Short Communication

Farther inland invasion of Finlayson's squirrel *Callosciurus finlaysonii* (Horsfield 1823) poses a new conservation challenge for the endemic near threatened Calabrian black squirrel *Sciurus meridionalis* Lucifero 1907 (Rodentia: Sciuridae)

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Abstract - Understanding both native and non-native species ecology, including their distribution and interaction, is crucial for making informed decisions on conservation and management strategies, particularly for endemic threatened species. In this study, we report an update on the non-native Finlayson's squirrel *Callosciurus finlaysonii* invasion of southernmost Campania (Italy), where the species is rapidly expanding its range towards inland areas. Our observational data confirmed the pattern of invasion for the Finlayson's squirrel, extending the species' presence 10 km further inland than what was reported before. Here, we also collected the first evidence of black morph squirrels' occurrence potentially attributable to the Calabrian black squirrel, *Sciurus meridionalis*, a near-threatened and little-studied tree squirrel endemic of southern Italy. As a habitat of good quality, the area of potential new presence for this endemic squirrel represents an ecological corridor possibly enhancing individual dispersal from the neighbouring region into new suitable areas. However, due to the invasion of Finlayson's squirrel, the two species likely became sympatric here, with endemic squirrels possibly suffering the competing effect of the alien species. We highlighted the importance of in-depth studies, including genetic surveys, to better understand the occurrence and ecology of the Calabrian black squirrel outside its historical range, and to plan effective control actions to prevent further expansion of the Finlayson's squirrels.

Key words: Calabrian black squirrel, ecological corridor, Finlayson's squirrel, inter-regional studies, sympatric distribution.

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Riassunto - L'ulteriore invasione dello scoiattolo di Finlayson *Callosciurus finlaysonii* (Horsfield 1823) pone una nuova sfida alla conservazione del quasi minacciato scoiattolo nero meridionale *Sciurus meridionalis* Lucifero 1907 (Rodentia: Sciuridae).

Comprendere l'ecologia delle specie native ed esotiche, incluse la loro distribuzione e interazione, è fondamentale per prendere decisioni informate sulle strategie di conservazione e gestione, in particolare per le specie endemiche minacciate. In questo studio, riportiamo un aggiornamento sull'invasione dell'esotico scoiattolo di Finlayson *Callosciurus finlaysonii* nella parte più meridionale della Campania (Italia), dove la specie sta rapidamente espandendo il suo areale verso le aree interne. Le nostre osservazioni hanno confermato la direzione di invasione dello scoiattolo di Finlayson, estendendo la presenza della specie 10 km più all'interno di quanto riportato in precedenza. Qui abbiamo anche raccolto le prime prove della presenza di scoiattoli neri potenzialmente attribuibili allo scoiattolo nero meridionale *Sciurus meridionalis*, una specie arboricola quasi minacciata e poco studiata endemica dell'Italia meridionale. Essendo un habitat di buona qualità, l'area di potenziale nuova presenza di questo scoiattolo endemico rappresenta un corridoio ecologico possibilmente utile ad agevolare la dispersione individuale dalla regione vicina verso nuove aree idonee. Tuttavia, a causa dell'invasione dello scoiattolo di Finlayson, le due specie sono probabilmente diventate simpatriche in quest'area, con gli scoiattoli endemici potenzialmente sottoposti all'effetto competitivo della specie aliena. Di conseguenza, abbiamo sottolineato l'importanza di studi futuri approfonditi, comprese indagini genetiche, al fine di comprendere meglio la presenza e l'ecologia dello scoiattolo nero meridionale al di fuori del suo areale storico, nonché di pianificare azioni di controllo efficaci per impedire un'ulteriore espansione dello scoiattolo di Finlayson.

Parole chiave: corridoio ecologico, distribuzione simpatrica, scoiattolo nero meridionale, scoiattolo di Finlayson, studi inter-regionali.

With increasing global trade and ongoing climate change, the introduction of non-native species and their expansion continue to increase (Bertolino *et al*., 2020; McKinney & Lockwood., 1999; Seebens *et al*., 2017), representing a major threat to endemic species, biodiversity in general, human and ecosystem health worldwide (Stoett *et al*., 2019). In Europe, where non-native mammal species are mainly introduced for hunting or through escapes from captivity and intentional releases (Genovesi *et al*., 2009), squirrels (Rodentia: Sciuridae) are highly invasive species, with the Eastern grey squirrel *Sciurus carolinesis* Gmelin 1788 replacing the native Eurasian red squirrel *Sciurus vulgaris*

Linnaeus 1758 in many countries, and the Finlayson's squirrel *Callosciurus finlaysonii* (Horsfield 1823) (Fig. 1a) rapidly expanding its range in Italy (Bertolino *et al*., 2020; Wauters *et al*., 2023).

