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A framework for prioritising present and potentially invasive mammal species for a national list

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Abstract

The European Union (EU) has recently adopted a regulation on invasive alien species that foresees the possibility of developing lists of species of National Concern. We developed a prioritisation process for alien mammals already established in Italy, but not yet included in the EU list (n = 6 species) and a systematic horizon-scanning procedure to obtain ranked lists for those species that are already introduced worldwide or traded in Italy (n = 213). Experts were asked to score these species, by evaluating their likelihood of establishment and spread and the magnitude of their potential impacts on biodiversity, economy, human-health and society. The manageability of each species was also evaluated, both for the proritisation and the horizon-scanning processes. We produced five lists that ranked species according to their potential spread and impacts and their manageability. These will allow policy-makers to select outputs according to a balance between risk assessment and risk management, establishing priorities for alien species management at the national level.

Keywords
Biodiversity, horizon scanning, human well-being, impact, Mammalia, non-native species, prioritisation

Introduction

Establishing a proactive strategy on invasive alien species – i.e. species that are non-native to an area and which may cause environmental or economic harm or adversely affect human health – requires a clear focus on prevention (Simpson et al. 2009). Avoiding the establishment of new species or their spread over large areas greatly reduces the risk that they become invasive (Finnoff et al. 2007). Effective prevention strategies require the identification of those species which are not yet present in a country, but which are likely to enter in the short-medium period, through active pathways (Simpson et al. 2009). This can be done through horizon-scanning protocols. On the other hand, those species which already established could be prioritised for management, through rapid eradication, spatial containment or population control, according to their present spread and manageability.

In 2014, the European Union adopted a regulation (EU Regulation 1143/2014) on the prevention and management of the introduction and spread of invasive alien species. The regulation is based on a list of 'Invasive Alien Species of Union Concern' (hereinafter, Union list), identified through a detailed risk assessment (Roy et al. 2017) evaluated by a Scientific Forum and a Committee with representatives of all Member States. To be included in the list, species have to meet a number of criteria: first, to be alien to the territory of the European Union (excluding the outermost regions); second, to have been assessed as invasive or potentially invasive through a risk assessment. Species included in this list are subject to strict provisions for preventing their introduction into the European Union. The regulation includes a ban on import, trade, breeding, release into the environment and the obligation to produce management plans for already established species (Genovesi et al. 2014). The Union list was based on available risk assessments compliant with the minimum standards (Roy et al. 2017), but subsequently, a horizon-scanning approach was used to rank species to be subjected to risk assessment (Roy et al. 2015).

Horizon scanning is a systematic process aimed at identifying emerging issues which may represent threats or opportunities to society (Sutherland and Woodroof 2009). In the field of biological invasion, horizon scanning allows for the rapid screening of a large number of species through expert opinion and consensus method

(Sutherland et al. 2011). This procedure has already been successfully applied to rank species according to their likelihood of arrival, establishment and impacts (e.g. Roy et al. 2014; Gallardo et al. 2016). In the UK, horizon scanning was able to correctly identify some alien species that subsequently invaded the country, such as *Dreissena rostriformis* or *Vespa velutina* (Aldridge et al. 2014; Roy et al. 2014; Budge et al. 2017). Horizon scanning can thus produce dynamic lists of potential invasive alien species that can be prioritised in regulations.

Within the framework of this EU Regulation, Member states may establish a list of Invasive Alien Species of National Concern, to which provisions and restrictions foreseen for the species of Union Concern may be applied at the national level. Species could be included in national lists only after the evaluation of the same risk assessment procedure used for evaluating species at the EU level (Roy et al. 2017). In 2018, a national legislative decree (no. 230/2017), aimed to adapt national law to EU Regulation 1143/14, entered into force in Italy. The decree provides for the adoption of a national list of invasive or potentially invasive species with the same provisions and restriction foreseen for the Union list.

As a contribution to the development of such a list, the Italian Mammal Society (Associazione Teriologica Italiana: www.mammiferi.org) gathered a group of experts to draw up a proposal for a list of alien mammal species of national concern. This activity was part of a larger initiative promoted by the national Institute for Environmental Protection and Research (ISPRA, identified in the national decree as the governmental agency that technically supports the Ministry of Environment in the application of the EU Regulation at the national level) which addressed the use of a standardised protocol for the assessment many different taxa (e.g. other vertebrates, invertebrates and plants, from terrestrial, freshwater and marine organisms).

Experts tasks: *i*) carry out the horizon scanning to identify species not yet present in Italy, which could potentially enter, establish, spread and produce impacts in the country and *ii*) prioritise the management of alien species already present in the country. The horizon-scanning and prioritisation initiatives were based on the analysis of the invasion process and on the resulting unified framework proposed by Blackburn et al. (2011). The framework breaks down the invasion process into a series of stages (arrival in a new area, introduction, establishment and spread), each one characterised by barriers that need to be overcome by individuals, in order to reach the subsequent stage. Additionally, we also considered the impacts that a species could potentially produce on biodiversity, economy, society and human health.

A comprehensive framework for risk analysis encompasses evaluations regarding both risk assessment and options for management of species (Booy et al. 2017; Kumschick et al. 2020b). Risk assessment evaluates the species based on the likelihood of their successful establishment and spread over large areas, and according to the magnitude of their potential impacts over biodiversity or human well-being. Risk management, on the other hand, accounts for the level of manageability of the species, in terms of the effectiveness of prevention measures and the feasibility of their rapid eradication or control. For instance, species that are difficult to eradicate must be considered a priority for prevention (e.g. through trade restriction), while easy-to-manage species could still be eradicated or controlled after establishment.

Our approach was to develop a support system to help policy-makers establishing national priorities. We thus produced different lists highlighting alien species with a higher likelihood of arrival, establish and spread and that could produce negative impacts on biodiversity or human well-being as a consequence of invasion. These evaluations were then integrated with species manageability.

