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Ecology, spread and impacts of invasive alien mammals in Europe

Background

Biological invasions are one of the main drivers of biodiversity change and decline in recent human history (IPBES, 2019). Worryingly, the number and diversity of these invasions is expected to increase even further in the future (Seebens *et al.*, 2020), as some of their main drivers – such as international trade and transports (Hulme, 2009), land-use change (Essl *et al.*, 2020) and climate change (Bellard *et al.*, 2018) continue to intensify. While many of the species introduced in new areas fail to establish (i.e., form a self-sustaining population) or remain innocuous in their new range, others succeed and can spread on significant distances, causing severe impacts on native biotas (Blackburn *et al.,* 2019), ecosystems services (Vilà and Hulme, 2017) and human livelihoods (Bradshaw *et al.*, 2016), becoming Invasive Alien Species (IAS).

Mitigate the growing threat of biological invasions is one of the main aims of international agreements such as the Post-2020 Biodiversity Framework (CBD), the Agenda 2030 for Sustainable Development (UN) and the Regulation 1143/2014 (EU). The European Union (EU) adopted this latter to prevent and manage the introduction and spread of alien species. The core of this Regulation is the Union List, a list of IAS considered to cause substantial economic and ecological damages in one or several Member States. Species included in the List are subject to restrictions, and Member States are required to collect information and take action on pathways of introduction, early detection and rapid eradication of these species, and to manage species that are already widely spread in their territory (EU, 2014). As new IAS can be introduced continuously into the EU and the alien species already present are spreading and expanding their range, the List is constantly reviewed and updated (the last one was in 2019).

Mammals are one of the most studied taxa in invasion biology, due to their close relationship with humans, leading them to reach every continent except Antarctica and settling in a wide array of new ecosystems (Genovesi *et al.*, 2012). Invasive mammals are threatening global biodiversity through competition (Mazzamuto *et al.*, 2017), disease transmission (Collins *et al.*, 2014), habitat alteration (Nogales *et al.*, 2014), hybridisation (McFarlane *et al.*, 2020), native species replacement (Põdra and Gómez, 2018) and predation (Dahl and Åhlén, 2019). Moreover, invasive mammal predators are connected to 58% of modern reptile, bird and mammal extinctions (Doherty *et al.*, 2016). Among the 66 species currently comprised in the Union List, 11 are mammals (~ 17%), while 6 additional ones are suggested to be included (Carboneras *et al.*, 2018).

Project aims

This project will focus on invasive mammals of European Union concern, to push forward the understanding of their invasion ecology and provide essential guidance for policy and management. Many knowledge gaps still exist regarding invasive mammals ecology in the alien range, and understanding their invasion dynamics and impacts is of crucial importance for taking appropriate actions on pathways of introduction, implementing measures of early detection, rapid response, and impact mitigation strategies. As so, this work aims to fill important knowledge gaps that currently affects the fulfilling of these goals.
Accordingly, the general objectives of the project are:

1. To qualitatively review the invasion history, ecology and impacts of invasive mammals and build a basis for subsequent analyses.
2. To quantitatively assess the factors of mammals' invasion and spread across the EU.
3. To perform an evidence- and expert-based assessment of the environmental impacts caused by the species across the EU through EICAT protocols.

The study area will be the territory encompassed by the Member States of the Council of Europe, excluding their oversea territories, and 8 European Biogeographical Regions (thereafter, EBR): the Alpine, Atlantic, Black Sea, Boreal, Continental, Mediterranean, Pannonian and Steppic regions (EEA, 2019). EBR describe different ecological assemblages of habitat types and species that can thus show different responses to biological invasions.

Chapter 1. Invasion history, ecology and impacts of alien mammals in Europe

This work aims to provide an in-depth review of the past and present status of invasive mammals in Europe, painting an exhaustive picture of their invasion ecology and history based on the most recent publications. To achieve this goal, this chapter will be composed of different sections mirroring the three main stages of the invasion process (Blackburn *et al.*, 2011):

1. Introduction stage: includes a review of every aspect of introduction: date and location of the first introduction, timing and number of introduction events, and pathways.
2. Establishment stage: the multiple factors allowing or preventing species' survival in the new European range will be investigated, such as species characteristic, environmental factors and anthropogenic drivers.
3. Invasion stage: variables involved in this stage will be identified to understand what promoted or hindered the spread of the study species in the EU. Mechanism and consequences of species' impacts will be reviewed.