Native from Southeast Asia, Finlayson's squirrels (3-4 pairs) have been introduced for ornamental purposes in the middle of the 1980s in south Italy (Aloise & Bertolino, 2005). Starting from the releasing point (Maratea, Basilicata region), this species is spreading along the Tyrrhenian coast both northwards (north of Sapri, Campania region) and southwards (Calabria region), as well as colonizing inland areas (Bertolino & Lurz, 2013; Fig. 2). During 2008-2016, this alien squirrel has in fact invaded inland areas of southernmost Campania with a rate of expansion of approximately 1.4 km/year, reaching a point located about four times further from the coast than it was previously reported (maximum distance from the coast: 3.6 km, Aloise & Bertolino, 2005; 14.5 km, Iudici *et al*., 2016; Fig. 2). Despite the long time since the Finlayson's squirrel was first reported to be present and expanding in this area (Aloise & Bertolino, 2005) and since it was identified as a management priority for eradication (Bertolino *et al*., 2020), no action has been implemented to prevent further spread of this species, not even within protected areas, whose primary aim is to preserve the integrity of ecosystems.

Competition with alien species, along with habitat fragmentation and loss, are the main threats to the native squirrel species in Italy (Bertolino *et al*., 2014; Mortelliti *et al*., 2011; Rima *et al*., 2009; Santicchia *et al*., 2018). Moreover, invasive species have also been proven to act as a stressor that significantly increases the concentrations of glucocorticoids in native species (Santicchia *et al*., 2018). Among Italian native squirrel species, the Calabrian black squirrel (Fig. 1b) represents a tree squirrel endemic to southern Italy. Originally restricted to three disjointed populations of the main Calabrian massifs (Pollino, Sila, and Aspromonte), during the last decades, the species experienced a range expansion that made the northern Calabrian populations to connect (Rima *et al*., 2009), but also expanding northwards the species range into Basilicata (Mori & Menchetti, 2014; Bartolomei *et al*., 2016; Wauters *et al*., 2017; Amori & Castiglia, 2018; Cordeschi *et al*., 2021; Fig. 2). However, the restricted range and the limited ecological data (e.g., Cagnin *et al*., 2000; Rima *et al*., 2009) led to including the species as *Near Threatened* in the IUCN Italian red list (Rondinini *et al*., 2022). Previously considered a sub-species of the Eurasian red squirrel, the Calabrian black squirrel is genetically (Grill *et al*., 2009; Wauters *et al*., 2017) and morphologically (Amori *et al*., 2014) different from *S. vulgaris*, having larger body size (e.g., skull width and length, mandible length, hind foot length, and overall body weight), with a monochromatic black coat, white undersides, and the presence of ear tufts during the winter (Fig. 1b). The coat colour of Eurasian red squirrels, on the other hand, is highly variable (Grill *et al*., 2009), normally ranging from red to brown-grey, showing dark brown to blackish colouration in some areas of the species' range in central Apennines, which could complicate discrimination of *S. meridionalis* and *S. vulgaris* based on morphology (https://www.mammiferi.org/specie/). However, recently published data suggest that *S. vulgaris* and *S. meridionalis* are allopatric (separated by ~150 km), with the southernmost limit for the former corresponding to northern Campania (Cordeschi *et al*., 2021; Wauters *et al*., 2017; Fig. 2).

In this note, we report observational data, collected opportunistically in southern Campania in the period 2017-2022, on Finlayson's alien squirrel and on what, identifying the species on the basis of morphological characteristics, could potentially be the endemic Calabrian black squirrel (Figs. 1 and 2). As a matter of fact, although there is considerable variation in colour patterns (Boonkhaw *et al*., 2017), unlike squirrels in the genus *Sciurus*, none of the species in the genus *Callosciurus* has ear tufts in any season (Tamura, 2009; Fig. 1a). On the other hand, acknowledging the lack of supporting genetic evidence, the distance from the areas in the central Apennines where Eurasian red squir-