Methods

Horizon scanning, aimed at producing lists of potentially invasive alien species, was based on: *i*) their likelihood of establishing viable alien populations if imported and released in Italy, *ii*) their potential to impact biodiversity and human well-being and *iii*) their level of manageability, so as to prioritise species for prevention or management. For species already present in the country, the prioritisation process was carried out mainly to rank them for management purposes (Nentwig et al. 2010; Booy et al. 2017). Both processes followed a structured approach that involved five steps (Gallardo et al. 2016; Matthews et al. 2017).

Step 1: Lists of species

The list of species for the horizon scanning included mammals showing at least one alien population worldwide and not yet included in the Union list. The list was built upon information collected from GRIIS (http://www.griis.org/), GISD (http://www.iucngisd.org/gisd/) and CABI (https://www.cabi.org/ISC), and integrated with occasional reports from available scientific literature. Since pet trade is a main pathway of recent mammal introductions (Bertolino 2009; Genovesi et al. 2015), we also scanned the web to identify those species that are traded in Italy and which could potentially escape from captivity. From the resulting list, we then excluded: (*i*) domesticated species, (*ii*) species native to Italy, (*iii*) taxa *incertae sedis* (i.e. potential synonymous to those naturally present in Italy), as well as (*iv*) recently split taxa. Non-native species that were occasionally recorded in Italy, but with no confirmed reproduction events, were also included in this list, for example, the Prevost's squirrel *Callosciurus prevosti*, the Patagonian mara *Dolichotis patagonum* and the Indian crested porcupine *Hystrix indica*. The final list considered for horizon scanning included 212 species (see Suppl. material 1).

The prioritisation list included all non-native species which had been recorded with reproductive populations in Italy (see Loy et al. 2019) and which were not included in the Union list (*sensu* EU Regulation 1143/2014). We did not consider species that had been introduced in Italy before 1500 (i.e. the fallow deer *Dama dama*, the mouflon *Ovis aries*, the wild rabbit *Oryctolagus cuniculus*, the Sardinian hare *Lepus capensis* *mediterraneus*, the black rat *Rattus rattus*), as well as those of uncertain allochthony or for which the introduction date is not defined, i.e. the Norway rat *R. norvegicus* and the crested porcupine *Hystrix cristata*. This decision follows the Italian legislation (Decreto Ministero Ambiente – Ministry of the Environment Decree, 19 January 2015), stating that these species should not be managed as non-native species. The selection ended up with six species retained for the prioritisation list analysis.

For each species in both prioritisation and horizon-scanning lists, we reported the native range following the Taxonomic Database Working Group (TDWG) categories (Europe, Africa, Asia-temperate, Asia-tropical, Australasia, Pacific, North America, South America and Antarctica) and the functional group (predator, herbivore, omnivore).

Step 2: Assessment form

For each species in the lists, we evaluated the following aspects: taxonomy, presence/absence in Italy, likelihood of arrival into the country or escape from confinement, likelihood of establishment and spread, either natural or human aided (with subsequent releases, Hulme et al. 2007), with a scoring system ranging from 1 (low likelihood) to 5 (high likelihood); degree of potential impact on social and economic activities, human health and biodiversity, scoring from 1 (low) to 5 (high), effectiveness and acceptability of prevention and control measures (scoring 1–5, with 5 indicating a species easier to manage). The potential impacts on species and habitats included in annexes of international regulations (Birds Directive 79/409/EEC, Habitats Directive 92/43/EEC) were also added (Table 1).

For horizon scanning, we also reported whether each species was present in zoological gardens or other confined environments in Italy, by checking the zoological garden species lists and the website www.zootierliste.de/en. For both prioritisation and horizon-scanning lists, the main introduction pathways were also reported following the classification provided by the Convention of Biological Diversity (CBD) (Harrower et al. 2018; see also Faulkner et al. 2020 and Pergl et al. 2020 for a discussion of its implementation).

The potential impact on native biodiversity was estimated for both lists, using the evidence-based Environmental Impact Classification of Alien Taxa (EICAT) system (Blackburn et al. 2014; Hawkins et al. 2015; see also Volery et al. and Kumschick et al. 2020a). This protocol scores the progressive severity of the impact produced by an alien species considering if it affects individuals, populations or communities. Ranking from 1 (low) to 5 (high), the EICAT scheme ranges from negligible impacts to a reduction in performance of native individuals, a native population decline and a local extinction, which is naturally reversible or irreversible (IUCN 2020). The EICAT process relies on a complete review of published evidence about the impacts of alien species (Evans et al. 2016). Each expert assessed the potential impact on biodiversity using a simplified EICAT assessment, based on a rapid scan of the main literature. For the same reason, when the impact on biodiversity was classified at

Table 1. Database structure for horizon scanning (HSL) and prioritisation (PL).

Information	HSL	PL
Common and scientific name	×	×
Native range	×	×
Functional group	×	×
Presence/absence in Italy in the wild/occurring in confinement	×	×
Rank 1 – 5: 1 minimum, 5 maximum value		
Likelihood of arrival or escape from confinement	×	
Likelihood of establishment	×	×
Likelihood of natural spread	×	×
Likelihood of human-assisted spread	×	×
Probable main introduction pathway	×	
Likelihood of re-invasion		×
Potential of impact on biodiversity	×	×
Potential of impact on economy	×	×
Potential of impact on human health	×	×
Potential of impact on social aspects	×	×
Likelihood of colonisation and potential impact on habitat and species of European concern, listed in the annexes of Birds or Habitats Directives (yes/no and list)	×	×
Rank 1 – 5: 1 more difficult to manage, 5 more easy to manage		
Effectiveness of prevention measures, including trade regulation, measures related to intentional imports, practicality of carrier treatment etc.	×	
Effectiveness of control measures, including ease of species identification in the field	×	×
Current eradication feasibility		×
Potential eradication feasibility on a small geographical area		×
Eradication potential cost		×
Potential side effects of the eradication		×
Inferred social acceptability of eradication		×
Potential cost of environmental restoration		×
Notes	×	×
References	×	×

the lowest level (i.e. 1), the species was considered a low priority and the remaining fields were not completed. In this way, species that could have a high impact on human well-being, but a low environmental impact, were excluded. This approach was chosen in agreement with ISPRA, following the EU Regulation that specifically addresses species that have or could have adverse impact on biodiversity. We recognise that some species may have been evaluated with a potential low impact simply because they have not yet been studied in their range of introduction. However, we preferred to focus on species with demonstrated, or inferable from similar species (e.g. of the same genus), impacts.

