Compilation of costs of prevention and management of invasive alien species in the EU

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Contents

Executive Summary 3

Introduction 4

1. Review of existing cost-analysis approaches 6

   The assessment of costs and benefits of measures for prevention and management of IAS 7

   The economic assessment of the cost-effectiveness of measures of IAS prevention and/or management 10

2. A framework and standardised method to collect information on costs of IAS prevention and management measures 11

   Proposed methodology for the collection of data on costs of IAS prevention and management. 11

   Database hosting the relevant quantitative and qualitative information 14

3. A method of multi-criteria analysis applicable to generic species/habitats. 16

   Background 17

   Guidance document and template for the multi-criteria analysis 21

4. Results and discussion 28

   Evidence of costs and effectiveness of prevention and management of terrestrial vertebrates 28

   Application of multi-criteria method 35

5. Conclusions and recommendations 49

   Considerations to improve knowledge on costs of prevention and management of IAS 50

   Multi-criteria analysis as a way of producing policy-relevant information 55

   Recommendations 58

6. References 60

Executive Summary

Invasive alien species (IAS) have multiple impacts on biodiversity, related ecosystem services, human health and the economy, while their management brings further consequences. We reviewed the available methodologies to assess and analyse the costs and benefits of relevance to IAS prevention and management, including economic, biodiversity, environmental, social and welfare considerations, measured in different currencies. On the basis of such review, and with the aim to improve the evidence available on the costs, benefits and effectiveness of prevention and management of IAS, we proposed a database structure and a methodology to record in a standardised manner the information on costs and efficiency of measures targeting IAS. We also consider the use of other methods to support decision making where the available evidence may be limited.

To validate and discuss the proposed database structure and methodology, we collected data on prevention and management measures applied to terrestrial vertebrates, which were chosen as a test group. Such data were retrieved from an existing database on the costs of eradications, together with publications found through a structured search for information relating to vertebrate Species of Union Concern, and the analysis of a selection of projects financed through the LIFE programme, whose data were obtained also thanks to direct interviews with the relevant project managers. We identified relatively little relevant information from the literature searches, despite the great number of activities and measures undertaken toward the IAS problem. This was particularly true for information on costs, but also on general considerations about practicality, social acceptability, wider environmental and biodiversity impact and effectiveness of measures.

Potentially, LIFE projects could be a key source of specific and reliable information on IAS prevention and management, however - despite the detailed technical and financial reporting which characterises the programme - there is no structured or mandatory requirement to ensure that such data are systematically retrieved from projects. We proposed a method to ensure that any relevant information useful to inform decision makers and project managers is duly stored and circulated.

We also describe how purely economic analyses to inform major aspects of IAS policy are limited in their wider application. Multi-criteria methods can better include diverse currencies and deal with incomplete or qualitative data to support decision making. Based upon experience in Great Britain in a similar context, we described a multi-criteria method to inform the best management option to meet specific objectives. The proposed protocol, which uses expert opinion informed by the available literature and evidence, was tested on terrestrial vertebrates. We then consider how the results and application of multi-criteria methods and other sources of evidence can inform key management decisions at different stages of the invasion process and consider the ways in which multi-criteria methods might be further developed and applied in future.

Introduction

The availability of reliable and detailed information on the costs of prevention and management measures related to invasive alien species (IAS) is key to the effective implementation of Regulation (EU) 1143/2014. While there are some relevant data from the scientific literature, a large volume of information, derived from the ever-increasing number of activities focusing on prevention and management of IAS carried out in Europe and beyond, is not always (easily) accessible.

Most information is only available in grey literature and technical reports, and some is not published at all. While there is a rich literature on management measures and reports of particular programmes, the information on costs has not been effectively collated and disseminated. The few existing datasets focusing on management programmes do not include information on costs (Keitt et al. 2011) or such costs are not of immediate use (e.g. LIFE database[1]) as there is no breakdown to identify costs specifically spent for IAS actions. A number of studies have attempted to compile cost/effort information for particular taxa, management objectives, or specific financial programmes, but there is a need for a more systematic and comprehensive approach to collect and share data on prevention and management costs. It is also likely that relevant data does not exist for many species or methods, and decisions will often need to be made in the absence of published information.

Analyses of the information on the measures and costs of prevention and management are also needed to identify the most cost-effective and feasible approaches for use in different circumstances. While the financial costs are a key component, the wider considerations of practicality, social acceptability, wider environmental and biodiversity impact, as well as effectiveness of the measures, also need to be considered.

With the objective to fill in the knowledge gaps on costs of prevention and management measures of IAS, the following tasks are developed and analysed/discussed in this report:

1. A review of existing cost-analysis approaches, fully considering questions of practicality, social acceptability, wider environmental and biodiversity impact and effectiveness of measures, and identifying best practice and gaps.

2. A framework and standardised method to collect cost information on prevention and management measures (based on the finding of task 1) that can be applied for generic species/habitats, fully considering practicality, social acceptability, wider environmental and biodiversity impact and effectiveness of measures. It will be accompanied by a database to hold the relevant quantitative and qualitative information on costs and other considerations (practicality, social acceptability, wider environmental and biodiversity impact and effectiveness of measures) that the method, developed under this task, is expected to yield. As a minimum this should include details of species, method applied, objectives (prevention, eradication, complete removal, on-going control), location, year, area, cost or effort,

[1] http://ec.europa.eu/environment/life/project/Projects/index.cfm

practicality, social acceptability, wider environmental and biodiversity impact and effectiveness of measures.

3. A method of multi-criteria analysis applicable to generic species/habitats to assist Member States and stakeholders in the prioritisation of the most cost-effective measures of prevention and management of IAS, when developing programmes to prevent the spread of species and to manage the existing populations. Related to this we provide the results and application of multi-criteria methods and other sources of evidence to inform key management decisions at different stages of the invasion process. This includes a discussion of the cost-effectiveness of multi-species programmes, and the application of this approach to other taxa and environments.

The results achieved by testing the effectiveness of the methodology and the multi-criteria analysis to “terrestrial vertebrates” are presented and discussed, and recommendations for future action are provided.

1. Review of existing cost-analysis approaches

Assessing the costs of prevention and management of IAS is complex. IAS have multiple impacts on the environment, economy and wider society, while their management brings further consequences. Ideally, a sound assessment of the costs, benefits and effectiveness of prevention and management of IAS needs to be carried out. In many fields of human endeavour, economic analyses of costs and benefits underpin decision making by assessing possible actions, evaluating implemented measures and comparing them (Born et al 2005; Cellini and Key 2010). These include a wide range of specific analyses, such as economic cost-benefit analysis (Naidoo and Ricketts 2006; Shwiff 2012) and cost-effectiveness analysis (Boardman et al. 1996; Cullen et al. 2001, 2005; Naidoo et al. 2006; Laycock et al. 2009 2011, Caudell el al. 2010).

For clarity, while 'costs and benefits' refer to the collation of information on these effects, 'cost-benefit' is a specific form of economic analysis where both costs and benefits can be monetised, while 'cost-effectiveness' is another form of economic analysis where only the costs can be monetised.

The costs and possible benefits associated with alien species can be separated into four broad categories:

a) the costs associated with IAS presence (costs of inaction).
b) the benefits of IAS presence (benefits of inaction).
c) the costs of IAS prevention and management.
d) the benefits of IAS prevention and management.

These four categories include a wide range of economic, biodiversity, environmental, social and welfare considerations (Booy et al. 2017) which are measured in different currencies. While some can readily be measured in economic terms (e.g. the annual management cost of removing fouling from pipes) others are more challenging (e.g. the intrinsic value of a threatened native species) and cannot easily be converted into economic estimates**.** Therefore, analyses that rely solely on the economic costs and benefits have a number of limitations. For example, Schlaepfer et al. (2011) argued that cost-benefit analyses of any management option for IAS must include the subjective valuation of species (Dudgeon and Smith 2006, Evans et al. 2008, Sandler 2010). The currencies used to measure these different elements are difficult to monetise (Hoagland and Jin 2006), although this approach has been used in some cases (Lupi et al. 2003, Nunes and Van Den Bergh 2004). Bacher et al. (2017) conclude that attempts to quantify socio-economic impacts in monetary terms are unlikely to provide a useful basis for evaluating and comparing impacts of invasive alien taxa because they are notoriously difficult to measure, they are often context-dependent, and important aspects of human well-being are ignored.

The analysis of costs and benefits is also limited by the availability of data and the uncertainty inherent to complex ecological systems. The increasing number and diversity of IAS poses further challenges, with a need for rapid methods of assessment that can be readily applied in situations where the underpinning data is often sparse or absent.

Below, we present a discussion of the main costs and benefits related to the four categories listed above, reflecting as far as possible the negative and positive impacts on biodiversity, related ecosystem services, economy and human health.

The assessment of costs and benefits of measures for prevention and management of IAS

a) the costs associated with IAS presence (costs of inaction)

The costs of the presence of IAS have been the subject of a number of extensive reviews. These have been conducted at a national scale (Pimental et al. 2000, 2005, McNeely 2001, Wittenberg et al. 2006, Gren et al. 2009, Clout 2002, Reinhardt et al. 2003, Williams et al. 2010, Hoffman and Broadhurst 2016), by economic sector (Holmes et al. 2009, Aukema et al. 2011), by taxa (Sindon et al. 2004, Olson 2006, Lovell et al. 2006, Nentwig and Vaes-Petignat 2014, Bradshaw et al. 2016), by environment (Duncan et al. 2004, Reaser et al. 2007) and by stakeholder group (Pratt et al. 2017). Although the criteria for costing have varied between projects, these studies produced economic estimates of the costs of the presence of individual species or the combined costs of the IAS present in a region.

IAS can influence people's realized activities via changes in environmental factors, economic settings, or the social context. Different constituents of human well-being may be affected: security; material and immaterial assets; health; and social, spiritual and cultural relationships (Narayan et al. 2000, Pejchar and Mooney 2009, Bacher et al. 2017). For example, the presence of noxious weeds can reduce the attractiveness of areas for outdoor recreation (Eiswerth et al. 2005) hence resulting in lower public acceptance and impact tourism. A range of studies have examined the socio-economic consequences of alien species (Binimelis et al. 2007, Duncan et al. 2004, Reaser et al. 2007).

Studies have reviewed the impacts on different taxa (Cambray 2003, Clavero et al. 2009, Hejda et al. 2009), with a focus on plants (Liao et al. 2008, Pyšek et al. 2012, Vila et al. 2011), insects (Kenis et al. 2009, Nentwig and Vaes-Petignat 2014) and mammals (Nentwig et al. 2014), as well as on particular environments (Molnar et al. 2008, Bax et al. 2003, Jones et al. 2008, Medina et al. 2011, Meyer et al. 2004), and on ecosystem services (Vila et al. 2010).

Overall, it is difficult to monetise the cost of IAS impacts in relation to elements other than economic related activities or specific ecosystem services. For example, assessing costs of species extinctions or the loss of species from an ecosystem is usually considered impractical or unrealistic.

b) the benefits of IAS presence (benefits of inaction)

Introduced species can have indirect benefits on native species (Schlaepfer 2011), for example through the provision of habitat (Sogge et al. 2008), shelter (Chen 2001), pollination services (Cox 1983, Dick 2001), seed dispersal (Foster and Robinson 2007), and food (Shapiro 2002, Tablado et al. 2010). Alien species have also been introduced as biocontrol agents (Stiling et al. 2005, Clewley et al. 2012) with the objective of controlling other species, which may themselves be IAS (Morrison et al. 1998, Sheppard et al. 2006, Hoddle 2004, Thomas and Reid 2007). The same effects have also been observed following unintentional introductions, with the new species sometimes limiting the numbers of earlier invaders (Harding 2003, Russell et al. 2014, Strayer et al. 2017). Similarly, alien species have been used to help support a variety of ecosystem functions (D'antonio and Meyerson 2002), i.e. the reinforcement and stabilization of flood defences (Wootton et al. 2005, Lugo 1997), the reduction of nitrification to improve water quality (NRC 2004, Elliot at al 2008, Dionisio-Pires et al. 2009) and to support habitat restoration (Ewel and Putz 2004, Berens et al. 2008, Lugo 2004, Rodriguez et al. 2006, Ruesink et al. 2005). Species are introduced also simply because they are considered attractive (Su et al. 2014, Ginn et al. 2008, Liu et al. 2012), and hence have aesthetic value (Garcia-Llorente et al. 2008, Nunez and Simberloff 2005).

In some cases, some authors argued that the introduction of alien species to an area – at least at a simple local level and in the short term - may bring benefits, e.g. by increasing local species number (Schlaepfer et al. 2011, Thomas 2011, 2013). However, the claimed benefits would be balanced by possible detrimental effects on native species number and abundance (Schwartz et al. 2006, Vitousek et al. 1997). Some authors also argued that the introduction of a species to a new area may reduce the prospects of its global extinction (Willis et al. 2009, Thomas 2011, Jolly and Colbourne 1991). Introduced species have also been purposely introduced to areas to replace an extinct native species (Griffiths et al. 2010). However, the use of introductions as a conservation tool has been questioned given the uncertainties in predicting the consequences of new introductions and the associated costs should the species become invasive (Ricciardi and Simberloff 2009). All the benefits presented above are difficult to translate into simple economic terms.

Lastly, human society is built upon the agricultural production of food. A small number of domesticated crop and livestock species underpin modern agriculture and forestry, and these have been widely transported across the globe. Similarly, industrial forestry plantations along with the consumptive use of alien species for fuel, food and for hunting, provide significant economic and social benefits to many societies (Ewel et al. 1999) and financial estimates of these benefits can be derived.

c) the costs of IAS prevention and management

The costs of IAS prevention and management have been the subject of a number of papers and reviews. Some studies were undertaken at the regional scale, e.g. in the EU (Silva et al. 2014, Scalera 2010, Scalera et al. 2017, Scalera and Zaghi 2004, Tucker et al. 2013) and in Australia (Hoffman and Broadhurst 2016). Reviews of the costs of eradication have also been published for specific taxa, including plants (Rejmanek and Pitcairn 2002), forest insects (Brockerhoff et al. 2010), and mammals (Martins et al. 2006, Howald et al. 2007, Robertson et al. 2017). Holmes et al. (2015, 2016) proposed a breakdown of management costs to include five sub-categories covering planning, implementation, non-target species management, remoteness and human population considerations.

Apart from the direct financial costs of management, there are a range of indirect and secondary costs that also need to be considered. For example, an effective rapid response to a new invasion (Wittenberg and Cock 2001, Broome et al. 2002, Anderson 2005) can require access to skills and equipment which costs appear suitable to monetisation, although there is little available information on which to base these. The removal of an introduced species can meet significant disapproval or resistance from the public, key sectors or other stakeholders (Estevez et al. 2015). This may prevent, delay or add to the political cost of the proposal. Control measures, particularly of vertebrates, raise concerns for the welfare of the individuals involved, and any detriment to their welfare must be seen as an additional cost of management (Littin et al. 2004, Littin and Mellor 2005). Assessing the potential welfare implications of different control measures and the adoption of codes of best-practice to minimize harm should form a key element of responsible management (Sharp and Saunders 2005, 2011). The welfare costs of vertebrate control are recognized as a key factor influencing the public acceptability of any proposed management (Sharp et al. 2011). However, it is difficult to monetise the costs of animal welfare.

The removal of an IAS from an area can have wider consequences for the environment. These can include the indirect effects of the management on other species, and the consequences of the removal of the species itself. Control measures are rarely specific to one species; pesticides can kill other plants; toxins, traps and shooting can result in the deaths of non-target species (Dowding et al. 1999, Eason et al. 2002). The introduction of new species as biocontrol agents can also have unintended consequences for native species (Howarth 1991, Louda et al. 2003, Denslow and D'Antonio 2005, Messing and Wright 2006). The removal of one IAS can also lead to increases in another (Witmer et al. 2007, Bergstrom et al. 2009) or unexpected changes in other non-IAS fauna (Ruscoe et al. 2011) with wider effects on the ecosystem (Zarneske et al. 2010). The unpredictable nature of these consequences, and their detrimental effects (Rinella et al. 2009, Ballari et al. 2016) have led to calls for a whole ecosystem-approach to assessing the consequences of removal of IAS (Zavaleta et al. 2001) although monetising this assessment would be challenging in practice.

The early identification of a newly established IAS increases the scope for a rapid response and its cost-effective removal (Deltoro et al. 2013, Bogich et al. 2008, Vander Zanden et al. 2010). Surveillance to detect new incursions bears costs (Hauser and McCarthy 2009) and this cost increases with the requirement for rapid detection. Studies have examined the economic benefits of optimising surveillance (Epanchin-Niell et al. 2014, Sims and Finnoff 2013, Holden et al. 2016). Citizen science offers a particularly valuable avenue to support the wide-scale surveillance of alien species and new incursions (Gallo and Waitt 2011) although this comes with a number of costs and limitations (Crall et al. 2010, 2011). The coordination of data from citizen science, national monitoring schemes and targeted surveillance can provide a rapid reporting capability to support rapid detection (Roy et al. 2014b). These costs appear suitable to monetisation although there is little available information on which to base this.

d) the benefits of IAS prevention and management

Ideally, effective management should lead to the removal of the negative consequences of the species presence on biodiversity, ecosystem services, the economy and human health and well-being. By reducing the risk that an alien species may enter and establish in a new environment, the future potential costs of its presence, impacts and management are reduced. The uncertainty associated with the consequences of successful invasions influences the optimal strategy to reduce these risks (Horan et al. 2002).

However, complete removal may not be possible and a proportional reduction to some or all of the costs may be the best that can be achieved (Tatentzap et al. 2009). Similarly, even the complete removal of a species may not result in the restoration of the previous conditions, for example, following the extinction of a native species, the environment might switch to an alternative stable state (Scheffer et al. 2001; Beisner et al. 2003), given the presence of other IAS (Witmer et al. 2007), time lags in the system (Graham and Veitch 2002) or the consequences of the method of removal (Flory and Clay 2009).

Management may take place before an IAS population has reached its full extent in a new environment. By limiting its further spread, its future impact may be limited (Keller et al. 2008). This may deliver benefits to areas that have yet to be invaded, although the costs are borne by the areas where the species is already present (Robertson et al. 2015). Understanding the timing (Crooks et al. 1999), dynamics (Arim et al. 2006, Suarez et al. 2001, Sexton et al. 2009) and limits (Jeschke and Strayer 2008) of spread can help guide and optimise management (Vander Zanden and Olden 2008) and improve its efficiency and effectiveness, although the unpredictability of spread may limit this approach (Melbourne and Hastings 2009).

Overall, although some elements of the costs associated with the benefits of IAS prevention and management may be monetised, this is not straightforward or regularly undertaken.

The economic assessment of the cost-effectiveness of measures of IAS prevention and/or management

A range of studies have compared the cost-effectiveness of IAS prevention or management at different stages along the invasion process. These have concluded that the cost-effectiveness of prevention or rapid response to remove new species greatly outweighs that of ongoing management (Leung et al. 2002, Panzacchi et al. 2007, Keller et al. 2008, Deltoro et al. 2013). For example, Harris and Timmins (2009) estimate that for introduced plants in New Zealand, early removal costs are on average 40 times lower than later attempts to extirpate widely established populations. While prevention may be more cost-effective than eradication or control, prevention can only intercept a proportion of incoming species and all three approaches will be required.

Furthermore, a number of studies have described the cost-effectiveness or cost-benefit of individual species management strategies to determine whether the benefits of a project were greater than the costs (Zavaleta 2000, Leung et al. 2002, Le Maitre et al. 2002, Van Wilgren et al. 2004, Burnet et al. 2007, Keller et al. 2007, Panzacci et al. 2007, Pascal et al. 2008, Wise et al. 2012, Reyns et al. 2018). These have typically been species- or environment-specific. A number of studies have compiled cost/effort information from different eradication or complete removal projects for particular taxa (Rejmánek and Pitcairn 2002, Martins et al. 2006, Howald et al. 2007, Bradshaw et al. 2016, Brockerhoff et al. 2010, Robertson et al. 2017). These have used a single measure of effectiveness – the complete removal of a species from a defined area. These studies demonstrated how the area over which control takes place is the major determinant of total cost, how cost per unit area decreases with scale (Robertson et al. 2017) and comparative information on the relative costs of managing different taxa (Martins et al. 2006, Howald et al. 2007). Only a few standardised databases are available and relate to specific contexts, for example, DIISE[2] on island eradications (Keitt et al. 2011). Overall there is a need for more information on management costs to extend this approach (e.g. DIISE does not include any information on costs). Species removal can also bring (non-monetary) costs in relation to animal welfare, social acceptability and the environment, although these considerations have not been included in the published reviews.

A range of optimised management approaches have been used, for example, to balance the use of different control measures, to deploy effort in space and time (Sharov and Liebhold 1998, Eiswerth and Johnson 2002, Taylor and Hastings 2004, Haight and Polasky 2010, Sims 2011, Epanchin-Niell et al. 2012, 2014, Baker and Bode 2016) or to reduce the associated uncertainties (Olsen and Roy 2002, Burgman et al. 2010, Gren 2008). More detailed analyses have explored the most effective management approaches based on the species life-history (Buhle et al. 2005, Sims and Finnoff 2013, Sims et al. 2016) or other characteristics (Evans et al. 2008, Blackwood et al. 2010). Related to this, a range of studies have worked to optimise policy interventions, for example, taxation levels or rates of inspection (Mérel and Carter 2008, Springborn et al. 2016) to achieve management objectives. These have applied principles such as dynamic optimisation and optimal control based on bioeconomic modelling to support decision-making processes (McDermott 2015, Liu and Sims 2016, Epanchin-Niell 2017).

2. A framework and standardised method to collect information on costs of IAS prevention and management measures

In this chapter we discuss the methodology for the collection of data on costs of IAS prevention and management and propose an outline database structure designed to record the relevant information.

Proposed methodology for the collection of data on costs of IAS prevention and management.

Step 1) Define the object of the research: the target taxa, i.e. which taxa are the object of the study, have to be clearly defined. The study could be targeting one or more species or group of species, in which case the relevant scientific names, along with the most common synonyms and common names, should be clearly identified.

Step 2) Data mining: A preliminary search should be done using different tools depending on the specific source of data identified:

a) Literature search
b) Project/species databases

[2] http://diise.islandconservation.org/

c) Questionnaires and interviews

2.a) Literature search: The scientific literature includes published reviews of the measures and costs of different IAS eradications in relation to scale, including of plants (Rejmanek and Pitcairn 2002); forest insects (Brockerhoff et al. 2010); mammals from islands (Martins et al. 2006, Howald et al. 2007, Holmes et al. 2015, 2016) or larger land masses (Robertson et al. 2017) and there is scope to add to this list. However, this literature contains a number of shortcomings, such as under-reporting of failed eradications (Bradshaw et al. 2016), or that very few studies (Gardener et al. 2010) systematically document the cases where eradication could have been applied but was not attempted. However, these reviews document how costs change in relation to area, and recording the area over which management, either for eradication or long-term management, is undertaken should be a key consideration.

Different literature search strategies exist to find relevant published articles, chapters and reports, e.g. through internet-based searches (including online platforms such as Google Scholar, Web of Science, etc.) or other novel tools. The results usually depend on the underlying search effort, and on the use of appropriate (more or less specific) search terms. The preliminary results of any search need to be filtered (manually) for relevant data on costs for prevention and management, e.g. by selecting publications according to the information provided in titles and abstracts, and by scanning the selection in more detail. References cited within the selected publications, particularly in review papers, as well as in technical reports and grey literature, should be also screened and included as appropriate. In principle, only the primary source of information or study should be used. Extensive, standardized literature search should ideally aim at a systematic review. However, as this could be extremely time consuming, the search may be limited to a reasonable number of working days, depending on the time and resources available.

2.b) Project/species databases: data search on public databases available online, which could have a focus on either projects or species, could be used as a basis for effective data retrieval.

Within the EU, some funding programmes (e.g. LIFE, Horizon 2020) have supported projects related to IAS management and research and as such may represent a source from which to extract data on costs of management and prevention measures (Silva et al. 2014, Scalera 2010, Scalera et al. 2017, Scalera and Zaghi 2004, Tucker et al. 2013). However, it may be difficult to separate costs attributed to different activities, only some of which will be directly applicable to management. Nevertheless, the use of online tools such as the LIFE database (and CORDIS[3] at least in part) is considered useful to fill in any information gaps because some information may be unpublished, but still possible to retrieve with some effort.

