Received: 23 April 2017 | Accepted: 15 August 2017

DOI: 10.1111/1365-2664.12997

POLICY DIRECTION

Journal of Applied Ecology | BRITISH ECOLOGICAL SOCIETY

A prioritised list of invasive alien species to assist the effective implementation of EU legislation

Carles Carboneras[1] | Piero Genovesi[2] | Montserrat Vilà[3] | Tim M. Blackburn[4] | Martina Carrete[3] | Miguel Clavero[3] | Bram D'hondt[5] | Jorge F. Orueta[6] | Belinda Gallardo[7] | Pedro Geraldes[8] | Pablo González-Moreno[9] | Richard D. Gregory[1] | Wolfgang Nentwig[10] | Jean-Yves Paquet[11] | Petr Pyšek[12,13] | Wolfgang Rabitsch[14] | Iván Ramírez[15] | Riccardo Scalera[16] | José L. Tella[3] | Paul Walton[17] | Robin Wynde[1]

[1]Royal Society for the Protection of Birds, Sandy, UK; [2]IUCN Species Survival Commission, Invasive Species Specialist Group, Institute for Environmental Protection and Research, Rome, Italy; [3]Estación Biológica de Doñana (EBD-CSIC), Seville, Spain; [4]University College London, London, UK; [5]Biology Department, Ghent University, Ghent, Belgium; [6]SEO/BirdLife, Madrid, Spain; [7]Pyrenean Institute of Ecology (IPE-CSIC), Zaragoza, Spain; [8]Sociedade Portuguesa para o Estudo das Aves, Lisbon, Portugal; [9]CABI UK, Egham, UK; [10]University of Bern, Bern, Switzerland; [11]Natagora, Namur, Belgium; [12]Institute of Botany, The Czech Academy of Sciences, Průhonice, Czech Republic; [13]Department of Ecology, Faculty of Science, Charles University, Prague 2, Czech Republic; [14]Environment Agency Austria, Vienna, Austria; [15]BirdLife International, Cambridge, UK; [16]Via Valentino Mazzola, Roma, Italy and [17]Royal Society for the Protection of Birds Scotland, Edinburgh, UK

Correspondence
Carles Carboneras
Email: carles.carboneras@rspb.org.uk

Funding information
Czech Science Foundation, Grant/Award Number: 14-36079G; Czech Academy of Sciences, Grant/Award Number: RVO 67985939 and Praemium Academiae; Ministry of Economy and Competitiveness, Grant/Award Number: SEV-2012-0262 and CGL2015-65346-R

Handling Editor: Claudia Bieber

[Correction added after online publication on 8 February 2018: Following publication of the paper, the authors have become aware of a few errors in the species list (Supporting file ST2). The accompanying errata file contains the following corrections: one deletion from the species list due to taxonomic synonymy (*Myriophyllum brasiliensis*), 3 re-assignations to the correct taxonomic group (*Codium fragile, Draeculacephala minerva* and *Epochra canadensis*) and 16 orthographic corrections of species whose names appear misspelled in the databases. These changes are only minor and in no way have any impact on the conclusions of the main paper].

Abstract

1. Effective prevention and control of invasive species generally relies on a comprehensive, coherent and representative list of species that enables resources to be used optimally. European Union (EU) Regulation 1143/2014 on invasive alien species (IAS) aims to control or eradicate priority species, and to manage pathways to prevent the introduction and establishment of new IAS; it applies to species considered of Union concern and subject to formal risk assessment. So far, 49 species have been listed but the criteria for selecting species for risk assessment have not been disclosed and were probably unsystematic.
2. We developed a simple method to systematically rank IAS according to their maximum potential threat to biodiversity in the EU. We identified 1,323 species as potential candidates for listing, and evaluated them against their invasion stages and reported impacts, using information from databases and scientific literature.
3. 900 species fitted the criteria for listing according to IAS Regulation. We prioritised 207 species for urgent risk assessment, 59 by 2018 and 148 by 2020, based on their potential to permanently damage native species or ecosystems; another 336 species were identified for a second phase (by 2025), to prevent or reverse their profound impacts on biodiversity; and a further 357 species for assessment by 2030.
4. *Policy implications*. We propose a systematic, proactive approach to selecting and prioritising IAS for risk assessment to assist European Union policy implementation. We assess an unprecedented number of species with potential to harm EU

biodiversity using a simple methodology and recommend which species should be considered for risk assessment in a ranked order of priority along the timeline 2018–2030, based on their maximum reported impact and their invasion history in Europe.

KEYWORDS

Aichi target 9, alien species, conservation, conservation policy implementation, EU biodiversity strategy, EU IAS regulation, European Union, invasive, risk assessment, species of concern

1 | INTRODUCTION

The adoption by the European Union (EU) of Regulation 1143/2014 on invasive alien species (IAS; European Union, 2014) is the most important European environmental policy measure to date towards meeting CBD Aichi target 9 ("By 2020, IAS and pathways are identified and prioritised, priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment"; Convention on Biological Diversity, 2010) and EU Biodiversity Strategy target 5 ("By 2020, IAS and their pathways are identified and prioritised, priority species are controlled or eradicated and pathways are managed to prevent the introduction and establishment of new IAS"; European Commission, 2011). The backbone of the Regulation is a list of species alien to the EU (the so-called Union list) and identified as invasive through an evidence-based risk assessment, in accordance with prescribed criteria. Listing of a species means it is banned from import, trade, possession, breeding, transport, use and release into the environment (Genovesi, Carboneras, Vilà, & Walton, 2014); it also determines whether a species' main pathways of unintentional introduction and spread can be considered for an action plan, to be developed by the Member States within 3 years following inclusion (Scalera, 2015). The conservation community has highlighted the importance of listing based on a system that is flexible, responsive and that can be updated as frequently as needed (Carboneras, Walton, & Vilà, 2013; Tollington et al., 2016).

