escaped the negative effects of parasitism (Torchin *et al.*, 2003). Introduced squirrels have been reported to pose sanitary risks to humans and native species by their carriage of arthropod vectors that may transmit pathogens (Craine *et al.*, 1995; Shinozaki *et al.*, 2004; Pisanu *et al.*, 2010; Marsot *et al.*, 2011). However, the role of these parasites in the success of an exotic species' invasion is still unclear.

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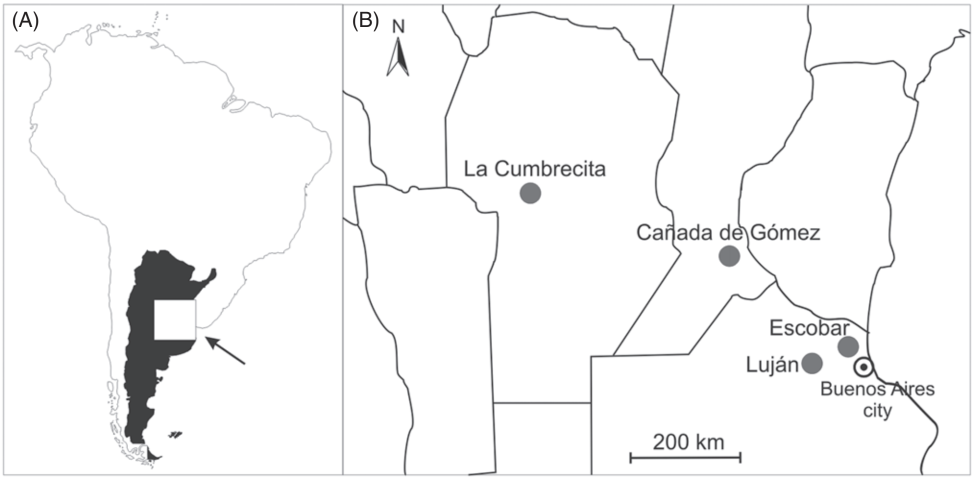

Fig. 1. (A) Location of the area of interest within Argentina, and (B) locations of the four invasion foci next to the cities of Luján and Escobar in Buenos Aires province, Cañada de Gómez in Santa Fé province, and La Cumbrecita in Córdoba province.

The red-bellied squirrel, *Callosciurus erythraeus* (Pallas), is native to Southeast Asia and was intentionally introduced into Argentina, Belgium, France, Japan and the Netherlands (Tamura, 2009). The origin of the first wild population in Argentina is well known: in 1970 10 red-bellied squirrels were obtained from a pet shop in the Netherlands and taken to a ranch near the town of Jáuregui (34°34′ S, 59°11′ W), Luján district, Buenos Aires province (Aprile & Chicco, 1999). By 1973, about five individuals had escaped or had been released from captivity; these animals initiated a population that has increased in abundance and range distribution to manifest in a predicted invasion of major proportions (Guichón & Doncaster, 2008). This arboreal squirrel inhabits rural and urban areas in close association with humans and domestic animals (Guichón *et al*., 2005) and has spread successfully, creating new foci of invasion, by virtue of repeated translocations and the trade in exotic pets (Benitez *et al*., 2010).

No previous parasitological studies have been conducted on the red-bellied squirrel in Argentina. Therefore, the aim of this study was to describe the fauna of arthropod parasites associated with this species in all invasion foci confirmed in Argentina. The results are interpreted in the context of the invasion process according to previous findings in native and other introduced ranges.