[3] https://cordis.europa.eu/projects/home_en.html

The search of data may follow the same approach as the literature search outlined in point 2.a), e.g. through targeted searches, using more or less specific keywords. If the search should be limited to specific countries or years, this can be done through the available filters in the database. Also, in this case, the search may be limited to a reasonable number of projects, depending on the time and resources available. Normally, the information collected in this way will serve as a basis for gathering additional details (specific project outputs, including papers and technical/financial reports published in local languages, undergraduate theses, survey and monitoring reports, etc.).

At the global level, information on island eradications is compiled by DIISE (Keitt et al. 2011), which is available on-line and currently describes 1,858 bird and mammal island eradication attempts, of which 1,420 are described as successful. These document the areas over which different measures have been successfully applied, but do not include information on the costs or effort involved.

The use of the online databases should be used in association with step 2.c) because relevant data may not be readily available and may need correspondence with the data holders, e.g. the project managers, the funding agencies and administrations, etc.

2.c) Questionnaires and interviews: a key constraint highlighted in many papers and reports on IAS management costs is the generalised lack of published information on the issue, despite the many management interventions undertaken in different countries. A way to access such information is through direct contact with the key actors, i.e. by means of dedicated questionnaires and interviews, especially by email (in a limited number of cases dedicated skype and telephone calls may be required).

For example, in relation to the use of the database of LIFE projects, questionnaires and interviews have been used for the collection of data from authors of papers, project beneficiaries, European Commission services and relevant agencies (including the LIFE units), or external monitoring teams. This approach also helps to overcome problems where the information is normally available in a multitude of languages, which the researchers are not familiar with. The questionnaires may be shared through a word template, an excel spreadsheet or an online survey platform.

In the case of LIFE projects, in order to use the database most efficiently and to access unpublished information, contacts may be established with the LIFE Unit(s) at EC DG ENV or EASME. For this purpose, a shortlist of pre-selected projects (together with the questionnaire to indicate the type of information needed) may be circulated to such institutional actors, as well as the external monitoring team experts, who have detailed knowledge on a large number of projects. This may help to further refine the list of projects, by identifying those that are actually relevant or those that should be dropped from further analysis (e.g. on the basis of a lack of quantitative data). Also, this may give the opportunity to be informed by the existence of particularly relevant projects that have been accidentally disregarded (e.g. in case of lack of correspondence with the key words used in the database).

Contacts can be found through dedicated social networks and fora (e.g. a major example which proved to be very effective for this purpose is the Aliens-L[4]), a list server managed by the IUCN/SSC Invasive Species Specialist Group (ISSG), dedicated to IAS that threaten biodiversity. It allows users to freely seek and share information on invasive species and related issues, by facilitating the linkages between global experts and practitioners.

Step 3) Data collection: the data collected through step 2) need to be entered into a dedicated database. For example, ideally a relational database (with different tables for different aspects – taxonomy / locations / habitats / management measures / impacts) would allow to prepopulate data and classifications schemes (speeding up data entry – using check boxes etc. and minimizing human error) and link multiple records (species) to individual management measures, or vice versa etc. It may be developed in Access or online (e.g. by using open source database such as PostgreSQL). In this way it is possible to fill it in without having to do data merges, avoiding errors and potential duplication.

Database hosting the relevant quantitative and qualitative information

An outline of the database structure designed to record information on the costs and effectiveness of IAS management and prevention was developed. The objective was to provide a protocol that is suitable to accommodate data from the different sources described in the previous chapter. In particular, it is meant to facilitate data entry from any type of publication, as well as from interviews (hence it can be used as a basis for a questionnaire to be circulated to people directly involved in relevant projects).

Field	Format of Data	Explanation	Drop down menu
Record ID	Numeric	Provides a unique ID number, starting with **P f**or preventative measures, **E** for eradication measures, **C** for control measures - **followed by 3 numbers** starting at 001. Therefore, the 1st control measures will be coded C001, the third eradication measure E003, etc.	No
Measure (Overall Management Objective)	Categorical	Choose from Prevention, Eradication or Control (If the objectives of a programme change, for example, if eradication fails and it moves to control, then these should be described separately as different entries)	Yes
Species	free text	Indicate the best available information, ideally Latin name (e.g. either genus, species or subspecies). If no precise Latin name is available, add common name or whatever available in the data source	No
Synonyms	free text	Taxonomic synonyms	No
Genus	free text	The genus that the species belongs to	No
Family	free text	The family that the species belongs to	No
Class	free text	The class that the species belongs to	No
Phylum	free text	The phylum that the species belongs to	Yes

[4] http://www.issg.org/about.htm#networking

Field	Format of Data	Explanation	Drop down menu
EU concern	Categorical	Two categories: Yes (Y) or No (N). IAS known to be going through the RA process should be indicated with a "?"	Yes
Goal (Specific Management Objectives)	free text	Describes the specific goal, for example, remove all populations from a defined area, reduce the spread of the species, or keep impacts at an acceptable level.	No
Action (Type of Method Applied)	Categorical	Categories are: Prevention - legal status; Prevention - best practice; Prevention - cultural methods; Eradication - shooting; Eradication - trapping; Eradication - hand removal; Eradication - pesticides or herbicides; Eradication - poisoning or toxicants; Eradication - other (disease, fumigants, draining); Eradication - Integrated methods; Control - shooting; Control - trapping; Control - hand removal; Control - pesticides or herbicides; Control - poisoning or toxicants; Control - biological; Control - Integrated methods; Control - other	Yes
Activity (Description of Method Applied)	free text	Describes the methods applied in detail - not costs; results etc.	No
Location	free text	Where the study was performed	No
Country	free text	The country where the data come from	No
Habitat	Categorical	Categories are: freshwater, terrestrial, marine, not reported	Yes
Project status	Categorical	Categories are: Planned, Ongoing; Completed, Hypothetical, not reported	Yes
Effort	free text	This describes the unit of effort indicated below.	No
Units of effort	free text	The units of effort, e.g. traps in operation per km2, number of trappers employed per year, man days, man months, costs per individual removed etc.	No
Duration of effort	free text	A quantitative description; for example, five days trapping per month, continuous trapping for 10 years	No
Effect	free text	Quantitative description of management outcome - for example, successful eradication, reduction in population density from 20 to 10 per km2, 10% reduction in reported damage	No
Effectiveness	Categorical	Categories are: very effective, effective, moderate, ineffective, very ineffective, not reported	Yes
Social acceptability	Categorical	Categories are: very acceptable, acceptable, moderate, unacceptable, very unacceptable, not reported	Yes
Practicality	Categorical	Categories are: very practical, practical, moderate, impractical, very impractical, not reported	Yes
Wider environmental impact of management	Categorical	Categories are: Minimal, moderate, massive, not reported	Yes
Wider socio-economic impact of management	Categorical	Categories are: Minimal, moderate, massive, not reported	Yes
Describe wider impacts of management	free text	Describe the wider impacts of management (accidental trapping of non-target species?)	No
Reasons for not meeting management goal	free text	If applicable, what/why didn't work about the activity	No
Original Currency	free text	Monetary currency	Yes
Project name	free text	Indicate full project name (and code, if appropriate)	No
Funding instrument	free text	Indicate funding instrument (as appropriate) and source (Government funded-national level, European funds, private funds, NGO/env donors, etc)	No
Start date	Date	Start date of the project; Indicate preferably dd/mm/yyyy, at least year	No
End date	Date	End date of the project; Indicate preferably	No

Field	Format of Data	Explanation	Drop down menu
		dd/mm/yyyy, at least year	
Months	Numeric	Duration of the project (indicate in the notes whether there was an extension to the end date to meet management objectives)	No
Total cost	Numeric	Only for measures addressing IAS directly (hence no restoration or other side measures) otherwise add explanatory note in comments	No
Year of Cost Estimate	Numeric	If the year of the cost estimate does not coincide with the end year of the project, give the year to which the currency estimate relates, so that inflation can be accounted for in future	No
Total area (ha)	Numeric	Only for measures addressing IAS directly (hence no restoration or other side measures) otherwise add explanatory note in comments	No
Unit	free text	Choose between costs/ha/y or costs/ha as appropriate	No
Average cost per unit area	Numeric	The average cost of the management/prevention measure per unit area; Use explanatory note in comments	No
Breakdown	Categorical	Categories: Published, unpublished Indicate whether a breakdown is available from published or unpublished work (insert N/A if not available)	Yes
Personnel costs	Numeric	Include information on costs for personnel, including permanent or temporary staff, consultants, etc.	No
Equipment/infrastructure costs	Numeric	Include costs for durable goods	No
Other costs/overheads	Numeric	Include any costs that do not fall under personnel or durable goods	No
Source	free text	Bibliographic reference	No
Cost estimate reproducibility	Categorical	Categories are: Reproducible, irreproducible	Yes
Webpage	free text	Provide link to webpage from which data were retrieved; Mandatory if relative to data excerpted from online database	No
Contact	free text	Website and email of project manager if necessary/appropriate	No
Comment	free text	Add any additional comments, provide additional clarifications	No
Impact on biodiversity	free text	Positive side-effect of the measure on the overall biodiversity	No

3. A method of multi-criteria analysis applicable to generic species/habitats.

The assessment of different IAS management alternatives faces a number of challenges. It needs to consider the economic elements of management, along with other currencies which are less readily presented in simple economic terms. Methods are also needed which can be used where there is little or no published information on costs or method effectiveness. A method should also be able to compare between different alternatives, prioritising the different choices faced by a manager (for example, which method to choose, which species to deal with first, or when to choose eradication or long-term management as the goal?). It also needs to be able to include the effects of scale on these choices, what works well at a small scale may be very different from what is effective over large areas.

This chapter describes a multi-criteria method based on expert elicitation that can be applied in a variety of different ways to deal with these problems. It builds on the method developed for use in the prioritisation of IAS eradications in Great Britain (GB; Booy et al 2017). This approach can be used to compare between different management alternatives in a structured way and we describe how the method can be applied to answer a range of management questions such as the prioritisation of species for eradication, the selection of management methods and how to consider the effects of scale when choosing between eradication and long-term control. This last question is examined in detail.

Background

Triantaphyllou (2000) describes multi-criteria decision-making techniques involving the numerical analysis of alternatives. These modelling and methodological tools are designed to find optimal solutions to complex problems where assessment criteria or data are measured in different or conflicting currencies, including when only incomplete or imprecise information is available, or where human evaluation is needed (Kahraman 2008). For example, when choosing to buy a second-hand car, the criteria used in decision making might include cost, comfort, safety, attractiveness, previous mileage, damage, reputation of the seller and fuel economy; criteria which are measured in a range of currencies, cannot be practically combined into simple economic terms and include one sole element of judgement. Clearly structuring complex problems and explicitly evaluating multiple criteria allows the comparison of alternate options and leads to more informed and better decisions. These methods can also provide outputs directly tailored to support decision making, for example Liu and Wang (2007) describe approaches to assess alternative methods based on their policy utility. These are all distinct advantages compared to the use of cost-benefit approaches to prioritisation (Carrasco et al. 2010, Courtois et al. 2018).

Decision making in relation to IAS prevention and management is subject to similar challenges as these complex problems. As discussed previously, the assessment of relevant costs and benefits needs to encompass a range of different currencies. In addition, the available information is often incomplete, hence expert opinion may be needed to provide assessments. Expert opinion is already widely used to support decision making in IAS policy, and provides the basis of risk assessment and horizon scanning undertaken at EU level (Roy et al. 2014a, Roy et al. 2015). Given the range of alien species that become invasive, any method should be broadly applicable to any taxa (Nentwig et al. 2010) and, given the large numbers of species involved, it should be efficient to apply (Andersen et al. 2004; Hulme et al. 2009). It should be possible to apply the method even where data are lacking, taking into account uncertainty, that needs to be well documented and justified (Vanderhoeven et al. 2017).

A key policy requirement is to prioritise IAS for prevention and management action and to identify the most appropriate objectives of the relevant measures envisaged. In the related fields of human, animal and plant health, risk assessment is used alongside risk management as part of a wider risk analysis framework to guide the prioritisation of action. These methods use a combination of quantitative and qualitative data and expert opinion covering a range of different currencies, including economic cost, to assess the risks, impacts or feasibility of management. Multi-criteria methods allow these diverse criteria to be used to support decision making.

An example is the method recently developed by Booy et al (2017) which was used to assess the feasibility of eradicating different IAS from Great Britain. This method involves four stages to compare between different cases, setting the scenario, setting the management method and objective, undertaking the assessment, and interpreting the results.

In Booy et al (2017), for each species, a scenario was produced which described the species' range within GB, United Kingdom (UK), together with a description of the management method to be applied and its objective of eradication. It then used semi-quantitative response and confidence scores to assess five key criteria:

1. Effectiveness
2. Practicality
3. Cost
4. Impact (of management)
5. Acceptability

Two supplementary criteria were also considered:

6. Window of opportunity
7. Likelihood of re-invasion

Each of these cases was then assessed based on these criteria to produce an overall assessment of feasibility for each species. These species assessments were then compared to produce an overall ranking of eradication feasibility for the different species (Fig 1). These different species feasibility of management assessments were then combined with existing risk assessments for the same species to prioritise species for eradication.

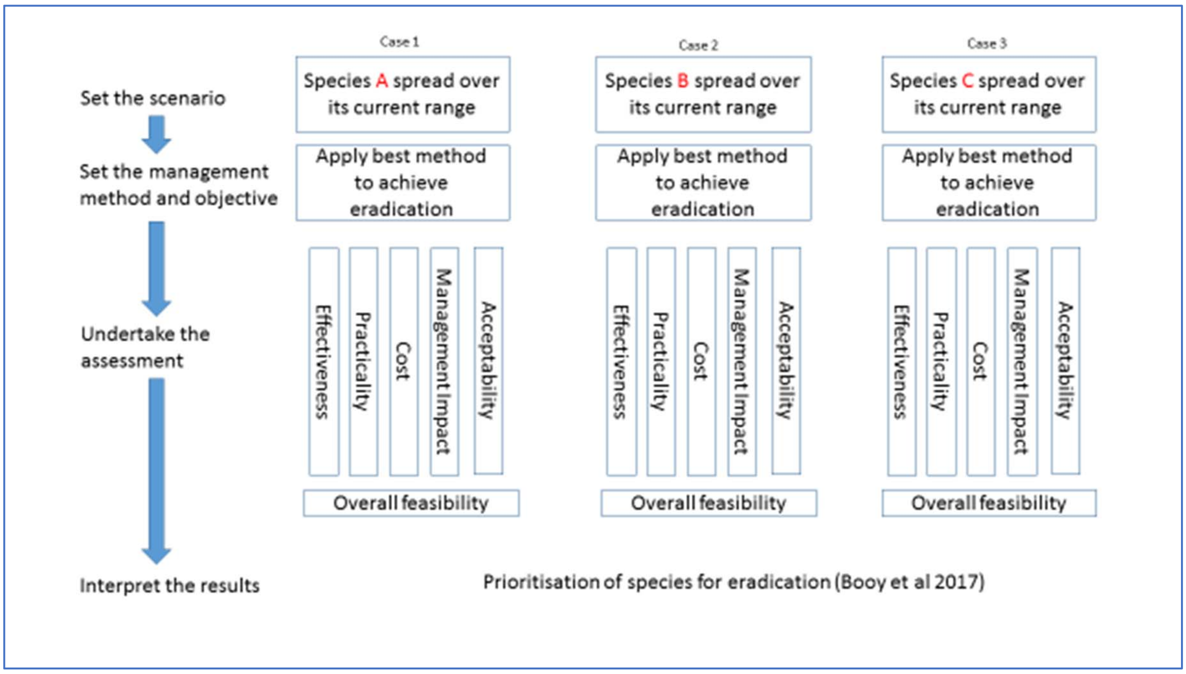

Figure 1 - Schematic description of the risk management method of Booy et al. (2017) to assess the overall feasibility of eradication of different invasive alien species.

By altering the selection of the species, control measures, management objective and scale, the multi-criteria approach of Booy et al. (2007) can be applied to generic species/habitats to assist in the prioritisation of the most cost-effective prevention and management measures.

For example, a common management decision is to decide "*at what point the eradication of a species from an area is no longer feasible?*". Figure 2 illustrates how this approach might be applied to assess the changing feasibility of eradicating a species in relation to the size of the area over which it has spread. In this example, a range of scenarios are produced describing areas of different size, while other variables - i.e. the species, the management options and the objectives - remain constant. While the scenario may change, the same assessment criteria can be applied, as in Booy et al. (2017).

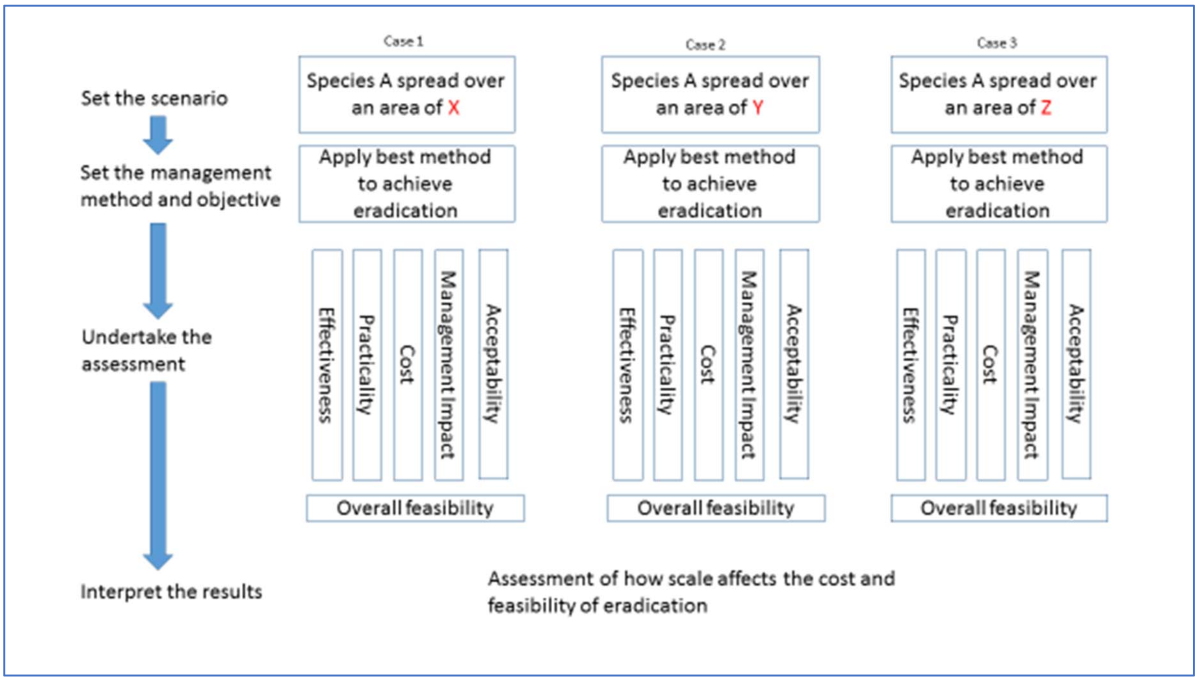

Figure 2 - A schematic description of how the multi-criteria risk management method might be applied to assess the feasibility of eradicating an invasive alien species at different scales.

In addition to the compilation of information from the literature and completed projects (e.g. collected as described in section 2), assessments using the method developed by Booy et al. (2017) require experts to estimate the likely cost of the case under consideration. Given the paucity of information and experience of managing many IAS, including many already included in the List of Union Concern, this approach - based on expert elicitation - may also provide a method to obtain cost estimates in a structured form to guide decision making.

There are other available methods for multi-criteria analysis, such as the method developed by Schmiedel et al. (2016), who describe a process to help select management methods that may be appropriate to use for the prevention, eradication or long-term management of different species. This publication collates the methods used to manage defined target species from the available literature and assesses each method on three criteria: effectiveness, ecological impact, and impact on human health, to produce a list of those considered appropriate for use. This method has the advantage that it is evidence-based and links the available choices to the published evidence, if available. However, it does not help prioritise amongst those measures considered appropriate, nor consider wider criteria such as cost, practicality or acceptability which are included in the method of Booy et al. (2017). It also does not consider the effects of scale which is a key element when comparing management options. The Schmiedel et al. (2016) approach is also restricted to measures described in the literature or used by practitioners, limiting its use for species where there is little available information or experience.

Although there was some potential in the adoption of the method proposed by Schmiedel et al. (2016), the approach based on Booy et al. (2017) was considered more ambitious and promising in terms of overall potential to assess the feasibility of management measures, and as such was adopted for this report.

In particular, this latter approach was considered suitable to answer the following key questions, in line with the approach outlined in Figure 2:
• How to assess the effects of scale on the feasibility and cost of management (eradication)?
• When to choose between eradication or long-term management as the management objective for a species?

Guidance document and template for the multi-criteria analysis

In this section, we provide the multi-criteria analysis guidance and template (as developed by Booy et al. 2017, for approach detailed in Figure 1) that was used to help inform the selection of the most cost-effective management option to answer the two questions stated above (as per Figure 2). These are the guidelines that describe the criteria produced and used by Booy et al (2017) and that are further developed to explore the effects of scale described in this report.

This method is based on the following key criteria, which are described in detail below:
1. Effectiveness
2. Practicality
3. Cost
4. Impact (of management)
5. Acceptability
6. Window of opportunity
7. Likelihood of re-invasion

Setting the criteria for assessment
To apply the multi-criteria analysis framework, it is first necessary to define the key terms to be used to create the different cases for comparison. This should specify the species, define the objectives of management, describe the size of the area over which management will be conducted, and select the management measures to be applied.

Define the objectives of management
Once the species has been specified, the first priority should be to select the objectives of management. The objectives will fall into three main categories – prevention, eradication and control (long-term management). They should also be defined in terms that allow the possible success or otherwise of management to be assessed, so typical objectives might include:
- To prevent the species entering and establishing a defined area.
- To eradicate the species by removing all individuals from a defined area.
- To stop the spread of the species beyond the limits of its current distribution.
- To reduce the local abundance of the species to a level where the level of damage caused to a resource is considered acceptable.

These are only examples of possible management objectives, but the greater the degree of quantification that can be achieved, the more effective will be the assessment of overall management feasibility and cost-effectiveness.

Describe the area over which management will be conducted
In defining the scenario, one should consider (but only include if relevant):

- How widespread the species is (or will be at the point of detection) in the management area;
- The types of habitats / environments in which the species is (or will be) present;
- How many spatially distinct populations there are (or will be);
- What the size of the total population is (or will be).

As the current or potential extent of IAS populations is often only known in general terms, a series of categories are provided at the end of this guidance which may be useful to describe the likely areas involved where there is some uncertainty.

Select the measures to be applied
A variety of approaches are available from which to select the appropriate measure for management. These may be drawn from current practice elsewhere or based on screening a variety of possible measures. In many cases, management may involve the use of multiple measures and these can be assessed along with the use of individual measures.

For each permutation of species, management objective, area and measures, produce a separate case which can then be assessed.

Assessing the individual case
Each case should be assessed using the criteria defined under the headings in Table 1 below to complete the template.

The response score is a 5-point scale from 1-5 (Table 1). In all cases 1 is the least favourable and 5 the most. For example, a very effective approach scores 5, a very ineffective approach scores 1; whereas a very inexpensive case (i.e. the cost favours taking action) scores 5, a very expensive one scores 1.

Table 1 - Assessment criteria for response scores.

