Restricted access to private properties limits management of invasive alien species: A literature review and case studies

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Restricted access to private properties limits management of invasive alien species: a literature review and case studies

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Abstract
Biological invasions are one of the major drivers of global environmental changes and there is the need to develop integrated strategies to counteract this phenomenon. Eradication is an effective management option to mitigate the deleterious impacts of invasive alien species (IAS). It can be achieved if all reproductive animals are removed and population recovery is prevented. However, animals may survive removal operations in private areas if interventions are not allowed. Here, we present 1) three case studies in which restricted private property access prevented the local eradication of invasive alien populations, and 2) a list of reasons for denying access to private properties and actions implemented or suggested by managers to facilitate access extracted from 29 reviewed papers. The restricted access affected the local eradication of three Eastern grey squirrel (*Sciurus carolinensis*) populations in Italy. In Lombardy region, in one area a planned eradication did not start and in another an eradication failed for the refusal from the owner of a large private property to grant access to managers. In Umbria region, the lack of collaboration from an Italian financial institution produced a delay of 15 months in the removal. In our case studies, therefore, a single person or institution denied access for a personal gain or for pretended internal security. The reasons behind landowner opposition may be diverse and individual attitudes towards IAS management will depend on interactions with owners. According to our review, in many cases the denial of access takes place in a general climate of mistrust or opposition to the project as the results of a limited engagement of local people. Such opposition often jeopardizes control activities, with profound consequences of decisions by private owners on eradication at the landscape scale. Bottom-up approaches aiming at involving stakeholders can increase the possibility to achieve IAS eradication, however appropriate legislation remains pivotal to enforce eradication in case of non-cooperative behaviour.

Keywords: eradication, citizens' involvement, literature review, management, introduced species, *Sciurus carolinensis*

1. Introduction

Biological invasions are one of the major drivers of human-induced global environmental changes, which are negatively impacting biodiversity, ecosystem services and human well-being (Simberloff et al., 2013; Shackleton et al. 2019). Since the magnitude of biological invasions continues to increase (Seebens et al. 2017), there is the need to develop strategies to improve our capacity to counteract this phenomenon (Simberloff et al., 2013).

Eradication is nowadays considered as one of the most effective management options to counteract the deleterious impacts caused by invasive alien species (hereafter IAS). Successful eradications have led to substantial results in terms of species conservation and ecosystems restoration (Jones et al. 2016; Robertson et al. 2017). Removing populations of IAS makes a significant contribution to the global conservation goals required by the Convention on Biological Diversity (CBD 1992), such as the Aichi Biodiversity Target 9 (i.e., invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated) and Target 12 (i.e., threatened species extinctions are prevented). In accordance with these targets, the EU Biodiversity Strategy for 2030 requires to manage established IAS so to decrease the number of Red List species they threaten by 50% (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0380&from=EN).

Eradication is particularly effective within the framework of an early warning and rapid response system, which can allow to quickly remove small propagules and avoid the establishment and spread of invasive species (Booy et al. 2020; Robertson et al. 2020). The strengthening of early warning systems and the implementation of a rapid response capacity are critical elements for integrated pest management and for the effective containment and control of epidemic animal diseases. However, eradication may be a valid management option also at later invasion stages, since many populations that established across large spatial scales have been successfully eradicated (Jones et al. 2016; Robertson et al. 2017). Many successful eradications happened on islands (Jones et al. 2016), but even on mainland some populations can have the characteristics of an island population, living in isolated habitats surrounded by a non-permeable matrix (Adriaens et al. 2015).

Eradication is "the complete and permanent removal of all wild populations from a defined area by a time-limited campaign" (Bomford & O'Brien 1995). Assessing the feasibility of an eradication campaign requires the evaluation of several biological and technical parameters, as well as social and political factors which can affect the success of any management countermeasure (Bomford & O'Brien 1995; Crowley et al. 2017). Here, we focus on some criteria considered fundamental to achieve eradication (Bomford & O'Brien 1995): the rate of individuals' removal must exceed the rate of the target population increase at any density; immigration should be prevented; and all reproductive or potentially reproductive animals should be exposed to removal. The first criterion is associated with the removal effort, and thus to human power, motivation and funds available. Removal rate usually declines at low population densities and for a reduction of the population size to zero is necessary to maintain a high removal effort, even for a long time (Gosling & Baker 1989). The second criterion, i.e. immigration prevention, can be achieved for areas delimited by effective barriers, whether they are real physical barriers or margins maintained by control to prevent recolonization, or with isolated populations. The last criterion requires that all reproductive and potentially reproductive animals must be removed to avoid a population recovery. The three criteria are interconnected, since

animals that are not at risk of removal could continue to reproduce and spread into previously targeted areas where all individuals were eliminated, thus increasing the population density.

Fundamental criteria to achieve eradication might not be satisfied when invasive species colonize private areas in which the unavailability of the owners constrains the access to managers. This may be more common in urbanized areas. Land or private property owners could deny access to their properties, thus directly or indirectly contrasting the removal of invasive individuals and jeopardizing control activities. Indeed, Bomford & O'Brien (1995) identified not only the criteria essential for achieving IAS eradication, but also some other 'desirable criteria' which determine if eradication is a priority over other management approaches. They also recognized that the socio-political environment plays a role in determining the prospects for successful eradication. The socio-political criteria include avoiding conflict with communities, or reduce the conflict as much as possible, having clear administrative goals, and removing legal barriers; this last point includes securing access by managers to private land to ensure all animals are removed.

Many eradication projects received strong opposition from NGOs and other sectors of the society concerned for animal welfare and the use of lethal measures (e.g. Bertolino & Genovesi 2003; Crowley et al. 2017, 2019). Although several papers have already proposed strategies to avoid, mitigate or resolve conflicts with different sectors of the society (e.g. Perry & Perry 2008; Crowley et al. 2017, 2019), how the access of private properties can jeopardize alien species management has been overlooked.

We present three Italian case studies in which restricted private property access prevented the local eradication of invasive Eastern grey squirrel (*Sciurus carolinensis*, hereafter grey squirrel) populations (in Lombardy region) and significantly delayed the effective removal of another invasive population of the same species (in Umbria region). We also review the literature to find other cases where non-cooperative interactions with owners of land and private properties hampered eradication projects and to explore which actions have been implemented, or suggested, to address this issue.

2. Grey squirrel case studies

The grey squirrel is an American species replacing the native Eurasian red squirrel (*Sciurus vulgaris*, hereafter red squirrel) in Great Britain, Ireland and Italy, where the alien species has been introduced for ornamental purposes or as escaped pets (Bertolino 2008). The replacement is mainly due to exploitation competition for food resources, with the introduced species more efficient in their use (Wauters et al. 2002a, b). In Great Britain, where grey squirrels carry a squirrelpox virus which is lethal for the native species, the replacement is much faster (Tompkins et al. 2003). This virus is not present in grey squirrels in Italy (Romeo et al. 2018) where, however, spillover of a common parasitic helminth of grey squirrels to naïve red squirrels occurs (Romeo et al. 2015; Santicchia et al. 2020).

The grey squirrel was introduced in Italy multiple times from 1948 onwards (Martinoli et al. 2010; Loy et al. 2019); also, alien grey squirrels were translocated from one area to another within the country (Signorile et al. 2016). The primary introduction and secondary translocation of animals generally occurred for ornamental purposes, with animals released in private properties, urban green areas or nearby (Martinoli et al. 2010). In urban parks and private properties, grey squirrels reach high densities also due to supplementary feeding provided by citizens, thus becoming easily visible and highly appreciated by owners and visitors (Merrick et al. 2016). Grey squirrel populations in urban and suburban parks may function as sources of propagules for the colonization of surrounding landscapes, depending upon the characteristics of the environment and the distance to suitable woodlands.