In the implementation phase, the EU Member States agreed the first list of IAS of Union concern of 37 species in 2016, formally adopted by the European Commission (2016b), and a recent update of 12 additional species in June 2017 (European Commission, 2017). The total list of 49 species thus covers less than 5% of the more than 1,000 established IAS with known ecological or economic impacts in Europe (Vilà et al., 2010). The listing process is reputedly dynamic such that new species can be added in regular updates and additional funding sources are mobilised by the EU to perform risk assessments. This approach addresses the concerns expressed by both scientists and policy makers who welcomed the preliminary adoption of the initial list, while indicating that although it is a step in the right direction, the number of species included does not match the magnitude of the threat to EU biodiversity. To assist the updating process, in parallel to the present work, the EC commissioned a study to prioritise species for risk assessment through horizon scanning (Roy, Adriaens, et al., 2015), focusing on species that are either absent from Europe, or in the early stages of establishment. The study evaluated 251 species posing a threat to EU biodiversity and ecosystems and highlighted 95 species as high priorities for risk assessment, mostly based on their impacts elsewhere. However, the horizon scanning was set to specifically exclude IAS that are relatively widespread within the EU.

Alien species need to go through formal risk assessment before they can be discussed by the EU Member States and potentially added to the Union list (Roy, Scalera, et al., 2015). According to the EU legislation, the EC must justify that concerted action at EU level is required to prevent the introduction, establishment or spread of a given species before it can be considered for listing.

Member States may submit to the EC requests for the inclusion of IAS on the Union list. In the past, though, national selection of species deserving formal risk assessment was based on undisclosed criteria and it did not appear to be preceded by a systematic consideration of all species that potentially qualify. As a result, the list of currently available risk assessments is a biased sample clearly skewed towards well-known terrestrial or freshwater species that are already present in Europe and with expanding populations. Here, we try to address this bias by, first, developing a simplified methodology to help identify species suitable for listing as IAS of EU concern and to prioritise them for risk assessment. Second, we run a large number of potential species, catalogued in a comprehensive set of databases, through this screening process. We use this methodology to propose a prioritised list of IAS for formal risk assessment, along with an indication of the time frame for their assessment. Our contribution aims at assisting the effective implementation of the EU Regulation on IAS by providing a road map for a proactive, rather than a responsive, list of species to be considered by the EC and its Member States for further follow up.

2 | MATERIALS AND METHODS

We followed a modified version of the participatory method defined by Sutherland, Fleishman, Mascia, Pretty, and Rudd (2011) to identify the issues, agree on methodologies and progress by consensus. Our work consisted of four complementary phases; the first two were an expert workshop and a policy workshop, both focused on developing the criteria for species choice and screening. The third step was to review potential species, based on available literature and focusing on those that fulfilled the EU Regulation criteria for listing; we associated each species with a category of impact, following the principles of EICAT (Environmental Impact Classification for Alien Taxa, Hawkins et al., 2015), with a stage in their EU invasion curve (Delisle,

Lavoie, Jean, & Lachance, 2003; Pyšek & Prach, 1993) and with a pathway of introduction according to the classification of Convention on Biological Diversity (2014). The fourth step was to prioritise the list of species along a timeline for risk assessment based on a "distribution × impact" criterion developed at the workshops.

2.1 | Expert workshop

Twenty-one invasion biologists and senior conservationists from across Europe took part in a workshop held in Seville (Spain), 21–22 January 2015. Participants were experienced in addressing the impacts of IAS on biodiversity in several European biomes and in the development of Risk Assessments for IAS (see list of co-authors). They represented a range of expertise on different taxa and biome types and were selected favouring those with a track record of working in the interaction between science and policy as shown by, e.g., their active participation in the European Group on Biological Invasions (NEOBIOTA), the IUCN Invasive Species Specialist Group, and the Scientific Forum on the EU Regulation on IAS.

The workshop goal was to develop a decision tree to help identify potential species for risk assessment, based on the listing criteria set out by the EU IAS Regulation. The discussions aimed at developing a set of biologically relevant questions to distinguish species potentially suitable for listing as IAS of EU concern (Figure 1). Participants evaluated risk assessment methodologies to estimate the impact of IAS. They reviewed and recommended the type and scope (global, regional, national) of available databases of known IAS, and considered how to make sure that all relevant pathways of introduction of IAS in the EU are adequately covered. They also discussed the advantages and disadvantages of setting a predetermined length of a species list.