Criteria	**Response Score**				
	1	**2**	**3**	**4**	**5**
Effectiveness	Very ineffective	Ineffective	Moderate effectiveness	Effective	Very effective
Practicality	Very impractical	Impractical	Moderate practicality	Practical	Very practical
Cost	>€10M	€1-10M	€200k-1M	€50-200k	<€50k
Negative impact	Massive	Major	Moderate	Minor	Minimal
Acceptability	Very unacceptable	Unacceptable	Moderate acceptability	Acceptable	Very acceptable
Window of opportunity	Very short < 2 months	Short 2 – 12 months	Moderate 1 – 3 years	Long 4-10 years	Very long >10 years
Likelihood of	Very likely	Likely	Moderate	Unlikely	Very unlikely

reinvasion			likelihood		
Conclusion (overall feasibility of eradication)	Very low	Low	Medium	High	Very high

A confidence rating should be provided for every response score. Confidence is recorded on a 3-point scale: 1 (low), 2 (medium), 3 (high). Even where evidence is lacking, assessors should make best judgements and use the confidence rating score to reflect uncertainty. As this approach is more widely applied, there may be scope to improve on the definition of these terms, for example providing more detailed descriptions of the difference between 'high' and 'very high'. However, this is not a simple matter and would require testing and review before clear definitions could be used to avoid any linguistic ambiguities and that any definitions were appropriate across environments and taxa.

Effectiveness

This part of the assessment scores how effective the defined case would be regardless of other issues, such as the practicality of deploying methods, costs, acceptability of methods, etc. which are taken into account elsewhere. For example, the eradication strategy for an invasive alien fish in a river could be to flood it with the piscicide rotenone – this would likely score 'very effective' despite low scores associated with practicality, impact and acceptability.

Points to consider:

- How effective has this approach proven to be in the past or in an analogous situation?
- How effective is the approach despite the biology / behaviour of the target organism?

For clarity, the term "effectiveness" refers to the stated objective of the measure, for example, for eradication "can the measure remove all individuals from the area defined?". Management may also have less specific longer-term objectives, such as producing a positive impact on biodiversity, although this may not always be immediately evident and may require time/resources to be monitored/evaluated in the long-term. Care is needed to separate the short and long-term objectives of management when defining the questions to be answered.

Practicality

How practical is it to deploy the described case? In particular, consider barriers that might prevent the use of the measure(s) such as issues gaining access to relevant areas, obtaining appropriate equipment, skilled staff, chemicals, etc. should be considered. If there are any legal barriers to undertaking the work these should be assessed here.

Points to consider:

- How available are the methods in the risk management area?

- How accessible are the areas required to deploy the measure(s)?
- How easy would it be to obtain relevant licences or other approvals / permissions (e.g. access permission) to undertake the measure(s)?
- How easy would it be to overcome legal barriers?
- How safe are the measure(s) used in this approach (are there health and safety barriers)?

Cost

Cost relates to the total direct cost of undertaking the management measure(s) within the defined area. Total cost includes the cost of staff, resources, materials, etc. over the entire time period involved in the application of the management measure(s), and any required post surveillance and follow-up. Note indirect costs (e.g. loss of business) are considered an *impact* and should not be recorded here.

The period over which costs would be incurred (i.e. number of years that costs might need to be incurred for an eradication, or the recurrent costs per year for long-term control) should be indicated in the comments, as well as, if possible, whether the cost would be evenly spread, frontloaded or back loaded. The range of costs in the different categories are based on Booy et al. (2017) for GB. It may be necessary to scale these if this method is applied at smaller or larger scales.

Note: In this section, costs refer only to the costs of implementing the management measure, and not to the costs associated with the impact of the species.

Impact

Impact relates to the impact of the management measure(s) itself. It is important to note that any indirect economic impacts (i.e. economic consequences of the management measure(s) rather than the cost of the strategy itself) are recorded here and not under 'cost'.

Points to consider within this criterion:

- How significant is the environmental harm caused by this measure(s)?
- How significant is the economic harm caused by this measure(s)?
  Examples of economic harm might include: reduction in the ability to trade or do business as a result of the management method; loss of earnings; reduction in tourism; reduction in house prices; etc.
- How significant is the social harm, including to human health, caused by this measure(s)?
  Examples of social harm might be a reduction in a person's use or enjoyment (e.g. preventing them walking in a woodland or fishing in a river), disruptions of communities, etc.

Given the range of economic, environmental and social impacts (and welfare impacts when managing vertebrates), it may be worthwhile to score each of these components separately and then provide a single overall assessment of impact (or, if appropriate, any benefit) based on these individual terms. This approach would need to be trialled, in particular to determine the most representative way of combining sub-scores in to an overall assessment. There may also be situations where it might be necessary to consider the potential positive side effects of management, and development would be needed to incorporate this.

As a remark, here the term "impact" refers only to "negative side-effects" of the assessed measure (positive effects may also exist, but they are not considered or discussed here).

Acceptability

Acceptability relates to significant issues that could arise as a result of disapproval or resistance from the general public and stakeholders (e.g. individuals, groups or sectors). This does not include regulatory or legislative barriers which are considered under practicality.

Points to consider within this criterion:

- How acceptable is the measure(s) likely to be to environmental / animal welfare groups?
  Note this question relates to potential criticism / resistance that the approach would meet from environmental / animal welfare groups.
- How acceptable is the measure(s) likely to be to the general public?
- How acceptable is the measure(s) likely to be to other stakeholders?

Assessing the window of opportunity

The window of opportunity relates to how quickly the species will spread to the point that the assessed case is no longer relevant. It is linked to the mechanism and rate of spread, which is considered during the risk assessment.

This criterion is highly relevant when considering eradication as a management objective, but there may be cases, for example long-term management, where this is of limited relevance and could be marked as not applicable.

Assessing the likelihood of re-invasion

If the management aims to remove all individuals of the target species from an area how likely is it that re-invasion will occur?

This criterion is highly relevant when considering eradication as a management objective, but there may be cases, for example long-term management, where this is of limited relevance and could be marked as not applicable.

Determine the overall feasibility

This is the conclusion of the assessment. A score should be provided for the overall feasibility of the methods used to successfully achieve the stated objective taking into account each of the different criteria. Assessors should provide a score they judge to be appropriate, taking other scores into account (but note that the overall score is not necessarily the mean of other scores).

The assessment of the overall feasibility of the eradication as described above can help decide when eradication may no longer be a viable objective, and, when either long-term management then needs to be considered (default option), or if inaction (to do nothing) is the only possible alternative.

Template for IAS multi-criteria risk analysis

Risk management area:			
Management Objective:			
Organism/Species name:			
Assessor name(s):			
Date / version:			
Step	**Response**	**Confidence**	**Justification**
Define the scenario			
Define the management measure(s)			
How effective is the measure(s)?	5 - V EFFECTIVE 4 – EFFECTIVE 3 – MODERATE 2 – INEFFECTIVE 1 - V INEFFECTIVE	3 – HIGH 2 – MED 1 – LOW	
How practical is the measure(s)?	5 - V PRACTICAL 4 – PRACTICAL 3 – MODERATE 2 – IMPRACTICAL 1 – V IMPRACTICAL	3 – HIGH 2 – MED 1 – LOW	
How expensive is the measure(s)?	5 (<€50K) 4 (€50-200K) 3 (€200K-1M) 2 (€1-10M) 1 (>€10M)	3 – HIGH 2 – MED 1 – LOW	
How much negative impact would the measure(s) have?	5 – MINIMAL 4 – MINOR 3 – MODERATE 2 – MAJOR 1 – MASSIVE	3 – HIGH 2 – MED 1 – LOW	
How acceptable is the measure(s)?	5 - V ACCEPTABLE 4 – ACCEPTABLE 3 – MODERATE 2 – UNACCEPTABLE 1 - V UNACCEPTABLE	3 – HIGH 2 – MED 1 – LOW	
What is the window of opportunity for implementing the measure(s)?	5 (10+ YRS) 4 (4-10 YRS) 3 (1 – 3 YRS) 2 (2 MTHS - 1 YR)	3 – HIGH 2 – MED 1 – LOW	*Add N/A if not relevant to the scenario*

	1 (< 2 MTHS)		
What is the likelihood of reinvasion?	5 – V UNLIKELY 4 – UNLIKELY 3 – MODERATE 2 – LIKELY 1 – V LIKELY	3 – HIGH 2 – MED 1 – LOW	*Add N/A if not relevant to the scenario*
Conclusion (overall feasibility of management)	5 – V HIGH 4 – HIGH 3 – MEDIUM 2 – LOW 1 – V LOW	3 – HIGH 2 – MED 1 – LOW	

When defining the area over which a species has spread it is often difficult to define the total area or how to present a population when its range is fragmented. The following table (Table 2) provides a useful classification of species distributions to help guide this description when setting the scenario of consideration. It can be used to indicate the likely number of sites containing the species and the combined area of these populations. Populations are considered discrete if they would be unlikely to recolonise from other areas after removal. The total area is that from which the species would need to be removed, i.e. for three populations of a species each covering 10 ha and each 100 km apart, the total area is 30 ha.

Table 2 - Table for coding the scenario based on a number of discrete populations and total area.

		Total combined area of populations					
		<1ha	1-10ha	10ha-1km2	1-10km2	10-100km2	>100km2
Number of discrete populations	1-3	A1 1-3 discrete populations estimated covering a total area of <1ha	A2 1-3 discrete populations estimated covering a total area of 1-10ha	A3 1-3 discrete populations estimated covering a total area of 10ha-1km2	A4 1-3 discrete populations estimated covering a total area of 1-10km2	A5 1-3 discrete populations estimated covering an area of 10-100km2	A6 1-3 discrete populations estimated covering an area of >100km2
	4-10	B1 4-10 discrete populations estimated covering a total area of <1ha	B2 4-10 discrete populations estimated covering a total area of 1-10ha	B3 4-10 discrete populations estimated covering a total area of 10ha-1km2	B4 4-10 discrete populations estimated covering a total area of 1-10km2	B5 4-10 discrete populations estimated covering a total area of 10-100km2	B6 4-10 discrete populations estimated covering a total area of >100km2
	10-50	C1 10-50 discrete populations estimated covering a total area of <1ha	C2 10-50 discrete populations estimated covering a total area of 1-10ha	C3 10-50 discrete populations estimated covering a total area of 10ha-1km2	C4 10-50 discrete populations estimated covering a total area of 1-10km2	C5 10-50 discrete populations estimated covering a total area of 10-100km2	C6 10-50 discrete populations estimated covering a total area of >100km2
	+50	D1 50+ discrete populations estimated covering a total area of <1ha	D2 50+ discrete populations estimated covering a total area of 1-10ha	D3 50+ discrete populations estimated covering a total area of 10ha-1km2	D4 50+ discrete populations estimated covering a total area of 1-10km2	D5 50+ discrete populations estimated covering a total area of 10-100km2	D6 50+ discrete populations estimated covering a total area of >100km2

4. Results and discussion

In this chapter, the results of the implementation of the research carried out to collect information on costs of managing invasive alien terrestrial vertebrates are reported and discussed. In particular, such results refer to data collected through dedicated searches and analysis of: a) the relevant scientific literature, and b) the database of LIFE projects (with the support of direct interviews). The search protocol to identify relevant papers and projects dealing with prevention and management measures is described, along with the process for the extraction of data to enter into the database. Comments on the process and the availability of data are also provided here.

The results and application of the multi-criteria analysis and other sources of evidence, to inform key management decisions at different stages of the invasion process, are also described. An element of validation of the overall approach is also provided, e.g. by the comparison of the assessment of different eradications through an expert elicitation exercise with the observed results from a sample of documented eradications extracted from the scientific literature.

Evidence of costs and effectiveness of prevention and management of terrestrial vertebrates

To collect information on costs and effectiveness of prevention and management of terrestrial vertebrates, with a focus on those in the current list of Species of Union Concern, data were accessed from the following sources:

- Scientific literature
- LIFE database and direct interviews

All data were stored into the database called “IAS management costs database”.

The IAS management costs database

The “IAS management costs database” was built as explained in Chapter 2 as an excel spreadsheet (provided as annex to this report). Drop down menus were added for the classification schemes suggested (in grey cells) to make data recording consistent - they are listed (linked to) the 'Drop Lists' tab, to allow any necessary rewording. Conditional formatting was also added in, so any duplicate Record ID number would be highlighted automatically. Cells were formatted accordingly down to row 501 - so drop-down menus will work to here. To avoid confusion, compilers were instructed not to leave blank cells (hence to indicate N/A if data were not available or the field was considered not relevant).

Scientific literature

As a first step, a database on eradications compiled by Newcastle University was used, describing the reported costs of successful IAS eradications worldwide and the areas over which they were untaken. Analyses of the information on mammals has already been published (Robertson et al. 2017, in press) and further information continues to be added. Studies describing the eradication of species frequently provide detailed information on the objectives, scale and success of the programme. They also regularly provide information on the costs or effort required for success. Key information was collected from published reviews of the methods and costs of different eradications related to mammals (Martins et al. 2006, Howald et al. 2007, Holmes et al. 2015, 2016, Robertson et al. 2017, in press). Based on these sources, the database contains records of 71 successful mammal eradications that specify both the area from which the species was removed and the associated cost. This includes information on eradications over significant areas, including the two phases of the Hebridean mink programme (3,411 km^2) (Roy et al. 2015), the five separate muskrat eradications in the UK (totalling 5,219 km^2) and the UK eradication of the coypu (19,210 km^2) (details and full references given in Robertson et al. (2017)). Recent years have also seen a number of large island eradications worldwide. Cruz et al. (2009) describe the eradication of goats from the 584 km^2 Santiago Island in Galapagos; Parkes et al. (2014) predicted the effort required to remove cats from the 1,680 km^2 Stewart Island off New Zealand, while the current rat removal on South Georgia will cover 3,538 km^2 (Piertney et al. 2016). As a consequence, the reported studies are spread over eight orders of magnitude in area and six orders of magnitude in cost.

To integrate the information with additional literature, we used Web of Science to identify papers published since 1970 which included the scientific names of the 16 terrestrial vertebrate species currently listed as Species of Union Concern, together with 'Prevention OR Containment OR Eradication OR Management OR Control'. This was intended to provide a representative sample of the scientific literature related to these species and these activities, and it was not intended to be a definitive, comprehensive search. In total, this search produced 1,287 scientific publications related to the terrestrial vertebrate Species of Union Concern and linked to the key search terms. These papers were sifted for relevance, as follows: 1) first by reading their titles, then if relevant, 2) by reading their abstracts, and if relevant, 3) by reading the papers' full content. On inspection, only 29 papers contained useful information, with one related to prevention, eight to eradication and 20 to some form of control (long-term management). The number of papers containing relevant information varied by species. For five (31%) of the 16 species, we found no relevant information; for a further eight (50%) we found only one or two papers; the remaining four species had between three and six relevant papers. The results of the literature search are presented in Table 3. This describes the number of management-related papers found per species, broken down into those related to prevention, eradication or control.

Table 3 - Total number of publications since 1970 and their relevance found in a literature search in Web of Science using the species name and the search terms 'Prevention OR Containment OR Eradication OR Management OR Control'.

Species of Union Concern	No. papers inspected	No. relevant to prevention	No. relevant for eradication	No. relevant for control	Total Relevant papers
Alopochen aegyptiacus	3	0	0	0	0
Callosciurus erythraeus	16	0	1	1	2
Herpestes javanicus	33	0	2	1	3
Lithobates catesbeianus	126	0	0	2	2
Muntiacus reevesi	35	0	0	2	2

Myocastor coypus	77	0	1	4	5
Nasua nasua	36	0	0	0	0
Nyctereutes procyonoides	78	0	0	0	0
Ondatra zibethicus	53	0	1	2	3
Oxyura jamaicensis	18	0	1	0	1
Procyon lotor	355	0	0	2	2
Sciurus carolinensis	144	0	2	4	6
Sciurus niger	36	0	0	1	1
Tamias sibiricus	21	0	0	0	0
Threskiornis aethiopicus	9	0	0	0	0
Trachemys scripta	247	1	0	1	2
TOTAL	1287	1	8	20	29

Successively, the full dataset (including the two batches described above, for a total of 71 + 29 records) was reviewed, and the original literature sources (particularly in such cases where the information was extracted from review papers) were analysed in detail. The objective was to double check that the information included in the database was correct, hence to prevent any mistake and inconsistencies (including on names of target species i.e. in the case of *Rattus* sp.) and add details if available. In fact, most info on eradication campaigns came from reviews, which in a few cases reported incorrect details or were subsequently misinterpreted (e.g. reporting as successful a campaign which was actually interrupted due to impacts on endangered non-target taxa, i.e. a failed campaign). Furthermore, 15 new entries previously not included in the database were added, totalling 113 records; in a few cases, entries for which only human effort was reported were also added (i.e. allowing for monetary quantification of personnel costs only).

Overall, the literature searches and the Newcastle database provided information on management activities targeting 26 species (21 mammals, 3 birds, 1 amphibian and 1 reptile). As a remark, 37 records are relative to 11 species of Union Concern. In total 113 records were included in the database, of which 83% relative to eradication measures and 16% to long-term management. Only one record was relative to prevention. As a side note, 48% of the records were extracted from three main review papers (Martins et al. 2006, Holmes et al. 2016, Robertson et al. 2017), an amount that rises to over 57% if we consider the records for eradication only.

Most of the records included some information on effectiveness of the implemented measures (around 92%, but this reflects the fact that the eradications were by definition effective) and for nearly 50% of the records it was possible to retrieve some kind of information on effort required to implement the management activities. Additionally, for 9 records it was possible to retrieve some information on benefits for biodiversity derived from the implementation of the management toward IAS.

Apart from the information on successful eradications, very few papers and reports could be used to retrieve information on costs of managing vertebrate IAS. In fact, information on costs was available in slightly more than 57% of records, which in most cases allowed to calculate the cost per unit area (almost 50% of records). In some case, additional information on costs is available for specific budget categories (e.g. personnel, equipment or other costs, although figures on total costs are not always available Apart from the information on successful eradications, the majority of papers focused on methods and results and did not report any information on costs, although more reported some measure of effort. Thus, in most cases, papers do not report costs, and when they do, details on specific budget categories (e.g. personnel, equipment etc.) are not explicitly reported. While a number of costs may be obtained (or estimated) by means of a more targeted research (e.g. most equipment prices can be retrieved from manufacturers) - thereby decreasing the margins of uncertainty on project costs - expenses associated with project management, consumables, and personnel are far more difficult to retrieve or estimate. In a very limited number of cases, for example when effort is reported in terms of total man years or total man hours, it may be possible to estimate personnel costs, as units of efforts can be used as proxies for monetary quantification of human costs. For example, Personnel costs could be estimated assuming a defined cost per man year of effort (e.g. figures in the range $50,000 to $200,000 US$ as suggested by Robertson et al. 2017). However, in some cases, effort is only reported in a way that does not allow for quantification of costs (e.g. trap-nights).

While there was a useful set of data on the areas and costs of successful eradication, the remaining literature provided little and scattered information, particularly in relation to the Species of Union Concern. Moreover, it provided little information on overall feasibility or the wider considerations of acceptability (found in 4 records only), practicality (4 records), wider environmental impact (4 records) and socio-economic impact (3 records). Information on benefits to biodiversity due to eradication of vertebrate IAS was also systematically checked in all publications but appeared very rarely reported (only 8 records). This was probably due to two main reasons:

a) most studies and reports only stick to the eradication per se, and even post-eradication campaigns only aim at assessing the actual success of the eradication process;
b) when post-eradication monitoring of biodiversity is reported, costs/expenses/total efforts are not; thus, such two aspects rarely occur within the same project/report/paper.

LIFE database and direct interviews

The “IAS management costs database” was designed to include both data from scientific literature and data from unpublished sources, including project databases and interviews to project managers and beneficiaries. For this reason, a number of LIFE Nature projects dealing at least in part with the IAS have been selected and analysed in detail to further populate the database. As a preliminary step, a list of 63 LIFE projects (potentially useful to fill in the required fields of the proposed database) was produced through a search on the LIFE database[5]. This preliminary search was made by consulting the dedicated section regarding IAS, as well as searching for keywords (among which the name of the target IAS or the protected species threatened by IAS, e.g. sea-birds threatened by rats). After a first analysis the list was further extended taking into due consideration the key thematic reports on IAS published within the LIFE programme (Scalera and Zaghi 2004, Silva et al. 2014). The use of such reports along with the web-summaries of each project, available in the LIFE database, allowed to identify a few additional projects particularly relevant for our study

[5] http://ec.europa.eu/environment/life/project/Projects/index.cfm

that had been accidentally disregarded, or to drop such projects whose activities on IAS were too marginal or not relevant. An important contribution was also provided by a recent publication (Scalera et al. 2017) produced in occasion of the LIFE Platform meeting on IAS, held in Milan on 29-30 November 2017, which focused on the LIFE projects dealing with the management of IAS (and which in some cases included also details on relevant costs).

In total, 30 LIFE projects were selected for further analysis, targeting the following species: *Neovison vison, Sciurus carolinensis, Nyctereutes procyonoides, Rattus rattus, Rattus norvegicus, Oxyura jamaicensis, Trachemys scripta* and *Lampropeltis getula californiae*. These 30 projects were chosen on the basis of their potential to contribute with data useful to fill in the database (hence projects still in progress or closed too many years ago were usually not considered). Additionally, a special attention was paid to ensure representativeness of species and countries. Once the selected projects were identified, the database was pre-populated with the information extracted from technical reports and other information available online from the websites of the relevant projects. Since detailed information on costs and relevant units was rarely available in these reports, direct contacts with the contact persons of these projects were also undertaken by email (contact details of the project beneficiaries are available in the web-summaries of the projects in the LIFE database).

All project beneficiaries were provided with a questionnaire (represented by the specific record of the database relative to their own project) and were requested to verify and integrate the information pre-filled on the basis of the material found online. Overall, project beneficiaries were given about 4 weeks to finalise this check. In total, replies were received from 12 projects only. Six more projects could be added in the database as the information available in the material found online was deemed sufficient for our purpose. Therefore, the final dataset includes information from a total of 18 LIFE projects. The source of information was generically indicated by quoting the code of the project. The following table summarises the projects for which detailed information was included in the database.

	Project	Source
American mink – *Neovison vison*		
1	LIFE00 NAT/UK/007073 - Mink control - Mink control to protect important birds in SPAs in the Western Isles	Online material
Grey squirrel - *Sciurus carolinensis*		
2	LIFE09 NAT/IT/000095 - EC-SQUARE - Eradication and control of grey squirrel: actions for preservation of biodiversity in forest ecosystems	Feedback from beneficiaries
3	LIFE13 BIO/IT/000204 - LIFE U-SAVEREDS - Management of grey squirrel in Umbria: conservation of red	Feedback from beneficiaries
4	LIFE14 NAT/UK/000467 - SciurusLife – Sciurosity – Evolving IAS Grey Squirrel Management Techniques in the UK	Feedback from beneficiaries
Raccoon dog - *Nyctereutes procyonoides*		
5	LIFE09 NAT/SE/000344 - MIRDINEC - Management of the invasive Raccoon Dog (*Nyctereutes procyonoides*) in the north-European countries	Online material
Rats – *Rattus sp.*		
6	LIFE05 NAT/UK/000141 - Canna Seabirds - Canna seabird recovery project	Feedback from beneficiaries
7	LIFE08 NAT/IT/000353 - Montecristo 2010 - Montecristo 2010: eradication of invasive plant and animal aliens and conservation of species/habitats in the Tuscan Archipelago, Italy	Online material
8	LIFE11 NAT/IT/000093 - Pelagic Birds - Conservation of the main European population of *Calonectris d. diomedea* and other pelagic birds on Pelagic Islands	Feedback from beneficiaries

	Project	Source
9	LIFE11 NAT/UK/000387 - Seabird Recovery LIFE Project: Scilly Isles - Maintaining and enhancing the Isles of Scilly SPA through the removal of rats from two key islands	Feedback from beneficiaries
10	LIFE12 NAT/IT/000416 - LIFE Puffinus Tavolara - Protection of the largest population of *Puffinus yelkouan* on Earth and containment and eradication of invasive alien species	Feedback from beneficiaries
11	LIFE13 NAT/UK/000209 - LIFE Shiants - Protecting and restoring the Shiant Isles SPA through rat removal, and safeguarding other seabird island SPAs in the UK	Online material
12	LIFE13 NAT/FR/000075 - LIFE PETRELS - Halting the decline of endemic Petrels from Reunion Island: demonstration of large-scale innovative conservation actions	Feedback from beneficiaries
13	LIFE13 NAT/GR/000909 LIFE ELClimA - Conservation measures to assist the adaptation of *Falco eleonorae** to climate change	Feedback from beneficiaries
14	LIFE14 NAT/IT/000544 - Life PonDerat - Restoring the Pontine Archipelago ecosystem through management of rats and other invasive alien species	Online material
Ruddy duck - *Oxyura jamaicensis*		
15	LIFE05 NAT/UK/000142 - ERDUK - Eradication of Ruddy ducks in the UK to protect the white-headed duck	Feedback from beneficiaries
Red-eared slider - *Trachemys scripta*		
16	LIFE09 NAT/ES/000529 - LIFE TRACHEMYS - Demonstration strategy and techniques for the eradication of invasive freshwater turtles	Online material
17	LIFE12 NAT/IT/000395 LIFE EMYS - Ligurian Invasive Fauna Eradication pro indigenous *Emys orbicularis* restocking	Feedback from beneficiaries
California kingsnake - *Lampropeltis getula californiae*		
18	LIFE10 NAT/ES/000565 - LAMPROPELTIS - Control of the invasive species *Lampropeltis getula californiae* on the island of Gran Canaria	Feedback from beneficiaries

The projects analysed in this study span a period of 14 years, from 2000 to 2014 (some of the 2014 projects are not finished yet). Some of these projects provided replies on more than one method, so the total number of records collected in the database is 28. Overall, 16 projects regard Eradication, 11 Control and one Prevention. Interestingly, 2 additional projects started with a focus on Eradication which during the implementation turned into Control as the initial objective revealed to be too ambitious (this concerns in both cases a project on *Trachemys scripta*).