Modelling simulations have shown that the grey squirrel can potentially spread across most of Europe (Bertolino et al. 2008; Di Febbraro et al. 2016, 2019). Therefore, introduced populations have been actively managed for eradication or spatial control when too widespread (Bertolino et al. 2015). In Italy, squirrels are generally removed through live-trapping and euthanasia; only for a small

population in Genoa Nervi (Liguria) and for part of the population in Umbria, live-trapped animals were surgically sterilized and released in an urban park (Scapin et al. 2019).

The current invasive range of the species in Italy encompasses open territories, protected areas, small and large cities, public green areas and many private properties. Therefore, the management of populations requires the collaboration of many institutions (e.g., local wildlife and park services, regional authorities, mayors of municipalities) and the involvement of citizens. Particularly, in the presence of large private properties within the range of a target population, it is essential to involve the owners to get access. Therefore, the management plans have foreseen to identify and contact landowners; however, their collaboration is not always granted. Decision on whether to adhere or not could be based on a plethora of elements. First of all, landowners can refuse to collaborate because they are against killing the squirrels. Social conflicts in IAS management have been described for multiple taxa and they are generally related to the lethal techniques adopted (Bertolino & Genovesi 2003; Estévez et al. 2015). In particular, humaneness seems to be the most important factor regarding the decision to support or oppose squirrel control activities, and methods which do not involve any direct killing are the most acceptable (Dunn et al. 2018). The grey squirrel is indeed perceived as an appealing mammal, and divergence of views on the need to euthanize animals easily arise (Bertolino & Genovesi 2003; Benson 2013). For these reasons, the citizen's attitude towards grey squirrels and the removal activities has been considered a critical element to inform grey squirrel management in Italy (La Morgia et al. 2017).

2.1. Lombardy

In Lombardy region (Italy), the grey squirrel invasive range is fragmented in numerous nuclei distributed across seven large areas. Control activities started in three areas within the European EC-SQUARE LIFE project and continued after the end of the project. Aim of this LIFE project was to develop methods to eradicate or control grey squirrel populations in different socio-ecological contexts.

2.1.1. Case 1

One of the area, called Adda, was composed by 6 subunits, two in close proximity with only red squirrels and the other four at increasing distances and colonised by grey squirrels (Fig. 1). In subunits 3-5, nearly the whole territory was accessible to managers. After two years of trapping, grey squirrels were extirpated from these sub-units in 2014, and native red squirrels from neighbouring populations consequently recolonized subunit 5 (Fig. 1).

Successful removal of the grey squirrel in subunit 6 was interrupted by one private estate owner refusing to grant access to a large park (Table 1, 6 ha, 2.3% of the subunit) inhabited by an important subpopulation of grey squirrels. This estate was used as a revenue for matrimonies, company feasts, and other receptions and grey squirrels represented an extra attraction for the park. In collaboration with the authorities of the regional park managing the surrounding landscape, we had several phone calls and email exchange, instrumental in explaining the importance of removing the local squirrels for the entire regional control project. Additionally, we repeatedly proposed to arrange meetings in order to reach a management compromise. Despite these efforts, the owner never accepted to meet project staff, not even when the town administration proposed to act as facilitator. Repeated contacts with the other owners highlighted that many of them would be willing to allow entry if the animals were first removed from the largest property, which, hosting numerous squirrels, acted as a source of dispersing animals by.

To avoid the spread of grey squirrels toward other areas, a periodical trapping activity was implemented in public places around the private properties in subunit 6. Between 2014 and 2017, grey squirrels from this subunit dispersed along the river corridors into subunit 5, colonizing also the woodland that hosted the largest local red squirrel population (see also Santicchia et al. 2020). In subunit 5 and 6, 170 animals have been removed from 2014 onwards (82 in susunit 6, Table 1). Hence,

in this case, the lack of collaboration from the owner of a key property has prevented the complete eradication of the grey squirrel from a large area and transformed the intervention into an expensive ongoing control program.

2.1.2. Case 2

In the Lariano triangle (Fig. 1), an incipient small and localised population of grey squirrels was concentrated in and around a vast estate of an international foundation. Contacts with the administrators were held by email and phone and the eradication project was presented and explained. The administrators asked extra evidence to back up the conservation importance of grey squirrel control, and we obtained two letters of support to our project by two of the most eminent American academic researchers working on grey squirrels in their native range. Despite these letters strongly advocated that our project was crucial for the conservation of native red squirrels, the foundation declined access to the estate for carrying out grey squirrel trapping because of a presumed violation of the security and privacy of their international hosts. This refusal had cascading effects on neighbouring smaller private landowners. Since at least 60% of the local population occurred in the land owned by the foundation, the neighbouring landowners no longer recognized the purpose of admitting us to work on their properties and decided not to collaborate. The eradication of this small nucleus of grey squirrels was therefore considered not possible.

2.2. Umbria

In Umbria Region, in 2015 the grey squirrel was present with one population distributed over an area of 36.9 km^2 in the city of Perugia and neighbouring areas. Management actions have been implemented in the framework of the European LIFE U-SAVEREDS project, aimed at eradicating grey squirrels from this area, and are still ongoing. Management units (MU) were identified by considering anthropogenic and natural features of the area, and general knowledge about the local distribution of the species (Fig. 2). Two large and fenced properties were identified as critical areas for the success of the eradication plan. These properties were both characterized by a strategic geographic position across the invaded area and habitats highly suitable for the grey squirrel.

The first key property was in MU28 (Table 1), in the core area of the grey squirrel invasive range. The landowner granted access to this property in January 2016 and the grey squirrels' removal started immediately after. To avoid recolonization, captures were also implemented in the neighbouring MUs and the accessible area summed up to 55% of the total spatial extent of the MUs (Fig. 3a). 366 and 201 squirrels were removed, respectively in 2016 and 2017 (Fig. 4). As a consequence of the control activities, the local densities of grey squirrels seemed substantially reduced, as revealed by the results of density surface models (DSMs, Hedley & Buckland, 2004; Miller et al., 2013) fitted to direct observations of the animals gathered in 2015 (Fig. 3b) and 2017 (Fig. 3c) through a point transect distance sampling approach (Buckland et al., 2001). At the end of the project, in October 2018, no grey squirrels were detected in MU28.

The second key property was located further to the north-east, within MU65 (Table 1). Removal of the grey squirrel from this area was considered relevant for the overall success of the project because the MU is close to a north-eastern ecological corridor potentially connecting the Perugia city area to the Apennines (Fig. 2). The managers of the large property were contacted following the directions of a communication plan focusing on targeted communication and a meeting was organized. However, at the end they refused any collaboration. The area is owned by an Italian financial institution and the reason for the refusal to cooperate was ascribed to security issues. After the denial of this major landowner, a very low proportion of small landowners accepted to collaborate with the project activities and the total accessible area for grey squirrel control was very limited (16%, Table 1, Fig. 3d). Capture activities were substantially delayed for 15 months (Fig. 4) and when they started, traps were placed at the boundaries of some private properties, mainly along public roads. This strategy required a considerable increase in the time devoted to fieldwork to place and constantly

check the traps during the day. The results achieved from 2015 to 2017 in terms of reduction of the grey squirrel densities are shown in Fig. 3e and 3f.

Because of the difficulties encountered, the eradication of the grey squirrel from the Perugia area could not be achieved within the time frame of the LIFE Project (2014-2018), creating problems to find additional resources for the following years. Nevertheless, the densities of the alien species estimated through conventional distance sampling were significantly reduced, from 3.37 ind./ha (coefficient of variation, CV = 0.18) in 2015, to 0.38 ind./ha (CV = 0.21) in 2017. The removal campaign is still ongoing and recent monitoring revealed the presence of the native red squirrel in new areas, including the first key private property.

3. Literature review

We conducted an extensive literature review in April 2021 to exemplify cases in which restricted access to private properties hampered management of invasive species. We searched for studies in Google Scholar by using the following keywords: access restriction, accessibility, alien species, control, eradication, invasive species, restricted access, management, private properties. Additional references were retrieved tracking the bibliography of selected articles.