When the impact on native biodiversity was higher than 1, we also estimated their potential for impact on human activities (economic impact), human health and society. These latter evaluations were based on the Socio-Economic Impact Classification of Alien Taxa (SEICAT; Bacher et al. 2017), which evaluates the level of observed changes in peoples' activities. Ranking from 1 (low) to 5 (high), this system is connected to negative effects on peoples' well-being, such that the alien taxon makes it difficult for people to perform their normal activities, to effects leading to changes in the frequency or the local disappearance of an activity, which might be irreversible even if the invasive species is removed. SEICAT is an evidence-based classification system, based on a complete review of literature. Similarly to EICAT, it was applied through a simplified process that considered main references only.

Negative influence on species and habitats protected by EU legislations (Birds Directive 79/409/EEC and Habitats Directive 92/43/EEC) was reported only when clear evidence was detected in scientific literature. For both lists, we also recorded whether species were included in the annexes of other EU regulations and international conventions (e.g. CITES).

The effectiveness of management strategies, for example, eradication, was evaluated, also by taking into account the ease of species identification in the field. The feasibility of eradication was assessed for the prioritisation list only and it was considered low for those species with a wide introduction range and high for localised species (Panetta and Timmins 2004; Robertson et al. 2017; Wilson et al. 2017). Prioritisation was also based on the estimated costs for the management of established species, on potential side effects of eradication methods (e.g. potential impacts on native species), on the social acceptability of eradication and control methods (Booy et al. 2017) and on the estimated costs connected with the environmental restoration following the management intervention.

Step 3: Bioclimatic models

Since climate is one of the main factors limiting the establishment of new species in an area (Redding et al. 2019), we produced suitability maps to help assessors evaluating the climatic similarity between Italy and the native range of each species. Overall, we considered five bioclimatic variables. Four of them described climate conditions: annual mean temperature, temperature seasonality, total annual precipitation and precipitation seasonality. Altogether, these variables explain most of the climatic variation at the global scale (Buckley and Jetz 2008). We also considered the normalised difference vegetation index (NDVI), which is a proxy for vegetation productivity. Climate maps at a resolution of 10 × 10 arc-minutes were obtained from the WorldClim dataset (Fick and Hijmans 2017), while NDVI map was retrieved from the "land cover" project of the climate change initiative of the European Space Agency (Verhegghen et al. 2014). For each species, we extracted its range from IUCN distribution maps (IUCN 2016) and rasterised each range at 10 × 10 arc-minutes resolution. Due to the lack of true absences, we sampled 3,000 pseudo-absences within a radius of 1,000 km from each species' range (Chapman et al. 2019).

Climatic suitability was obtained through an ensemble of species distribution models (Araújo and New 2007), using the package 'biomod2' (Thuiller et al. 2016) within the statistical software R (R Core Team 2020). We ran a total of five different models: boosted regression trees, classification tree analysis, generalised additive models, multivariate adaptive regression splines and random forests. In order to get model evaluations, we performed a 5-fold cross-validation and, for each run of the model, we randomly sampled 67% of the presences for model training and 33% of the presences for testing. The performance of each model was assessed through the True Skill Statistic (TSS), a method for assessing the accuracy of species distribution models, which returns values ranging from -1 to 1, where a value of 0 indicates a performance of a random model, while a value of 1 indicates a perfect agreement between observed data and model predictions (Allouche et al. 2006). Finally, an ensemble model was obtained through the sum of the occurrence probability predicted by each of the five models, weighted by the model's TSS.

For each species, the ensemble model was projected on the Italian and European bioclimatic conditions, in order to obtain a visual representation of the predicted suitability across the country.

Step 4: Expert-based assessment

Eleven mammal experts were involved in three workshops. In the first one, the procedure was discussed with other experts who had previously engaged in at least one horizon-scanning exercise. Subsequently, five species were selected from different taxonomic orders, giving to each mammal expert the task of their independent evaluation, before a second workshop.

In the second workshop, the five species were assessed collectively, by highlighting and resolving differences between assessors' judgements. After the second workshop, each expert assigned the scores to five new species, different from those evaluated previously.

In the last workshop, 1–2 species evaluated by each assessor were scored together, discussing the reasons behind each score. After these workshops, all the species were divided and assigned to experts, each one assessing species belonging to different taxonomic orders, including the previous that were re-evaluated independently.

References on species impacts necessary to fill ICAT Schemes (EICAT and SEICAT) scores were searched in scientific literature (Google Scholar, Scopus and ISI Web of Knowledge) and in GISD and CABI websites. When scientific literature was not available for a certain species, forms were filled using available information on similar, phylogenetically-related taxa, which are expected to have similar ecological requirements and adaptation capabilities (e.g. introduced species of the same genus, see, for example, Lambdon 2008; Bertolino 2009; Gallien and Carboni 2017).