2.2 | Policy workshop

Twenty-two policy professionals from conservation organisations and other interest groups took part in a subsequent workshop, focusing on policy, held in Brussels (Belgium) on 24–25 March 2015. Building on the results of the expert workshop, the group attempted to identify the combination of distribution and impact potential as an indicator of individual threat to biodiversity in the EU; they then developed systematic criteria for the risk-assessment prioritisation of species with different characteristics. Participants agreed on using a combination of IAS attributes expressed as a "distribution × impact" matrix (Figure 1). The rows showed a distribution category corresponding to the current stage of a species' "invasion curve" in Europe (Figure 2), while the columns corresponded to their maximum reported impact in the available databases, based on the authors' assessment following the EICAT guidelines (Hawkins et al., 2015). Each matrix cell was associated with a priority category in the implementation timeline. The group also worked on the development of an advocacy strategy for the successful listing of priority IAS in the timeframe set up by the EU Regulation.

2.3 | Species screening

We carried out a desk-based search of IAS databases and review papers listing species with reported impacts on biodiversity or ecosystem services that might be relevant to Europe. We used the information on species impact anywhere in their invaded distribution range available from the IAS databases reviewed at the workshops: five global and regional IAS databases, five regional assessments, specific review papers and the seven national lists of EU Member States (Table S1). From those sources, we used the information on the maximum reported impact of species and their distribution in the EU. We complemented that information with a literature review of scientific papers providing evidence on the impact of particular species, which allowed for the additional assessment of 157 species. There was considerable overlap among the databases and a great deal of taxonomic issues (e.g., synonyms) so, after clearing, we were left with 1,323 potentially suitable species. These were screened through the decision tree (Figure 1) and the criteria agreed at the expert and policy workshops. Those species that qualified for assessment were assigned to categories in the "distribution × impact" matrix based on the information in the databases.

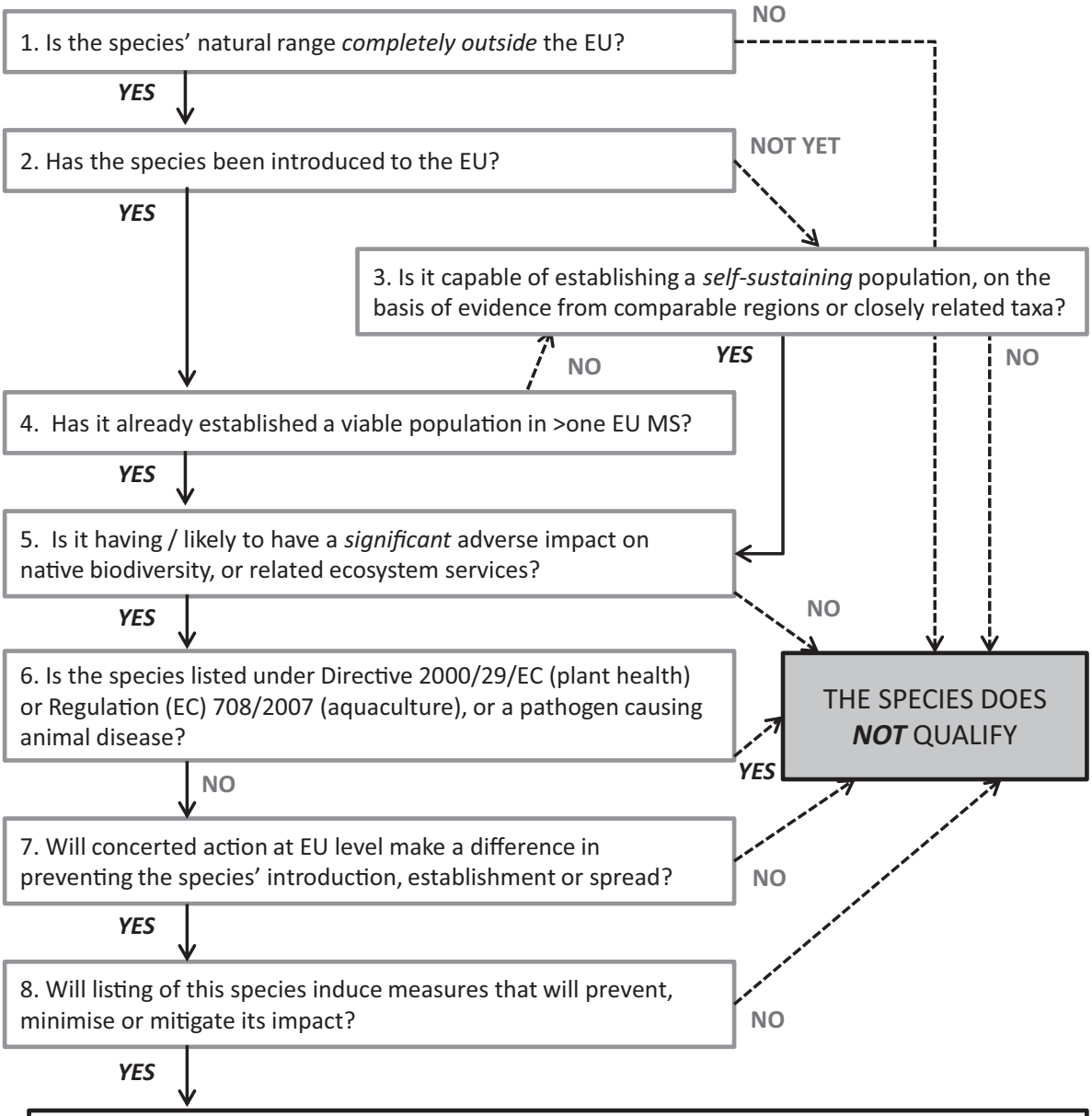
One of the authors (CC) led on the database and literature review; the co-authors then reviewed the species assessments according to their expertise. We followed Branquart et al. (2016) to account for uncertainty, based on evidence of the species' presence, impacts in Europe and variability in its behaviour. To keep the process simple and in agreement with the EU Regulation, we limited the assessment of a species' impact to biodiversity and ecosystem services, as there are now methods to allow systematic classification and comparison of IAS impacts on the environment, but these do not apply to socio-economic impacts in all cases (see Blackburn et al., 2014; Hawkins et al., 2015; Kumschick et al., 2015).