We retrieved 29 papers: 26 reporting difficulties in controlling or eradicating IAS because of restricted access to private properties and three that explicitly declared the support of citizens and the possibility to act in private lands (Supplementary Material 1). In one of these three cases, residents even self-taxed themselves to pay a private trapper to remove iguanas (Engeman et al. 2018). It is probable that many other successful projects were supported by private owners, without this being specifically reported in the literature.

The papers retrieved deal with projects on mammals (12 papers), birds (2), reptiles (3), amphibians (6), insects (3), and plants (4). From these articles, we extracted sentences (edited for synthesis) that referred to the difficulty of accessing private properties and the indication of actions taken by managers to gain access (Supplementary Material 1). These texts were then elaborated in a list of reasons for denying entry to private lands as emerged from the literature and actions that have been undertaken or suggested as useful to overcome this opposition and facilitate access (Table 2).

Restricted access to private properties severely reduced the efficacy of the eradication campaign directed against, for example, the invasive American bullfrog (*Lithobates catesbeianus*) in France (Piria et al. 2017) and the guttural toad (*Sclerophrys gutturalis*) in South Africa (Vimercati et al. 2017; Davies et al. 2020). Even for the Asian tiger mosquito (*Aedes albopictus*), control has been occasionally hampered by access restriction. Although Unlu and Farajollahi (2012) reported high public support to control mosquitoes in Trenton (New Jersey, USA), several residents rejected any mosquito surveillance and control measures on their property as in Monmouth County (New Jersey, USA) (Fonseca et al., 2013). A very similar difficulty arose in Malaga (Spain), where management of the Asian tiger mosquitoes was limited by its spread across private houses that were not accessible to managers (Dana et al. 2019). Removing plants from private properties can also be problematic. Among 30 eradication projects covering 23 potentially invasive plant species with limited distributions on four Galapagos Islands, only four projects were successful, and all occurred inside the property of a single owner (Gardener et al., 2010). Among the remaining 26 projects on the contrary, six failed because landowners denied permission to carry on eradication in their properties (Gardener et al. 2010).

In many projects, citizens were not informed, not engaged, or not supportive (Table 2). People denying entrance to their lands did so more often in a general climate of distrust or opposition to the project. These cases were often the results of a limited engagement of local people. When opposition raises, it is often too late to reverse the established belief. Therefore, a proactive approach is suggested, possibly involving the local community from the first phases of planning and decision. Engaging local people could result in a rise of the project and, in some cases, also in the participation

of volunteers in the management of the target species (Sarat et al. 2015; Halliwell et al. 2019). Community engagement should, however, be effective and not only a proposed goal. An outreach campaign alone does not ensure the actual involvement of citizens, and confrontation meetings with main stakeholders are necessary (Varnham et al. 2011; Engeman et al. 2018). Inclusive models of engagement require collaborations between experts and laypeople to evaluate various management options (Crowley et al. 2017), and this must be based on mutual credibility. For instance, on Great Barrier island (New Zealand), part of the local community was concerned by aerial application of toxins used to eradicate rats, and it required at least five years to establish "a more informed and sympathetic societal framework" (Ogden & Gilbert 2009).

Human relations with animals could be complex and emotional. For instance, ornamental pets are often selected because they convey positive emotions to buyers. Therefore, when alien populations are established in urban areas, they can easily become an attraction for people. In the Netherlands, the support of citizens was considered crucial for the success of the red-bellied tree squirrel (*Callosciurus erythraeus*) eradication campaign, as many squirrels lived in private gardens (La Haye 2019). The collaboration of the local community was gained by spaying trapped squirrels and maintaining them in captivity rather than causing their death. When residents could not accept the use of toxic bait in rats and mice eradication, live trapping was used as a supplementary technique (Engeman et al. 2018). Adapting eradication protocols is, therefore, a possibility to engage and find a middle-ground with local communities. However, such adaptation is not always possible since the behaviour of neophobic or trap-shy rodents could make live-trapping ineffective, or sterilization (Scapin et al. 2019) and maintenance of large number of animals in captivity could be problematic due to cost, infrastructure needed, and animal welfare. Croft et al. (2021) concluded that fertility control alone is unlikely to achieve rapid enough population reduction to prove a viable cost-effective alternative to completely replace culling of grey squirrels. Therefore, the adaptation of protocols to answer requests from the community should always focus on the management goal. On the contrary, Kalnicky et al. (2014) found that citizens accepted coqui frogs (*Eleutherodactylus coqui*) when they were more common on their property; therefore, managers may be more effective at engaging citizens in control efforts before habituation becomes widespread.

When the local community is engaged, providing evidence of results could help involving reluctant landowners. On Anglesey island (UK), the grey squirrel eradication led to the re-establishment of native red squirrels, thus persuading many sceptics on the need to remove alien species. The re-establishment of the charismatic red squirrel also provided significant socio-economic benefits to green tourism (Schuchert et al. 2014; Halliwell et al. 2019). Conversely, in New Zealand, the eradications of goat (*Capra hircus*) and Himalayan tahr (*Hemitragus jemlahicus*) populations failed because landowners restricted hunting access to their land being concerned about losing a valued food resource (goats, Parkes 1990) or the availability of trophy males for fee-paying clients (tahrs, Forsyth et al. 2001).

The lack of legislation that provides staff powers of access to private lands for IAS control has been proposed as a negative point in some projects (Dana et al. 2019; La Haye 2019; Davies et al. 2020). Such legislation was adopted in Great Britain and South Africa, but it has not been applied yet in both countries (Crowley et al. 2017; Davies et al. 2020) and therefore its effectiveness is still unknown.

4. Discussion

An eradication is successful when all the individuals of the target population are removed (Bomford & O'Brien 1995). Accordingly, all areas where animals are present should be accessible to managers. For species widespread over large ranges and that will inevitably be present in many private properties, this entails the need to contact many owners for gaining the permission to access their properties; therefore, gaining access has been recognized as one of the greatest challenges for many

management programs. Dana et al. (2019) also suggested that the permission to work on private properties should be included in the feasibility analysis of IAS management actions. Indeed, lack of access to part of the area occupied by an invasive population may imply that not all reproductive and potentially reproductive animals are exposed to removal, an aspect which is obviously fundamental to achieve eradication (Bomford & O'Brien 1995).

Here, we presented three case studies regarding the attempted eradication of invasive grey squirrels, which failed or were delayed because of the refusal from the owners of large key properties to grant access to managers.

In Lombardy, the lack of collaboration from the owner of a large property – who was interested in having the squirrels as an attraction for those attending matrimonies, company feasts, and other receptions – prevented the eradication of the grey squirrel population from a management subunit, while the species was successfully removed from other three adjacent subunits. In these subunits, management actions resulted in the recolonization of the forested habitats from native red squirrels which had gone extinct due to the competition with their invasive congener. Nevertheless, a complete eradication was not achieved and, despite ongoing control activities, the grey squirrel is currently re-invading the areas from which it was extirpated. In another management unit, the refusal to collaborate by an international foundation led to consider the eradication of a small grey squirrel population as impractical.

In Umbria, two large and fenced properties were identified as critical areas for the success of the eradication plan. In the first area (MU28), grey squirrels were initially widespread and abundant. However, the main property and other landowners collaborated, so that grey squirrels were fully extirpated. In the second area (MU65), the landowner of the main property and many other landowners did not collaborate. Here, the lack of collaboration postponed the start of the removal activities and increased trapping effort and overall cost having to remove invasive squirrels at the boundaries of the inaccessible private properties, which significantly increased the time devoted to fieldwork. Overall, in Umbria the removal activities resulted in a significant reduction of the density of the alien species, while the native red squirrel colonised new areas. Nonetheless, the delay of a year and a half in the start of the management actions did not allow to reach the eradication within the four years of the European LIFE project and new financial resources now need to be sought.

A review of the literature provided evidence of similar situations where eradication projects failed due to the lack of collaboration from private owners. Even the support for the control of Asian tiger mosquito, which poses a high human health risk, is known to vary widely across different areas, with some residents refusing any kind of inspection (Fonseca et al. 2013, Dana et al. 2019).