Methods

The necessary information on species ecology and invasion history will be obtained from available databases and Risk Assessments for each species; a systematic search of recent works in Scopus, WoS and Google Scholar with appropriate keywords will be performed. Relevant publications will be identified from TITLE-ABS and then subjected to examination.

Chapter 2. Correlates of alien mammal spread in Europe

To prevent further invasions of the study species in the EU, a profound understanding of their spread process is required; this process is the result of the combination between species invasion history and traits, and invaded environment characteristic. In Chapter 2, information obtained in Chapter 1 regarding the invasion stage will be used to develop a quantitative analysis of possible factors promoting species spread.

Methods

The Spread Rate (SR) for each study species will be estimated as SR = D/RT, where *D* is the distance of the first point of introduction to the current invasion front in the EU, and *RT* is Residence Time (years passed since the introduction). As species SR can be influenced by biotic and abiotic characteristics of the invaded ecosystem, it will be estimated for each EBR invaded. Necessary information to estimate the SR will be obtained from DAMA database and GMA Lab.
A wide array of factors possibly involved in determining the SR, investigated and collected during Chapter 1, will be tested to be positively/negatively associated to it using Generalized Linear Mixed Models (GLMMs) (R package 'nlme') with binomial error distribution. Variables will be scaled and tested for collinearity; only a subset showing a Variance Inflation Factor < 5 will be used for modelling. Environmental variables median values per each IMUC range placed in different EBR will be extracted using QGIS.

Human-assisted dispersal is a leading factor behind biological invasions; accordingly, it is assumed that colonization pressure (i.e., the number of different locations in which the species has been introduced; Lockwood *et al.*, 2013) can show a positive effect on SR. After an alien species has successfully established in

a new environment, its natural dispersal ability helps in its spreading process; it is expected that the two measures will be related (Jeschke, 2018).
Climatic niche conservatism (the degree of shared climatic space between the native and alien niche) shapes the global distribution of alien mammals (Guisan *et al.*, 2014); thus, SR should be higher when an alien finds a high degree of similarity between invaded and native environment.
Besides climatic factors, biotic interactions play a major role in species colonization of new environments. Species-rich ecosystem could be more difficult to invade for alien species, as complex networks can show a higher biotic resistance to newcomers and hinder their SR (Jeschke, 2018). However, anthropogenic disturbance (here expressed as Human Footprint Index) can reduce this resistance, thus enhancing invaders' SR, which are generally able to thrive in disturbed environments (Lockwood *et al.*, 2013).
Intrinsic species traits allow alien species to invade new ecosystems; thus, species possessing high reproductive potential (fast life-history traits), a broad niche (great native range size, a wide array of suitable habitat types and dietary items) and high dispersal ability have proven to be successful invaders, and are expected to show high SR (Jeschke, 2018).
Generalist species ecologically distinct from others can successfully colonize multiple environments, probably relying on different ecological strategies, resulting in interspecific competition avoidance (Cooke *et al.*, 2020), thus low biotic resistance.

Chapter 3. Understanding and assessing alien mammal impacts in Europe

Provide a systematic impact-based evaluation of alien taxa poses many challenges, as IAS impacts vary across species, ecosystems, space and time. A recent, standard framework has been adopted by the IUCN for this purpose: the Environmental Impact Classification of Alien Taxa (EICAT), an expert-based evaluation and categorization of impacts based on their magnitude (Blackburn *et al.*, 2014; IUCN, 2020a).
The EICAT assessment is innovative and can be used in various way, also on native species or to produce habitat-specific assessments (that will not be officially recognized by IUCN but are useful for conservation managers). EICAT is used in Europe as a reference to select species that will undergo full risk assessment for inclusion in the Union List (EU, 2014) and related national lists (Bertolino *et al.*, 2020, in Italy). Examples of ways to apply EICAT data, protocol and classification include policy (international agreements), conservation planning (risk assessments, prioritization of alien taxa for management, site prioritization of regions threatened by biological invasions), monitoring, education, and fundraising.

Methods

An EICAT assessment consists of different phases performed by different authorities:

- pre-assessment phase: contributors gather raw data from the alien ranges of the species being assessed, using an established search protocol, including published and grey literature.
- assessment: every single record is assessed by the assessors, following EICAT Categories and Criteria, and assigned to an EICAT Category. The severity of EICAT Categories is directly proportional to the level of biological organization involved. Categories reflect those of the IUCN Red Lists and are as follows:
    - Minimal Concern (MC): discernible impacts, but no effects on individual fitness of natives;
    - Minor (MN): fitness of individuals reduced;
    - Moderate (MO): changes to populations;
    - Major (MA): reversible community changes;
    - Massive (MV): irreversible community changes and native species extinctions.