Step 5: Prioritised lists of non-native mammals

From the final database, we compiled five prioritised lists of mammal species, based on their potential impacts on biodiversity and human well-being. Impacts were evaluated first separately and then together and we also assigned a manageability score, reflecting the possibility to effectively manage the species. For the horizon scanning, we first calculated a score for the likelihood of arrival and spread as follows (Fig. 1):

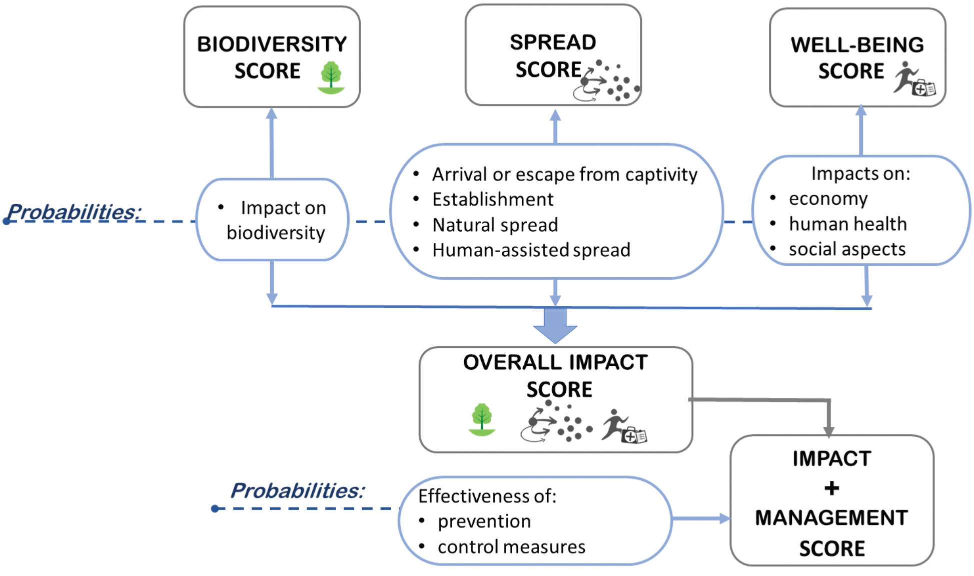

Figure 1. Scores used to produce priority lists from horizon scanning and information on probabilities used to calculate them.

– *SPREAD score* = likelihood of arrival in Italy or escape from captivity if already present × likelihood of establishment × [(likelihood of natural spread + likelihood of human assisted spread)/2] (maximum value = 125);
– *BIODIVERSITY score* = SPREAD score × potential impact on biodiversity (maximum value = 625);
– *WELL-BEING score* = SPREAD score × [(potential impact on economy + potential impact on human health + potential impact on social aspects scores)/3] (maximum value = 1875).

The SPREAD score considered that, at the beginning of the invasion process, a species needs to overcome some natural or artificial barriers, to arrive in Italy and spread and that barriers, like those imposed in captivity (e.g. a fence or a cage) might be effective at preventing a species from becoming an invader (Blackburn et al. 2014). The BIODIVERSITY and WELL-BEING scores considering both the likelihood of spread and the potential of impacts are actually risk scores.

We then combined the three scores into an OVERALL IMPACTS score of the likelihood of impacts. In accordance with EU Regulation, the overall score was calculated with a formula that assigned a higher weight to impacts on biodiversity:

– *OVERALL IMPACTS score* = SPREAD score × [potential impact on biodiversity + (potential impact on economy + potential impact on human health + potential impact on social aspects scores)/6)] (maximum value = 937.5).

An effective strategy aiming at mitigating the impact caused by alien species should consider both the likelihood of prevention and the feasibility and effectiveness of management, once species are established. For this reason, experts were asked to evaluate the manageability of the various species, according to the effectiveness of available prevention measures, including intentional imports and trade regulation, practicality of carrier treatment and the effectiveness of control measures, as well as ease of species recognition in the field. A final score, which considered the likelihood of impacts, feasibility of prevention and effectiveness of control measures was calculated as:

– *IMPACT* + MANAGEABILITY *score* = OVERALL IMPACTS score × effectiveness of prevention measures × (effectiveness of control measures/2) (maximum value = 11718.75),

with an emphasis on prevention rather than control. A TOTAL RANK was then calculated for each species as the sum of ranks in the previous lists.

For the prioritisation of those species that were already present in Italy, scores were similar (Fig. 2), except for the SPREAD score, which did not include the likelihood of arrival or escape and for IMPACT + MANAGEABILITY score which was calculated as:

– *IMPACT* + MANAGEABILITY *score* = OVERALL IMPACT score [((effectiveness of control measures + current eradication feasibility + eradication potential cost + side effects of the eradication + social acceptability of eradication)/5)].

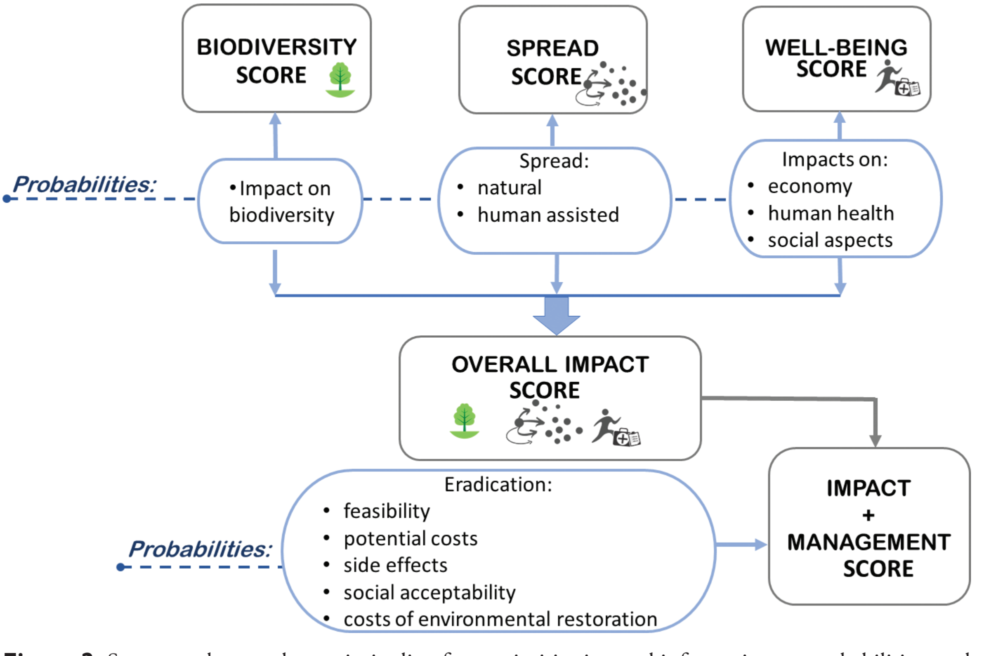

Figure 2. Scores used to produce priority lists from prioritisation and information on probabilities used to calculate them.