2.4 | Species priority ranking

Based on their attributes and the criteria developed at the workshops (Figure 1), we placed species on the "distribution × impact" matrix and assigned them to a category of priority defined by the end of the year when a risk assessment should be attempted, according to expert opinion. The spectrum ranged from 2018 for the most urgent cases, through 2020 and 2025, to 2030 for the less urgent. The latter category bears in mind that some species may currently be in a lag phase (Crooks, 2005; Pyšek & Prach, 1993). In the case of species with a major (MR) impact, we prioritised those in the initial stages of invasion over widespread ones (Figure 1).

3 | RESULTS

Out of the 1,323 species quick-screened through the decision tree, 900 fulfilled the criteria for listing under the EU IAS Regulation; we retained those and ranked them by priority (see Table S2). The main reasons for discarding the other 423 species were: (1) being native



The species should go through risk assessment by the following priority year:

EU DISTRIBUTION \ IMPACT ON BIODIVERSITY	MC - Minimal concern	MN - Minor	MO - Moderate	MR - Major	MV – Massive
Absent	2030	2030	**2025**	**2020**	**2020**
Initial	2030	2030	**2025**	**2020**	**2018**
Scattered	2030	2030	**2025**	**2020**	**2018**
Widespread	2030	2030	**2025**	**2025**	**2018**
Ubiquitous	2030	2030	**2025**	**2025**	**2018**

FIGURE 1 Decision tree developed by the expert and policy workshops and used for screening 1,323 candidate invasive alien species. See text for impact categories (rows). Nine hundred species were finally retained and ranked by priority. Darker shading indicates higher priority

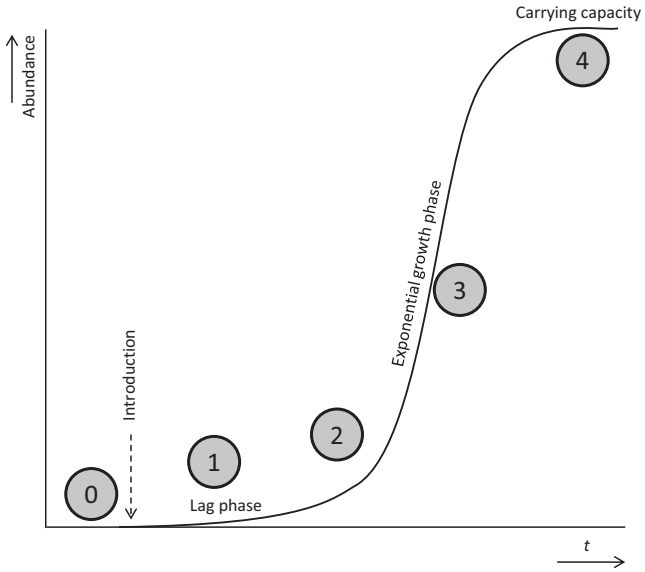


FIGURE 2 Theoretical invasion curve as followed by an ideal invasive population, with indication of the stages used in our assessment of each species" distribution and invasion history: 0 = absent from the EU; 1 = restricted to initial location of introduction; 2 = occurring over scattered locations; 3 = occurring over numerous locations/widespread; 4 = ubiquitous

to some part of the EU (133); (2) being regulated by specific legislation on plant or animal health (174) or legislation on aquaculture (10); (3) being an ancient introduction to European ecosystems or being so widespread that listing would be unlikely to make any difference in mitigating their impact and/or preventing their spread, or would be completely anti-economical (9). The remaining 97 species could not be assessed because the databases and the literature reviewed did not provide sufficient evidence of their known or potential impact, so they were classed as "data deficient".

The 900 retained species represented a wide range of taxa, with 26% vertebrates, 29% invertebrates and 40% plants (Table 1). They were also well distributed across six broad introduction pathway types (Convention on Biological Diversity, 2014; Hulme et al., 2008; Saul et al., 2017), with a predominance of escape as a pathway (53% of all species) (Table 1). The screening process identified a group of 207 species as needing urgent formal risk assessment (59 by 2018 and 148 by 2020), in time for the scheduled review of the EU IAS Regulation by 1 June 2021, and a second group of 336 priority species, recommended for formal risk assessment by 2025. A further 357 species qualified as less urgent priority (by 2030) due to their relatively lower impact on biodiversity or ecosystem services (Table S2).