Indeed, private decisions can have profound consequences for eradication at the landscape scale (Costello et al., 2017). Social factors play an overriding role in determining the success of eradications or other management options (Bremner & Park 2007; Crowley et al. 2017). While a number of projects received strong support from local inhabitants (Saunders et al. 2007, Engeman et al. 2018), conflicts raised in the community can frustrate management attempts. Negative attitudes can arise from mutualistic wildlife value orientations (Manfredo et al. 2009), which are common in urbanized areas, where negative emotions connected with wildlife management could be amplified (Jacobs et al. 2014; Lioy et al. 2019). In this context, also species charisma may influence media portrayal and public perceptions, promoting opposition to management (Jarić et al. 2020).

Management projects not supported by the whole community can more easily cause owners to refuse to collaborate. In our case studies, indeed, we noticed that the behaviour of owners seemed to be influenced by the attitude of the neighbours, with individual decisions partly depending on interactions across owners, as in a network game (Jackson & Zenou, 2014; Costello et al., 2017).

The whole social and ecological context should be addressed to engage landowners in invasive species management. Indeed, besides ethical issues, there may be other reasons for landowners to decide whether or not to adhere to the proposed management plans. In some cases, the owners simply do not want people inside their properties, while the decision to be involved may also depend on the level of contribution by other citizens and the likelihood of the plans being effective and maintaining

an ecological balance (Niemiec et al. 2017). Informing and involving community stakeholders is important in creating socially acceptable eradication operations, which facilitate interactions with landowners and cooperative behaviours. Landowners may be willing to share responsibility with the central governments for the eradication of invasive alien species, depending on their perspectives. The latter are in turn associated with ecological and social features of the landscape, and with conservation perceptions and policy preferences that can be affected by communication and information networks (Siebert et al. 2006; Urgenson et al. 2013).

Bottom-up approaches aiming at the involvement of community stakeholders have thus been considered as a potential solution for the management of invasive species. In this respect, door-to-door campaigns and direct contact with owners could facilitate cooperative interactions (Baldacchino et al. 2017). Such actions certainly require time and resources, but they have proven valid at engaging citizens, and they can certainly be most effective in the early stages of invasion, before habituation or even affection to the alien species becomes widespread (Kalnicky et al. 2014). Examples of successful engagement include the control of invasive pines in a coastal zone of southern Brazil (de Sá Dechoum et al. 2018), of coqui frogs (*Eleutherodactylus coqui*) introduced to Hawai (Beard et al. 2000), and the cooperation among multiple agencies, a private resort and local citizens to eradicate Polynesian rats (*Rattus exulans*) on Cocos Island, Guam (Engeman et al. 2018).

However, there are cases where involvement may fail or be incomplete. Landowners may be motivated to control invasive species, but they may not be fully aware of their role in spreading species to other areas (Fenichel et al. 2013). This problem is related to a mismatch of scales at which the different processes occur. Biological invasions take place at the landscape scale, with movement of animals (or spread, for plants) that may occur among multiple private properties. On the contrary, individual owners are generally incentivised to consider the costs and benefits of controlling species in their own property only, rather than considering the damage at landscape level, thus generating 'externalities' (Fenichel et al. 2013, Epanchin-Niell & Wilen 2014). Owners may also differ in their experience and perception of the issue, for instance because damage or control costs vary between different properties. Additionally, owners might not be informed on the issue or might disregard the consequences of their actions on adjacent owners, thus adopting a non-cooperative behaviour that compromises management (Costello et al. 2017).

Despite efforts to involve community stakeholders and citizens, there may be cases where owners refuse to grant access to their lands for the most diverse reasons. In our case studies, the refusal came from a financial institution and an international foundation with armed surveillance, which did not want strangers on their properties, and from a private owner, who believed grey squirrels were a useful attraction for a business associated with social ceremonies, such as weddings and other parties. Since in these cases non-cooperative behaviours from a minority of people can jeopardize the results of the project, a top-down approach that enforces eradication to reluctant landowners may be identified as an alternative solution. For example, in Europe, the Regulation (EU) 1143/2014 on invasive alien (the IAS Regulation) has introduced an obligation to manage the species included in a list of Invasive Alien Species of Union Concern. The EU Member States have transposed this IAS Regulation, and in different countries IAS operations may take place on private properties according to national laws. Interestingly, and in relation to our case studies, the Italian law (National Legislative Decree 230/2017) now provides that the competent authorities (i.e., the Majors) adopt the measures necessary to guarantee access to private areas in case it is requested by the eradication of such IAS of Union Concern. However, the Decree was not in force when grey squirrel eradications were attempted in Lombardy and Umbria. A similar legislation is in force in many European countries (e.g., Belgium, France, England, Scotland) and in South Africa (Davies et al. 2020). Having enforced a legislation is not a guarantee for a successful outcome. Legislative action creates tension, with enforcement counteracting the engagement that would be gained by a more collaborative approach. We therefore do not support a general application of this enforcement but consider the availability of a dedicated legislation as fundamental to address specific situations.

Squirrel eradications may be particularly difficult. The perceived impact can be low or even null, since the invasive squirrels can also be interpreted as 'a good' by some citizens and landowners, while they can be regarded as a nuisance ('a bad') by others. As a consequence, the access to private properties could be regarded as one aspect of a more complex issue related to communication and removal techniques that are employed (Piria et al. 2017). The involvement of citizens in the decision making process and as volunteers in management activities can increase the success of invasive species eradication, reduce their cost, and help raise awareness and build public support (Bryce et al. 2011; Ford-Thompson et al. 2012; de Sá Dechoum et al. 2019). Nonetheless, the existence and enforcement of the correct legislation is pivotal in case of failure of the bottom-up approach.

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Table 1
Area covered and available for trapping and removal efforts for the case studies in Perugia (Umbria) and along Adda (Lombardy).

Region	***Lombardy***		***Umbria***			
Area	Adda		Perugia			
Management Unit	Subunit 6		MU 28 & neighbouring units		MU 65	
Difficulties						
Access to the main private property	No		Yes		No	
Surface areas	ha	% total area	km^2	% total area	km2	% total area
Total area	35.02		6.2		2.2	
Area of the main private property	6.51	18.59	0.4	6.45	0.06	2.73
Accessible private properties	0	0.00	0.8	12.90	0.13	5.91
Total accessible area	26.45	75.53	3.4	54.84	0.36	16.36
Trapping activity						
Period/Dates	2011-2017		2016-2018		2016-2018	
Trap-days	1380		6315		2726	
Trap-days/km2	394		1019		1239	
Squirrels removed	82		567		184	
Squirrels removed/trap-days	0.06		0.09		0.07	

Table 2
Reasons reported for denying access to private land properties as retrieved from the review of 29 articles, and actions implemented or suggested by scientists, managers or policy makers to facilitate access.

Reasons for denying access to private lands	Actions to facilitate access
Citizens are not informed or engaged	• Educate stakeholders about biological invasions • Public meeting, mailings, and door-to-door visits • Many small meetings are probably better than larger public meetings • Outreach with all available means, e.g. TV, radio, social media, newspaper and magazine articles, talks and presentations, website, newsletters • Establish agreements with owners about land management to improve relations between managers and them
Disagreement about species impacts	• Provide information during meeting and through media
People are skeptical about eradication's success	• Explain why eradication is needed and how it will be achieved
People distrust local authorities	• Involve the local community through a bottom-up approach
Citizens are not supportive	• Engagement of local people to raise the profile of the project • Involving local volunteers in the project • Show the return of native species after alien removal • Adapt eradication protocols • Adopt humane methods of killing • Animals sterilized instead of being euthanized • Explore the perception of landowners and stakeholders through interviews or other approaches.
The alien species is considered a resource	• Provide alternative socio-economic benefits
Citizens do not see any link with the local economy	• Provide more comprehensive socio-economic benefits (e.g. through green tourism for charismatic native species)