Results

Bioclimatic models

Bioclimatic models were produced for all the species that were included in the horizon scanning and prioritisation. Maps, projected at the European level, assisted experts in the assessment of the likelihood that the various species could establish viable populations and spread in Italy. As an example, four maps are reported in Fig. 3: for two species (*Apodemus uralensis*, *Bison bison*) the predicted suitability of Italian territory was considered low, while, for other two (*Sciurus anomalus*, *Sylvilagus floridanus*), it was high.

Prioritisation list

All of the six species that were already present in Italy showed a high likelihood of natural dispersal from their release sites, apart from *Ammotragus lervia*. The first three species, *Sylvilagus floridanus*, *Cervus nippon* and *Callosciurus finlaysonii*, were on top in all the five partial lists that were produced, indicating their high invasibility.

Likelihood of re-invasion was considered high for small-sized species, i.e. those more often traded as pets (*Callosciurus finlaysonii*, *Genetta genetta*), as well as for game species (*Sylvilagus floridanus*) or species farmed for fur (*Neovison vison*). Only *A. lervia* showed an impact on habitats of European interest, i.e. the habitat 4090 (Endemic oro-Mediterranean heaths with gorse). Most species in the prioritisation list showed a medium to high impact on native biodiversity, a medium to low impact on economy and low impact on social aspects and human health (Fig. 4, see Suppl. material 2 for the complete score database).

The prioritisation process highlighted *Sylvilagus floridanus*, *Cervus nippon* and *Callosciurus finlaysonii* as priority species for management actions and, possibly, eradication (Table 2).

Horizon scanning

Amongst the 212 species considered for the horizon scanning, 77 (36.3%) were classified as having an impact score from 3 to 5 and only 18 (8.5%) had major or massive impacts (Fig. 5, see Suppl. material 2 for the complete score database). A total of 164 species had an impact on biodiversity greater than 1 and were identified as relevant for further assessment. The complete list of species is reported in Suppl. material 3.

The first 30 species of the horizon scanning list, ordered according to their *TOTAL rank* are reported in Table 2 with their relative rank position for spread and their different impacts. Notably, in the first ten positions, there are seven rodents, including two rat (*Rattus tanezumi*, *R. exulans*) and three squirrel species (*Callosciurus prevosti*, *Callosciurus notatus*, *Sciurus anomalus*). The first five species (*Rattus tanezumi*, *C. prevosti*, *Mephitis mephitis*, *R. exulans* and *Mastomys natalensis*) are in the first six

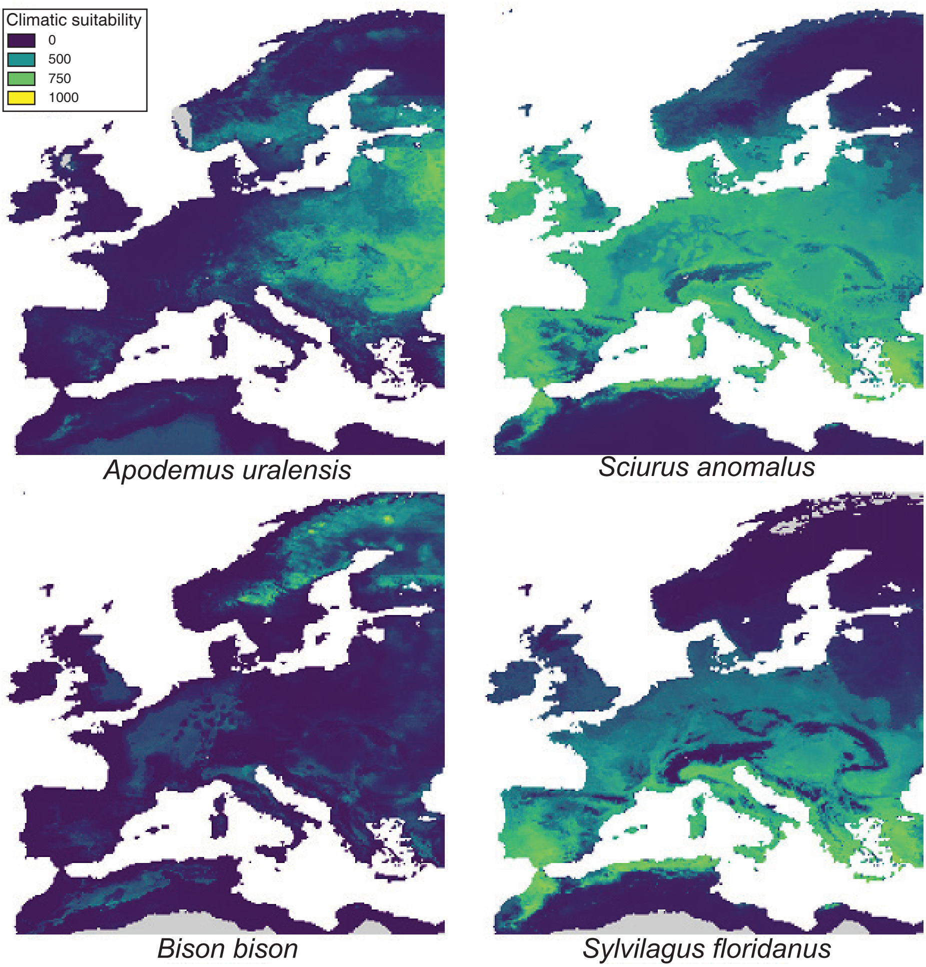

Figure 3. Map produced from bioclimatic models for two species with low (left) and two with high (right) suitability in Italy.

positions in all five partial lists, indicating their high potential for becoming invasive, if arriving in Italy.