The feedback provided by the project beneficiaries was heterogeneous. In total, 6 out of 12 projects filled in all the fields properly directly in the database. In a couple of other cases the beneficiaries sent an e-mail with (some of) the data requested by the questionnaire (focussing mainly on costs) directly in the body of the message, and attached some publications to support further analyses, but did not fill in the database themselves.

Overall, thanks to both the data extracted from the on-line material and the help from the project beneficiaries, the fields regarding the Goal of the project, the Action, the Activities in details, the Effect of the project could be all filled in for all the 18 projects. In 8 cases out of 18, it was also possible to provide an assessment of the positive impacts on biodiversity and/or the local economy of these projects, as this information was easily accessible from the Layman's reports and from their web-sites. This is particularly true for the projects regarding the control/eradication of rats, in most cases as the main aim of the relevant projects was the conservation of some specific protected native species/habitats.

Concerning costs, in all cases it was possible to retrieve the information on the total budget related to the eradication/control/prevention activity or the cost per unit area. The breakdown was provided for 8 cases only (all unpublished information, hence derived from the data provided directly by the project beneficiaries). The data on the effort and/or unit of effort could be extrapolated from 12 out of 18 projects.

One of the most critical information to retrieve was the data regarding Social Acceptability, Practicality and Wider impacts, which was rarely available. However, the information from the LIFE project - as opposed to most data from the scientific literature - allowed also to retrieve some useful information on benefits for biodiversity derived from the implementation of the management toward IAS, as in most cases the main aim of such projects was the conservation of some specific protected native species/habitats.

We show the project account below (relative to the project LIFE05 NAT/UK/000142 - ERDUK Eradication of Ruddy ducks in the UK to protect the white-headed duck) as an example of best practice in relation to the full and detailed compilation of the questionnaire/database.

Record ID	Xx
Measure (Overall Management Objective)	Eradication
Species	***Oxyura jamaicensis***
Synonyms	
Genus	*Oxyura*
Family	Duck
Class	Bird
Phylum	Vertebrate
EU concern	Yes
Goal (Specific Management Objectives)	Remove the European population of the species (the 95% resident in the UK)
Action (Type of Method Applied)	Eradication – shooting
Activity (Description of Method Applied)	Shooting
Location	128 sites across England, Scotland and Wales
Country	UK
Habitat	Freshwater
Project status	Completed
Effort	Costs per individual removed
Units of effort	€ 526 per bird removed
Duration of effort	Five years and seven months (September 2005 to March 2011)
Effect	Over 7,170 Ruddy Ducks were culled during the eradication programme, most of them during the winter months. As a result, numbers in the UK fell from around 4,400 in 2005 to probably fewer than 100 birds in March 2011.
Effectiveness	Very effective
Social acceptability	Moderate/neutral
Practicality	Practical
Wider environmental impact of management	Minimal
Wider socio-economic impact of management	Minimal
Describe Impact	Environmental impact limited - short-term disturbance caused by shooting on sensitive sites was offset by agreed limits on frequency and duration of shooting, plus agreement on refuge areas for native species in many cases. Non-target species accounted for less than 0.5% of birds shot. Socio-economic impact also minimal - opposition was limited to a small number of animal rights activists and birdwatchers who were unable to cause any significant disruption to the programme which was, on the other hand, supported by all the major conservation NGOs in the UK including RSPB, WWT and county Wildlife Trusts.
Reasons for not meeting management goal	The original estimation of the population size in the UK was probably too low, highlighting the difficulties of conducting a population census of this kind. However, the

	project attained very good information on how the population behaved as its numbers decreased, and what methods of control were the most effective.
Currency	Euro
Project name	**LIFE05 NAT/UK/000142 - ERDUK - Eradication of Ruddy ducks in the UK to protect the white-headed duck**
Funding tool	LIFE
Start date	set-05
End date	mar-11
Months	67
Total cost	€ 3,770,771
Year of Cost Estimate	2018
Total area	242,495 km²
Unit	
Average cost per unit area	€15.55 per km²
Breakdown	Unpublished
Personnel costs	52.6% **Eight control staff employed full-time**
Equipment/infrastructure costs	4.30%
Other costs/overheads	Other costs 36.5% (mainly travel and subsistence costs, consumables e.g. running costs for vehicles, and bonus payments for staff).
Source	- Iain Henderson pers. comm. 2018 - Henderson, 2009. The progress of the UK Ruddy Duck eradication programme. British Birds 102: 680-690. - Robertson P. A. et al, 2014. Towards the European eradication of the North American Ruddy Duck. Biological Invasion 17.1: 9-12. DOI: 10.1007/s10530-014-0704-3.
Cost estimate reproducibility	Reproducible
Webpage	http://www.nonnativespecies.org//index.cfm?pageid=244
Contact	See LIFE database
Comment	The UK Government committed to funding the additional work required to achieve full eradication. Since 2011, the UK has invested € 814,000. This led to a reduction in the UK population from around 100 birds in 2011 to around 20 individuals in 2017.
Impact on biodiversity	Not available
Socio-economic impact	Not available

Application of multi-criteria method

The application of multi-criteria methods and other sources of evidence can help to inform key management decisions at different stages of the invasion process. These include the hierarchy of priorities to firstly prevent, if that is not appropriate to then eradicate, and if that is not appropriate to then consider control (long-term management) including both reducing impact and limiting spread. At each of these three stages there are a series of questions which will inform the decision to manage, or to devolve to the next stage in the hierarchy.

- What is the management objective?
- What method will be applied?
- Is management feasible?
- Will management be cost-effective?

Together, evidence from the published literature, online databases of projects, and expert elicitation based on the multi-criteria method of Booy et al (2017) can help inform the decision on whether to proceed with management to achieve a specific objective, or to devolve to the next stage in the hierarchy. Different considerations will apply when considering prevention, eradication and control. Not all questions will need to be answered in each case; if no methods exist, as can apply to some marine species, then there is no need to consider feasibility or cost. Similarly, if management is not considered feasible, for example through legal constraints, wider environmental impacts or concerns regarding humaneness or public acceptability, then cost is not relevant. If methods are available and feasible, they may still not be considered cost-effective.

In this section the results of the application of the multi-criteria analysis undertaken to assist in the prioritisation of management measures in the field are presented. This approach is currently being applied by Newcastle University and is based on terrestrial vertebrates (including some mammalian species listed as Species of Union Concern) a group for which data already exist, based on the available published literature and an expert elicitation work is already underway[6].

Expert elicitation

et al. This exercise was based on the assessment of a range of simulated cases, each of which described a species, the methods used for their control and the area over which the species had spread. A team of fifteen experts contributed as volunteers to this study. They were selected on the basis of their experience on the assessment or management of IAS in Europe. Fifteen mammal species were identified for inclusion in this study Siberian chipmunk *Eutamias sibiricus*, Grey squirrel *Sciurus carolinensis* Pallas's squirrel, *Callosciurus erythraeus* Small Asian mongoose, *Herpestes javanicus* Coypu, *Myocastor coypus*, Reeves's muntjac *Muntiacus reevesi,* Coati *Nasua nasua,* Raccoon *Procyon lotor,* Raccoon dog *Nyctereutes procyonoides*, Muskrat. *Ondatra zibethicus* Brush tailed possum, *Trichosurus vulpecula* Axis deer, *Axis axis* American bison *Bison bison,* Sika deer *Cervus nippon* and Finlayson's squirrel *Callosciurus finlaysonii.* These were all species either listed or considered for listing as Species of Union Concern. They included species not yet present in Europe, others that were already present, some of which were widespread, and included a number where successful eradications had already taken place in some member states. The species were selected to represent a wide range of body sizes. For each species, a combination of control methods, primarily based on trapping and shooting, were described as considered to be the most effective and acceptable to be used in continental Europe. Hypothetical cases were generated which described the area over which the species had spread, these covered five different scales (1km^2, 10km^2, 100km^2, 1,000km^2 and 10,000km^2). Cases did not take into account the current actual distribution of the species, they were entirely hypothetical. Similarly, the cases were not geographically specific, assessors were instructed

[6] **Disclaimer.** Newcastle University has led on an expert elicitation exercise to assess how scale affects the costs and feasibility of eradication. This work was supported by Newcastle University and a number of volunteers and was not undertaken as part of this report although the relevant (preliminary) results are reported and discussed here. However, since the overall work is still in preparation, this report only includes summary details of the main findings. A detailed presentation of the results, analysis and discussion will be included in the relevant scientific paper which has yet to be published (Robertson et al, in prep).

to consider the species as occurring in suitable habitat in continental Europe, without reference to specific member states or regions. Thus, an individual case would describe a species (15 options), the methods available for its eradication (only the most effective and acceptable option considered), the area over which the species had established (5 options) giving a total of 75 possible permutations. Each expert was asked to assess 45 different cases structured in such a way that each assessed three different cases for each species. Together the experts undertook 675 assessments. The assessment of each case followed the risk management method of Booy et al. (2017). Each assessor provided response and confidence scores for each of the seven risk management components (i.e. Effectiveness, Practicality, Cost, Impact, Acceptability, Window of Opportunity and Likelihood of Reintroduction), as well as an Overall Score (i.e. overall feasibility of eradication). Since the information from this study is based on expert opinion and has yet to be published, it was not added to the database (see Disclaimer in footnote 6).

In the following paragraphs, a reply to the four questions formulated above is provided.

Setting management objectives

The first question on management objectives is key as without this the other questions cannot be adequately assessed even if data is available. Ideally these objectives should be SMART – Specific, Measurable, Assignable, Realistic and Time-limited. Framing objectives in this way is relatively straightforward for prevention and eradication: for example, species *x* will be completely removed from area *y* over the next *z* years, and this makes the assessment of the success or otherwise of a study simple. However, particular care is needed when identifying the objectives for control (long-term management) which can include varied outcomes such as limiting spread, reducing abundance or levels of damage. Each of these needs to be defined in a measurable way if feasibility, cost-effectiveness and success are to be determined– for example if the objective is to reduce damage, then by how much, over what period of time to be considered successful? The information collected from the literature related to control highlights the problems associated with the definition of objectives. While some studies present their objectives with sufficient detail to allow their success and cost-effectiveness to be assessed (e.g., Panzacchi et al. 2007, Bertolino and Viterbi 2010), in the majority of cases, the objectives are described in only general terms (catch animals, reduce damage) without the detail necessary to support similar assessments.

Of the 20 studies dealing with control, nine dealt with the reduction of levels of damage, including damage to agriculture (Bertolino and Viterbi 2010, Bos and Ydenberg 2011, Cocchi and Riga 2008, Panzacchi et al. 2007, van Loon et al. 2017), forestry (Lawton and Rochford 2007, Waeber et al. 2013) or biodiversity (Ratnaswamy et al. 1997). In two of these cases the findings were linked to specific objectives that allowed the success or otherwise of control to be quantitatively assessed (Panzacchi et al. 2007, Bertolino and Viterbi 2010). In three additional cases, review or modelling papers made recommendations on the target level of population density or effort required to reduce damage (Mayle and Broom 2013, Putman et al. 2011, Rushton et al. 2006) but these did not assess actual control programmes. Other studies focused on levels of population reduction (García-Díaz 2017, Krause et al. 2014, Louette 2012, Louette, Devisscher and Adriaens 2013, Waeber et al. 2013) without linking these to particular outcomes of spread or damage reduction. Johnson et al. (2016) related their reduction study to the design of consequent rabies disease control objectives.

Studies of control may also have multiple objectives. For example, Bos and Ydenberg (2011) and van Loon et al. (2017) considered damage to both agriculture and flood defences. Bertolino, Perrone and Gola (2005), Panzacchi et al. (2007) and Waeber et al. (2013) considered multiple objectives of damage and spread reduction. It is not uncommon for studies to succeed in one objective but fail in another. For example, Panzacchi et al. (2007) and Bertolino and Viterbi (2010) discuss coypu control in northern Italy, where the methods successfully reduced damage to a level which was considered cost-effective but were unsuccessful when considering eradication or limiting spread as objectives. Studies may also redefine their objectives to fit their results, for example while eradication may have been the preferred outcome, the approach was not effective enough to achieve this, so the study objective was downgraded to become reducing abundance. All of these issues make it difficult to assess the success and cost-effectiveness of control against specific objectives for many of the control studies identified from the scientific literature.

Selecting appropriate methods

A variety of different approaches are available to select appropriate methods. The published literature can be reviewed to determine the methods used to manage the Species of Union Concern, or similar species. Many methods are already widely used for other wildlife species with a corresponding literature.

When considering the available methods to support prevention activities for mammals, the review of the published literature on the management of terrestrial vertebrates of Union Concern only identified a single publication of relevance to prevention – a modelling study of social considerations in education strategies to reduce the risk of the public releasing unwanted pet *Trachemys scripta* into ponds and lakes (Teillac-Deschamps et al. 2009). The most widely used methods to support prevention are often not species specific and may be based on pathway management, including approaches such as border inspection, restricting trade and raising awareness. The identification of appropriate methods to support prevention needs to be based on a wider source of evidence than the published literature on particular species. Assessing the available methods for prevention may be better undertaken by assessing pathways and more generic species groupings.

For the eradication of mammals, data are available that describe the most frequently used approaches for different groups (Keitt et al. 2011). These document 1,859 attempted and successful eradications and provide a useful resource to examine the most commonly used methods for the eradication of different groups (Figure 2). Trapping was the most commonly used method for felids, canids and mustelids; toxicants were most frequent for rodents and lagomorphs, while hunting/shooting was most common for ungulates. This source includes data from across the world, hence it is possible that the specific methods listed in this database may not always be appropriate for use in the EU. This database is also specific to island eradications, which may introduce a variety of biases. It also only contains comprehensive data on mammals, hence similar data would be needed to guide work on other taxa.

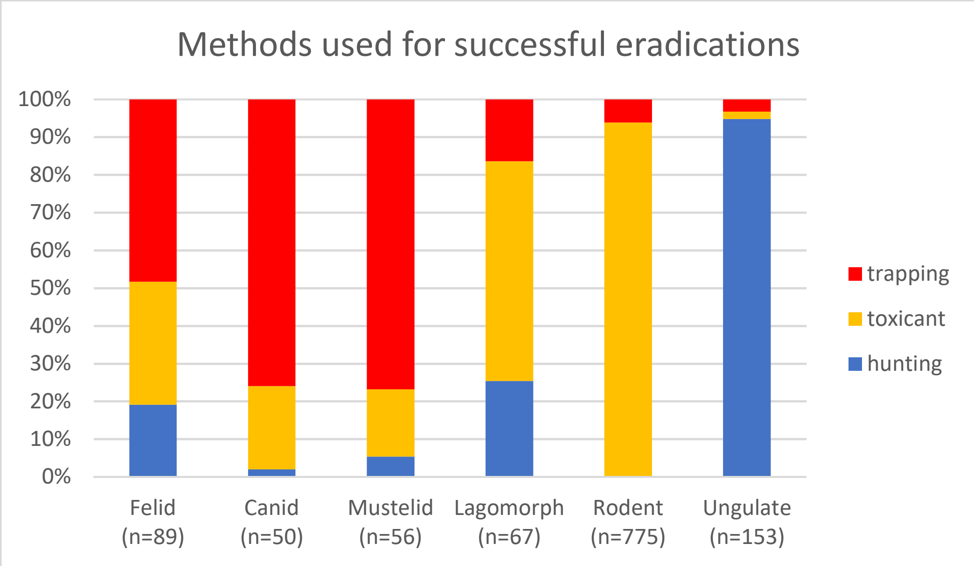

Figure 2 - The primary methods used to successfully eradicate mammal species from different taxonomic groups, based on information contained within the island eradication database described by Keitt et al. (2011). Information downloaded from http://diise.islandconservation.org/ on 28/11/2017.

In many cases the methods considered for eradication are also likely to be those considered for control (long-term management). However, control may also use methods to manage the movement or activity of animals, which are unlikely to form a key part of any eradication programme.

Is management feasible?

The feasibility of management includes the consideration of a range of different criteria that may influence whether a method is appropriate to use to meet a specific objective. Booy et al. (2017) present a multi-criteria approach to this issue which breaks feasibility into a series of sub-components including Practicality, Effectiveness, Wider Impact (which can include social, environmental, economic and welfare impacts) and Acceptability. Booy et al. (2017) also includes Cost as a sub-component which will be discussed in the next section. These criteria are measured in a variety of different currencies as described in chapter 1.

The available literature on the feasibility of different methods of prevention for mammals is limited. As described above, the review of published studies on Species of Union Concern found only a single study of relevance to the prevention of establishment (Teillac-Deschamps et al. 2009). No other evidence of relevance to the assessment of practicality, wider impacts, effectiveness or resource requirements of different prevention measures for terrestrial vertebrates was found. Methods of expert elicitation could be used to assess the feasibility of different approaches to prevention, although no studies or sources of evidence using expert elicitation for this purpose were found. It may be possible to design studies to approach this issue along the lines of those applied by Booy et al. (2017), but currently it seems that no published methodology exists for such work.

More evidence is available from which to assess the likely feasibility of eradication. The area over which a species has spread is likely to be a key determinant of the feasibility of eradication. The database on island mammal eradications (Keitt et al. 2011) provides a resource to examine the areas over which successful eradications have been undertaken using different methods. In particular, it can be used to assess the scale at which particular methods cease to be used.

For example, Figure 3 compares how frequently trapping and hunting have been used to successfully eradicate different groups of mammals at different scales. This shows how different methods used on different taxa decline in use as scale increases. Just because a method might have been used at a small scale does not mean it can be recommended for use at larger scales. For example, for rats and mice, there are no documented successful eradications based on trapping for areas greater than a few km^2. By contrast, over 20% of successful ungulate eradications worldwide have been from areas of greater than 100km^2. This provides useful information from which to judge whether some combination of species, area and method has been the basis of a successful eradication elsewhere in the world. This approach can also be used to compare the use of methods. Figure 4 compares the successful rat and mouse eradications worldwide based on trapping or the use of toxins. Although both approaches have been used successfully at small scales, for larger areas the only documented successful eradications have been based on toxins, which have been used successfully on areas of up to 1,000km^2.

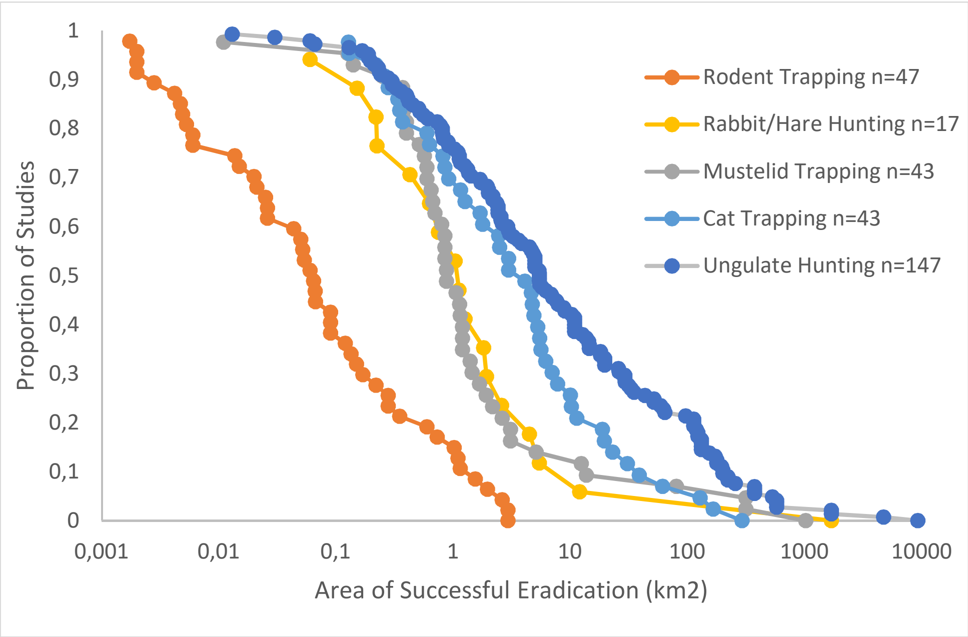

Figure 3 - The areas over which successful eradications have taken place, using either trapping of rodents (rats and mice) or ungulate hunting (deer and goats). This is based on records from the database described by Keitt et al. (2011) (http://diise.islandconservation.org/). The vertical axis is the proportion of studies that took place

on areas larger than the corresponding figure on the horizontal axis, illustrating how the number of documented eradications decreases with area. For example, less than half of all the described studies on the use of rodent trapping took place over areas greater than 0.1 km^2, while no studies using this method were reported for areas greater than a few km^2.

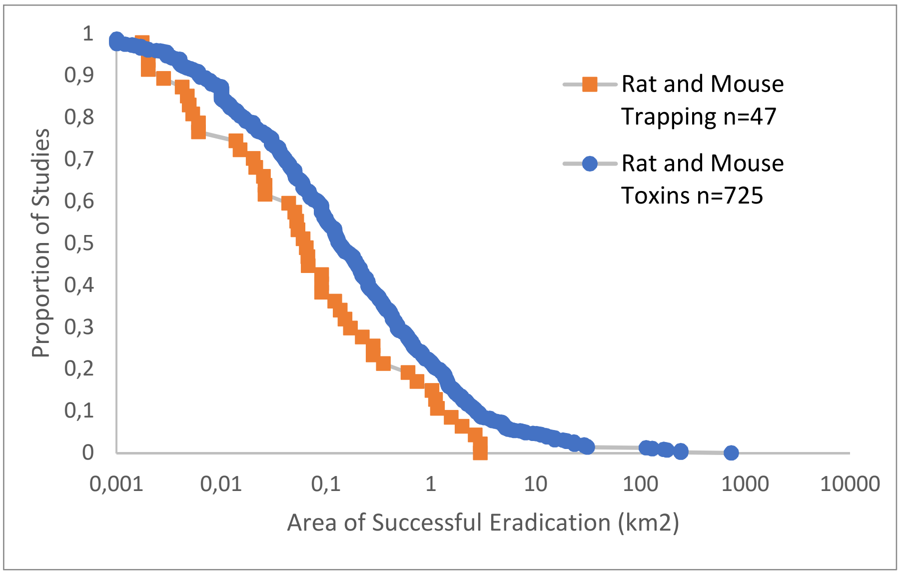

Figure 4 - The areas over which successful eradications of rats and mice have taken place, using either trapping or the use of toxicants. This is based on records from the database described by Keitt et al. (2011) (http://diise.islandconservation.org/). The vertical axis is the proportion of studies that took place on areas larger than the corresponding figure on the horizontal axis, illustrating how the number of documented eradications decreases with area. For example, while no studies using trapping were reported for areas greater than a few km^2, while the use of toxins had been applied over areas up to 1,000 km^2.