Considering their current status in the EU, 167 (81%) of the 2018–2020 priority species were either absent or in the early stages of invasion (categories: "absent," "initial" or "scattered" as described in Figure 3). In the second group of 336 priority species by 2025, 124 (37%) were either absent or in the early stages of invasion, while 212 species (63%) qualified as widespread or ubiquitous (categories: 'widespread" and "ubiquitous" as in Figure 3). There was also considerable overlap between our priorities and those established in the EC horizon scanning (Roy, Adriaens, et al., 2015) for the 251 species that are common to both analyses, as shown in Figure 4.

Uncertainty in the assessment of species impact was medium in 76% of cases and low in 12%; we estimated high uncertainty in 7% of the species recommended for risk assessment by 2030, 4% of 2025, 1% of 2020 and 0% of 2018 priorities.

4 | DISCUSSION

We present a systematic approach for selecting IAS for risk assessment in the EU, together with the outcome of applying it across an unprecedented number of taxa, with varying impacts and invasion history. Based on published evidence of impact placed in a basic "distribution × impact" matrix, we were able to rapidly prioritise a large number of species. The expert group advised against setting any caps to either the number of species recommended for formal risk assessment or to the Union list of IAS of concern, as it was not possible to find any biologically sound argument to pre-determine their length (Carboneras et al., 2013).

We identify 207 high priority species needing urgent risk assessment. As of June 2017, 48 of those species have risk assessments available or in progress and 25 are included in the current EU IAS list. However, in order to keep the process agile, we recommend formal risk assessments of the remaining 159 species before the end of 2020, in time for the planned review of the application of the EU Regulation *including the Union list*, due by 1 June 2021 (Art. 24.3).

We recommend that the second group of 336 priority species must be put through risk assessment immediately afterwards; 39 of those have risk assessments available or in development (23 have been included in the first EU list) so, as of June 2017, 297 priority species are still pending risk assessment. We recommend the risk-assessment process to be completed for those species by 2025. The remaining 357 species classify as lower priority for risk assessment because their impact on biodiversity or ecosystem services is considered to be minor or of minimal concern. At least a sample of those species should also be put through formal risk assessment in order to confirm their priority status. This exercise is less urgent, so we propose a wider time frame of 10 years to conclude it.

Our method allows for a swift preliminary analysis but it cannot replace a full formal risk assessment; that is, the comprehensive, evidence-based process that enables estimating the probabilities of a species' introduction, establishment, spread and impact (Leung et al., 2012), which is required by the EU Regulation. Our prioritisation specifically aims at helping to set the species order in which the formal risk assessments need to be carried out. We used expert opinion to set the criteria, to establish the methodology and to identify the sources of information but we stuck to the information contained in the databases so as not to introduce more bias in our analysis. Our review considered the maximum reported impact for any species, in line with the principles of EICAT, which may be different from the average or most likely impact. The EICAT classification is still in progress and individual species assessments are yet to be developed, reviewed

TABLE 1 Breakdown of the 900 species retained and ranked in this analysis, grouped by taxonomic group and pathway of introduction

	Pathway of introduction						Grand total	%
	Release	Escape	Contaminant	Stowaway	Corridor	Unaided		
Mammalia (mammals)	11	40		1			52	5.8
Aves (birds)	8	61		1			70	7.8
Reptilia (reptiles)	4	25	1				30	3.3
Amphibia (amphibians)	3	3	2				8	0.9
Pisces (fish)	31	28	1	6	7		73	8.1
Tunicata (tunicates)				16			16	1.8
Echinodermata (echinoderms)			1				1	0.1
Mollusca (molluscs)		10	10	31	1		52	5.8
Insecta (insects)	6	2	95	12		2	117	13.0
Crustacea (crustaceans)	2	13	2	28	1	1	47	5.2
Myriapoda (myriapods)			2				2	0.2
Arachnida (arachnids)		3	4				7	0.8
Annelida (annelids)			1	11			12	1.3
Nematoda (roundworms)			2	1			3	0.3
Platyhelminthes (flatworms)			1				1	0.1
Ctenophora (comb jellies)				2			2	0.2
Cnidaria (stinging jellyfish)				2	1		3	0.3
Bryozoa (bryozoans)				5			5	0.6
Ascomycota (fungi)				1			1	0.1
Spermatophyta (seed plants)	9	282	57	4	1		353	39.2
Pteridophyta (ferns and horsetails)		3	1				4	0.4
Bryophyta (mosses)				1			1	0.1
Chlorophyta (green algae)		3		3			6	0.7
Rhodophyta (red algae)		1	5	9	1		16	1.8
Heterokontophyta (brown algae)			3	7	1		11	1.2
Haptophyta (haptophytes)				1			1	0.1
Dinophyta (dinoflagellates)				6			6	0.7
Grand total	74	474	188	148	13	3	900	100
%	8.2	52.7	20.9	16.4	1.4	0.3		

Definitions of pathways follow Convention on Biological Diversity (2014): release (intentional introduction for the purpose of human use in the natural environment); escape (unintended escape/release/liberation into the natural environment from confined conditions into which initially purposefully imported or otherwise transported); contaminant (unintentional movement as contaminants of a commodity that is intentionally transferred through international trade, development assistance, or emergency relief); stowaway (unintentional moving of live organisms attached to transporting vessels and associated equipment and media; corridor (unintentional introduction into a new region following the construction of transport infrastructures (e.g. canals, tunnels) in whose absence this spread would not have been possible); unaided (secondary natural dispersal across borders of invasive alien species that have been introduced by means of any of the above pathways).

and internationally agreed. Our group of experts assessed individual species impact based on the EICAT criteria, on our own knowledge and on the information contained in the databases and literature available but, because our expertise did not cover the entire spectrum of European taxa and ecosystems (Table S4), our assessment must be taken as indicative and subjective.