The most frequent potential introduction pathway for the species considered in the horizon scanning list was their escape from zoos and aquaria and their escape or release of pets from private houses, followed by intentional releases (Figure 6).

Discussion

Addressing the threats posed by species introductions requires a set of interventions aimed at preventing the arrival of new species and controlling those which are already

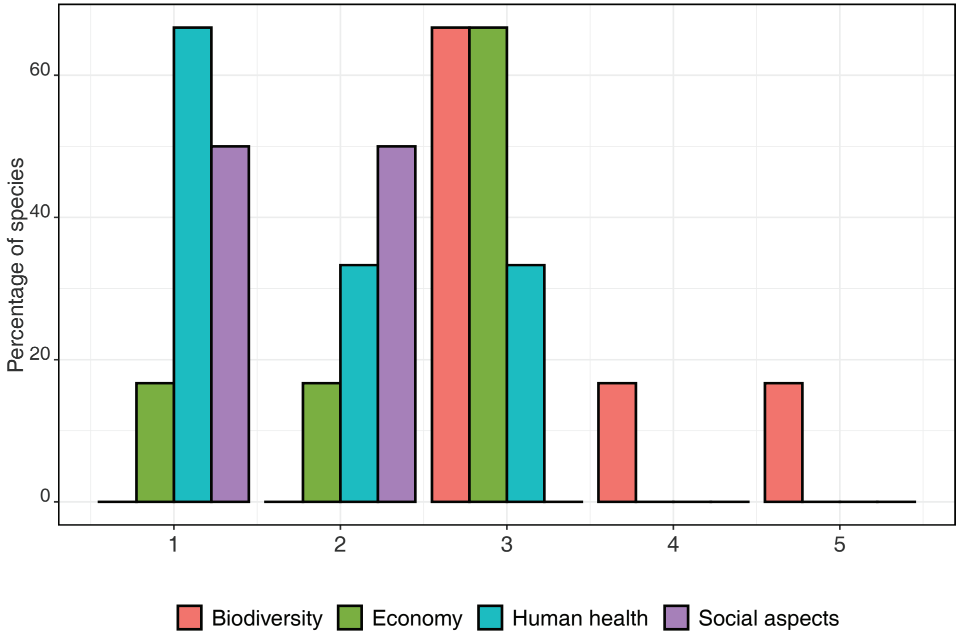

Figure 4. Ranking of impacts of mammalian species listed within the Prioritisation List in Italy.

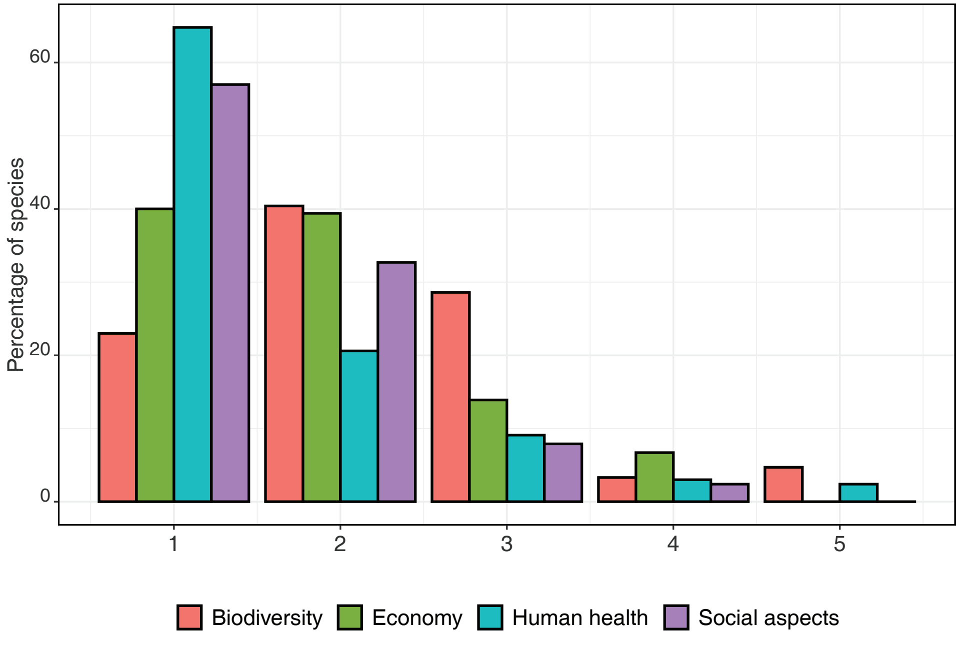

Figure 5. Ranking of impacts of mammalian species listed within the Horizon-scanning List in Italy.

Table 2. Ranked lists of species considered in prioritisation and horizon scanning according to the predicted likelihood of spread, potential impacts on biodiversity and well-being and manageability; the total rank is the sum of the species positions in the previous lists. For horizon scanning, only the first 30 species are reported (for complete lists, see Suppl. material 3).

Species	Spread	Biodiversity	Well-being	Overall impacts	Impacts + manageability	Total Rank
Prioritisation						
Sylvilagus floridanus	1	2	2	1	1	7
Cervus nippon	3	1	1	2	2	9
Callosciurus finlaysonii	2	3	3	3	3	14
Genetta genetta	4	5	5	4	4	22
Neovison vison	5	4	4	5	6	24
Ammotragus lervia	5	6	6	6	5	28
Horizon scanning						
Rattus tanezumi	2	1	1	1	4	9
Callosciurus prevosti	1	2	3	2	1	9
Mephitis mephitis	3	4	4	4	3	18
Rattus exulans	5	3	5	3	6	22
Mastomys natalensis	4	15	2	5	14	40
Microtus levis	5	8	6	6	16	41
Callosciurus notatus	8	6	17	9	2	42
Lepus granatensis	13	5	15	8	5	46
Sciurus anomalus	10	12	8	11	10	51
Genetta pardina	9	10	13	12	12	56
Cervus canadensis	15	7	18	10	7	57
Apodemus uralensis	5	8	7	6	36	62
Capreolus pygargus	17	10	18	13	11	69
Tamiops macclellandi	11	13	25	15	8	72
Mustela lutreola	17	18	18	18	15	86
Funambulus pennantii	11	20	10	19	31	91
Axis axis	27	27	9	21	9	93
Hystrix indica	27	15	18	16	17	93
Tamiasciurus hudsonicus	16	15	28	17	27	103
Herpestes ichneumon	27	27	18	28	22	122
Tamias striatus	26	26	27	27	21	127
Atelerix albiventris	17	20	40	22	30	129
Sciurus lis	17	20	40	22	33	132
Paguma larvata	38	35	11	28	22	134
Mungos mungo	34	20	40	22	19	135
Martes zibellina	34	19	30	20	33	136
Trichosurus vulpecula	34	33	14	31	38	150
Cricetus cricetus	27	46	18	37	24	152
Castor canadensis	38	25	29	28	32	152
Suncus murinus	23	24	30	25	51	153