Fig. 1 – Individual of Finlayson's squirrel *Callosciurus finlaysonii* (a), and Calabrian black squirrel *Sciurus meridionalis* (b) observed in the southernmost part of Campania (south Italy), during 2017-2022. Photographs: A. Iudici (a), O. Gallo (b). / Individui di scoiattolo di Finlayson *Callosciurus finlaysonii* (a) e scoiattolo nero meridionale *Sciurus meridionalis* (b) osservati nella parte più meridionale della regione Campania (sud Italia), nel periodo 2017-2022. Fotografie: A. Iudici (a), O. Gallo (b).

rels have been reported to show blackish coloration, and the proximity (~7 km) with the current known range of *S. meridionalis* (Fig. 2) makes us believe that our observations of black morph squirrels are likely attributable to the Calabrian black squirrel. This considered, we attributed 39 squirrel observations to *C. finlaysonii*, confirming its known distribution and expansion pattern with a further inland extension (~10 km) of the range of this alien species (Fig. 2). In contrast, black squirrels were detected only twice at the very same site (once in March and once in October 2022; Fig. 1b) during an opportunistic survey on the presence of the Eurasian otter *Lutra lutra* in the upper Tanagro river valley (Fig. 2). This site represents not only an occurrence record out of the current known *S. meridionalis* range, but also the first potential observation of Calabrian black squirrel expansion into Campania.

With an elevation range of 560-900 m a.s.l., except for the areas occupied by croplands and riparian vegetation along the Tanagro river, the habitat in the new occurrence site of the Calabrian black squirrel is mainly characterized by deciduous forest dominated by oaks (*Quercus cerris* L., *Q. pubescens* Willd. subsp. *pubescens*), with smaller patches of *Castanea sativa* Mill. and coniferous plantations of *Pinus nigra* J.F.Arnold. This diversified landscape offers good-quality habitat for Calabrian black squirrels, which positively select both oak (*Quercus* spp.) and pine (*Pinus nigra* J.F.Arnold subsp. *laricio* Palib. ex Maire and *P. nigra* J.F.Arnold) dominated mixed forests, while they use beech *Fagus sylvatica* L. woods mainly where they are contiguous or close to other preferred habitat types (Cagnin *et al*., 2000; Rima *et al*., 2009).

The site we have identified as one of the possible presence of *S. meridionalis* is located in a continuous and ecologically suitable habitat, geographically situated in a context that could represent a potential ecological corridor for dispersal from already colonised areas towards new suitable areas in the Cilento, Vallo di Diano and Alburni National Park (PNCVDA; Fig. 2). Although, to the best of our knowledge, the species has never been reported for the PNCVDA, which is only 2 km away from the observation point (Fig. 2), it cannot be ruled out that this well-preserved protected area (the second largest national park in Italy) could easily be colonised by the Calabrian black squirrel, on which only data on habitat selection and population density are currently available from populations inhabiting two of the historical areas of presence, where the species occurs scattered and at low densities (PNP: 0.03-0.72 ha, Rima *et al*., 2009; PNS: 0.44-0.61 ha, Cagnin *et al*., 2000).

By updating Finlayson's squirrel distribution and reporting the possible presence of the Calabrian black squirrel in