Our exercise coincided with Roy, Adriaens, et al.'s (2015) EU-wide horizon scanning assessment, which focused on species that were either absent from the EU or in the early stages of establishment. We used information from that analysis, particularly on the impact of certain species, to feed our categorisation of species in the "distribution × impact" matrix. However, our assessment was not limited to species whose invasion stage was in the "absent–initial–scattered locations" range (428 species in our analysis) but also looked at species in the "widespread" and "ubiquitous" categories, which summed to 472 species, 52% of our total. Figure 4 shows the considerable

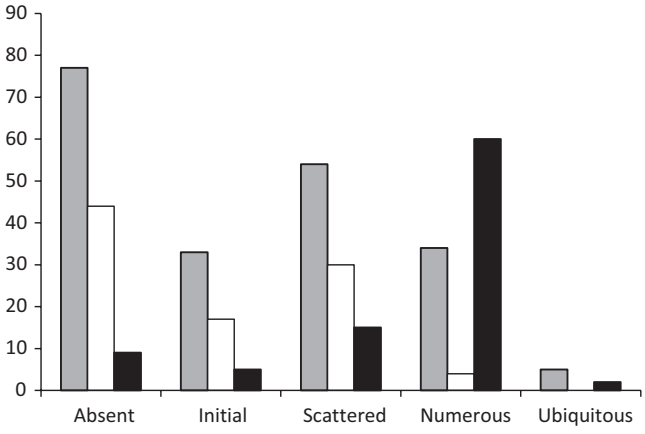


FIGURE 3 Distribution of the 207 highest priority species (to be risk assessed by 2018 and 2020; see text) resulting from our analysis against their stage in the invasion curve (grey bars), compared to the 95 "very high" and "high" priority species identified by Roy, Adriaens, et al. (2015) (white bars) and the 91 species for which risk assessments are available or under development (Roy, Scalera, et al., 2015; European Commission 2016a) (black bars). Invasion stage categories as in Figure 2

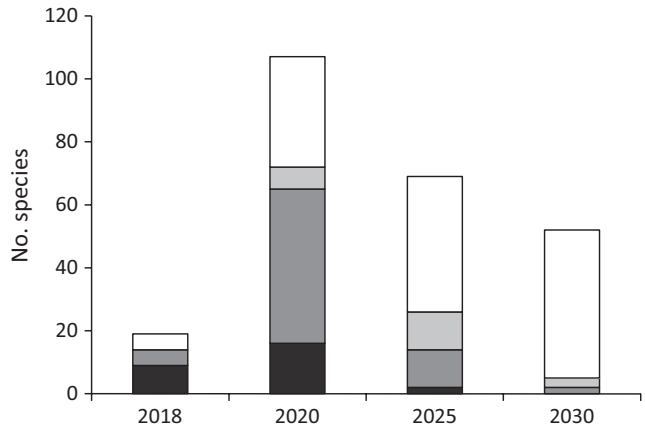


FIGURE 4 Distribution of the 251 species analysed in the EC horizon scanning (Roy, Adriaens, et al., 2015) showing how they fall in our prioritisation, as indicated by the year when risk assessment should be available. Black bars represent "very high" priority species in Roy, Adriaens, et al. (2015); dark grey = high priority; light grey = medium priority; white = low priority

overlap in the priority ranking of the 251 species shared between the EC horizon scanning and our analysis. "Very high" and "high" priority species in Roy, Adriaens, et al. (2015) make up 64% of the species that we propose for risk assessment before the end of 2020, while 77% of the "low" priority species in the EC horizon scanning fall in either the 2025 or the 2030 targets in our analysis.

Our work prioritises species based on their impact on biodiversity and ecosystem services only, because that is the scope of the EU Regulation and because evidence is lacking on the socioeconomic impact of many IAS (but notice the correlation between biodiversity and socioeconomic impacts described by Rumlerová, Vilà, Pergl, Nentwig, & Pyšek, 2016). Species on our priority list may have different probabilities of being introduced and/or of becoming established, something that should be determined in a formal risk assessment. However, our work fills a policy gap and assists policy implementation by proposing species in a ranked order to be considered for risk assessment in the recommended time frames. This is particularly relevant given the limited resources available for this purpose in the current national and EU policy context, and the importance of optimising their use. While the formal risk assessment of 900 species will evidently take a long time, our exercise facilitates the process by providing a systematic method to decision-making. Our work may also help identify the required funding sources and relevant amounts to be mobilised. This is pivotal to ensure that EU-compliant risk assessments are finalised in an appropriate timescale. The European Commission website proposes supporting action on IAS through its existing financing instruments, LIFE, Horizon 2020, Rural Development 2014–2020 and Regional Development funding (European Commision, 2016a). The ongoing LIFE project IAP-RISK, e.g., seeks to develop EU-wide risk assessments for 16 invasive alien plants by 2017. The whole potential of EU funding should be fully explored, as the capacity to deliver, and therefore to prevent further damage, will likely be limited by the availability of resources (see Scalera, 2010; Tollington et al., 2016).