established. In this study, we prioritised those alien mammal species which are already established in Italy and we used a horizon-scanning approach to highlight the potential risk posed by those species that may arrive or escape captivity in the future.

The prioritisation process ranked *S. floridanus* as the most impacting and easiest to manage alien mammal in Italy. *Sylvilagus floridanus* is an American cottontail introduced in Italy in the 1960s for hunting, which has indirect detrimental effect on native hares through apparent competition mediated by the predator *Vulpes vulpes* (Cerri et al. 2017). The second ranked species was the still localised sika deer *Cervus nippon*, which hybridises with the native red deer *Cervus elaphus* (Smith et al. 2018), followed by the

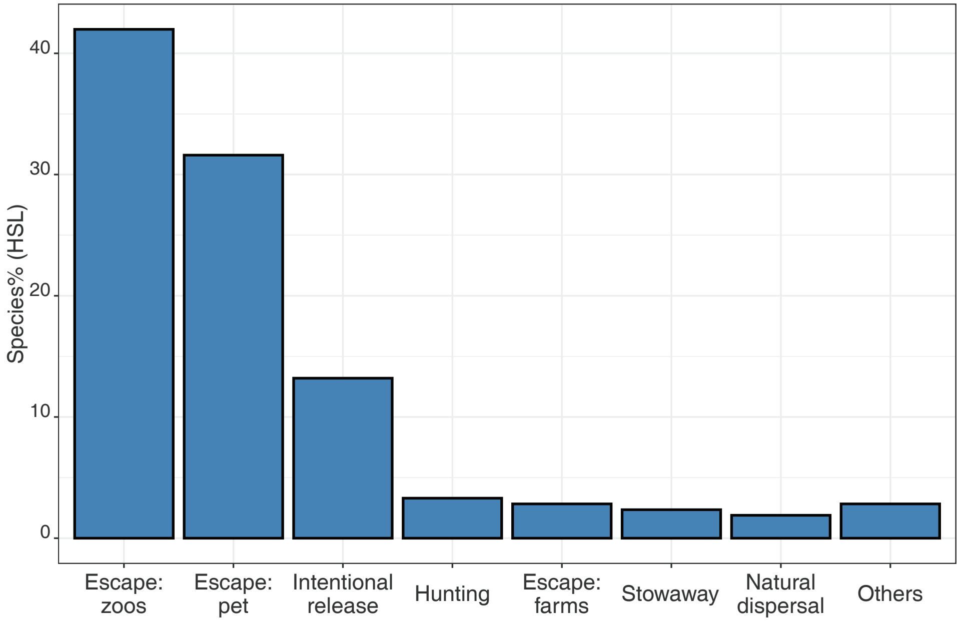

Figure 6. Pathways of introduction of mammal species in Horizon-scanning List.

rapidly spreading Finlayson's squirrel *Callosciurus finlaysonii* (Ancillotto et al. 2018). Notably, four out of 11 (36%) mammal species already listed in the Union list are squirrels. In fact, many squirrel species are highly invasive in Europe (Bertolino 2009; Di Febbraro et al. 2016, 2019) and the Eastern grey squirrel (*Sciurus carolinesis*) is replacing the native Eurasian red squirrel (*Sciurus vulgaris*) in many countries (Bertolino 2008).

Three species, *Sylvilagus floridanus*, *Cervus nippon* and *Callosciurus finlaysonii* were considered a priority for management actions and, possibly, eradication. However, at present only *Sylvilagus floridanus* is irregularly subjected to culling programmes in some areas, besides being a huntable species. *Cervus nippon* and *Callosciurus finlaysonii* are not managed at all, despite their potential impacts on native species and their relatively limited spatial distribution, which would enable successful management actions (Ancillotto et al. 2018; Loy et al. 2019). This denotes a lack of rapid reaction and the need to raise the awareness about the social and ecological impacts that these and other alien species can cause.

As specified in the Methods section, this study does not deal with well-known invasive species, such as rats and mice (e.g. see Capizzi et al. 2014), only for reasons related to the time of their introduction. However, these species can be of great management importance, often higher than most of those listed here and their lack of inclusion in this work does not imply the lack of motivation for their control or eradication.

Horizon scanning for potential alien species traditionally produces a final overall list of prioritised species (e.g. Roy et al. 2014, 2015). In this work, we produced five distinct lists and a final overall ranking, related to the likelihood of adaptation to local landscape and spread, to impacts on biodiversity and human well-being, alone or synergistically, and the feasibility of preventing the introductions and/or to control populations eventually established. These lists could be used to prioritise species for prevention measures, because they are likely to establish and spread over large areas if arriving in Italy, producing relevant impact on biodiversity and human well-being. A strategy aimed at prevention or, at least, rapid removal after introduction, should be particularly in place for those species that are considered difficult to manage, because controlling their populations, once established and widespread, would not be feasible.

