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Editorial: Ecology, impact, and management of squirrel invasions

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Editorial on the Research Topic
Ecology, impact, and management of squirrel invasions

Worldwide, conservationists are faced with introductions of squirrel species of different geographic origins (Mazzamuto et al., 2021). The invasion of American grey squirrels (*Sciurus carolinensis*) and their impact on Eurasian red squirrels (*S. vulgaris*) through multiple mechanisms represents a textbook example of biological invasions dominating the research literature (Figure 1A). However, numerous other established alien squirrels affect biodiversity, leading to declines in native species and economic damages (e.g. Bertolino and Lurz, 2013).

Managing alien squirrel populations is often controversial and met with public opposition, therefore their removal necessitates knowledge on different management techniques and on the social-ecological network surrounding these invasions. The science of squirrels' invasion reflects the complexity of the topic and has evolved over time (Adriaens et al., 2023). Initially strongly focusing on invasion mechanisms, the literature is now increasingly addressing species traits linked to invasiveness, interactions with other species, and management, policy and decision-making (Figure 1B). Several papers also deal with human dimensions. The management literature focuses mostly on techniques for population control, with an increased attention for developing alternative approaches such as fertility control (Figure 1C). Whereas prevention and eradication are crucial to conservation, they are relatively little documented. Habitat management and conservation paradoxes receive little attention, indicating a knowledge gap and a need for holistic approaches that consider ecosystem resilience and processes.

The growing awareness of biological invasions and associated developments in biosecurity legislation create a demand for evidence on effective methods for prevention, rapid response and control of established populations of invasive squirrels. This Research Topic aims to close some of that knowledge-doing gap (Esler et al., 2010). It includes original research papers, a perspective, and reviews, highlighting the multidisciplinary nature of this topic at the interface of ecology, modeling, and decision making. Two contributions focus on interventions for eradicating introduced squirrel species in Japan and the Netherlands. Tamura and Yasuda summarize papers and reports originally written