Materials and methods

Between November 2008 and March 2010, red-bellied squirrels were trapped alive in all invasion foci in Argentina: (a) Luján, Buenos Aires province, where two study sites located 10 km apart were sampled: National University of Luján (34°33′ S, 59°07′ W) and Open Door (34°30′ S, 59°04′ W); (b) Escobar (34°21′ S, 58°48′ W), Buenos Aires province, 35 km from Luján; (c) Cañada de Gómez (32°48′ S, 61°23′ W), Santa Fe province, 290 km from Luján, and (d) La Cumbrecita (31°53′ S, 64°46′ W), Córdoba province, 610 km from Luján (Fig. 1). Distances amongst study sites exceeded the daily movements and the expected dispersal distances of this species (Guichón & Doncaster, 2008). Squirrels inhabit rural, suburban and urban habitats where they live in highly fragmented woodland patches mainly composed of introduced tree species. In each study site, 30–50 cage traps were set at fixed points 40 m apart on tree branches for 4 days consecutively. All captured squirrels were anaesthetized

Table 1. Arthropod parasites recovered from 437 red-bellied squirrels, *Callosciurus erythraeus*, captured between November 2008 and March 2010 in four invasion foci in Argentina.

Arthropods	Squirrels, *n*	Arthropods collected, *n*	Prevalence	Intensity, mean (range)	Invasion foci
Siphonaptera (fleas)					
Polygenis (*Polygenis*) *rimatus* (Jordan, 1932)	3	4	0.68%	1.3 (1–2)	Lu
Diptera (botflies)					
Cuterebra sp.	4	4	0.91%	1.0	Lu, Es
Acari (mites)					
Mesostigmata *Androlaelaps fahrenholzi* (Ewing, 1925)	3	4	0.68%	1.3 (1–2)	Lu, CG
Ornithonyssus cf. *bacoti*	1	1	0.23%	–	Lu
Trombidiformes *Cheyletus* sp. (group *eruditus*)	26	41	5.90%	1.6 (1–6)	Lu, Es, CG, LC

CG, Cañada de Gómez, $n = 28$; Es, Escobar, $n = 39$; LC, La Cumbrecita, $n = 10$; Lu, Luján, $n = 390$).

Table 2. Arthropod parasites reported for *Callosciurus erythraeus* indicating known parasite distribution and squirrels' site of collection.

Arthropod species	Known geographical distribution	Site of collection	References
Insecta			
Siphonaptera (fleas)			
Stivaliidae			
Medwayella robinsoni (Rothschild, 1905)	Malayan and Indo-Chinese subregions; Malaysia, Thailand*	Malayan peninsula	Shinozaki *et al*. (2004)
Ceratophyllidae			
Monopsyllus anisus Rothschild, 1907	Central and East Asia, Siberian province; Japan, China, Russia*	Japan	Shinozaki *et al*. (2004)
Nosopsyllus fasciatus (Bosc, 1800)	Worldwide*	France	Dozières *et al*. (2010)
Ceratophyllus euteles (Jordan & Rothschild, 1911)	Indo-Chinese and East Asian subregions; China*	China	Jordan (1932)
Macrostylophora bispiniforma Li *et al*. 1976	East Asian subregion; China*	China	Li *et al*. (1976)
Macrostylophoraliae (Wang Dwenching, 1957)	East Asian subregion; China*	Southeast Asia	Traub (1972)
Megathoracipsylla pentagonia Liu *et al*. 1980	East Asian subregion; China*	China	Liu *et al*. (1982)
Rhopalopsyllidae			
Polygenis (*Polygenis*) *rimatus* (Jordan, 1932)	Patagonian, Andean and Brazilian subregions Argentina, Brazil*	Argentina	Present study
Phthiraptera (lice) Anoplura			
Enderleinellidae			
Enderleinellus kumadai Kaneko, 1954	Borneo, Malaysia, Taiwan, Thailand (southern Asia†‡)	Belgium, France, Japan	Durden & Musser (1994); Dozières *et al*. (2010)
Enderleinellus corrugatus Johnson, 1959	China, Hainan Island, Thailand (southern Asia†‡)	China, Thailand	Chin (1979); Durden & Musser (1994)
Hoplopleuridae			
Hoplopleura erismata Ferris, 1921	India, Malaysia, China, Thailand (southern Asia†‡)	Belgium, China	Blagoveshchenskiy (1972); Durden & Musser (1994); Dozières *et al*. (2010)
Polyplacidae			
Neohaematopinus callosciuri Johnson, 1959	Borneo, Malaysia, China, Taiwan, Thailand (southern Asia†‡)	Japan, Thailand, China	Blagoveshchenskiy (1972); Durden & Musser (1994); Shinozaki *et al*. (2004); Zuo *et al*. (2011)
Diptera (botflies)			
Oestridae (Cuterebrinae)			
Cuterebra sp.	America§	Argentina	Present study
Arachnida			
Acari (mites and ticks)			
Mesostigmata (mites)			
Laelapidae			
Laelaps nuttalli Hirst, 1915	Worldwide¶	China	Huang *et al*. (2010)
Laelaps turkestanicus Lange, 1955	Asia, former USSR¶, China**	China	Huang *et al*. (2010)
Laelaps traubi Domrow, 1962	China**	China	Huang *et al*. (2010)
Eulaelaps dremomydis Gu & Wang, 1984	China**	China	Huang *et al*. (2010)
Androlaelaps fahrenholzi (Ewing, 1925)	Worldwide¶	Argentina	Present study
Hypoaspis pavlovskii (Bregetova, 1955)	China**	China	Huang *et al*. (2010)
Macronyssidae			
Ornithonyssus cf. *bacoti*	Worldwide¶	Argentina	Present study