  Information from the records is stored in a database following a unified template that includes taxonomy, assessment information, geographic range, habitat and ecology, impacts and mechanisms, management actions, research needed, bibliography, supporting information, and a summary. Each taxon is then assigned to a global EICAT Category, based on the highest criterion level met by any of the impacts caused by the species. Both classifications will be specific for each EBR.

- review: all classifications come with a confidence level, depending on the presence of confounding effects, data quality, etc. All assessments undergo a review process before being accepted for publication by IUCN.

Project data

The proposed project can rely on a substantial amount of data already collected by the involved research teams. Additional necessary data will be obtained from the literature. The complete list of data sources is as follows:

- Distribution of Alien MAmmals (DAMA) database (Biancolini D., GMA Lab);
- First Record Database (Seebens *et al.*, 2017);
- mammal colonization pressure database (Biancolini D., GMA Lab);
- COMBINE database (Soria C., GMA Lab);
- niche conservation measure (Biancolini D., GMA Lab);
- ecological distinctiveness (Cooke *et al.,* 2020);
- native range maps, native mammal richness and suitable habitat categories (IUCN, 2020b);
- Human Footprint Index (Sanderson *et al.*, 2002);
- a database supplied by Essl F.'s research team on species' impacts;
- comprehensive literature review.

Research activities

The PhD project will be carried out under the co-supervision of Prof. Carlo Rondinini from Sapienza Università di Roma, Prof. Mag. Dr. Franz Essl from the University of Vienna and Dr. César Capinha from the University of Lisbon. Accordingly, 18 months of the three-years will be spent abroad in the host institution(s). Periodically, online-meeting will take place to discuss important issues and plan the next steps of the project; further, interaction among teams is assured by an annual meeting in person between the PhD candidate and the supervisors.
Other useful international collaborations will be arranged with Dr. Franck Courchamp, head of the Biodiversity Dynamics lab at CNRS (France), Prof. Dr. Sven Bacher, at the University of Fribourg (Switzerland), and Prof. Petr Pyšek, at the Institute of Botany, Academy of Sciences of the Czech Republic. All of the above-mentioned collaborators are strongly involved in the study and development of essential framework in invasion ecology which is used to assess alien species' impacts.

Half of the first year of the PhD will be dedicated to an extensive literature review to update current databases and collect recent information on invasive mammal species in Europe (Chapter 1). In this way, the student will also deepen the knowledge of the invasion biology field.
On this solid and updated basis, within the second half of the first year the analysis of factors influencing alien mammals spread in Europe will start (Chapter 2). To achieve this goal, online courses and webinars will be attended to deepen the knowledge on the use of the necessary tools to perform the analyses, i.e. Geographic Information Systems software (GRASS GIS, QGIS) and R statistical software. The correct use of these essential tools will also be guaranteed by the co-supervisor César Capinha, currently teaching GIS and R classes at the University of Lisbon.
The impact analysis will begin by the second year of the PhD (Chapter 3). During this phase, the research stay at the University of Vienna in Franz Essl's Lab will provide essential tools to correctly interpret and apply the EICAT protocol.
Approaching the end of every Chapter, the work that has been done by far will be carefully checked, and the supervisors will be updated on the progress made approximately every two months. During the course of this PhD, each year the student will attend classes, activities, symposia and courses to gain the expected CFU. These activities, following a previous acceptance by the PhD commission, will either take place at Sapienza Università di Roma, at the University of Vienna or at other international universities and institutions.

International periods of research stay will be arranged during the PhD itself, depending on the teams' availability. Moreover, the student will attend national and international congresses to keep track of recent developments in the fields of conservation and invasion biology, network with colleagues, present early results through poster and oral presentations, establish new collaborations and improve research skills.
All the planned activities, especially the international ones, are subjected to the rapid development of the pandemic situation.
The goal of this project is to produce a dissertation of original work and exceptional quality within 3 years. Accordingly, the results of each chapter will be published in quality publications in international journals. Potential target journals include *Mammal Review, Journal of Animal Ecology, Biological Invasions, NeoBiota, Conservation Biology, Global Change Biology, Global Ecology and Conservation,* and *Diversity and Distributions.*

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