Emotional and complex human relationships with the IAS exist	• Provide information during meetings and through other means • Act rapidly before habituation to the species becomes widespread
Restricted access to private lands	
Some owners deny to grant access to private lands	• Get permission from relevant landowners and involve the community • Adopt legislation that provides staff powers of access to private lands for IAS control
Areas are restricted for hunting	• Get permission from relevant landowners and involve the community
Areas are restricted for a disease outbreak	• Work in other areas and wait
Plants are not effectively controlled/regulated by landowners	• Authorities should support the efforts of those private landowners who do not regulate the plants

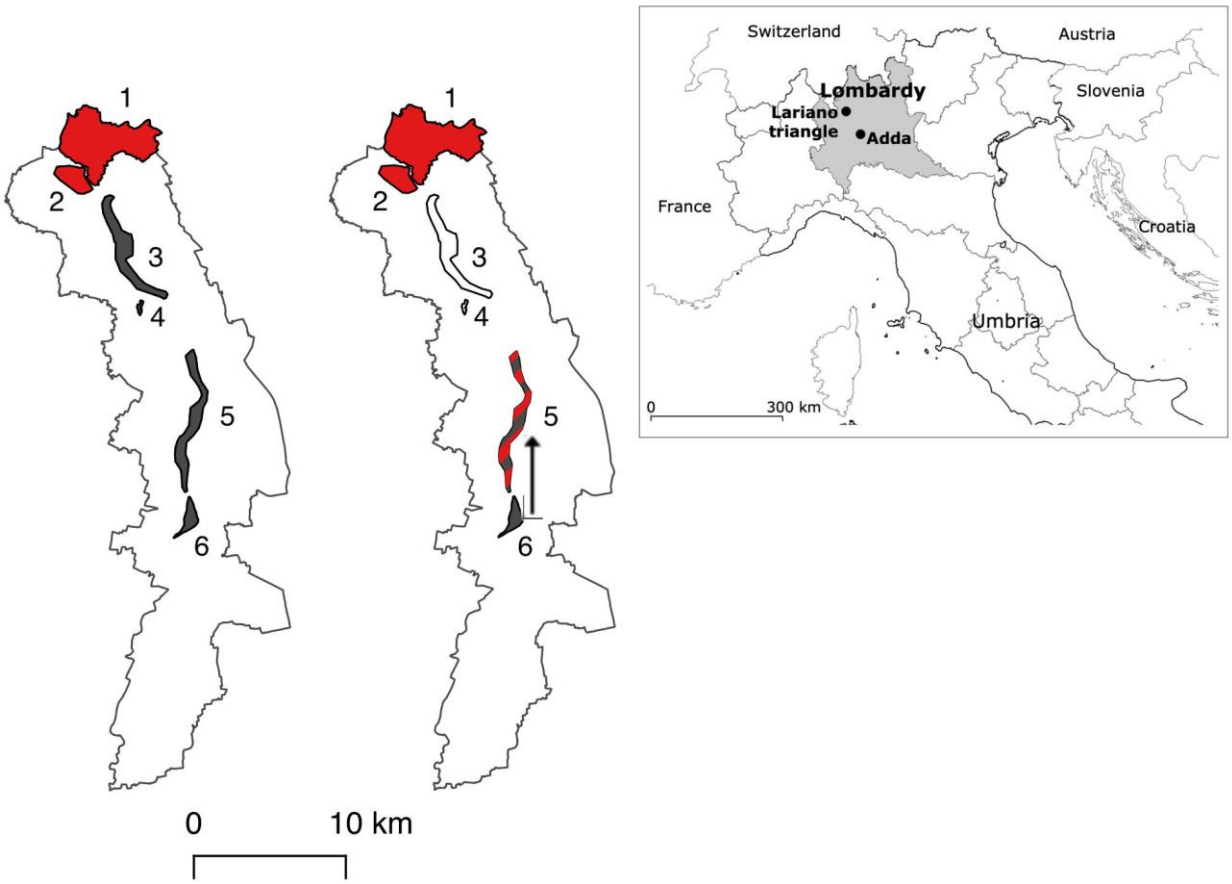

Fig. 1. Adda management area in Lombardy. On the left, the subunit 3-6 (in dark grey) where grey squirrels were present at the beginning of the activities (left); on the right, subunits (3-5) where grey squirrels were removed. After grey squirrel removal, subunit 5 was first recolonized by red squirrels and then by grey squirrels in dispersion from subunit 6.

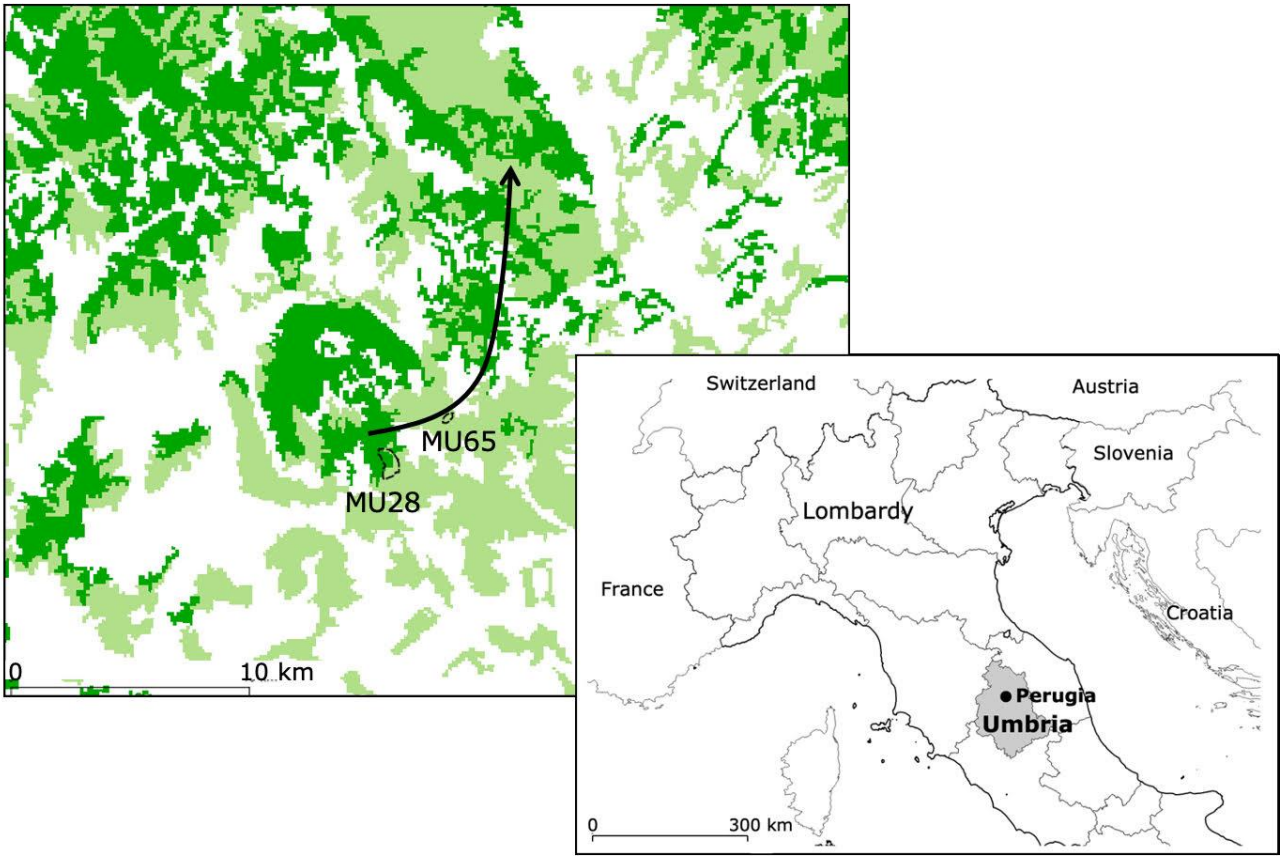

Fig. 2. Location of the Umbria Region and the city of Perugia in Italy, and map showing the distribution of woodlands in the managed areas and surroundings (dark green: broad-lived and mixed forests; light green: other woodlands). The map also shows the location of the two large and fenced properties identified as critical areas for the success of the eradication plan in the MU28 and MU65. The black arrow suggests the direction for the potential expansion of the grey squirrel via a north-eastern ecological corridor connecting the Perugia city area to the Apennines.