Reviewing the available data in this way can help document the choices and experience of other programmes but this approach needs to be treated with caution. These data do not include any assessment of practicality, social acceptability, wider humaneness, environmental and biodiversity impacts, effectiveness or resources. Just because a species was eradicated in one location using a particular method, does not mean that this would be acceptable or practical in another. The current limits to the scale at which different methods have been successfully applied also do not reflect what may be possible, it just may not have been attempted yet. While the published data records both successful and failed eradications, it is recognised that the published literature preferentially records success (Dwan et al. 2008) and may under-report failures. For example, the successful coypu eradication in the UK is well documented (Gosling and Baker 1987, Gosling and Baker 1989, Baker and Clarke, 1988, Gosling, et al. 1988, Baker 2006), but the failed attempt in the 1960s to eradicate the American mink from the UK mainland is barely recorded (Sheail 2004) although it took place on a similar scale. The degree of under-reporting of failure is impossible to quantify, but it limits the confidence with which we can rely on the published literature to assess the success rate of attempted eradications. More significantly, the most common response to a new species entering an area is to do nothing, which means that the number of attempted eradications is small in comparison. Very few studies (Gardener et al. 2010 is an exception) systematically document the cases where eradication could have been applied but was not attempted. The published literature on eradications is also focused on a relatively small number of species. For example, the majority of published mammal eradications relate to the removal of rats, goats and small carnivores from islands (Nogales et al. 2004, Howald et al. 2007, Keitt et al. 2011). For many species there is little or no published information on eradications (or long-term management) and this applies to many of the listed Species of Union Concern.

The available literature and databases on eradications are useful to help assess feasibility but fall short as described above. In other areas of invasion biology, expert opinion is used to inform management where the published information may be limited, for example in the risk assessment process (McGeoch et al. 2016, Roy et al. 2014b, Roy et al. 2017). Booy et al. (2017) have used expert elicitation to compare the feasibility of eradicating different species to aid their prioritisation for management in the GB. Using the same approach, the unpublished Newcastle University expert elicitation study examined how the perceived feasibility of eradication was influenced by the area over which a species had spread. Taking all of the mammal species into account, the percentage of cases where eradication was assessed as either 'feasible' or 'very feasible' declined with area. When the species was present over an area of only $1km^2$, eradication was assessed as feasible in 84% of cases. By contrast, at 10,000 km^2, this percentage fell to 11%. The subsidiary criteria were all also strongly effected by area, with this being particularly pronounced for practicality and the negative impacts associated with management (Figure 5).

The decline in feasibility with area closely reflects the published information on the number of successful eradications in relation to area (Figure 3) suggesting that the assessors were reflecting current practice and the perceived difficulties of achieving eradication at larger scales. As the analysis of this data proceeds, it will be possible to break these results down by species, in particular to examine the effects of body size on the feasibility of eradication at different scales and examine in more detail how the criteria of effectiveness, practicality, negative impact and acceptability interact.

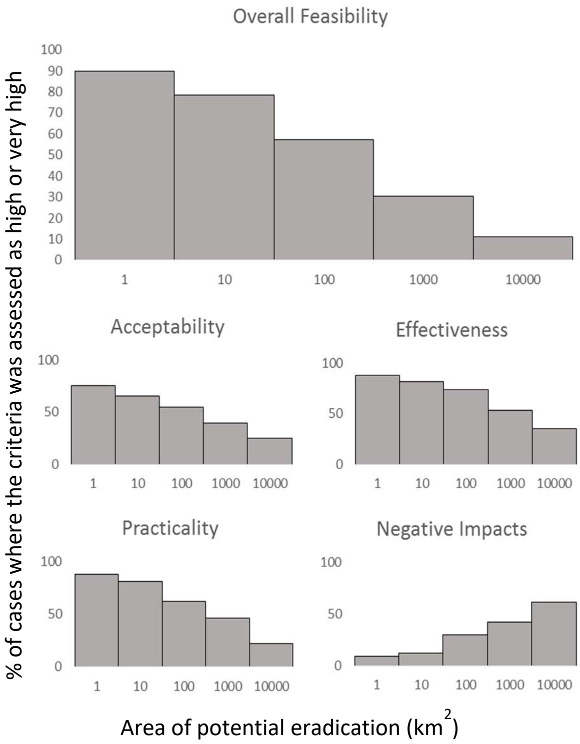

Figure 5 - The results of an expert elicitation exercise to examine how the overall feasibility of eradication and the subsidiary criteria of acceptability, effectiveness, practicality and negative impacts, varied with the size of the area over which the eradication would be conducted. Data from Robertson et al. (in prep).

Together, these data sources provide relevant information to base a decision on whether eradication is a feasible objective for the management of a particular species. The area over which the species has spread appears to be the major determinant of the feasibility of eradication, and strongly influences all of the other criteria such as practicality, effectiveness, negative impact and acceptability.

The literature searches identified twenty papers which presented information relevant to control (long-term management). While this exercise was not intended to create a comprehensive account of all relevant studies, the small numbers found for many Species of Union Concern is problematic and it is unlikely that there is a large existing literature on the control of many of these species, the exceptions being coypu, muskrat and the grey squirrel. Studies dealing with on-going management actions often failed to provide specific objectives, or these objectives were poorly defined and only presented in very general terms, making it difficult to assess their effectiveness or wider feasibility.

Very few of the identified studies provided direct comments on the Social Acceptability, Practicality, Wider Social or Environmental Impacts of management. In only five of the 29 cases (17%) was information given, two comments related to social acceptability (Bertolino and Genovesi 2003, Tellac-Deschamps et al. 2009), two provided information on non-target captures in traps (Bertolino, Perrone and Gola 2005, Baker 2010) and one on the potential wider environmental consequences of introducing predatory fish as a control agent (Louette 2012). The published studies were also limited to cases where a decision had already been made that they were acceptable, while what might be considered acceptable in one region may not apply to others. The published scientific literature on individual management cases seems unlikely to provide a source for the detailed assessment of these issues.

As a remark, the proposed method for multi-criteria analysis, includes criteria on the **'risk of reinvasion**' and **'window of opportunity**' and the assessors were asked to include these in their assessments for completeness. However, as they were assessing hypothetical scenarios without information on the potential risk of reinvasion or details of the actual geographic regions concerned, it was not considered appropriate to include these criteria in any further analysis. These criteria may be considered 'optional' and only of value in particular circumstances. For example, while relevant to the assessment of specific eradications, they are of less value when considering hypothetical scenarios where key information may not be available, or in relation to control (long-term management).

Will management be cost-effective?

At present there appears to be little published information on the costs or effectiveness of prevention in relation to terrestrial vertebrates. The single publication of relevance to prevention (Teillac-Deschamps et al. 2009) did not include any information on potential costs. The most widely used methods to support prevention (e.g. border inspection, restricting trade and raising awareness) are often also not species specific. Attributing the costs of these approaches to individual species is problematic.

The review of the published literature on the management of Species of Union Concern identified eight studies containing relevant information related to eradication. These included two studies documenting the removal of mongoose from a Japanese island (Konine et al. 2016) and predictions of the costs of future eradication (Fukasawa et al. 2013). The review also identified studies of relevance to the costs of the eradication of muskrats and coypu (Baker 2010, Robertson et al. 2017), Pallas' squirrel (Adriaens et al. 2015, Mazzamuto et al. 2016), ruddy duck (Robertson et al. 2015) and grey squirrels (Bertolino and Genovesi 2003, Schuchert et al. 2014, Robertson et al. 2017).

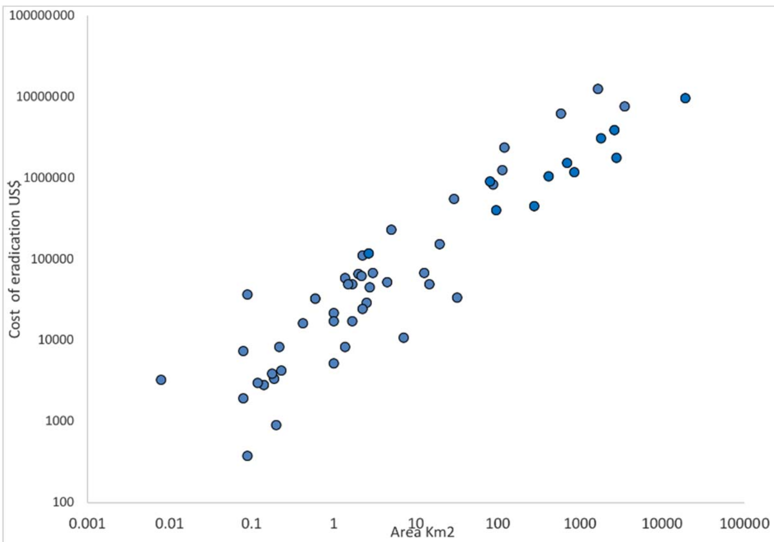

Figure 6 - The relationship between the area of successful mammalian eradications and the cost, standardised to US$ at 2018 values. Both axes on logarithmic scales. Adapted from Robertson et al. (2017, in press).

Robertson et al. (2017, in press) have used this information to examine how the costs of successful eradications change with area, extending the result of similar analysis made by Martins et al. (2006) for islands, and finding that the total costs increase in a predictable manner as the area of each eradication increases (Figure 6). For a given area, the costs of eradication vary by approximately an order of magnitude (x10). As area increases, the costs per unit area also decrease. As a generalisation, the costs per unit area reduce by 10% each time the area of the eradication doubles. These data are largely derived from island eradications and deal with a limited number of species. Other approaches are needed to complement this one and to consider the costs of eradicating species such as those of Union Concern where there is currently no published information.

In fact, there is evidence that mammal removals show economies of scale, with the cost per unit area reduced as the total area of removal increases (Armsworth et al. 2011, Shwiff et al. 2012). Many examples from the scientific literature suggest that site area has implications for all types of costs and can be a significant driver in damage and opportunity costs (Naidoo and Ricketts 2006; Rondinini et al. 2006; Mackenzie 2012). The scale at which different methods have been successfully applied is also limited, with this restricting the scope for effective removal for some methods/taxa. However, experience and new methodological developments are leading to their use on increasing scales (Eiswerth and Johnson 2002, El-Sayed et al. 2009, Jones et al. 2015, Webber et al. 2015). It is possible to monetise these costs in some cases, although the available information on cost or effort has not been standardised or collated.

Together with assessing the feasibility of management, expert elicitation can be used to estimate the costs of specific scenarios. The expert elicitation exercise described above asked for details of the predicted cost required for eradication for each of the scenarios in a series of five categories (<€50k, €50-200K, €200K-1M, €1-10M, > €10M). Considering only those cases where the assessors considered eradication to be either 'feasible' or 'very feasible' provided the range of costs associated with each scale (Figure 7).

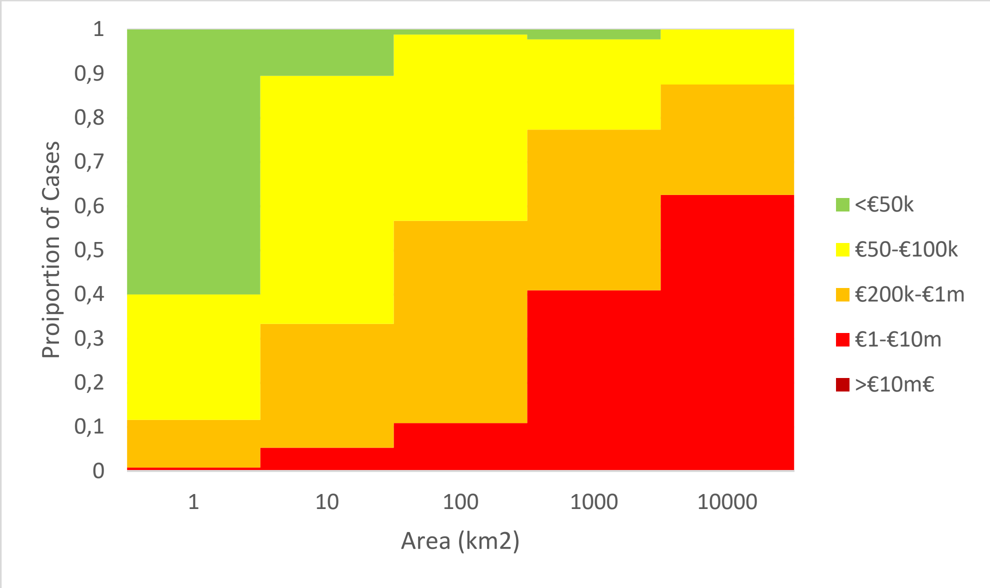

Figure 7 - The distribution of costs for those cases considered feasible or highly feasible (scores of 4 or 5) from the expert assessments. No cases were considered feasible where the costs were predicted to be over €10m.

Testing the application of the multi-criteria method to inform management decisions

As described in the previous sections, limitations in the availability of data can restrict our ability to make informed management decisions. We highlight four specific areas where this limitation is particularly apparent – assessing the costs and feasibility of prevention, assessing the feasibility of eradication, determining the objectives of long-term management, and assessing the costs and feasibility of long-term management (Table 3). This is not to say that no evidence exists on these topics, rather that the current evidence base is small and is increasing slowly.

We also showed that in the absence of published evidence on these issues, an alternative approach to inform decision making is the use of expert elicitation. This is particularly relevant in these cases, as experts and practitioners are routinely making decisions based on their understanding of these processes, but their evidence is often not included in their publications, or not provided in a comparable format. Expert elicitation provides a route to access this existing but unpublished knowledge in a structured way.

The multi-criteria method designed to assess the management of IAS helped to provide an answer to the following two questions:

- How to assess the effects of scale on the feasibility and cost of eradication?
- When to choose between eradication or long-term management as the management objective for a species?

In the next sections, as well as providing an answer to these two questions, we also compare the estimated costs from the expert elicitation exercise with what has been reported in practice.

How to assess the effects of scale on the feasibility and cost of eradication?
We asked 15 experts to assess the costs and overall feasibility of eradicating a range of different IAS mammal species at a range of different scales (1 km^2, 10 km^2, 100 km^2, 1,000 km^2 and 10,000 km^2) using the most appropriate available methods for use in a European context. In each case, the experts applied the multi-criteria approach of Booy et al. (2017) to assess Cost, Acceptability, Effectiveness, Practicality and Negative impacts as well as providing an assessment of overall Feasibility. We found that all of these measures were strongly affected by scale. When a species was spread over only a small area, costs were low, practicality, effectiveness and acceptability were typically high, negative impacts were low, while overall feasibility was typically high. As the area over which the species was established increased, cost and negative impacts increased, while practicality, effectiveness, acceptability and overall feasibility declined (Figure 5).

In themselves these results are not surprising, it is widely acknowledged that eradication is most feasible during the early stages of an invasion and before a species has become widely spread. What this method provides is an assessment of how these measures change with scale, and the point at which eradication may no longer be a realistic management objective. Rejmánek and Pitcairn (2002) discuss this same issue for the eradication of invasive plant species, suggesting that eradication with currently available methods is rarely feasible once a plant species has established over an area in excess of 10 km^2. From the data based on mammals, when the species was present over an area of only 1 km^2, eradication was assessed as feasible by the experts in 84% of cases. By contrast, at 10,000 km^2, this percentage fell to 11% (Figure 5). It is clear that the eradication of mammals is considered feasible at significantly larger scales than is the case with plants.

These data are presented for all 15 mammal species combined, and this exercise included a wide range of species of different body sizes. This report illustrates how this multi-criteria method can be used to provide information to guide management in the absence of published literature on a topic. For example, it is likely that the feasibility of eradication for small bodied species, which tend to have a relatively fast rate of reproduction and to be difficult to survey, will decline rapidly with area, while for larger bodied species eradication may still be feasible at large scales. This is already implied from the data presented on the scale at which successful eradications have been described in the scientific literature. From the published literature, for rats and mice, there are no documented successful eradications based on trapping for areas greater than a few km^2. By contrast, over 20% of successful ungulate eradications worldwide have been from areas of greater than 100km^2 (Figure 3).

When to choose between eradication or long-term management as the management objective for a species?
In Table 2 we describe how a key management decision is whether to proceed with the eradication of a species, or if this is not feasible, to consider the options for long-term management. This is a critical decision in IAS management, if eradication is feasible it could completely remove the species from an area, prevent its spread into new areas, and remove the current and potential future costs and impacts. Eradication is recognised as the preferable outcome once an IAS has established in an area. However, the number of attempted and successful eradications remains small, and effective eradication often

requires a rapid process of decision making and the allocation of resources. In many cases, eradication is seen as 'too difficult', or management is only considered once a species has already become so widespread that eradication may no longer be feasible. A better understanding of the threshold, in particular the area over which the species has spread, at which the eradication of a species moves from feasible to non-feasible, would help inform this critical decision. While there are a small number of species and methods for which sufficient information is available in the published literature, such as the management of rodents on islands (Figure 4), for most of the species of Union Concern there is relatively little published information on which to base decisions (Table 1). The data presented in Figure 5 demonstrate how expert elicitation can be used to inform management decisions in areas where the published literature is scarce.

For example, for a mammal species spread over an area of 1 km^2 the expert elicitation results suggest eradication would be feasible in the majority of cases (84%) and the most commonly estimated costs would be less than €50,000. At a scale of 10 km^2, feasibility falls to 70% and costs are typically in the range €50,000-€100,000. At 1,000 km^2, feasibility has fallen further to 30% while costs rise to typically fall between €1,000,000-€10,000,000. At the largest scale considered, 10,000 km^2, in only 11% of cases was eradication considered feasible, primarily of only the largest bodied species, and there were no examples of an eradication costing more than €10,000,000 being considered feasible.

Comparing the results of expert elicitation with the costs reported in practice.

The use of the expert elicitation exercise to produce quantifiable estimates, for example of cost or the feasibility of management at different scales, was chosen because there is sufficient evidence on costs published in the literature to allow comparisons with real data from current management activities and provide a form of validation.

Both the data from successful eradications published in the literature and expert elicitation suggest similar cost ranges with increasing area. For an area of 10 km^2, the published data on successful eradications (Figure 6) suggests costs fall most frequently in the range of €10,000 – €100,000 while the most common cost estimates from expert elicitation fall in the range €50,000-€100,000 (Figure 7). For an area of 1,000 km^2 the equivalent ranges are €1,000,000-€10,000,000 from both data sources. From a preliminary comparison, it would appear that the estimated costs of successful eradication based on expert elicitation fall within comparable ranges of costs to those derived from the published literature. Further analysis at the species level is still required. As more data are obtained and analysis proceeds, it should be possible to more fully explore the effects of taxa, body size, environment and different methods on these relationships.

Given the shortage of published information on many of the Species of Union Concern, expert elicitation may offer a route to help inform decision making. Given the accepted hierarchy of management priorities from prevention, then eradication through to long-term management, it is important for managers to decide when to shift their management objectives. The information described above could support this, in particular to decide when eradication may no longer be a viable objective and, when either long-term management then needs to be considered (default option), or if inaction is the only possible alternative. The information described is not predictive, it does not make the decision for the manager, rather it may help inform an evidence-based assessment and allow the comparison and prioritisation of different cases. Before proceeding with an eradication, a more detailed case-specific assessment would clearly be required.

5. Conclusions and recommendations

Aichi Target 9 from the Convention for Biological Diversity (CBD) commits signatories to identify and prioritise IAS, their pathways, and to then control or eradicate priority species, a commitment that carries significant economic and social costs. The prioritisation of action is key to the effective use of limited resources. This is embedded in the CBD's guiding principles for IAS management which recommend a hierarchy of prevention, then rapid eradication and lastly ongoing management.

This choice is reflected in EU legislation. Under Regulation (EU) 1143/2014, priority species are identified by risk assessment (McGeoch et al. 2016, Roy et al. 2014a, Roy et al. 2017) and then listed as Invasive Alien Species (IAS) of Union Concern. Member States are required to take appropriate action to prevent the introduction and spread of IAS of Union concern (article 7 and article 13). For early detections of the introduction or presence of IAS of Union concern (article 16), eradication is the required outcome (article 17), but derogations are possible based on either the unavailability of methods (i.e. if the eradication is demonstrated to be technically unfeasible because the eradication methods available cannot be applied in the environment where the invasive alien species is established), or non-target effects of the management measures taken (on human health, the environment or other species), or that the costs will be exceptionally high and disproportionate to the benefits of eradication (article 18). If eradication is not considered feasible or appropriate, or if the species is already widely spread in their territory, Member States are required to put in place effective long-term management measures, so that their impact on biodiversity, the related ecosystem services, and, where applicable, on human health or the economy are minimised (article 19). According to the regulation, such management measures shall be: 1) proportionate to the impact on the environment and appropriate to the specific circumstances of the Member States, 2) be based on an analysis of costs and benefits (and also include, as far as is feasible, the restoration measures referred to in Article 20), 3) be prioritised based on the risk evaluation and their cost effectiveness. The management measures shall consist of lethal or non-lethal physical, chemical or biological actions aimed at the eradication, population control or containment of a population of an invasive alien species.

The methodologies proposed in this report for the collection of information on costs of prevention and management of IAS, along with the information collected and analysed through the testing of such methodologies, may help implement the policy and legislation above and achieve the relevant objectives.

Considerations to improve knowledge on costs of prevention and management of IAS

Although the full range of costs associated with IAS and their management are difficult to measure simply in economic terms, the documentation and analysis of their economic costs underpin major elements of policy. The investment in prevention and management of IAS is large and increasing (Scalera 2010). However, resources are also limited and must be used efficiently and effectively. Policy makers and managers need to compare which prevention and management options are likely to be most cost-effective, so to prioritise which pathways or species should be managed and how.

Studies to document the economic costs of IAS impacts have raised their profile and the political support needed to take action. Comparisons of the cost-effectiveness of prevention and management measures at different stages in the invasion process are reflected in the priorities of the CBD guiding principles[7]. Economic analysis is the main method used to assess whether an investment or decision is sound, and optimisation methods guide the cost-effective planning of many surveillance and inspection regimes.

As a key finding, we realised that relatively little information appeared available in the literature, despite the great number of activities and measures undertaken toward the IAS challenge. This is particularly true for information on costs, but also on any general consideration about practicality, social acceptability, wider environmental and biodiversity impact and effectiveness of measures.

Potentially, LIFE projects could be a key source of specific and reliable data and information on IAS prevention and management, yet – despite the detailed technical and financial reporting which characterise the programme - there is no structured or mandatory requirement to ensure that such data are systematically retrieved from projects. We propose a method to ensure that any relevant information useful to inform decision makers and project managers is duly stored and shared.

Summary of the available evidence

Any programme needs to be based on a clear description of the management objectives. These are relatively straightforward for prevention and eradication and can be described in simple terms. However, for control (long-term management) the objectives are often more difficult to define and are rarely reported in a useful format in the published literature. It was also not uncommon for studies to present more than one objective (e.g. reduce local damage and limit spread) although they may be achieved to different levels. In the absence of clear objectives and published data it is difficult to assess the feasibility or cost-effectiveness of an approach.

Prevention should have a clear and simple objective, to prevent the species establishing in a defined area. However, when assessing information on the methods, feasibility or costs of prevention, there was little relevant information on a species basis in the available

[7] Convention on Biological Diversity, COP 6, Decision VI/23 on Alien Species that threaten ecosystems, habitats and species. Available at https://www.cbd.int/decision/cop/default.shtml?id=7197

literature. Expert elicitation provides an alternative approach to assess these issues in the absence of published materials, and this could be a productive approach for the future. In many cases the key management approaches to support prevention relate to pathway management rather than being specific to an individual species. Deciding to implement prevention management based on border inspections, trade restrictions or raising public awareness would be best applied to a range of species and pathways.