The *TOTAL rank* could be used to produce a final list, giving priority to species with the highest values in every partial assessment. At the national level, our assessment will be joined in a process involving the inclusion of assessments for other taxonomic groups, such as other vertebrates, invertebrates and plants, both marine and terrestrial. During the evaluations, experts from different taxonomic groups met in a couple of workshops where the scoring system was discussed in order to use the same scale of reference, for example, when assessing the possibility to eradicate a species, the score was given considering also species from other taxa as comparison. Merging different lists in a unified one is a still an ongoing process; however, the scoring methodology presented here will be applied to all taxa to produce a dynamic list which will include species-specific assessments of spread, impacts and manageability.

The resulting list will assist policy-makers in developing a sound list of alien species of national concern. Such a process will likely lead to the production of a final ranking, based on consensus building between experts and policy-makers, who could assign different weights to the various aspects of the invasion process. Our ranking system highlighted those species characterised by a higher likelihood to overcome different barriers through the invasion process (Blackburn et al. 2011), capable of spreading across large areas and likely to produce negative impacts on species and ecosystems or on human well-being, as well as more likely to be difficult to manage.

The EU Regulation on invasive species was specifically adopted to mitigate the impact of alien species on biodiversity (Genovesi et al. 2014). For this reason, when producing the *OVERALL IMPACTS score*, we weighted more impacts on biodiversity than on human activities. However, our scoring system could be easily adapted to alternative evaluations. For instance, impacts on human activities or the possibility to carry zoonoses may be considered relevant for prioritising the management of alien species. By including the likelihood of spread in calculating the impacts, we also prioritised species that will likely produce a lower impact over larger areas compared to others that will probably have higher impacts, but with a low risk of spread. The reasons behind this choice lies in the easier mitigation of high impacts, through control or eradication when species are still distributed over a restricted area, compared to the mitigation of lower impacts occurring across a vast geographical scale (Panzacchi et al. 2007; Robertson et al. 2017).

Finally, we also produced a list that considers the *OVERALL IMPACTS score* of a species and the feasibility of its management (*IMPACTS score* + MANAGEABILITY *score*), giving more weight to prevention compared to the possibility of control. It is now recognised that an integrated and hierarchical management strategy should act at the different stages of the invasion process, with an emphasis on prevention. The identification of main pathways allows us to prevent many species from entering recipient areas, while control and eradication is generally costly and should be species-specific (Panzacchi et al. 2007; Robertson et al. 2017).

The main pathways of introduction for the mammal species considered in this study are the escape from zoos and from private keepers, followed by intentional releases. This is in accordance with the pathways identified by Genovesi et al. (2009) for mammals already established in Europe. These authors reported that the most frequent pathways for mammal introductions were escapes from fur farms and zoos, intentional releases of animals from captivity and introductions for hunting. However, increasing security systems to captive animals and discouraging hunters from releasing alien mammals have reduced the importance of these pathways, while the release or escape of animals from the pet trade is increasing (Genovesi et al. 2009). In fact, amongst species already established in Italy and here considered for prioritisation, one third have been introduced for hunting (e.g. *S. floridanus*, *A. lervia*), but recently the escape or release of animals from captivity prevailed (e.g. *C. finlaysonii*, *C. nippon*).

Species included in the list of alien species of National Concern might be subject to strict regulation, which includes a ban on import, trade, possession and release (Genovesi et al. 2014). Therefore, we consider that prevention could be an efficient strategy for most of the evaluated species. However, since only a few mammals will probably be included in such a national list, other actions, such as the adoption of voluntary codes of conducts or guidelines for zoos (Scalera et al. 2012), pet trade (Davenport and Collins 2011) and hunting (Monaco et al. 2016), should be encouraged.

ICAT Schemes are two evidence-based classification systems for evaluating the ecological and socioeconomic impacts of non-native species (Blackburn et al. 2014; Bacher et al. 2017). Their assessment requires the collection and evaluation of all the papers reporting data on impacts produced by the target species in its global introduction range and their scoring according to different mechanisms of impact (Volery et al., 2020). Due to the high number of species to assess, we used an expert-based approach where single experts used ICAT Schemes as reference systems for scoring the species after a rapid search of literature and without considering the mechanism of impact. There is the perception that expert-based evaluations overestimate impacts produced by alien species. When mammals are scored worldwide for ICAT Schemes, a comparison with our assessments could be made.

Our work combined a prioritisation process of mammal species already established in Italy and not listed in the EU Regulation 1143/2014, with a horizon scanning of species traded in Italy or recorded as introduced worldwide. This resulted into ranked lists of species, based on their spread capabilities, their potential impacts on biodiversity and human well-being and the feasibility of their management. All these lists could be used to prioritise mammal species for prevention, banning their trade in Italy or for management. The developed database will be integrated with others produced through horizon scanning for invertebrates, vertebrates, plants, marine and terrestrial and will be used to produce a proposal for a list of Invasive Alien Species of National Concern (art. 12, EU Regulation 1143/2014).

In our evaluation, we chose not to consider those species with a low potential of impact on biodiversity (i.e. with a score = 1) and we also calculated the OVERALL IMPACTS score giving a higher weight to potential impacts on biodiversity with respect to potential impacts on economy, human health or on social aspects. This choice was justified by the focus of EU Regulation 1143/2014 on prevention, mitigation and minimisation of adverse impact on biodiversity caused by alien species and the provision to produce a list of 'Invasive Alien Species of National Concern' in accordance with the Regulation. The impacts on human health and the economy were then considered as a secondary aspect. However, the procedure developed in this study could be used as a blueprint for similar prioritisation initiatives (cf. Ziller et al. 2020), as the formulae could be adapted to produce one or more lists of species according to different priorities established by country regulations or policies.

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Supplementary material 1

This is the database produced during the research

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Data type: species data

Link: https://doi.org/10.3897/neobiota.62.52934.suppl1

Supplementary material 2

This is the R-script and the output of the analyses

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Data type: statistical data

Link: https://doi.org/10.3897/neobiota.62.52934.suppl2

Supplementary material 3

Complete ranking of the species

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