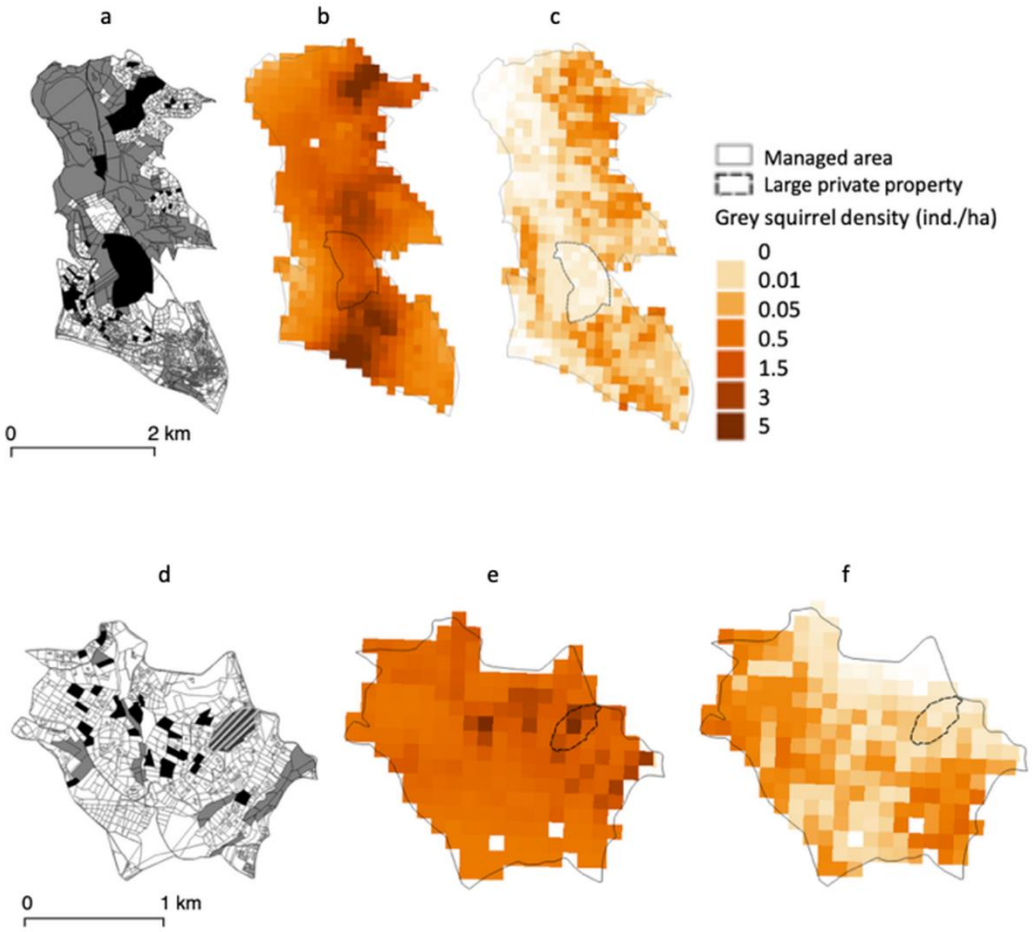

Fig. 3. Accessible areas and spatial distribution of grey squirrel densities in the Perugia area. Panels a, b and c refer to the areas surrounding the first large property (in MU28) and they show: the private accessible particles (in black), the free access areas (grey) and areas without grey squirrels (white) (a); the spatial distribution of grey squirrel density, as resulting from the density surface models fitted to distance sampling data gathered in 2015 (b) and in 2017 (c), i.e., before and after control activities. The same maps (d, e and f) are shown for the areas surrounding the second large property in MU65 (black area dashed in grey in panel d).

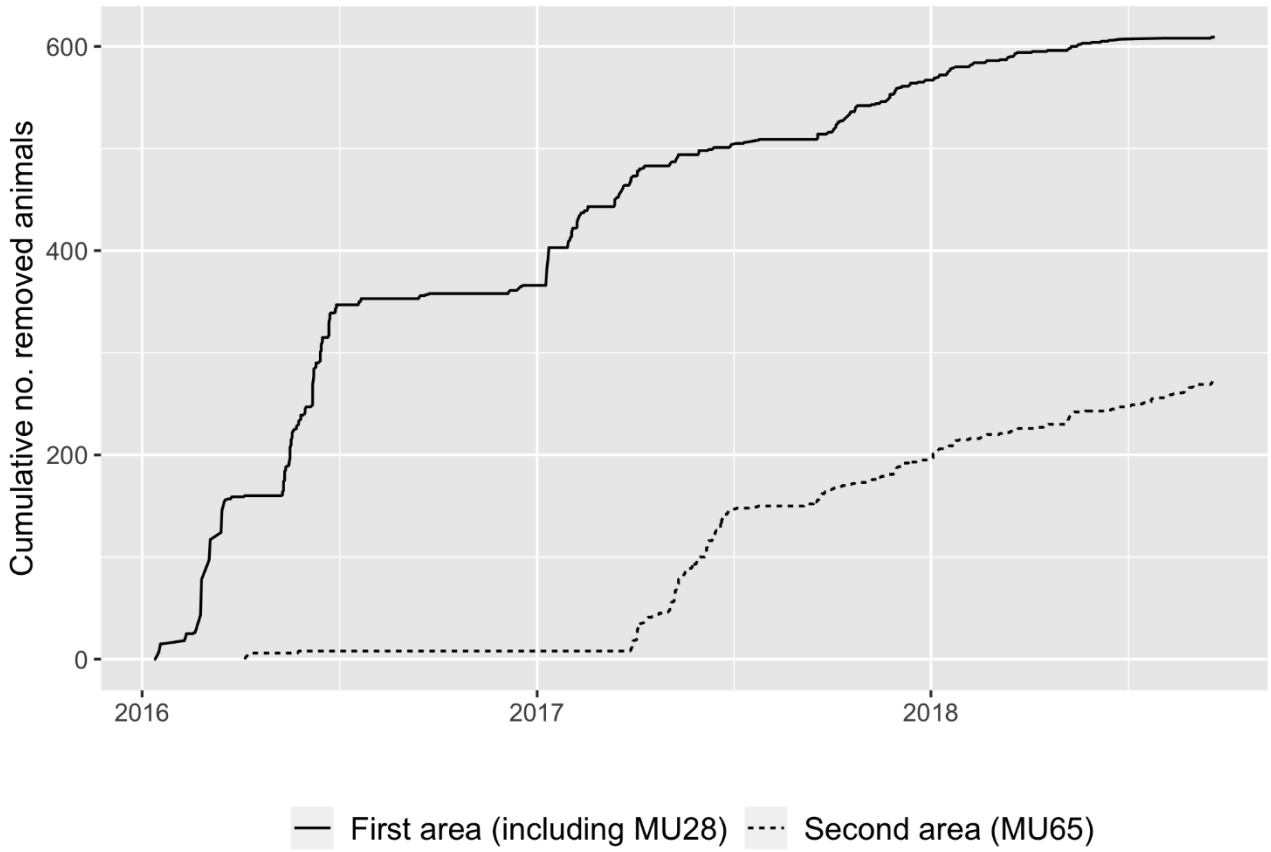

Fig. 4. Cumulative number of grey squirrels removed in the two areas of the Umbria case study. For the first area, the cumulative number includes the animals removed from both the accessible large property (MU28) and the surrounding areas. For the second area (including MU65), in 2016, a very low number of individuals was removed thanks to the collaboration of only a few landowners (see text for details). Starting from 2017, the removal strategy changed, and animals were removed at the boundaries of the inaccessible private properties.