The IAS Regulation establishes that Member States must carry out a comprehensive analysis and prioritisation of the pathways of unintentional introduction and spread of the species on the Union list of concern within 18 months of its adoption. Further, they must establish and implement action plans for priority pathways within 3 years of the adoption of the Union list (Scalera, 2015). Therefore, whether a specific pathway can be tackled by an action plan depends on the condition that at least one representative species is included on the EU list. This aspect is most relevant for the pathways of introduction and spread of marine species, which are very poorly represented in the initial official lists.

Over half way through the CBD Strategic Plan for Biodiversity 2011–2020 and its associated Aichi Biodiversity Targets (Convention on Biological Diversity, 2010), the window of opportunity for the EU to meet its 2020 objectives on IAS and their pathways of introduction is narrowing. The policy targets cannot be met with a modest list of 49 species selected through non-systematic criteria, and which represent less than 5% of the species estimated to cause ecological or economic impacts in Europe (Vilà et al., 2010). Science should play a key role in informing policy by providing an evidence-based framework for the selection of species that should be put through risk assessment to determine their suitability for listing.

The decision mechanisms of the Regulation 1143/2014 could obstruct the inclusion of species with high commercial or social interest on the list of IAS of EU concern. The EU voting system permits a group of Member States, representing 35% of EU citizens, to block a vote in the IAS Committee established by the Regulation for further updates of the listing of new IAS. Therefore, it will be important that the conservation and scientific communities not only inform policy with robust assessment methods, but also rigorously monitor the implementation of the principles of the legal framework.

Despite its intended simplicity, our assessment provides a wide spectrum of IAS in a ranked order of priority and points to which species should be considered for risk assessment, to help implement Regulation 1143/2014 effectively. Only by adopting a comprehensive, coherent and representative list of species will the EU achieve the objective of the IAS Regulation, which is to prevent, minimise and mitigate the adverse impact of the introduction and spread of IAS on biodiversity in the EU.

ACKNOWLEDGEMENTS

Estación Biológica de Doñana (EBD-CSIC) and the IUCN European Regional Office kindly hosted the expert and policy workshops, respectively, and contributed staff working time to their success. We thank the 22 policy experts who took part and helped develop the policy workshop held in Brussels in March 2015. Three anonymous reviewers provided comments and improved enormously the earlier versions of this manuscript. P.P. was supported by the Czech Science Foundation (project no. 14-36079G, Centre of Excellence PLADIAS), long-term research development project RVO 67985939 and Praemium Academiae award from the Czech Academy of Sciences. M.V. acknowledges support from the Ministry of Economy and Competitiveness through the Severo Ochoa Program for Centers of Excellence in R+D+I (SEV-2012-0262) and the project IMPLANTIN (CGL2015-65346-R). The following institutions and organizations provided funding to allow publishing open access: CABI UK, Czech Academy of Sciences, EBD-CSIC, ISPRA, Natagora, RSPB, SPEA and University of Bern.

AUTHORS' CONTRIBUTIONS

C.C., P.G. and M.V. conceived the ideas; all authors contributed to the design of the methodology; C.C. led on the collection and analysis of the data, with input from all authors; C.C., P.G. and M.V. led the writing of the manuscript. All authors participated in the scientific workshop, contributed critically to the drafts and species assessments, and gave final approval for publication.

DATA ACCESSIBILITY

Data available from the Dryad Digital Repository. DOI: https://doi.org/10.5061/dryad.5fm00 (Carboneras et al., 2017).

ORCID

Carles Carboneras http://orcid.org/0000-0002-9393-224X

REFERENCES

Blackburn, T. M., Essl, F., Evans, T., Hulme, P. E., Jeschke, J. M., Kühn, I., … Bacher, S. (2014). A unified classification of alien species based on the magnitude of their environmental impacts. *PLoS Biology*, *12*, e1001850.

Branquart, E., Brundu, G., Buholzer, S., Chapman, D., Ehret, P., Fried, G., … Tanner, R. (2016). A prioritization process for invasive alien plant species incorporating the requirements of EU Regulation no. 1143/2014. *EPPO Bulletin*, *46*, 603–617. https://doi.org/10.1111/epp.12336

Carboneras, C., Genovesi, P., Vilà, M., Blackburn, T. M., Carrete, M., Clavero, M., … Wynde, R (2017). Data from: A prioritised list of invasive alien species to assist the effective implementation of EU legislation. *Dryad Digital Repository*, http://doi.org/10.5061/dryad.5fm00.

Carboneras, C., Walton, P., & Vilà, M. (2013). Capping progress on invasive species? *Science*, *342*, 930–931.

Convention on Biological Diversity. (2014). Pathways of Introduction of Invasive Species, Their Prioritization and Management. UNEP/CBD/SBSTTA/18/9/Add.1. Secretariat of the Convention on Biological Diversity, Montréal.

Convention on Biological Diversity. (2010). Quick guide to the Aichi Biodiversity Targets. 9. Invasive alien species prevented and controlled. Retrieved from https://www.cbd.int/doc/strategic-plan/targets/T9-quick-guide-en.pdf

Crooks, J. A. (2005). Lag times and exotic species: The ecology and management of biological invasions in slow-motion. *Écoscience*, *12*, 316–329.