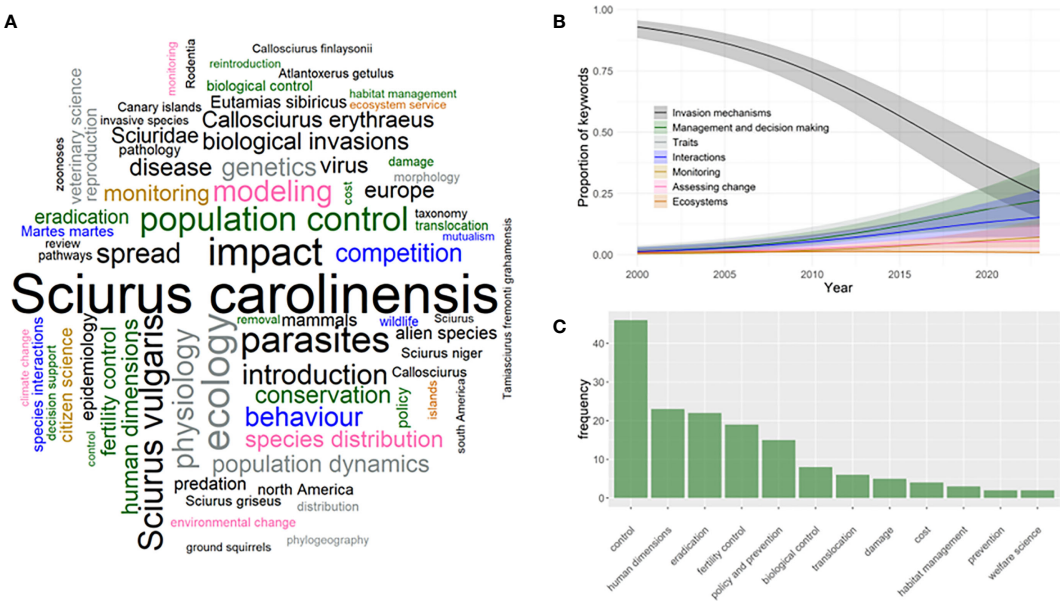

FIGURE 1
(A) Word cloud showing the relative importance of research topics related to squirrel invasions, **(B)** modeled change in the relative frequency of research categories since 2000 using a Dirichlet bayesian regression model, **(C)** detailed topics of the management literature. Based on a mapping of keywords (N = 1275) from 217 WoS papers on invasive squirrels since 2000 (Adriaens et al., 2023) using the classification of Stevenson et al. (2023).

in Japanese. They emphasize the need for tailored management approaches based on the ecology of the species, the landscape, and initial population density in a country with strong needs for endemic species conservation. Haye et al. report the successful eradication of a Pallas's squirrel population in the Netherlands. The campaign shows similarities with an earlier Belgian eradication (Adriaens et al., 2015), yet required sterilization and rehoming of squirrels to gain public support. Both contributions illustrate the importance of science-based management and researcher involvement in achieving eradication success.

Modeling approaches can provide insights into appropriate control plans, their short- and long-term effects. Cost-effective methods for estimating densities and predicting the time and effort needed for successful management have been explored for grey squirrels in the UK. Camera-trap indices can determine the number of feeders or traps required, and reduce the need for expensive equipment (Beatham at al.). van der Waal and Mill highlight the challenge of predicting the time and effort required for successful management of invasive species and discuss the importance of data collection for quantifying population abundance during adaptive management operations. The contributions from Japan, the Netherlands, and the United Kingdom also report the costs associated with the management actions. As response programs are often limited by available budgets, this information is of great value to invasive species managers in other countries.

Solving problems arising from non-native species invasions requires multidisciplinary approaches and public support. A systematic review of the red-grey squirrel paradigm by Wauters et al. reveals the complexity of mechanisms behind it, affected by landscape-level processes and multi-species interactions. The review highlights the strengths and weaknesses of different control strategies in European countries and emphasizes the importance of evidence-based communication to policy makers, stakeholders, and the public. Finally, the review on North American flying squirrels by Diggins demonstrates how neo-native species that expand their range through climate change and human induced environmental change can negatively impact recipient ecosystems through mechanisms similar to invasions.

Whilst clearly invasive squirrel research has developed to better inform the needs of managers and decision makers, some response programs remain little documented, such as the ones for Pallas's squirrel in Argentina (Benitez et al., 2013) and France (Chapuis et al., 2014). In the global south, article processing charges represent a barrier to publication (pers. comm. L. Guichon; Smith et al., 2021). This could be addressed by dedicated funding from networks like INVASIVESNET (Lucy et al., 2016) or by applied Research Topics in mammal society journals with lower or no article processing charges. The management work in Europe, for instance in the Crau plain and Cap d'Antibes (France), once published, could be helpful to other managers who want to plan scientific follow-up.

Balancing the effectiveness and welfare implications of methods used in squirrel management is crucial. Acceptability is an important aspect of risk management (Booy et al., 2017; Robertson et al., 2021) and will often determine the feasibility of control campaigns, especially with alien squirrels that appeal to the wider public (La Morgia et al., 2017). A recent welfare assessment of various methods is available which includes squirrel species regulated by the EU IAS Regulation (Smith et al., 2022). Nevertheless, welfare science related to invasive squirrel management is rare and requires data on impacts on (non-)target species in different welfare domains (cf. De Ruyver et al., 2023). We

anticipate this could be an exciting venue for future work in line with an increased traction for invasive squirrel management and a drive for management innovations. Lastly, proactive invasive species policies require an evidence base in horizon scanning and risk assessment (Peyton et al., 2020).

Author contributions

VLM: Conceptualization, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing, Visualization. MVM: Conceptualization, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing, Visualization. TA: Conceptualization, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing, Visualization.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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