Supplementary Material 1

Taxa	Species - Family	Country	Key point	Outcome	Reference
Mammal	Pallas's squirrel (*Callosciurus erythraeus*). Sciuridae	The Netherlands	All citizens in the area were informed and asked to report sightings. The help of citizens was crucial for the success of the eradication campaign as many squirrels were trapped in private gardens. A major difficulty was in securing access to all private groves and small patches of woodland. Hunters were especially reluctant to give permission to enter their properties. The species was successfully eradicated.	The promise that trapped squirrels would be sterilized and maintained in captivity instead of being killed was very important for support and collaboration of the local community. In instances of local people refusing to allow traps in their garden, other nearby locations were selected to trap resident squirrels. Gaining access to all or most private properties is fundamental for success and legally enforced access to land by professional personnel would be beneficial.	La Haye 2019
Mammal	Grey squirrel (*Sciurus carolinensis*) - Sciuridae	Great Britain	Government enforced disease protocols for Foot & Mouth disease outbreak severely limited access to woodland in 2001. Other restrictions encompassed a large commercial forest plantation during the period 2000–2001, and access to a hazel dominated woodland not granted until 2005.	The control of grey squirrels allows local people to see native red squirrels, get them involved in their conservation along with wider socio-economic benefits through green tourism. The public participation and socio-economic opportunities led to the project receiving funding to continue grey squirrel control.	Schuchert et al. 2014
Mammal	Grey squirrel (*Sciurus carolinensis*) - Sciuridae	Great Britain	Sites covered with control activities included private landowner forestry. Among reported difficulties getting permission to work on certain land holdings, e.g. Council owned woodland.	Education is crucial when it comes to eradication. The public are less likely to oppose control if they are well educated on the how and why of eradication.	Rice 2019
Mammal	Grey squirrel (*Sciurus carolinensis*) - Sciuridae	Great Britain	Recent engagement of local people in the project has helped to significantly raise the profile of the need to manage the grey squirrels. Ongoing volunteer recruitment and support is essential.	Local volunteers were happy to approach landowners to ask for permission to trap grey squirrels with access never having been refused.	Halliwell et al. 2019
Mammal	*Rattus exulans, R. rattus, R. norvegicus* - Muridae	New Zealand	Most people on Great Barrier are supportive of the rat eradication campaign, but do not believe it will succeed, and do not support aerial application of toxins. Also, many	A bottom-up approach to rodent eradication, led by the local community, is difficult for the non-perception of the ecological damage caused by rodents and because community	Ogden & Gilbert 2009

			islanders do not see any link between rats and the local economy, except in the context of being a nuisance around houses.	members advocating conservation measures affecting everyone's land may be treated with suspicion. On the other hand, top-down regulatory authorities can delay decisions, especially when they have no clear mandate. Rodent eradication is most effective with a multiple methods approach, but the application of a toxin is considered unacceptable.	
Mammal	Ship rat (*Rattus rattus*), house mouse (*Mus musculus*) - Muridae	Great Britain (Tristan da Cunha)	Rodent eradication on the inhabitated (270 people) island Tristan da Cunha was not attempted because initial consultation revealed that the entire community did not support the program and so its success was deemed unfeasible. The proposed eradication of mice from Gough Island (6 people) was fully supported.	The community was involved from the early stages of the project. People expressed their views during small meetings with government departments and not during a large public meeting. People were more interested in a better pest control around settlement and cultivation, without the risks they believed were associated with an island-wide rodent eradication project. Such projects might be more acceptable to island communities if perceived risks could be reduced and benefits to the community increased.	Varnham et al. 2011
Mammal	Gambian giant pouched Rat (*Cricetomys gambianus*) - Nesomyidae	USA (Florida)	Lack of cooperation by a small minority of property owners has hindered *C. gamnianus* eradication efforts on Grassy Key. A minority of property owners refused entry to their properties or would not allow toxic bait on their properties. Since the 2007 eradication effort, rats have occasionally been observed and captured near properties not granting access.	Public meeting, mailings, and door-to-door visits were conducted to obtain property owner approvals. A minority of property owners refused entry to their properties or would not allow toxic bait on their properties. Baiting was conducted as close as legally permissible to those properties with trapping anticipated as a necessary addition for eradication.	Engeman et al. 2018
Mammal - Reptile	Polynesian rats (*Rattus exulans*) - house mice (*Mus*	Australia (Cocos Island)	The objective was to provide safe breeding habitat for Guam rails by eradicating Polynesian rats and house mice and	The success required cooperation among multiple territorial and federal agencies and Resort. Public meetings informed and	Engeman et al. 2018

	musculus) – Muridae Mangrove monitor lizards (*Varanus indicus*) - Varanidae		suppressing monitor lizards on Cocos Island. Rodents were eradicated and lizards maintained at very low number.	received input from local citizens concerning the proposed eradication.	
Mammal	Feral goat (*Capra hircus*) - Bovidae	New Zealand (Great Barrier Island)	On the northern part of Great Barrier Island eradication of goats in a conservation reserve of about 3,230 ha was nearly achieved (the herd reduced almost to zero), but failed as Maori landowners restricted hunting access to their bordering land (about 800 ha). They considered feral pigs as a valued food resource, the. Goats can disperse into the reserve from the Maori land.	Managers must either control immigrant goats in perpetuity or gain access to the Maori land to kill the remaining goats.	Parkes 1990
Mammal	Himalayan tahr (*Hemitragus jemlahicus*) - Bovidae	New Zealand	Tahr eradication, once believed possible at least in theory is no longer considered a viable option, in part because not all tahr live in habitats physically or legally accessible to current control techniques.	The failure of intensive helicopter-based hunting, to remove a new tahr population is evidence that tahr would be extremely difficult to eradicate in less accessible areas. Eradication is no longer considered feasible.	Forsyth et al. 2001
Mammal	House mouse (*Mus musculus*) - black rats (*Rattus rattus*) - Muridae	Australia (Lord Howe Island)	Because of previous poor interactions with the Lord Howe Island Board, many islanders mistrusted the Board and this was often the basis for the opposition to project. Resistance from a small community group resulted in two legal challenges. Additional complications included initial active opposition to private land access and unaccepted personnel by the private landowners.	The project was difficult due to a poorly social engagement programme over many years. Future operations on inhabited islands should be community-led, which is likely to take several years; projects will be more complex and costly. Existing eradication protocols are likely to be changed in order to enable access to properties	Harper et al. 2020
Mammal	European red fox (*Vulpes Vulpes*) - Canidae	Australia (Tasmania)	Senior policy advisors and scientists who developed European red fox eradication policies on the inhabited island state of Tasmania, Australia were interviewed.	Respondents perceived that involving community stakeholders was important in creating socially acceptable eradication operations that enable access to private land to implement eradication options. However, scientists feel that community stakeholders'	Moon et al. 2015

				knowledge was limited and only those stakeholders who performed a clear function were considered valuable.	
Bird	Monk parakeet (*Myiopsitta monachus*) - Psittacidae	Great Britain (Borehamwood and the Isle of Dogs)	An eradication programme began in early 2011. Civil servants consulted with some stakeholder groups, but the project was not publicly announced. Homeowners in the target areas were approached and requested to allow agency staff to conduct management activities in their gardens. Opponents to the project asked residents not to co-operate.	Private individuals denying access to gardens created significant delays for the project. Since then, the Government has approved the Infrastructure Act (2015), which provides staff powers of access to private lands for IAS control, which has not been applied yet. Three drives of tension were identified: disagreement around monk parakeets impacts; emotional and complex human relationships with parrots; distrust on how the management plan was proposed.	Crowley et al. 2019
Bird	Ring-necked parakeet (*Psittacula krameria*) - Psittacidae	Seychelles	Lack of support did cause occasional problems with access to private land and misinformation. Fortunately, the parakeets were a known pest and commonly viewed as a threat to farming and endemic wildlife, so the majority of people encountered were in favour of the project and very supportive.	Outreach was important and efforts were made to reach as many people as possible to encourage them to call the team with any information on sightings. All available means were used: radio, TV, talks and presentations, newspaper and magazine articles, social media posts, website, newsletters, posters, stickers.	Bunbury et al. 2019
Reptile	Red ear slider turtle (*Trachemys scripta elegans*) - Emydidae	Spain	Red-eared slider turtle populations are located in areas frequently visited by the public and close to urban centres, which makes management more difficult in terms of access to private water bodies.	Activities were developed into a LIFE + *Trachemys* programme which was more successful in removing invasive turtles. Public awareness campaigns form part of the strategy. NGOs and volunteers were mobilized creating a wide network of collaborators involved in practical nature conservation.	Sarat et al. 2015
Reptile	Iguana (*Iguana iguana*) - Iguanidae	USA (Florida)	On Gasparilla Island, *Ctenosaura similis* eats expensive landscape plantings and invades houses, causing monetary damage and aggravating homeowners. It also threatens sensitive native flora and fauna.	Control was initiated by affected residents willing to self-tax to pay a private trapper to remove iguanas. Two counties employed different population reduction approaches: one used US Wildlife Service personnel, the other a private trapper.	Avery et al. 2014; Engeman et al. 2018