Delisle, F., Lavoie, C., Jean, M., & Lachance, D. (2003). Reconstructing the spread of invasive plants: Taking into account biases associated with herbarium specimens. *Journal of Biogeography*, *30*, 1033–1042.

European Commission. (2011). Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM/2011/0244_final.

European Commission. (2016a). Invasive alien species. Retrieved from http://ec.europa.eu/environment/nature/invasivealien/index_en.htm

European Commission. (2016b). Implementing Regulation (EU) 2016/1141 of 13 July 2016 adopting a list of invasive alien species of Union concern pursuant to Regulation (EU) No 1143/2014 of the European Parliament and of the Council. OJ L 189 (14.7.2016), 4–8.

European Commission. (2017). Commission Implementing Regulation (EU) 2017/1263 of 12 July 2017 updating the list of invasive alien species of Union concern established by Commission Implementing Regulation (EU) No 2016/1141 pursuant to Regulation (EU) No 1143/2014 of the European Parliament and of the Council. OJ L 182 (13.07.2017), 37.

European Union. (2014). Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. OJ L 317 (4.11.2014), 35–55.

Genovesi, P., Carboneras, C., Vilà, M., & Walton, P. (2014). EU adopts innovative legislation on invasive species: A step towards a global response to biological invasions? *Biological Invasions*, *17*, 1307–1311.

Hawkins, C. L., Bacher, S., Essl, F., Hulme, P. E., Jeschke, J. M., Kühn, I., & Rabitsch, W. (2015). Framework and guidelines for implementing the proposed IUCN Environmental Impact Classification for Alien Taxa (EICAT). *Diversity and Distributions*, *21*, 1360–1363.

Hulme, P. E., Bacher, S., Kenis, M., Klotz, S., Kuhn, I., Minchin, D., … Vilà, M. (2008). Grasping at the routes of biological invasions: A framework for integrating pathways into policy. *Journal of Applied Ecology*, *45*, 403–414.

Kumschick, S., Bacher, S., Evans, T., Marková, Z., Pergl, J., Pyšek, P., … Nentwig, W. (2015). Comparing impacts of alien plants and animals in Europe using a standard scoring system. *Journal of Applied Ecology*, *52*, 552–561. https://doi.org/10.1111/1365-2664.12427

Leung, B., Roura-Pascual, N., Bacher, S., Heikkilä, J., Brotons, L., Burgman, M. A., … Vilà, M. (2012). TEASIng apart alien-species risk assessments: a framework for best practices. *Ecology Letters*, *15*, 1475–1493.

Pyšek, P., & Prach, K. (1993). Plant invasions and the role of riparian habitats – A comparison of 4 species alien to central-Europe. *Journal of Biogeography*, *20*, 413–420.

Roy, H. E., Adriaens, T., Aldridge, D. C., Bacher, S., Bishop, J. D. D., Blackburn, T. M. … Zenetos, A. (2015). Invasive alien species – prioritising prevention efforts through horizon scanning. European Commission, Brussels (ENV.B.2/ETU/2014/0016).

Roy, H. E., Scalera, R., Booy, R., Branquart, E., Gallardo, B., Genovesi, P. … Zenetos, A. (2015). Organisation and running of a scientific workshop to complete selected invasive alien species (IAS) risk assessments. European Commission, Brussels (ARES(2014)2425342 - 22/07/2014).

Rumlerová, Z., Vilà, M., Pergl, J., Nentwig, W., & Pyšek, P. (2016). Scoring environmental and socioeconomic impacts of alien plants invasive in Europe. *Biological Invasions*, *18*, 3697–3711. https://doi.org/10.1007/s10530-016-1259-2)

Saul, W. C., Roy, H. E., Booy, O., Carnevali, L., Chen, H. J., Genovesi, P., … Jeschke, J. M. (2017). Assessing patterns in introduction pathways of alien species by linking major invasion data bases. *Journal of Applied Ecology*, *54*, 657–669. https://doi.org/10.1111/1365-2664.12819

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

Scalera, R. (2015). Guidance for Governments Concerning Invasive Alien Species Pathways Action Plans. Convention on the Conservation of European Wildlife and Natural Habitats. Standing Committee. 35th meeting, Strasbourg, 1-4 December 2015. T-PVS/Inf (2015) 24.

Sutherland, W. J., Fleishman, E., Mascia, M. B., Pretty, J., & Rudd, M. A. (2011). Methods for collaboratively identifying research priorities and emerging issues in science and policy. *Methods in Ecology and Evolution*, *2*, 238–247.

Tollington, S., Turbé, A., Rabitsch, W., Groombridge, J. J., Scalera, R., Essl, F., & Shwartz, A. (2016). Making the EU legislation on invasive species a conservation success. *Conservation Letters*, *10*, 112–120. https://doi.org/10.1111/conl.12214

Vilà, M., Basnou, C., Pyšek, P., Josefsson, M., Genovesi, P., Gollasch, S., … DAISIE Partners. (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*, 135–144.

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

How to cite this article: Carboneras C, Genovesi P, Vilà M, et al. A prioritised list of invasive alien species to assist the effective implementation of EU legislation. *J Appl Ecol*. 2018;55:539–547. https://doi.org/10.1111/1365-2664.12997