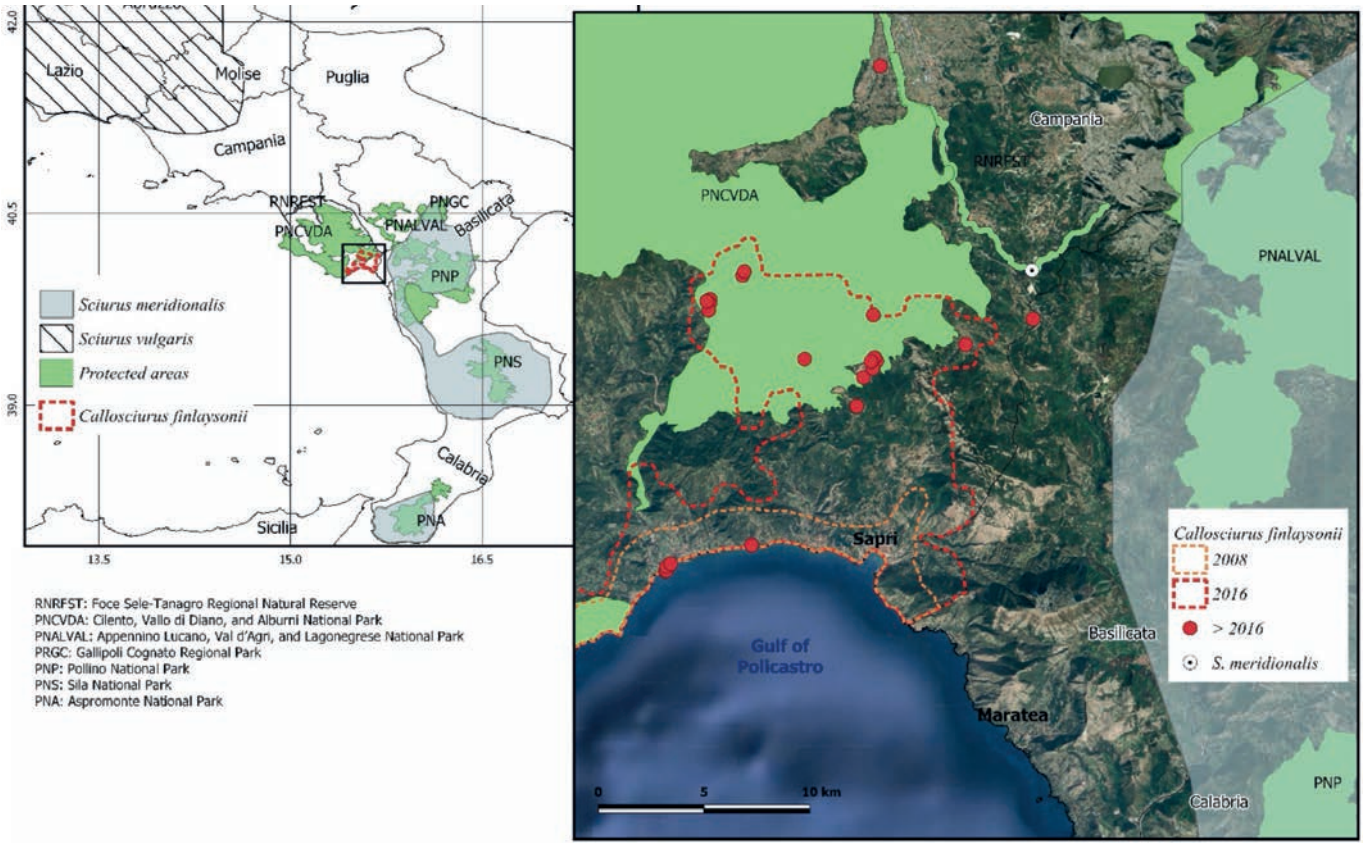

Fig. 2 – Direct observation locations of Finlayson's squirrel *Callosciurus finlaysonii* and Calabrian black squirrel *Sciurus meridionalis* in the extreme south of Campania (south Italy), during 2017-2022. The distribution of Finlayson's squirrel in Campania (Iudici *et al*., 2016) is also reported, while inset map shows the southern range limit of the Eurasian red squirrel *Sciurus vulgaris* and the current range of the Calabrian black squirrel (from Cordeschi *et al*., 2021). Green polygons show protected areas. / Siti di osservazione diretta dello scoiattolo di Finlayson *Callosciurus finlaysonii* e dello scoiattolo nero meridionale *Sciurus meridionalis* nell'estremo sud della Campania (Italia meridionale), nel periodo 2017-2022. Si riporta anche la distribuzione dello scoiattolo di Finlayson in Campania (Iudici *et al*., 2016), mentre la mappa nell'inserto mostra il limite meridionale dell'areale dello scoiattolo rosso eurasiatico *Sciurus vulgaris* e l'attuale areale dello scoiattolo nero meridionale (da Cordeschi *et al*. 2021). I poligoni verdi indicano le aree protette.

Campania, our note emphasises the need for in-depth studies aimed at assessing many as yet unexplored aspects of its biology. First of all, the research effort should include genetic surveys aimed at revealing the possible presence of the Calabrian black squirrel outside its historically recognised range. Secondarily, other aspects of the biology of this endemic species call for investigation, including site-specific assessments of its feeding ecology, reproduction, population dynamics, and interspecific relationships with the other coexisting and potentially competing squirrel species, particularly the alien Finlayson's squirrel. Actually, considering the close distance (~2.3 km) between the new potential presence site of the Calabrian black squirrel and the easternmost observation site of Finlayson's squirrel (Fig. 2), it is likely that the two species have already become locally sympatric. This hypothesis, if confirmed, makes even more urgent the need for studies aimed at improving knowledge of the Calabrian black squirrel and identifying the main variables that could compromise its survival. The combined information will ultimately serve as a key tool for making better-informed decisions on the conservation status of the endemic *S. meridionalis* and for planning appropriate management strategies to ensure the establishment of viable long-term populations and their maintenance, including effective containment of the Finlayson's squirrel.

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