Amphibian	Coqui frog (*Eleutherodactylus coqui*) - Eleutherodactylidae	USA (Hawaii)	One reason that eradication is viewed as no longer possible is because the coqui is often found on private properties, which means that landowners have to agree to and even participate in control operations. If some landowners fail to participate in control, a mosaic of refugia is created from which reinvasion can occur. For example, eradication on Kauai was hindered for many years because of a single landowner.	People with more frogs on their property and those who owned that property tended to have less negative attitudes toward the coqui. Managers may be most effective at engaging citizens in control efforts before habituation becomes widespread.	Kalnicky et al. 2014
Amphibian	American bullfrog (*Lithobates catesbeianus*) Ranidae	The Netherlands	Bullfrogs inhabited two ponds. At the first pond, the landowner fully cooperated and even helped to remove the bullfrogs. He knew his pond would be damaged severely, but believed protecting nature was more important. At the second pond, the landowner refused the eradication methods that had been used at the first pond. After 30 years of bullfrogs in his pond, he did not mind them anymore. The eradication surprised residents, because bullfrogs had been in Baarlo for 20 years but there was no opposition. Residents complained about the noise disturbance and some had even tried to eradicate the bullfrogs themselves.	After negotiations, it was agreed with the landowner of the second pond to either send captured bullfrogs to a university for research or tranquilize and kill them by means of a deadly injection. Precautions were taken to avoid the unnecessary killing of pond animals.	Vane & Runhaar 2016
Amphibian	American bullfrog (*Lithobates catesbeianus*) Ranidae	France	Managers leading the eradication programme have had to face recurring problems of access to private properties, and this has compromised the effectiveness of management actions. Although awareness and communication actions were undertaken and access to private properties improved over time, managers were confronted with strong opposition from landowners to the	A possible means to minimise these problems is to establish agreements with owners about land management, e.g. in exchange for the retrofitting of drainage systems and pond maintenance, managers would gain full management rights on the target site for one or two years. This system of agreements, which is a form of compensation agreed upon beforehand, is a means of dialogue	Piria et al. 2017

			proposed management actions. This included refusal to drain ponds or cut vegetation along the banks, demands to stop actions during the hunting season for waterfowl.	engagement that should improve relations between managers and owners.	
Amphibian	African clawed frog (*Xenopus laevis*) - Pipidae	France	This management successful project was carried out from 2011 to 2013.	Direct access to private property was possible thanks to the previous information efforts addressing the owners, who also participated in the trapping work.	Sarat et al. 2015
Amphibian	Guttural toad (*Sclerophrys gutturalis*) - Bufonidae	South Africa	Authors simulate different spatial scenarios of selecting targeted ponds for adult guttural toad extirpation. The scenarios were: no removal, adult removal from the ponds accessible, from medium and large ponds, from all ponds in the area.	Restricted property access significantly constrains management success in the extirpation of the guttural toad. Toads were all located in private properties not always accessible to managers. Inaccessible ponds are utilized by the toads as invasion hubs to spread across the area.	Vimercati et al. 2017
Amphibian	Guttural toad (*Sclerophrys gutturalis*) - Bufonidae	South Africa	Initial efforts at awareness raising and control were met with both resistance and enthusiasm from residents who resented nightly calls as an invasion of privacy, or appreciated the help to remove noisy invaders, respectively. Access to residential properties was a major issue that required persistent efforts by service providers to win over property owners.	The CAPE IAAWG has recognised the need for ongoing communication with initial stakeholders if eradication programmes are to succeed in the future. At that time there was no legal basis on which to access properties and remove toads. The NEM: BA Alien and Invasive Species Regulations of 2014 provides this legal basis, but this facility has not been used yet and legal precedent still needs to be established.	Davies et al. 2020
Insect	Asian tiger mosquito *(Aedes albopictus)* - Culicidae	Spain	*Aedes albopictus* control was unfeasible because it was impossible to enter house by house to control potential breeding sites.	All or part of the invading population is on private property and: (i) there is no will or permission from the owner to work on their property; (ii) there is no legislation that obliges the owner to facilitate access to undertake the removal of the target IAS.	Dana et al. 2019
Insect	Asian tiger mosquito *(Aedes*	USA	Acquiring access to private property or finding suitable shaded habitats to place traps	Asian tiger mosquito control required gaining permission from at least 36 residents each	Unlu & Farajollahi 2012.

	albopictus) - Culicidae		can be difficult. It was essential to maintain good public relations during surveillance efforts, because BGS traps should be located within private property for safety and easy access.	week. We experienced a low rate of refusal (<5%).	
Insect	Asian tiger mosquito *(Aedes albopictus)* - Culicidae	USA	Control teams were unable to access parcels mostly for two reasons: (1) locked garden gates not allowing access to the yard; (2) resident refusal of inspection and/or treatment. There were several residents in the study site who rejected any kind of mosquito surveillance and control measures on their property.	A substantial reduction in *A. albopictus* populations was achieved in urban but not in suburban sites. 44 parcels could not be inspected in Monmouth County, however this represented only 3% of the total, and did not affect the outcome of the project.	Fonseca et al. 2013
Plant	*Colocasia esculenta* - Araceae, *Ailanthus altissima* - Simaroubaceae	Spain	In Andalusia among 90 action proposal (control of plants and animals), not implemented (N=44), unsuccessful (22), successful (24), six projects involving plants were unsuccessful for several reasons, including lack of access to private property.	All or part of the invading population is on private property and there is no will or permission from the owner to work on their property; there is no legislation that obliges the owner to facilitate access to undertake the removal of the target IAS.	Dana et al. 2019
Plant	Persian hogweed (*Heracleum persicum*) - Apiaceae	Norway	This study identified private landowners (parcels uninhabited, rented or jointly managed by several households) in the city of Tromsø ho do not or only partially regulate invasive Tromsø palm on their parcels, enabling the plant to spread to other parcels. Owner living on-site were more likely to fully regulate the plant.	Authorities should focus their management efforts on supporting efforts of those private landowners who do not regulate the plant.	Meier et al. 2017
Plant	Multiple species	South Africa	Private landowner involvement is a key conservation challenge, because without adequate landowner involvement, invasive alien plants persist on the landscape and continuously reinvade cleared areas. The perception of landowners was explored through interview.	There was significant consensus among stakeholders concerning their preference for shared landowner and government responsibility and for a policy mix that combines incentives with disincentives.	Urgenson et al. 2013

Plant	Multiple species	Ecuador (Galapagos)	Only four of the 30 pilot projects proposed have reached completion. The lack of permission by the landowners who perceived a use of the plant for medicine, ornament, natural fibres, timber or for a sentimental attachment, stopped six of the projects.	The choice of species was based primarily upon their distribution and life history characteristics. Landowners were not involved in this decision making, nor was there any public consultation about the aims of eradicating introduced species with limited distributions. Often, the first time they were consulted was when landowners were asked for permission to enter their land for control and monitoring work.	Gardener et al 2010