Table 2. Continued

Arthropod species	Known geographical distribution	Site of collection	References
Haemogamasidae (mites)			
Haemogamasus kitanoi Asanuma, 1948	Asia, Russia¶	Taiwan	Allred (1969) in Shinozaki *et al.* (2004)
Haemogamasus dorsalis Teng & Pan, 1964	China**	China	Huang *et al.* (2010)
Haemogamasus oliviformis Teng & Pan, 1964	China**	China	Huang *et al.* (2010)
Ixodida (ticks) Ixodidae			
Haemaphysalis flava Neumann, 1897	Japan, China, Taiwan, South Korea, Russia††‡‡	Japan	Shinozaki *et al.* (2004)
Ixodes kuntzi Hoogstraal & Kohls, 1965	Nepal, Taiwan††‡‡	Taiwan	Hoogstraal & Kohls (1965)
Trombidiformes (mites)			
Cheyletidae			
Cheyletus sp. (group *eruditus*)	Worldwide§§	Argentina	Present study

*Medvedev *et al.* (2011); †Durden & Musser (1994); ‡Orrell (2011); §Pape (2001); ¶Strandtmann & Wharton (1958); **Huang *et al.* (2010); ††Kolonin (2009); ‡‡Guglielmone *et al.* (2003); §§Fain & Bochkov (2001).

subcutaneously using a ketamine–acepromazine mixture and their fur was combed and brushed. Squirrels were released after each trapping session and ectoparasites were recovered only at first capture. Samples of arthropods were filtered and stored in 96% ethyl alcohol. Filter papers were examined using a stereomicroscope and arthropods were individually prepared for identification. Mites were cleared in lactophenol and slide-mounted in Hoyer's medium; fleas were cleared in potassium hydroxide, dehydrated in ethanol of consecutive grades (80%, 90% and 100%) and slide-mounted on Canada Balsam. An optic microscope (10× and 40×) was used for taxonomic identification carried out in accordance with related keys and descriptions (Strandtmann & Wharton, 1958; Furman, 1972; Smit, 1987; Welbourn, 2006). Krantz and Walter (2009) was followed for higher taxa of Acari. Botfly larvae were removed with forceps and stored in 96% ethyl alcohol before identification using a stereomicroscope.

The prevalence of each arthropod species was calculated as the percentage of the total number of hosts examined that were parasitized with that species. Mean intensity was calculated as the total number of individuals of a particular parasite species over the total number of parasitized hosts (Bush *et al*., 1997).

Results

A total of 437 red-bellied squirrels were captured in the four invasion foci in Argentina during the study period. This allowed the description of parasites belonging to three taxa of arthropods (Table 1). The flea *Polygenis (Polygenis) rimatus* Jordan, the mites *Androlaelaps fahrenholzi* (Ewing) and *Ornithonyssus* cf. *bacoti*, and the botfly larvae *Cuterebra* Clark were each identified in one or two invasion foci. Mites *Cheyletus* sp. group *eruditis*) were found in the four invasion foci established in Argentina. Cheyletidae mites showed a higher prevalence (5.9%) than the parasitic arthropods (<1%). A relatively low mean intensity of one to two arthropods per squirrel was recorded in all groups (Table 1).