When considering eradication, this had the advantage of both a clearly defined objective together with relatively consistent and sufficient data from the literature to support assessment. However, the appropriate methods, feasibility and costs of eradication are likely to be heavily influenced by scale, the area over which a species has spread, which needs to be considered in any assessment. For mammals, there are published databases on the methods used to successfully eradicate species at different scales which, combined with reviews of the scientific literature, provide a useful basis on which to select methods. Mammals are thought to be particularly well provided with information on successful eradications, this would be less certain for other taxa. The published literature and information from LIFE projects on eradications provides relatively little information on which to assess the broader issues of feasibility, acceptability, practicality, effectiveness, and wider impact of different management approaches. However, expert elicitation methods have been published and applied to assess eradications and these provide useful insights into these issues and a route to directly compare different management alternatives. The published literature also provides many cases where mammal eradications have been costed, allowing comparisons and broad predictions of likely cost at different scales. However, these data mainly come from a small number of species on islands rather than the particular Species of Union Concern. Further analysis and the use of expert elicitation is needed to assess the effects of species characteristics such as body size, and the choice of methods, on the costs of successful eradications.

In this regard, the data coming from the LIFE projects could be very useful to fill in the knowledge gaps and integrate the information available from the published literature. However, such data may be not easy to retrieve, hence a clear and effective strategy, aimed at ensuring the circulation of the relevant data and capitalise on the achievements of the LIFE programme, need to be considered for implementation.

Control (long-term management) suffers from the poor definition of the relevant objectives in many cases, making it difficult to assess the feasibility or cost-effectiveness of different approaches. This is reflected in the literature on this topic, which although it contains numerous studies describing different forms of control, provides a much less consistent or comparable set of information than is available on eradication. Similar considerations apply to the information on control measures implemented through the LIFE projects.

A summary of the assessment of the available evidence relevant to management in the different stages of the invasion process, as found in the literature (but which may apply to the information from LIFE projects as well), is provided in Table 3.

Table 3 – Summary of the available evidence in relation to management in different stages in the invasion process. The colours reflect the quality of available information, with green for those areas where useful supporting information is already available, and red for those where there is a particular need for better information.

Stage	Questions	Available evidence
Prevention	What is the management objective?	For prevention this is usually straightforward.
	Which method will be applied?	Only limited information identified from the species literature; pathway management may be more effective than a species based approach, scope to use expert elicitation in future.
	Is management feasible?	
	Will management be cost-effective?	
	Decision – proceed with prevention or now consider eradication	
Eradication	What is the management objective?	For eradication this is usually straightforward.
	Which method will be applied?	For mammals, good information on methods available in databases and the literature, selection methods available.
	Is management feasible?	Species literature provides only limited information from which to assess feasibility. Existing expert elicitation methods are available to assess feasibility.
	Will management be cost-effective?	Good information from the literature to support this for mammals, supported by existing expert elicitation methods.
	Decision – proceed with eradication or now consider on-going management	
On-going management	What is the management objective?	The objectives of management are rarely defined in the literature which reflects current practice, guidance needed to support effective objective setting.
	Which method will be applied?	For mammals, good information available in databases and literature, selection methods available.
	Is management feasible?	Literature of limited use to assess feasibility or cost-effectiveness, confounded by lack of clear management objectives. Scope to use expert elicitation methods in future.
	Will management be cost-effective?	

The information on effort and cost extracted from the literature was presented in a wide variety of ways. Cost was variously reported as the total cost of the project, or as the cost per animal removed. Effort was reported as the numbers of animals removed, the effort applied (some measure of the number of traps deployed) or an estimate of man-power. In only two cases (10%) did the study provide evidence on the actual costs in a standardised manner (Panzacchi et al. 2007, Bertolino and Viterbi 2010). Similarly, in the LIFE projects the unit of effort used by beneficiaries was very variable too: “cost/individual removed” (9 records), followed by “man days” (4 records) and “full time trappers per year” (2 records), “baits/ha or km^2” (2 records), “number of traps” (2 records), “kg/ha of treatment” (1 record), “days of baiting” (1 record).

For the 20 studies on control measures collected during the literature search, information on effort for control was standardised whenever possible to measures per unit area (but care is needed when interpreting these, because a number of studies were based on very small areas where density estimates are unreliable). Costs per unit area are known to be scale dependent and scale needs to be included in any assessment. In some cases it may be possible to use the data on effort to estimate the overall cost of control. This is relatively straightforward for measures describing the manpower employed and may also be possible where effort is described as number of traps deployed per unit time, which can also be converted to man-power with some assumptions. However, costs per animal removed are unlikely to be as useful as these will be expected to vary in relation to the density of animals in the population.

The economic costs of IAS management include man-power together with the equipment and resources needed to undertake control. Such information on costs, and in some cases on unit area or on specific cost categories (personnel, equipment, other costs), was available from a number of sources from the literature. Similarly, for all LIFE projects it was possible to retrieve data on the total costs related to the management and prevention activities or the cost per unit area. However, both sources seemed to provide little opportunity to compare the detailed information on the breakdown of costs in a standardised manner.

In the case of the literature sources, the relevant data are usually reported in a way that makes comparisons problematic, as they can include costs over different time periods, in different countries, based on different assumptions of what to include, and involving dedicated staff costs or the use of volunteers. These issues are usually reduced where studies have been based on similar taxa, environments or methods of control, or where the cost is recorded as effort rather than in financial terms. Similarly, in relation to the LIFE projects, the comparison between the costs on measures for IAS is affected by the high number and variability of inputs received. For example, Holmes et al. (2015, 2016) reported useful information on costs for quite a few measures and species, but the budget categories used in this study (Planning, Implementation, Isolation, Non-target, Human population) are different from those suggested in the database (Personnel, Equipment, Other costs) and given their horizontal nature, are not comparable with those available from other publications and/or LIFE projects.

We also realised that data could not always fit into the proposed database structure, as in many case the compilers, in order to prevent the loss of information considered useful, felt the need to add extensive free text into the various fields and the comments, which of course does not allow for an easy and practical analysis and comparison of data. On the other hand, the risk of collecting biased or erroneous information is documented (see Holmes 2015, 2016).

Nevertheless, the necessity and the importance of ensuring the maintenance of a database focusing on the costs of IAS prevention and management remains fully justified. As a resource tool it will become increasingly useful as information accumulates. It should also guide the setting of minimum reporting standards for studies to ensure they provide more useful information in future. For example, a set of standardised reporting criteria for the objectives and costs of management interventions for biodiversity conservation was proposed by Iacona et al. (2018). The database structure proposed in the present work is in line with the main standards suggested by Iacona et al. (2018), hence we think that a similar approach for IAS management reporting would be particularly useful going forward. Collation of the costs of management will also provide a useful resource against which to inform and validate the results of other studies and researches, such as risk assessment, risk management and multi-criteria analysis.

The data presented here is only a sample of what could be retrieved from the LIFE programme which represents a large source of information and data in relation to costs for prevention and management of IAS in the EU, even though its potential has not been yet fully explored and exploited in this context (but see Tucker et al. 2013). However, a very big effort is required to retrieve the type of data and information required (e.g. following the proposed database structure), because the EU managed LIFE database – despite being a key information tool on this regard - was not intended to allow the extrapolation of IAS data for such purpose. In general, a large effort is required to achieve the level of detail useful for this type of study (e.g. following the proposed database structure), because the information is not stored in a way to allow for a detailed consultation from the public. In fact, most of the data on costs are likely to be unpublished and owned by the relevant beneficiaries, or otherwise stored in the files regarding the project, which may be not available to third parties (e.g. Final Report, Interim reports, Financial spreadsheets). In most cases, to compile the proposed questionnaire, the data may be not readily available not even to the project beneficiaries, hence it may require time and resources to present the data in a way that is compatible to the proposed database structure, and this may be not possible for all relevant beneficiaries (particularly in such cases when a project ended many years ago, as the contact persons, like the project manager, may have changed positions/work in the meantime). The information that can be found on public sources in several cases does not include information on costs and budget breakdown, as these data are considered sensitive. The same could apply to information such as the social acceptability of the interventions carried out. Therefore, while the collection of data from LIFE project is feasible and necessary, a new strategy is required to ensure that such data are systematically circulated to all interested actors, and this should probably be decided and implemented by the EC services (for example, the relevant DG ENV policy Unit and EASME).

The cost-effectiveness of multi-species programmes

In terms of eradication or long-term management, little information was available from the literature on which to assess the possibility of reducing the risks posed by multiple species and increase cost-efficiency of measures. In fact, in at least one case a paper (Mazzamuto et al. 2015) focusing on the management of *Callosciurus erythraeus* carried out within the project LIFE09 NAT/IT/000095 EC-SQUARE (see also below) did not explicitly consider the multi-species approach of the project.

In fact, some more precise information was available from the LIFE projects. For example, the aforementioned project EC-SQUARE, which focussed on the eradication of *Sciurus carolinensis* involved in some project areas also the species *Callosciurus erythraeus* (same methods applied). The same applied to the projects focusing on *Trachemys scripta* (LIFE12 NAT/IT/000395 LIFEEMYS and LIFE09 NAT/ES/000529 LIFE TRACHEMYS) that included the trapping of 8 to 10 additional species/subspecies of alien turtles (e.g. *Graptemys khoni*, *Graptemys preudographica*, *Mauremys leprosa*, *Mauremys sinensis*, *Pseudemys concinna*, *Trachemys scripta elegans*, *Trachemys scripta scripta*, *Trachemys scripta troostii*). In all cases mentioned above the information on costs and the methodologies did not change depending on the species, also because the extra targets were not initially included in the project. This is the case also for the project LIFE13 BIO/FR/000075 LIFE PETRELS which included measures for rats eradication, targeting both *Rattus rattus* and *Rattus norvegicus*. Feral cats were trapped too, and a separate breakdown of costs was provided for this species. Also, in the case of project LIFE12 NAT/IT/000416 LIFE Puffinus Tavolara, which included measures for the eradication of *Rattus rattus*, a separate line with information and related costs for the control of *Capra hircus* was provided too. Overall, from the data retrieved through the LIFE projects, it seems that this multi-species approach gave the projects the possibility to optimize costs and time.

Both the data from literature and from LIFE projects show that in any case, it is worth considering that in terms of methods. While similar methods may be appropriate for the control of different species, for example the use of live-capture traps, the details of setting and baiting these will be species specific, what works best for one species is unlikely to optimal for another. The main costs of management are typically manpower, and there may be scope for operators to undertake the control of more than one species as part of their job definition. This is often the case in other areas of wildlife management, with forest rangers or gamekeepers being responsible for the management of a range of species within a defined area rather than focused on a single species. There may be scope to employ 'IAS managers' with similar responsibilities, and their costs would be determined by the area over which they could effectively operate, which would depend on the nature and abundance of the species present and the specific management objectives for each. Lastly, legislative changes, for example adding species to the list of those that may be hunted in an area, may be applied to multiple species if appropriate, but again this would require case specific consideration.

As a closing remark, in relation to IAS costs for management and prevention, some EU financial instruments other than LIFE may provide useful information. An example are the rural development measures foreseen within the agri-environmental schemes, that most often have significant impacts on biodiversity. However, since no public database is available, it is not possible to obtain comprehensive and reliable information on projects funded through such financial tools. This clearly affected the possibility of extending the analysis beyond that relative to the resources allocated by LIFE. The situation is slightly different in the case of the funding mobilised through the H2020, which can be explored through the CORDIS[8] database, however since the main focus of this scheme is on research, it was not considered in this study (in any case contacts with the beneficiaries would be required to access any relevant information from single projects).

Multi-criteria analysis as a way of producing policy-relevant information

Born et al. (2005) recommended multi-criteria decision making as a way of including aspects of uncertainty and using qualitative as well as quantitative evaluation to support IAS policy, prevention and management. By combining ecological knowledge and economic evaluation, multi-criteria evaluation opens up new ways of producing policy-relevant results rather than intensifying what Born et al. (2005) describe as the mono-dimensional approach of purely monetary evaluation.

[8] https://cordis.europa.eu/projects/home_en.html

To date the only published use of the multi-criteria approach of Booy et al (2017) has been to prioritise eradication as a management objective. In this report we also demonstrate its use to assess the effects of scale on the decision to eradicate a species from an area or consider long-term management and a more detailed analysis of this data will feature in a future publication. We also outline how the method might be applied to the selection of appropriate management methods although demonstrating this application was beyond the scope of this report. We also highlight that this method produces expert-based estimates of the costs of management in a structured way and that these costs are broadly in line with those observed from real mammal eradications. This is a particularly useful aspect of this approach given the shortcomings of extracting useful cost information from the literature or project databases.

For this method to be consistently applied, it is important that the criteria are defined in a way that avoids linguistic ambiguity, is readily understandable by different assessors and which minimises between-assessor variability. While there is scope to increase the detail provided in the guidance, any such changes would need development and testing before being adopted. It is also worth remarking that there are a number of areas where the guidance provided for the implementation of this protocol could be enhanced. These include providing more detailed descriptions of terms such as 'high' or 'very high' in the assessment criteria; creating sub-categories of impact to better separate environmental, economic, social and welfare impacts; and in which circumstances the criteria of 'window of opportunity' or 'risk of reintroduction' need to be completed. In any case, it will be important to test any new descriptions or terms on a group of experts before adopting them, so to reduce the chances of introducing discrepancies or ambiguous terminology, and to reduce between-assessor variability. This would need to be undertaken before the guidance provided could be considered definitive.

The application of this approach to other taxa and suggestion for future improvements

In this report we focused on terrestrial vertebrates, and mammals in particular, where data is likely to be more abundant than for other taxa. For example, the compiled information on the methods used for successful eradications worldwide and their areas (Keitt et al. 2012) does not, to our knowledge, have an equivalent for other taxa. Considerable work would be required to compile such a resource and this could be added to the IAS management costs database. In many cases, management decisions need to be made in the absence of published information. For example, the literature related to the management of vertebrate of Union Concern was limited in scope and this is likely to apply also to other taxa. However, the methods applied to manage these species are also widely used in other circumstances and more method-based reviews may provide more useful information than selecting studies based on particular species.

Information on the costs of eradications for other taxa exists in a number of reviews (e.g. plants - Rejmanek and Pitcairn 2002, forest insects - Brockerhoff et al. 2010), and work at Newcastle University continues to collate new studies relevant to these wider taxa. A wider multi-taxa analysis of cost-area relationships would be a useful resource for the future.

Expert elicitation to assess the selection of suitable methods, costs and feasibility in relation to scale and different management objectives can be applied to wider taxa and offers a possible route to assessment. The original work by Booy et al. (2017) was based on a wide variety of taxa and the approach was specifically designed to support this. If this methodology is more widely applied, a dedicated database of expert-based results will develop over time, this is of a different form to that supported by the IAS management costs database described in this report. Consideration is needed on how information of this sort should be collated for the future.

Application of expert elicitation to inform other management decisions

The method developed here, based on Booy et al. (2017) could be further developed to be used to compare the cost-effectiveness of different control methods to achieve different management objectives.

The example of expert elicitation given in this report relates to the costs and feasibility of eradication in relation to geographic scale. However, there are ways in which the same approach could be applied to other management questions. A particular issue with IAS management relates to the effective choice of objectives and methods for long-term management. The literature to support decision making in this area is not as rich as for eradications and interpretation could be affected by the lack of reporting of clear management objectives. This would seem a particularly useful area in which to apply expert elicitation in future, and would have the distinct advantage that the objectives of management could be clearly set at the onset, supporting assessments that are difficult if based solely on the published materials. Not only could this help inform decisions regarding costs or the selection of methods, it would also allow comparisons of the costs and feasibility of the wide range of different long-term management objectives available, such as containment, reducing damage or limiting abundance, to help guide the formulation of feasible and effective long-term management plans.

A further application of the method developed by Booy et al. (2017) would be to assess the feasibility of applying different control measures (for example, trapping or shooting) to a species to achieve the same management objectives. Figure 5 illustrates how this might be undertaken, comparing cases where the scenario and management objective remains constant, but the chosen control method changes. In this case, the basic assessment criteria used by Booy et al. (2017) remain unchanged. Should the method be used to examine other questions (such as those outlined in Fig. 5), then some additional guidance would need to be developed to reflect the different requirements. There would be also scope to increase the detail provided with the assessment criteria, for example by separating 'Management Impact' into sub-categories of impact on different issues such as impacts on animal welfare, society, biodiversity or the environment. However, it is important that any such changes should be trialled and tested for clarity of meaning before being adopted.

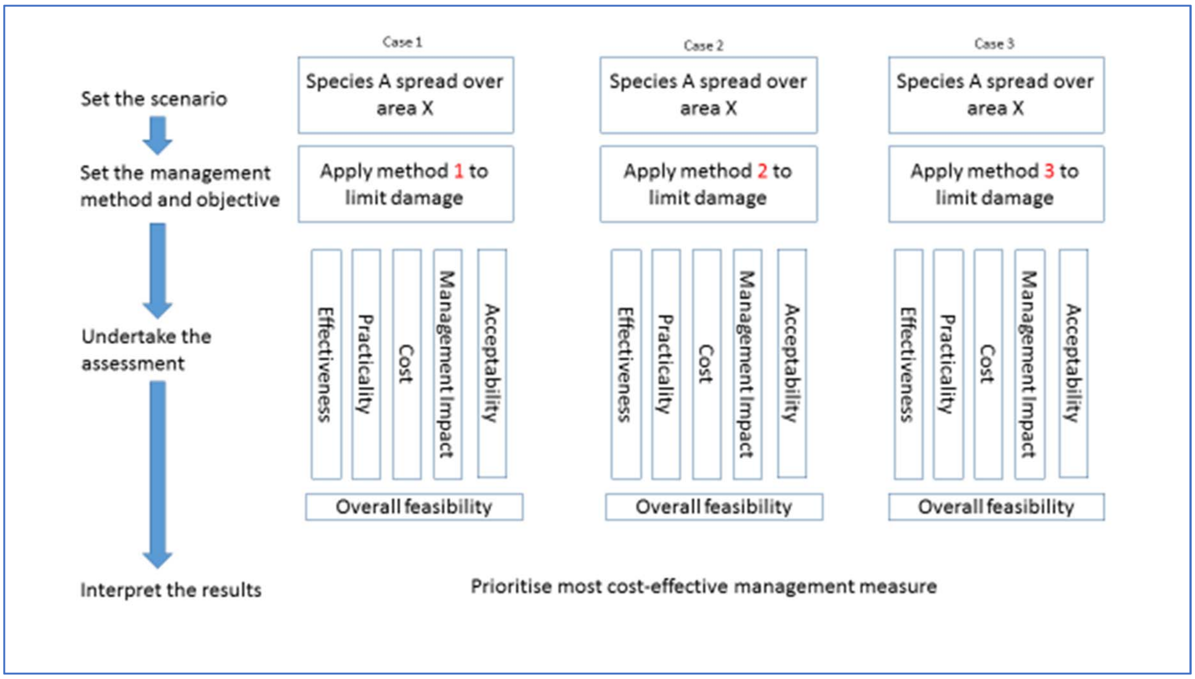

Figure 5 - A schematic description of how the multi-criteria risk management method might be applied to compare the cost-effectiveness of applying different measure to achieve the same management objective.

While this report has focused on the method of Booy et al. (2017), other methods have also been published for use in specific circumstances, such as the selection of appropriate methods (Schmiedel et al. 2016). There is scope to further develop both of these methods to improve the ease of use, breadth of application and to examine how they may complement each other in specific circumstances. However, these developments need careful consideration and testing before they can be recommended here.

Recommendations

1. A strategy with measures to keep the database on the costs of IAS prevention and management regularly updated and freely accessible as new information emerges is required.

2. At present, among all financial tools available at the EU level, actual and comprehensive data regarding IAS management are obtainable only through the LIFE database. In any case, the accessibility of the information on costs for IAS management and prevention is currently limited by the availability of the project beneficiaries to provide the required details. In this sense, a greater coordination effort between the involved Units of DG ENV and EASME would be crucial. For example, an agreement to ensure that, for all IAS related LIFE projects, the proposed database on management costs is filled in as a compulsory deliverable, would be a crucial step.

3. Greater synergies between different EU policy units would be required to ensure or facilitate the accessibility of information regarding measures on IAS funded through

funding schemes other than LIFE, such as the rural development measures foreseen within the agri-environmental schemes. Also in this case, in the light of the requirements of the EU Regulation on IAS, the use of the database on management costs should be extended to all IAS related projects.

4. An useful initiative to ensure appropriate circulation of information about results and experiences from project dealing on IAS management and prevention could be the promotion of a dedicated EU network of authorities, scientists, researchers, stakeholders, wildlife manager and practitioners, etc. This was already recommended at the LIFE Platform meeting on IAS held in Milan (Italy on 29-30 November 2017, which gathered together over 120 participants from a number of EU countries (see "Participants' conclusions and recommendations to the European Commission and EU Member States"[9]).

5. Multi-criteria analysis can represent a useful tool to support IAS policy, prevention and management. The application and testing of the multi-criteria analysis with the method developed on the basis of Booy et al. (2017) did not provide a definite area threshold of when to move from eradication to control for terrestrial vertebrates, or for any individual species. It is therefore currently not possible to assess and discuss the full range of strengths and weaknesses of this approach. In any case, additional work is required to further develop and test the available methodologies if they are to be applied to answer wider management questions.

[9] http://www.naturachevale.it/wp-content/uploads/2017/06/IAS-platform-meeting-outcome.pdf

6. References

Adriaens, T., Baert, K., Breyne, P., Casaer, J., Devisscher, S., Onkelinx, T., Pieters, S. and Stuyck, J., 2015. Successful eradication of a suburban Pallas's squirrel *Callosciurus erythraeus* (Pallas 1779)(Rodentia, Sciuridae) population in Flanders (northern Belgium). Biological invasions, 17(9), pp.2517-2526.

Andersen MC, Adams H, Hope B et al. (2004) Risk analysis for invasive species: general framework and research needs. *Risk Anal* 24:893–900

Anderson, L.W., 2005. California's reaction to *Caulerpa taxifolia*: a model for invasive species rapid response. *Biological Invasions*, *7*(6), pp.1003-1016.

Arim, M., Abades, S.R., Neill, P.E., Lima, M. and Marquet, P.A., 2006. Spread dynamics of invasive species. Proceedings of the National Academy of Sciences of the United States of America, 103(2), pp.374-378.

Armsworth, P.R., Cantú-Salazar, L., Parnell, M., Davies, Z.G. and Stoneman, R., 2011. Management costs for small protected areas and economies of scale in habitat conservation. *Biological Conservation*, *144*(1), pp.423-429.

Aukema, J.E., Leung, B., Kovacs, K., Chivers, C., Britton, K.O., Englin, J., Frankel, S.J., Haight, R.G., Holmes, T.P., Liebhold, A.M. and McCullough, D.G., 2011. Economic impacts of non-native forest insects in the continental United States. *PLoS One*, *6*(9), p.e24587.

Bacher, S., Blackburn, T. M., Essl, F., Genovesi, P., Heikkilä, J., Jeschke, J. M., Jones, G., Keller, R., Kenis, M., Kueffer, C., Martinou, A.F., Nentwig, W., Pergl, J., Pyšek, P., Rabitsch, W., Richardson, D.M., Roy, H.E., Saul, W-C.,Scalera, R., Vilà, M., Wilson, J.R.U., Kumschick, S. (2017). Socio-economic impact classification of alien taxa (SEICAT). *Methods in Ecology and Evolution,* 1–10.

Baker CM, Bode M (2016) Placing invasive species management in a spatiotemporal context. *Ecol Appl* 26(3):712–725

Baker, S. (2006). 'The eradication of coypus (*Myocastor coypus*) from Britain: the elements required for a successful campaign'. Assessment and Control of Biological Invasion Risks, pp.142–147. Kyoto, Japan: Shoukadoh Book Sellers and Gland, Switzerland: IUCN.

Baker, S.J. and Clarke, C.N. (1988). 'Cage trapping coypus (*Myocastor coypus*) on baited rafts'. Journal of Applied Ecology 25: 41–48.

Baker, S.J., 2010. Control and eradication of invasive mammals in Great Britain. Revue scientifique et technique, 29(2), p.311.

Ballari, S.A., Kuebbing, S.E. and Nuñez, M.A., 2016. Potential problems of removing one invasive species at a time: a meta-analysis of the interactions between invasive vertebrates and unexpected effects of removal programs. *PeerJ*, *4*, p.e2029.

Bax, N., Williamson, A., Aguero, M., Gonzalez, E. and Geeves, W., 2003. Marine invasive alien species: a threat to global biodiversity. Marine Policy, 27(4), pp.313-323.

Beisner, B., Haydon, D. & Cuddington, K. (2003). Alternative states in ecology. Front. Ecol. Environ., 1, 376–382.

Bergstrom, D.M., Lucieer, A., Kiefer, K., Wasley, J., Belbin, L., Pedersen, T.K. and Chown, S.L., 2009. Indirect effects of invasive species removal devastate World Heritage Island. *Journal of Applied Ecology*, *46*(1), pp.73-81.

Bertolino, S, Perrone, A and Gola, L. (2005) Effectiveness of coypu control in small Italian wetland areas. Wildlife Society Bulletin 33, no. 2: 714-720.

Bertolino, S. and Genovesi, P., 2003. Spread and attempted eradication of the grey squirrel (Sciurus carolinensis) in Italy, and consequences for the red squirrel (Sciurus vulgaris) in Eurasia. Biological Conservation, 109(3), pp.351-358.

Bertolino, S. and Viterbi, R., 2010. Long-term cost-effectiveness of coypu (Myocastor coypus) control in Piedmont (Italy). Biological invasions, 12(8), pp.2549-2558.

Binimelis R, Born W, Monterroso I, and Rodríguez-Labajos B. 2007. Socio–economic impacts and assessment of biological invasions. In: Nentwig N (Ed). Biological invasions. Berlin,

Blackwood, J., Hastings, A. and Costello, C., 2010. Cost-effective management of invasive species using linear-quadratic control. *Ecological Economics*, *69*(3), pp.519-527.

Bogich, T.L., Liebhold, A.M. and Shea, K., 2008. To sample or eradicate? A cost minimization model for monitoring and managing an invasive species. *Journal of Applied Ecology*, *45*(4), pp.1134-1142.

Booy, O., Mill, A.C., Roy, H.E., Hiley, A., Moore, N., Robertson, P., Baker, S., Brazier, M., Bue, M., Bullock, R. and Campbell, S. (2017). Risk management to prioritise the eradication of new and emerging invasive non-native species. *Biological Invasions*, 19:2401-2417.

Born, W., Rauschmayer, F. and Bräuer, I., 2005. Economic evaluation of biological invasions—a survey. *Ecological Economics*, *55*(3), pp.321-336

Bos, D. and Ydenberg, R., 2011. Evaluation of alternative management strategies of muskrat Ondatra zibethicus population control using a population model. Wildlife Biology, 17(2), pp.143-155.Brockerhoff

Bradshaw, CJA, Leroy, B, Bellard, C, Roiz, D, Albert, C, Fournier, A, Barbet-Massin, M, Salles , J-M, Simard, F, Courchamp, F. (2016). Massive yet grossly underestimated global costs of invasive insects. Nat. Commun. 7, 12986 doi: 10.1038/ncomms12986

Brockerhoff, E.G., Liebhold, A.M., Richardson, B. and Suckling, D.M., (2010). Eradication of invasive forest insects: concepts, methods, costs and benefits. *New Zealand Journal of Forestry Science* 40 suppl. S117-S135

Broome, K.G., Cox, A., Empson, R.A. and Hutchinson, W.M., 2002. Eradication planning for invasive alien animal species on islands-the approach developed by the New Zealand Department of Conservation. In *Turning the Tide: The Eradication of Invasive Species: Proceedings of the International Conference on Eradication of Island Invasives* (No. 27, p. 85). IUCN.

Buhle, E.R., Margolis, M. and Ruesink, J.L., 2005. Bang for buck: cost-effective control of invasive species with different life histories. *Ecological Economics*, *52*(3), pp.355-366.

Burgman, M.A., Wintle, B.A., Thompson, C.A., Moilanen, A., Runge, M.C. and Ben-Haim, Y., 2010. Reconciling uncertain costs and benefits in Bayes nets for invasive species management. *Risk Analysis*, *30*(2), pp.277-284.

Burnett, K., Kaiser, B. and Roumasset, J., 2007. Economic lessons from control efforts for an invasive species: Miconia calvescens in Hawaii. *Journal of Forest Economics*, *13*(2), pp.151-167.

Cambray, J.A., 2003. Impact on indigenous species biodiversity caused by the globalisation of alien recreational freshwater fisheries. Aquatic biodiversity, pp.217-230.

Carrasco, L., Mumford, J., MacLeod, A., Knight, J., and Baker, R. Comprehensive bioeconomic modelling of multiple harmful non-indigenous species. Ecological Economics, 69(6):1303 – 1312, 2010. Special Section - Payments for Environmental Services: Reconciling Theory and Practice.

Chen, L. Y. 2001. Cost savings from properly managing endangered species habitats. Natural Areas Journal 21:197–203.

Clewley, G.D., Eschen, R., Shaw, R.H. and Wright, D.J., 2012. The effectiveness of classical biological control of invasive plants. Journal of Applied Ecology, 49(6), pp.1287-1295.

Cocchi, R. and Riga, F., 2008. Control of a coypu *Myocastor coypus* population in northern Italy and management implications. Italian journal of zoology, 75(1), pp.37-42.

Cook, D.C., Thomas, M.B., Cunningham, S.A., Anderson, D.L. and De Barro, P.J., 2007. Predicting the economic impact of an invasive species on an ecosystem service. Ecological Applications, 17(6), pp.1832-1840.

Courtois, P., Figuieres, C., Mulier, C. and Weill, J., 2018. A Cost–Benefit Approach for Prioritizing Invasive Species. *Ecological Economics*, *146*, pp.607-620.

Cox, P. A. 1983. Extinction of the Hawaiian avifauna resulted in a change of pollinators for the ieie, *Freycinetia arborea*. Oikos 41:195-199.

Crall, A.W., Newman, G.J., Jarnevich, C.S., Stohlgren, T.J., Waller, D.M. and Graham, J., 2010. Improving and integrating data on invasive species collected by citizen scientists. Biological Invasions, 12(10), pp.3419-3428.

Crall, A.W., Newman, G.J., Stohlgren, T.J., Holfelder, K.A., Graham, J. and Waller, D.M., 2011. Assessing citizen science data quality: an invasive species case study. *Conservation Letters*, *4*(6), pp.433-442.

Crooks, J.A., Soulé, M.E. and Sandlund, O.T., 1999. Lag times in population explosions of invasive species: causes and implications. Invasive species and biodiversity management, pp.103-125.

Cruz, F., Carrion, V., Campbell, K.J., Lavoie, C. and Donlan, C.J., 2009. Bio-economics of large-scale eradication of feral goats from Santiago Island, Galapagos. The Journal of Wildlife Management, 73(2), pp.191-200.

D'antonio, C. and Meyerson, L.A., 2002. Exotic plant species as problems and solutions in ecological restoration: a synthesis. Restoration Ecology, 10(4), pp.703-713.

Deltoro V; Ballester G; Oltra JE; Pérez-Botella J; Pérez-Rovira P; Gómez-Serrano MA; Jiménez J, 2013. The practicalities of eradicating an extremely invasive cactus: Hudson pear *Cylindropuntia rosea* in the Valencia region (East Spain). Aliens: The Invasive Species Bulletin, No.33:23-27.

Denslow, J.S. and D'Antonio, C.M., 2005. After biocontrol: assessing indirect effects of insect releases. *Biological Control*, *35*(3), pp.307-318.

Dick, C. W. 2001. Genetic rescue of remnant tropical trees by an alien pollinator. Proceedings of the Royal Society B-Biological Sciences 268:2391-2396.

Dionisio Pires, L. M., . W. Ibelings, and E. van Donk. 2009- Zebra mussels as a potential tool in the restoration of eutrophic shallow lakes, dominated by toxic cyanobacteria. Pages 361-372 in G. Van der Velde, S. Rajagopal, and A. A. bij de Vaate, editors. The zebra mussel in Europe. Backhuys Publishers, Leiden, The Netherlands.

Dowding, J.E., Murphy, E.C. and Veitch, C.R., 1999. Brodifacoum residues in target and non-target species following an aerial poisoning operation on Motuihe Island, Hauraki Gulf, New Zealand. *New Zealand Journal of Ecology*, pp.207-214.

Dudgeon, D., and R. E. W. Smith. 2006. Exotic species, fisheries and conservation of freshwater biodiversity in tropical Asia: the case of the Sepik River, Papua New Guinea. Aquatic Conservation: *Marine and Freshwater Ecosystems* 16:203–215

Duncan, C.A., Jachetta, J.J., Brown, M.L., Carrithers, V.F., Clark, J.K., DiTomaso, J.M., Lym, R.G., McDaniel, K.C., Renz, M.J. and Rice, P.M., 2004. Assessing the economic, environmental, and societal losses from invasive plants on rangeland and wildlands. Weed Technology, 18(sp1), pp.1411-1416.

Dwan, K., Altman, D.G., Arnaiz, J.A., Bloom, J., Chan, A.W., Cronin, E., Decullier, E., Easterbrook, P.J., Von Elm, E., Gamble, C. and Ghersi, D. (2008). 'Systematic review of the empirical evidence of study publication bias and outcome reporting bias'. PloS One, 3(8): e3081.

Eason, C.T., Murphy, E.C., Wright, G.R. and Spurr, E.B., 2002. Assessment of risks of brodifacoum to non-target birds and mammals in New Zealand. *Ecotoxicology*, *11*(1), pp.35-48.

Eiswerth, M.E. and Johnson, W.S., 2002. Managing nonindigenous invasive species: insights from dynamic analysis. *Environmental and Resource Economics*, *23*(3), pp.319-342.

Eiswerth, M.E., Darden, T.D., Johnson, W.S., Agapoff, J. and Harris, T.R., 2005. Input–output modeling, outdoor recreation, and the economic impacts of weeds. *Weed Science*, *53*(1), pp.130-137.

El-Sayed, A.M., Suckling, D.M., Byers, J.A., Jang, E.B. and Wearing, C.H., 2009. Potential of "lure and kill" in long-term pest management and eradication of invasive species. *Journal of Economic Entomology*, *102*(3), pp.815-835.

Epanchin-Niell RS, Haight RG, Berec L et al. (2012) Optimal surveillance and eradication of invasive species in heterogeneous landscapes. *Ecol Lett* 15:803–812

Epanchin-Niell, R.S., 2017. Economics of invasive species policy and management. *Biological Invasions*, *19*(11), pp.3333-3354.

Epanchin-Niell, R.S., Brockerhoff, E.G., Kean, J.M. and Turner, J.A., 2014. Designing cost-efficient surveillance for early detection and control of multiple biological invaders. *Ecological Applications*, *24*(6), pp.1258-1274.

Evans, J. M., A. C. Wilkie, and J. Burkhardt. 2008. Adaptive management of nonnative species: moving beyond the "either-or" through experimental pluralism. *Journal of Agricultural & Environmental Ethics* 21:521–539.

Ewel, J.J. and Putz, F.E., 2004. A place for alien species in ecosystem restoration. Frontiers in Ecology and the Environment, 2(7), pp.354-360.

Ewel, J.J., O'Dowd, D.J., Bergelson, J., Daehler, C.C., D'antonio, C.M., Gómez, L.D., Gordon, D.R., Hobbs, R.J., Holt, A., Hopper, K.R. and Hughes, C.E., 1999. Deliberate introductions of species: research needs: Benefits can be reaped, but risks are high. BioScience, 49(8), pp.619-630.

Flory, S.L. and Clay, K., 2009. Invasive plant removal method determines native plant community responses. Journal of Applied Ecology, 46(2), pp.434-442.

Fukasawa, K., Hashimoto, T., Tatara, M. and Abe, S., 2013. Reconstruction and prediction of invasive mongoose population dynamics from history of introduction and management: a Bayesian state-space modelling approach. Journal of Applied Ecology, 50(2), pp.469-478.

Gallo, T. and Waitt, D., 2011. Creating a successful citizen science model to detect and report invasive species. *BioScience*, *61*(6), pp.459-465.

García-Díaz, P., Ramsey, D.S., Woolnough, A.P., Franch, M., Llorente, G.A., Montori, A., Buenetxea, X., Larrinaga, A.R., Lasceve, M., Álvarez, A. and Traverso, J.M., 2017.

Challenges in confirming eradication success of invasive red-eared sliders. Biological Invasions, 19(9), pp.2739-2750.

García-Llorente, M., Martín-López, B., González, J.A., Alcorlo, P. and Montes, C., 2008. Social perceptions of the impacts and benefits of invasive alien species: Implications for management. Biological Conservation, 141:2969-2983.

Gardener, M. R., Atkinson, R., & Rentería, J. L. (2010). Eradications and people: lessons from the plant eradication program in Galapagos. Restoration Ecology, 18(1), 20-29.

Ginn, F., 2008. Extension, subversion, containment: eco-nationalism and (post) colonial nature in Aotearoa New Zealand. Transactions of the Institute of British Geographers, 33(3), pp.335-353.

Gosling, L.M. and Baker, S.J. (1987). Planning and monitoring an attempt to eradicate coypus from Britain. Symposia of the Zoological Society of London 58: 99–113.

Gosling, L.M. and Baker, S.J. (1989). The eradication of muskrats and coypus from Britain. Biological Journal of the Linnean Society 38(1): 39–51.

Gosling, L.M., Baker, S.J. and Clarke, C.N. (1988). 'An attempt to remove coypus (*Myocastor coypus*) from a wetland habitat in East Anglia'. Journal of Applied Ecology 25: 49–62.

Graham, M.F. and Veitch, C.R., 2002. Changes in bird numbers on Tiritiri Matangi Island, New Zealand, over the period of rat eradication. Turning the tide: the eradication of invasive species, pp.120-123.

Gren, I.M., 2008. Economics of alien invasive species management-choices of targets and policies. *Boreal environment research*, *13*.

Gren, M., Isacs, L. and Carlsson, M., 2009. Costs of alien invasive species in Sweden. AMBIO 38: 135–140. doi: 10.1579/0044-7447-38.3.135

Griffiths, C. J., C. G. Jones, D. M. Hansen, M. Puttoo, R. V. Tatayah, C. B. Müller, and S. Harris. 2010. The use of extant non-indigenous tortoises as a restoration tool to replace extinct ecosystem engineers. Restoration Ecology 18:1–7.

Haight RG, Polasky S (2010) Optimal control of an invasive species with imperfect information about the level of infestation. Resour Energy Econ 32(4):519–533

Harding, J.M., 2003. Predation by blue crabs, *Callinectes sapidus*, on rapa whelks, *Rapana venosa*: possible natural controls for an invasive species? Journal of Experimental Marine Biology and Ecology, 297(2), pp.161-177.

Harris, S. and Timmins, S.M., 2009. Estimating the benefit of early control of all newly naturalised plants. *Science for Conservation*, (292).

Hauser, C.E., McCarthy, M.A. (2009) Streamlining 'search and destroy': cost-effective surveillance for invasive species management. Ecol Lett 12:683–692

Hejda, M., Pyšek, P. and Jarošík, V., 2009. Impact of invasive plants on the species richness, diversity and composition of invaded communities. Journal of Ecology, 97(3), pp.393-403.

Hoagland, P., and Jin, D., 2006. Science and economics in the management of an invasive species. BioScience 56:931-935

Hoddle, M.S., 2004. Restoring balance: using exotic species to control invasive exotic species. Conservation Biology, 18(1), pp.38-49.

Hoffmann, B.D. and Broadhurst, L.M., 2016. The economic cost of managing invasive species in Australia. *NeoBiota*, *31*, p.1.

Holden, M.H., Nyrop, J.P. and Ellner, S.P., 2016. The economic benefit of time-varying surveillance effort for invasive species management. *Journal of Applied Ecology*, *53*(3), pp.712-721.

Holmes, N.D., Campbell, K.J., Keitt, B., Griffiths, R., Beek, J., Donlan, C.J. and Broome, K., 2016. Correction: reporting costs for invasive vertebrate eradications. Biological Invasions, 18(10), pp.2801-2807.

Holmes, N.D., Campbell, K.J., Keitt, B.S., Griffiths, R., Beek, J., Donlan, C.J. and Broome, K.G., 2015. Reporting costs for invasive vertebrate eradications. Biological Invasions, 17(10), pp.2913-2925.

Holmes, T.P., Aukema, J.E., Von Holle, B., Liebhold, A. and Sills, E., 2009. Economic impacts of invasive species in forests. Annals of the New York Academy of Sciences, 1162(1), pp.18-38.

Horan, R.D., Perrings, C., Lupi, F. and Bulte, E.H., 2002. Biological pollution prevention strategies under ignorance: the case of invasive species. American Journal of Agricultural Economics, 84(5), pp.1303-1310.

Howald, G., Donlan, C., Galván, J.P., Russell, J.C., Parkes, J., Samaniego, A., Wang, Y., Veitch, D., Genovesi, P., Pascal, M. & Saunders, A. (2007). 'Invasive rodent eradication on islands'. Conservation Biology, 21(5), pp.1258-1268.

Howarth, F.G., 1991. Environmental impacts of classical biological control. *Annual Review of Entomology*, *36*(1), pp.485-509.

Hulme PE (2009) Trade, transport and trouble: managing invasive species pathways in an era of globalization. J Appl Ecol 46:10–18

Iacona, GD, , WJ, Mappin, B, , V, , PR, Coleshaw, T, Cook, C, Craigie, I, Dicks, L, Fitzsimons, JA, McGowan, J, Plumptre, A, Polak, T, Pullin, A Ringma, J, Rushworth, I, Santangeli, A, , A, Tulloch, A, Walsh, J and Possingham, HP (2018) Standardized reporting of the costs of management interventions for biodiversity conservation. Conservation Biology. https://doi.org/10.1111/cobi.13195

Jeschke, J.M. and Strayer, D.L., 2008. Usefulness of bioclimatic models for studying climate change and invasive species. Annals of the New York Academy of Sciences, 1134(1), pp.1-24.

Johnson, S.R., Berentsen, A.R., Ellis, C., Davis, A. and Vercauteren, K.C., 2016. Estimates of small Indian mongoose densities: Implications for rabies management. The Journal of Wildlife Management, 80(1), pp.37-47.

Jolly, J. N., and R. M. Colbourne. 1991. Translocations of the little spotted kiwi (Aptéryx owenit) between offshore islands of New Zealand. Journal of the Royal Society of New Zealand 21:143–149.

Jones, C., Warburton, B., Carver, J. & Carver, D. (2015). 'Potential applications of wireless sensor networks for wildlife trapping and monitoring programs'. *Wildlife Society Bulletin*, *39*(2), pp.341-348.

Jones, H.P., Tershy, B.R., Zavaleta, E.S., Croll, D.A., Keitt, B.S., Finkelstein, M.E. and Howald, G.R., 2008. Severity of the effects of invasive rats on seabirds: a global review. Conservation Biology, 22(1), pp.16-26.

Kahraman, C. ed., 2008. *Fuzzy multi-criteria decision making: theory and applications with recent developments* (Vol. 16). Springer Science & Business Media.

Keitt, B., Campbell, K., Saunders, A., Clout, M., Wang, Y., Heinz, R., Newton, K. and Tershy, B., 2011. The global islands invasive vertebrate eradication database: a tool to improve and facilitate restoration of island ecosystems. Island invasives: eradication and management. IUCN, Gland, Switzerland, pp.74-77.

Keller, R.P., Frang, K. and Lodge, D.M., 2008. Preventing the spread of invasive species: economic benefits of intervention guided by ecological predictions. *Conservation Biology*, *22*(1), pp.80-88.

Keller, R.P., Lodge, D.M. and Finnoff, D.C., 2007. Risk assessment for invasive species produces net bioeconomic benefits. *Proceedings of the National Academy of Sciences*, *104*(1), pp.203-207.

Kenis, M., Auger-Rozenberg, M.A., Roques, A., Timms, L., Péré, C., Cock, M.J., Settele, J., Augustin, S. and Lopez-Vaamonde, C., 2009. Ecological effects of invasive alien insects. Biological Invasions, 11(1), pp.21-45.

Krause, S.K., Kelt, D.A., Van Vuren, D.H. and Gionfriddo, J.P., 2014. Regulation of tree squirrel populations with immunocontraception: a fox squirrel example. Human–Wildlife Interactions, 8(2), p.3.

Lawton, C. and Rochford, J., 2007, January. The recovery of grey squirrel (Sciurus carolinensis) populations after intensive control programmes. In Biology and Environment: Proceedings of the Royal Irish Academy (pp. 19-29). Royal Irish Academy.

Le Maitre, D.C., van Wilgen, B.W., Gelderblom, C.M., Bailey, C., Chapman, R.A. and Nel, J.A., 2002. Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. *Forest Ecology and Management*, *160*(1), pp.143-159.

Leung, B., Lodge, D.M., Finnoff, D., Shogren, J.F., Lewis, M.A. and Lamberti, G., 2002. An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. *Proceedings of the Royal Society of London B: Biological Sciences*, *269*(1508), pp.2407-2413.

Liao, C., Peng, R., Luo, Y., Zhou, X., Wu, X., Fang, C., Chen, J. and Li, B., 2008. Altered ecosystem carbon and nitrogen cycles by plant invasion: A meta-analysis. New Phytologist, 177(3), pp.706-714.

Littin, K.E. and Mellor, D.J., 2005. Strategic animal welfare issues: ethical and animal welfare issues arising from the killing of wildlife for disease control and environmental reasons. *Revue Scientifique Et Technique-Office International Des Epizooties*, *24*(2), pp.767-782.

Littin, K.E., Mellor, D.J., Warburton, B. and Eason, C.T., 2004. Animal welfare and ethical issues relevant to the humane control of vertebrate pests. *New Zealand Veterinary Journal*, *52*(1), pp.1-10.

Liu Y, Sims C (2016) Spatial-dynamic externalities and coordination in invasive species control. Resour Energy Econ 44:23–38

Liu, H.W. and Wang, G.J., 2007. Multi-criteria decision-making methods based on intuitionistic fuzzy sets. *European Journal of Operational Research*, *179*(1), pp.220-233.

Liu, X., McGarrity, M.E. and Y. Li. 2012. The influence of traditional Buddhist wildlife release on biological invasions. Conservation Letters 5: 107–114.

Louda, S.M., Arnett, A.E., Rand, T.A. and Russell, F.L., 2003. Invasiveness of some biological control insects and adequacy of their ecological risk assessment and regulation. *Conservation Biology*, *17*(1), pp.73-82.

Louette, G., 2012. Use of a native predator for the control of an invasive amphibian. Wildlife Research, 39(3), pp.271-278.

Louette, G., Devisscher, S. and Adriaens, T., 2013. Control of invasive American bullfrog Lithobates catesbeianus in small shallow water bodies. European Journal of Wildlife Research, 59(1), pp.105-114.
Lovell, S.J., Stone, S.F. and Fernandez, L., 2006. The economic impacts of aquatic invasive species: a review of the literature. *Agricultural and Resource Economics Review*, *35*(1), pp.195-208.
Lugo, A. E. 1997. The apparent paradox of re-establishing species richness on degraded lands with tree monocultures. Forestry Ecology and Management 99:9–19.
Lugo, A. E. 2004. The outcome of alien tree invasions in Puerto Rico. Frontiers in Ecology and the Environment 2:265–273.
Lupi, F., Hoehn, J.P. and Christie, G.C., 2003. Using an economic model of recreational fishing to evaluate the benefits of sea lamprey (*Petromyzon marinus*) control on the St. Marys River. *Journal of Great Lakes Research*, *29*, pp.742-754.
Mackenzie, C. A. 2012. Accruing benefit or loss from a protected area: location matters. *Ecological Economics* 76,
Martins, T.L.F., Brooke, M.D.L., Hilton, G.M., Farnsworth, S., Gould, J. & Pain, D.J. (2006). Costing eradications of alien mammals from islands. *Animal Conservation*, *9*(4), pp.439-444.
Mayle, B.A. and Broome, A.C., 2013. Changes in the impact and control of an invasive alien: the grey squirrel (Sciurus carolinensis) in Great Britain, as determined from regional surveys. Pest management science, 69(3), pp.323-333.
Mazzamuto, M.V., Panzeri, M., Wauters, L., Preatoni, D. and Martinoli, A., 2016. Knowledge, management and optimization: the use of live traps in control of non-native squirrels. Mammalia, 80(3), pp.305-311.
McDermott, S. 2015. Optimal regulation of invasive species long-range spread: a general equilibrium approach. *BE J Econ Anal Poli* 15(4):1731–1752
McGeoch, M.A., Genovesi, P., Bellingham, P.J., Costello, M.J., McGrannachan, C. and Sheppard, A., 2016. Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion. *Biological Invasions*, *18*(2), pp.299-314.
McNeely, J.A., 2001. An introduction to human dimensions of invasive alien species. The Great Reshuffling: Human Dimensions of Invasive Alien Species. IUCN Publishers, Gland, Switzerland, pp.5-22.
Medina, F.M., Bonnaud, E., Vidal, E., Tershy, B.R., Zavaleta, E.S., Josh Donlan, C., Keitt, B.S., Corre, M., Horwath, S.V. and Nogales, M., 2011. A global review of the impacts of invasive cats on island endangered vertebrates. Global Change Biology, 17(11), pp.3503-3510
Melbourne, B.A. and Hastings, A., 2009. Highly variable spread rates in replicated biological invasions: fundamental limits to predictability. Science, 325(5947), pp.1536-1539.
Mérel, P.R. and Carter, C.A., 2008. A second look at managing import risk from invasive species. *Journal of Environmental Economics and Management*, *56*(3), pp.286-290.
Messing, R.H. and Wright, M.G., 2006. Biological control of invasive species: solution or pollution? *Frontiers in Ecology and the Environment*, *4*(3), pp.132-140.
Meyer, J.Y., 2004. Threat of invasive alien plants to native flora and forest vegetation of Eastern Polynesia. Pacific Science, 58(3), pp.357-375.