Discussion

The parasites reported in this study have not been previously listed for the red-bellied squirrel in either its native habitat or in areas to which it has been introduced (Table 2). Arthropod parasites associated with this species in its native range include several species of Siphonaptera and Laelapidae, three species of lice (Phthiraptera: Anoplura) and one species of tick (Ixodida: Ixodidae) (Table 2). None of the genera of laepid mites associated with the red-bellied squirrel in southwest China have ever been reported in Argentina, except for *Laelaps nuttalli* (Hirst, 1915) (Lareschi & Mauri, 1998). In other areas into which red-bellied squirrels have been introduced, such as in Belgium, France and Japan, these squirrels have been found to have carried parasites from their native range into the recipient community and also to have acquired new parasites from co-inhabiting native hosts (Table 2) (Shinozaki *et al*., 2004; Dozières *et al*., 2010).

The mites *A. fahrenholzi* and *O.* cf. *bacoti*, and the flea *P.* (*P.*) *rimatus* have worldwide or American distributions (Lareschi & Mauri, 998; Linardi & Guimarães, 2000) and are usually associated with sigmodontine rodents and marsupials (Autino & Lareschi, 1998; Lareschi & Mauri, 1998), which are native hosts sympatric with the red-bellied squirrel in Argentina. *Cheyletus* sp. mites have a worldwide distribution, are predators and are mostly associated with nests of birds and mammals or grain stores (Fain & Bochkov, 2001). *Cheyletus* sp. (group *eruditis*) mites are associated with nests of squirrels, including *Callosciurus* squirrels (Fain & Bochkov, 2001), although this is the first record of their association with *C. erythraeus. Cuterebra* is a Neotropical genus of an obligate subcutaneous parasite botfly (Colwell *et al*., 2006). In Argentina, these larvae have been reported in sigmodontine rodents (Zuleta & Vignau, 1990) and a native squirrel [Berg, 1876 in Guimarães *et al.*, 1983; see Pape (2001) for synonymia].

The low prevalence and mean intensity values of parasitic arthropods of the red-bellied squirrel in Argentina may be explained by the history of its introduction, the lack of sympatric phylogenetically related mammals, and its highly arboreal habits. These prevalences and mean intensity values of parasitic arthropods were lower than those reported for the red-bellied squirrel in other areas to which it has been introduced (Shinozaki *et al*., 2004; Dozières *et al*., 2010), where the success of its invasion in terms of range expansion and abundance seems lower than in Argentina (Tamura, 2004; Gerriet, 2009; Benitez *et al*., 2010). Community-scale comparisons (Colautti *et al*., 2004) also suggest a lower level of parasitism in red-bellied squirrels than in other co-inhabiting mammals (Lareschi *et al*., 2003; A. C. Gozzi *et al*., unpublished data, 2011). These findings suggest that the successful invasion of this exotic species may have been, in part, supported by its release from natural parasites.

This study indicates that the red-bellied squirrel introduced into Argentina serves as an occasional host of local parasites acquired mainly from sympatric wild mammals. Some of the arthropod parasites of *C. erythraeus* in Japan are competent vectors of pathogens (Shinozaki *et al*., 2004) and although the mite *O.* cf. *bacoti* and the flea *P. (P.) rimatus* were not tested for vector competence, the genus *Polygenis* Jordan is implicitly involved in the maintenance of sylvatic plague among wild rodents (Linardi & Guimarães, 2000), and the mite *Ornithonyssus bacoti* Hirst is known to be a potential vector of pathogens such as *Rickettsia* species (Reeves *et al*., 2007). The sanitary risks posed by the red-bellied squirrel in Argentina to native fauna seem to be low at present; however, given this species' urban and rural habits and the fact that it is perceived as an attractive animal and is thus the object of an illegal pet trade, preventive measures should be put in place to limit potential sanitary risks until further parasitological and zoonotic studies are concluded.

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