Molnar, J.L., Gamboa, R.L., Revenga, C. and Spalding, M.D., 2008. Assessing the global threat of invasive species to marine biodiversity. Frontiers in Ecology and the Environment, 6(9), pp.485-492.

Morrison, K. D., E. G. Reekie, and I. N. Jensen. 1998. Biocontrol of common St. Johnswort (*Hypericum perforatum*) with *Chrysolina hyperici* and a host-specific *Colletotrichum gloeosporioides*. Weed Technology 12:426–435.

Naidoo, R. and Ricketts, T.H., 2006. Mapping the economic costs and benefits of conservation. *PLoS biology*, *4*(11), p.e360.

Narayan, D., Cambers, R., Shah, M.K. and Petesch, P. 2000. Voices of the poor: crying out for change. New York: Oxford University Press for the World Bank.

Nentwig, W. and Vaes-Petignat, S., 2014. Environmental and economic impact of alien terrestrial arthropods in Europe. NeoBiota, 22, p.23.

Nentwig, W., Kühnel, E. and Bacher, S., 2010. A Generic Impact-Scoring System Applied to Alien Mammals in Europe. *Conservation Biology*, *24*(1), pp.302-311.

Nogales, M., Martín, A., Tershy, B.R., Donlan, C.J., Veitch, D., Puerta, N., Wood, B. and Alonso, J., 2004. A review of feral cat eradication on islands. Conservation Biology, 18(2), pp.310-319.

NRC. 2004. Nonnative oysters in the Chesapeake Bay. National Academy, Washington, DC.

Nunes, P.A. and Van Den Bergh, J.C., 2004. Can people value protection against invasive marine species? Evidence from a joint TC–CV survey in the Netherlands. *Environmental and Resource Economics*, *28*(4), pp.517-532.

Olson, L.J., 2006. The economics of terrestrial invasive species: a review of the literature. *Agricultural and Resource Economics Review*, *35*(1), pp.178-194.

Panzacchi, M., Cocchi, R., Genovesi, P. and Bertolino, S., 2007. Population control of coypu Myocastor coypus in Italy compared to eradication in UK: a cost-benefit analysis. *Wildlife Biology*, *13*(2), pp.159-171.

Parkes, J., Fisher, P., Robinson, S. and Aguirre-Muñoz, A., 2014. Eradication of feral cats from large islands: an assessment of the effort required for success. New Zealand Journal of Ecology, pp.307-314.

Pascal, M., Lorvelec, O., Bretagnolle, V. and Culioli, J.M., 2008. Improving the breeding success of a colonial seabird: a cost-benefit comparison of the eradication and control of its rat predator. *Endangered Species Research*, *4*(3), pp.267-276.

Pejchar, L. and Mooney, H.A. 2009. Invasive species, ecosystem services and human well-being. Trends in Ecology and Evolution, 52:273-288.

Piertney, S.B., Black, A., Watt, L., Christie, D., Poncet, S. and Collins, M.A., 2016. Resolving patterns of population genetic and phylogeographic structure to inform control and eradication initiatives for brown rats Rattus norvegicus on South Georgia. Journal of applied ecology, 53(2), pp.332-339.

Pimentel, D., Lach, L., Zuniga, R. and Morrison, D., 2000. Environmental and economic costs of nonindigenous species in the United States. *BioScience*, *50*(1), pp.53-65.

Pimentel, D., Zuniga, R. and Morrison, D., 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*, *52*(3), pp.273-288.

Pratt, C.F., Constantine, K.L. and Murphy, S.T., 2017. Economic impacts of invasive alien species on African smallholder livelihoods. Global Food Security.

Putman, R., Langbein, J., Green, P. and Watson, P., 2011. Identifying threshold densities for wild deer in the UK above which negative impacts may occur. Mammal Review, 41(3), pp.175-196.

Pyšek P, Jarošík V, Hulme PE, Pergl J, Hejda M, et al. (2012) A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. Global Change Biology 18: 1725–1737.

Ratnaswamy, M.J., Warren, R.J., Kramer, M.T. and Adam, M.D., 1997. Comparisons of lethal and nonlethal techniques to reduce raccoon depredation of sea turtle nests. The Journal of wildlife management, pp.368-376.

Reaser, J.K., Meyerson, L.A., Cronk, Q., De Poorter, M.A.J., Eldrege, L.G., Green, E., Kairo, M., Latasi, P., Mack, R.N., Mauremootoo, J. and O'Dowd, D., 2007. Ecological and socioeconomic impacts of invasive alien species in island ecosystems. Environmental Conservation, 34(2), pp.98-111.

Reinhardt, F., Herle, M., Bastiansen, F. and Streit, B., 2003. Economic impact of the spread of alien species in Germany. Berlin, Germany: Federal Environmental Agency (Umweltbundesamt).

Rejmánek, M. & Pitcairn, M.J. (2002). 'When is eradication of exotic pest plants a realistic goal.' Turning the tide: the eradication of invasive species, pp.249-253.

Reyns, N., Casaer, J., De Smet, L., Devos, K., Huysentruyt, F., Robertson, P.A., Verbeke, T. and Adriaens, T., 2018. Cost-benefit analysis for invasive species control: the case of greater Canada goose Branta canadensis in Flanders (northern Belgium). *PeerJ*, *6*, p.e4283.

Ricciardi, A. and Simberloff, D., 2009. Assisted colonization is not a viable conservation strategy. Trends in Ecology and Evolution, 24(5), pp.248-253.

Rinella, M.J., Maxwell, B.D., Fay, P.K., Weaver, T. and Sheley, R.L., 2009. Control effort exacerbates invasive-species problem. *Ecological Applications*, *19*(1), pp.155-162.

Robertson, P.A., Adriaens, T., Caizergues, A., Cranswick, P.A., Devos, K., Gutiérrez-Expósito, C., Henderson, I., Hughes, B., Mill, A.C. and Smith, G.C., 2015. Towards the European eradication of the North American ruddy duck. Biological Invasions, 17(1), pp.9-12.

Robertson, P.A., Adriaens, T., Lambin, X., Mill, A., Roy, S., Shuttleworth, C.M. and Sutton-Croft, M., 2017. The large-scale removal of mammalian invasive alien species in Northern Europe. Pest Management Science, 73(2), pp.273-279.

Robertson, P.A., Roy, S., Mill, A., Shirley, M., Adriaens, T., Ward, AI, Tatayah, V and Booy, O (in press) Invasive species removals and scale – contrasting island and mainland experience. In: Island Invasives Conference, Dundee.

Rodriguez, L. F. 2006. Can invasive species facilitate native species? Evidence of how, when, and why these impacts occur. Biological Invasions 8:927–939.

Rondinini, C., Wilson, K.A., Boitani, L., Grantham, H. and Possingham, H.P., 2006. Tradeoffs of different types of species occurrence data for use in systematic conservation planning. *Ecology letters*, *9*(10), pp.1136-1145.

Roy HE, Adriaens T, Aldridge DC, Bacher S, Bishop JDD, Blackburn TM, Branquart E, Brodie J, Carboneras C, Cook EJ, Copp GH, Dean HJ, Eilenberg J, Essl F, Gallardo B, Garcia M, García-Berthou E, Genovesi P, Hulme PE, Kenis M, Kerckhof F, Kettunen M, Minchin D, Nentwig W, Nieto A, Pergl J, Pescott O, Peyton J, Preda C, Rabitsch W, Roques A, Rorke S, Scalera R, Schindler S, Schönrogge K, Sewell J, Solarz W, Stewart A, Tricarico E, Vanderhoeven S, van der Velde G, Vilà M, Wood CA, Zenetos A (2015a) Invasive Alien

Species - Prioritising prevention efforts through horizon scanning. ENV.B.2/ETU/2014/0016. European Commission.

Roy, H., Schonrogge, K., Dean, H., Peyton, J., Branquart, E., Vanderhoeven, S., Copp, G., Stebbing, P., Kenis, M., Rabitsch, W. and Essl, F. (2014a). Invasive alien species–framework for the identification of invasive alien species of EU concern. (ENV.B.2/ETU/2013/0026). *European Commission, Brussels.*

Roy, H.E., Preston, C.D., Harrower, C.A., Rorke, S.L., Noble, D., Sewell, J., Walker, K., Marchant, J., Seeley, B., Bishop, J. and Jukes, A., 2014b. GB Non-native Species Information Portal: documenting the arrival of non-native species in Britain. *Biological Invasions*, *16*(12), pp.2495-2505.

Roy, H.E., Rabitsch, W., Scalera, R., Stewart, A., Gallardo, B., Genovesi, P., Essl, F., Adriaens, T., Bacher, S., Booy, O., Branquart, E., Brunel, S., Copp, G., Dean, H., D'hondt, B., Josefsson, M., Kenis, M., Kettunen, M., Linnamagi, M., Lucy, F., Martinou, A., Moore, N., Nentwig, W., Nieto, A., Pergl, J., Peyton, J., Roques, A., Schindler, S., Schönrogge, K., Solarz, W., Stebbing, P.D., Trichkova, T., Vanderhoeven, S., van Valkenburg, J., Zenetos, A. *(2017)* Developing a framework of minimum standards for the risk assessment of alien species. Journal of Applied Ecology. https://doi.org/10.1111/1365-2664.13025

Roy, S.S., Chauvenet, A.L.M. and Robertson, P.A., 2015b. Removal of American mink (*Neovison vison*) from the Uists, outer Hebrides, Scotland. Biological invasions, 17(10), pp.2811-2820.Rushton, S.P., Gurnell, J., Lurz, P.W. and Fuller, R.M., 2002. Modeling impacts and costs of gray squirrel control regimes on the viability of red squirrel populations. The Journal of wildlife management, pp.683-697.Sheail, J. (2004). 'The mink menace: the politics of vertebrate pest control'. Rural History 15(02): 207–222.

Ruesink, J. L., H. S. Lenihan, A. C. Trimble, K. W. Heiman, F. Micheli, J. E. Byers, and M. C. Kay. 2005. Introduction of non-native oysters: Ecosystem effects and restoration implications. Annual Review of Ecology, Evolution, and Systematics 36:643–689

Ruscoe, W.A., Ramsey, D.S., Pech, R.P., Sweetapple, P.J., Yockney, I., Barron, M.C., Perry, M., Nugent, G., Carran, R., Warne, R. and Brausch, C., 2011. Unexpected consequences of control: competitive vs. predator release in a four-species assemblage of invasive mammals. *Ecology Letters*, *14*(10), pp.1035-1042.

Rushton, S.P., Lurz, P.W.W., Gurnell, J., Nettleton, P., Bruemmer, C., Shirley, M.D.F. and Sainsbury, A.W., 2006. Disease threats posed by alien species: the role of a poxvirus in the decline of the native red squirrel in Britain. Epidemiology & Infection, 134(3), pp.521-533.

Russell, J.C., Sataruddin, N.S. & Heard, A.D. (2014). Over-invasion by functionally equivalent invasive species. Ecology, 95:2268–2276.

Sandler, R. 2010. The value of species and ethical foundations of assisted colonization. *Conservation Biology* 24:424–431.

Scalera R, Cozzi A, Caccamo C, Rossi I, editors (2017) A catalogue of LIFE projects contributing to the management of alien species in the European Union. Platform Meeting on Invasive Alien Species (IAS) 29-30 November 2017, Milan (Italy). LIFE14 IP/IT/000018 Nature Integrated Management to 2020 (GESTIRE 2020). Pp. 144.

Scalera R, Zaghi D (2004). Alien species and nature conservation in the EU. The role of the LIFE program. LIFE Focus. European Commission, Bruxelles. Pp.60.

Scalera, R., 2010. How much is Europe spending on invasive alien species? Biological Invasions, 12(1), pp.173-177.

Scheffer, M., Carpenter, S., Foley, J.A., Folke, C. & Walker, B. (2001). Catastrophic shifts in ecosystems. Nature, 413, 591–596.

Schlaepfer, M.A., Sax, D.F. and Olden, J.D., 2011. The potential conservation value of non-native species. *Conservation Biology*, *25*(3), pp.428-437.

Schmiedel, D., Wilhelm, E-G., Roth, M. et al. (2016) Evaluation system for management measures of invasive alien species. Biodiversity and Conservation 25:357–374

Schuchert, P., Shuttleworth, C.M., McInnes, C.J., Everest, D.J. and Rushton, S.P., 2014. Landscape scale impacts of culling upon a European grey squirrel population: can trapping reduce population size and decrease the threat of squirrelpox virus infection for the native red squirrel? Biological invasions, 16(11), pp.2381-2391.

Schwartz, M.W., Thorne, J.H. and Viers, J.H., 2006. Biotic homogenization of the California flora in urban and urbanizing regions. Biological Conservation, 127:282-291.

Sexton, J.P., McIntyre, P.J., Angert, A.L. and Rice, K.J., 2009. Evolution and ecology of species range limits. Annual Review of Ecology, Evolution, and Systematics, 40.

Shapiro, A.M., 2002. The Californian urban butterfly fauna is dependent on alien plants. Diversity and Distributions, 8(1), pp.31-40.

Sharov AA, Liebhold AM (1998) Bioeconomics of managing the spread of exotic pest species with barrier zones. Ecol Appl 8:833–845

Sharp, R.L., Larson, L.R. and Green, G.T., 2011. Factors influencing public preferences for invasive alien species management. *Biological Conservation*, *144*(8), pp.2097-2104.

Sharp, T. and Saunders, G., 2005. Humane pest animal control: codes of practice and standard operating procedures. *Humane pest animal control: codes of practice and standard operating procedures.*

Sharp, T. and Saunders, G., 2011. *A model for assessing the relative humaneness of pest animal control methods*. Department of Agriculture, Fisheries and Forestry.

Sheppard, A.W., Shaw, R.H. and Sforza, R., 2006. Top 20 environmental weeds for classical biological control in Europe: a review of opportunities, regulations and other barriers to adoption. Weed Research, 46:93-117.

Shwiff, S.A., Anderson, A., Cullen, R., White, P.C.L. and Shwiff, S.S., 2012. Assignment of measurable costs and benefits to wildlife conservation projects. *Wildlife Research*, *40*(2), pp.134-141.

Silva JP, Sopeña A, Sliva J (2014) LIFE and Invasive Alien Species. Publications Office of the European Union, Luxembourg, 1–78.

Sims C (2011) Optimal timing of salvage harvest in response to a stochastic infestation. Nat Resour Model 24(3):383–408

Sims C, Finnoff D (2013) When is a ‘‘wait and see’’ approach to invasive species justified? Resour Energy Econ 35:235–255

Sims, C., Finnoff, D. and Shogren, J.F., 2016. Bioeconomics of invasive species: using real options theory to integrate ecology, economics, and risk management. *Food Security*, *8*(1), pp.61-70.

Sogge, M. K., S. J. Sferra, and E. H. Paxton. 2008. Tamarix as habitat for birds: implications for riparian restoration in the southwestern United States. Restoration Ecology 16:146–154.

Springborn M, Lindsay AR, Epanchin-Niell RS (2016) Harnessing enforcement leverage at the border to minimize biological risk from international live species trade. J Econ Behav Org 132(B):98–112

Stiling, P. and Cornelissen, T., 2005. What makes a successful biocontrol agent? A meta-analysis of biological control agent performance. Biological Control, 34:236-246.

Strayer, D.L., D'Antonio, C.M., Essl, F., Fowler, M.S., Geist, J., Hilt, S., Jarić, I., Jöhnk, K., Jones, C.G., Lambin, X., Latzka, A.W., Pergl, J., Pysek, P., Robertson, P.A., von Schmalensee, M., Steffansson, R.A., Wright, J., Jeschke, J.M. 2017. Boom-bust dynamics in biological invasions: towards an improved application of the concept. Ecology Letters, 20:1337-1350.

Su, S., Cassey, P. and Blackburn, T.M., 2014. Patterns of non-randomness in the composition and characteristics of the Taiwanese bird trade. Biological Invasions, 16(12), pp.2563-2575.

Suarez, A.V., Holway, D.A. and Case, T.J., 2001. Patterns of spread in biological invasions dominated by long-distance jump dispersal: insights from Argentine ants. Proceedings of the National Academy of Sciences, 98(3), pp.1095-1100.

Tablado, Z., J. L. Telia, J. A. Sanchez-Zapata, and F. Hiraldo. 2010. The paradox of long-term positive effects of a North American crayfish on a European community of predators. Conservation Biology DOI: 10.1111/j.l523-1739.2010.0l483.x.

Taylor, C.M. and Hastings, A., 2004. Finding optimal control strategies for invasive species: A density-structured model for Spartina alterniflora. *Journal of Applied Ecology*, *41*(6), pp.1049-1057.

Teillac-Deschamps, P., Lorrillière, R., Servais, V., Delmas, V., Cadi, A. and Prévot-Julliard, A.C., 2009. Management strategies in urban green spaces: models based on an introduced exotic pet turtle. Biological Conservation, 142(10), pp.2258-2269.

Thomas, C.D., 2011. Translocation of species, climate change, and the end of trying to recreate past ecological communities. *Trends in Ecology & Evolution*, *26*:216-221.

Thomas, C.D., 2013. The Anthropocene could raise biological diversity. *Nature News*, *502*:7.

Thomas, M.B. and Reid, A.M., 2007. Are exotic natural enemies an effective way of controlling invasive plants? Trends in Ecology & Evolution, 22(9), pp.447-453.

Triantaphyllou, E., 2000. Multi-criteria decision making methods. In *Multi-criteria decision making methods: A comparative study* (pp. 5-21). Springer, Boston, MA.

Tucker G., Underwood E., Farmer A., Scalera R., Dickie I., McConville A., van Vliet W. (2013) Estimation of the financing needs to implement Target 2 of the EU Biodiversity Strategy. Report to the European Commission. Institute for European Environmental Policy, London.

van Loon, E.E., Bos, D., van Hellenberg Hubar, C.J. and Ydenberg, R.C., 2017. A historical perspective on the effects of trapping and controlling the muskrat (Ondatra zibethicus) in the Netherlands. Pest management science, 73(2), pp.305-312.

Van Wilgen, B.W., De Wit, M.P., Anderson, H.J., Le Maitre, D.C., Kotze, I.M., Ndala, S., Brown, B. and Rapholo, M.B., 2004. Costs and benefits of biological control of invasive alien plants: Case studies from South Africa: Working for Water. *South African Journal of Science*, *100*(1-2), pp.113-122.

Vander Zanden, M.J. and Olden, J.D., 2008. A management framework for preventing the secondary spread of aquatic invasive species. Canadian Journal of Fisheries and Aquatic Sciences, 65(7), pp.1512-1522.

Vander Zanden, M.J., Hansen, G.J., Higgins, S.N. and Kornis, M.S., 2010. A pound of prevention, plus a pound of cure: early detection and eradication of invasive species in the Laurentian Great Lakes. *Journal of Great Lakes Research*, *36*(1), pp.199-205.

Vanderhoeven, S., Branquart, E., Casaer, J., D’hondt, B., Hulme, P.E., Shwartz, A., Strubbe, D., Turbe, A., Verreycken, H., Adriaens, T. (2017) Beyond protocols: improving the reliability of expert-based risk analysis underpinning invasive species policies. *Biological Invasions*. doi:10.1007/s10530-017-1434-0

Vilà, M., Basnou, C., Pyšek, P., Josefsson, M., Genovesi, P., Gollasch, S., Nentwig, W., Olenin, S., Roques, A., Roy, D. and Hulme, P.E., 2010. How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. Frontiers in Ecology and the Environment, 8(3), pp.135-144.

Vilà, M., Espinar, J.L., Hejda, M., Hulme, P.E., Jarošík, V., Maron, J.L., Pergl, J., Schaffner, U., Sun, Y. and Pyšek, P., 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecology Letters, 14(7), pp.702-708.

Vitousek, P.M., D'antonio, C.M., Loope, L.L., Rejmanek, M. and Westbrooks, R., 1997. Introduced species: a significant component of human-caused global change. New Zealand Journal of Ecology, pp.1-16.

Waeber, K., Spencer, J. and Dolman, P.M., 2013. Achieving landscape-scale deer management for biodiversity conservation: The need to consider sources and sinks. The Journal of Wildlife Management, 77(4), pp.726-736.

Webber, B.L., Raghu, S. & Edwards, O.R., (2015). ‘Opinion: Is CRISPR-based gene drive a biocontrol silver bullet or global conservation threat?’ *Proceedings of the National Academy of Sciences*, *112*(34), pp.10565-10567.

Williams, F., Eschen, R., Harris, A., Djeddour, D., Pratt, C., Shaw, R.S., Varia, S., Lamontagne-Godwin, J., Thomas, S.E. and Murphy, S.T., 2010. The economic cost of invasive non-native species on Great Britain. *CABI Proj No VM10066*, pp.1-99.

Willis, S. G., J. K. Hill, C. D. Thomas, D. B. Roy, R. Fox, D. S. Blakeley, and B. Huntley. 2009. Assisted colonization in a changing climate: a test-study using two U.K. butterflies. Conservation Letters 2:46–52.

Wise, R.M., Van Wilgen, B.W. and Le Maitre, D.C., 2012. Costs, benefits and management options for an invasive alien tree species: The case of mesquite in the Northern Cape, South Africa. *Journal of Arid Environments*, *84*, pp.80-90.

Witmer, G.W., Boyd, F. and Hillis-Starr, Z., 2007. The successful eradication of introduced roof rats (*Rattus rattus*) from Buck Island using diphacinone, followed by an irruption of house mice (*Mus musculus*). *Wildlife Research*, *34*(2), pp.108-115.

Wittenberg, R. and Cock, M.J. eds., 2001. *Invasive alien species: a toolkit of best prevention and management practices*. CABI.

Wittenberg, R., Kenis, M., Blick, T., Hänggi, A., Gassmann, A. and Weber, E., 2006. Invasive alien species in Switzerland: an inventory of alien species and their threat to biodiversity and economy in Switzerland. *Invasive alien species in Switzerland: an inventory of alien species and their threat to biodiversity and economy in Switzerland.*

Wootton, L.S., Halsey, S.D., Bevaart, K., McGough, A., Ondreicka, J. and Patel, P., 2005. When invasive species have benefits as well as costs: managing *Carex kobomugi* (Asiatic sand sedge) in New Jersey’s coastal dunes. Biological Invasions, 7(6), pp.1017-1027.

Zavaleta, E., 2000. The economic value of controlling an invasive shrub. *AMBIO: a Journal of the Human Environment*, *29*(8), pp.462-467.

Zavaleta, E.S., Hobbs, R.J. and Mooney, H.A., 2001. Viewing invasive species removal in a whole-ecosystem context. *Trends in Ecology & Evolution*, *16*(8), pp.454-459.