BLACK LIST AND ALERT LIST OF THE AQUATIC INVASIVE ALIEN SPECIES OF THE IBERIAN PENINSULA (2022)

Transnational horizon scanning exercise focused on the high-risk aquatic invasive alien species for the Iberian inland waters





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Water fern or fairy moss (*Azolla filiculoides* Lam) © Daniel J. Layton CC BY-SA 3.0

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Authors

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LIFE INVASAQUA – TECHNICAL REPORT

American signal crayfish (*Pacifastacus leniusculus*) © José M. Zamora-Marín

LIFE INVASAQUA - Aquatic Invasive Alien Species of Freshwater and Estuarine Systems: Awareness and Prevention in the Iberian Peninsula
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Abstract:
An important goal of LIFE INVASAQUA is to develop tools that will improve management and increase the efficiency of the Early Warning and Rapid Response (EWRR) framework for Invasive Alien Species (IAS) in the Iberian Peninsula. Horizon scanning for high risk IAS is basic when implementing measures to reduce new invasions and to focus efforts on the species already recorded. We developed a transnational horizon scanning exercise focused on inland waters of Spain and Portugal in order to provide a black list of current established aquatic IAS and an alert list of potential aquatic IAS that may pose a threat to aquatic ecosystems and socio-economic sectors in the future. We followed a structured 5-steps approach for horizon scanning that combined existing evidence about IAS with an expert scoring of prioritized taxa. A total of 126 IAS were prioritised in the final black list, representing the 41.2% of alien taxa recorded in Iberian inland waters. The top 24 species had a very high risk of impact because they obtained the maximum values in the risk-assessment scoring process. Moreover, the alert list included 89 IAS with a relevant risk of invasion in the Iberian Peninsula in the future, resulting in 11 taxa on the top with a very high risk of invasion.

The resulting black list and alert list are important tools supporting the implementation of the IAS Regulation. Ultimately, the information included can be used for monitoring the achievement of the target of the EU Biodiversity Strategy to 2030 for combatting IAS, and also for the implementation of other EU policies with requirements on alien species, such as the Birds and Habitats Directives, and the Marine Strategy and Water Framework Directives.

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Foreword

Ana Cristina Cardoso
European Commission Joint Research Centre

The 5th Global biodiversity Outlook (2020) confirmed that Invasive Alien Species (IAS) are one of the main drivers of biodiversity loss globally. Within the European Green Deal, the EU Biodiversity Strategy for 2030 includes actions to reduce pressures from IAS, which will require stepping up the implementation of relevant legislation and international agreements, including the EU Regulation 1143/2014 on IAS.

The Commission report on the review of the application of the Regulation on IAS (2021) identified, inter alia, the need for improving coordination between Member States on the management of IAS on national lists, on management measures and pathways prioritization, and the lack of capacity to manage conflicts with stakeholders opposing listing of species or the adoption of management measures.

This LIFE INVASAQUA Horizon Scanning exercise delivers Black lists and Alert lists of IAS for the Iberian Peninsula, which comprise a significant knowledge pool in updating the national IAS catalogues, to inform coordinated actions on prevention, early detection and management of IAS, as well as managing the social acceptability of control strategies.

The collaborative approach adopted enabled LIFE INVASAQUA to prioritize high risk IAS in inland waters of the Iberian Peninsula, and represents an excellent example of a contribution towards improving the implementation of the Regulation on IAS.

Ana Cristina Cardoso
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*The information and views set out in this foreword are those of the author and do not necessarily reflect the official opinion of the European Commission.

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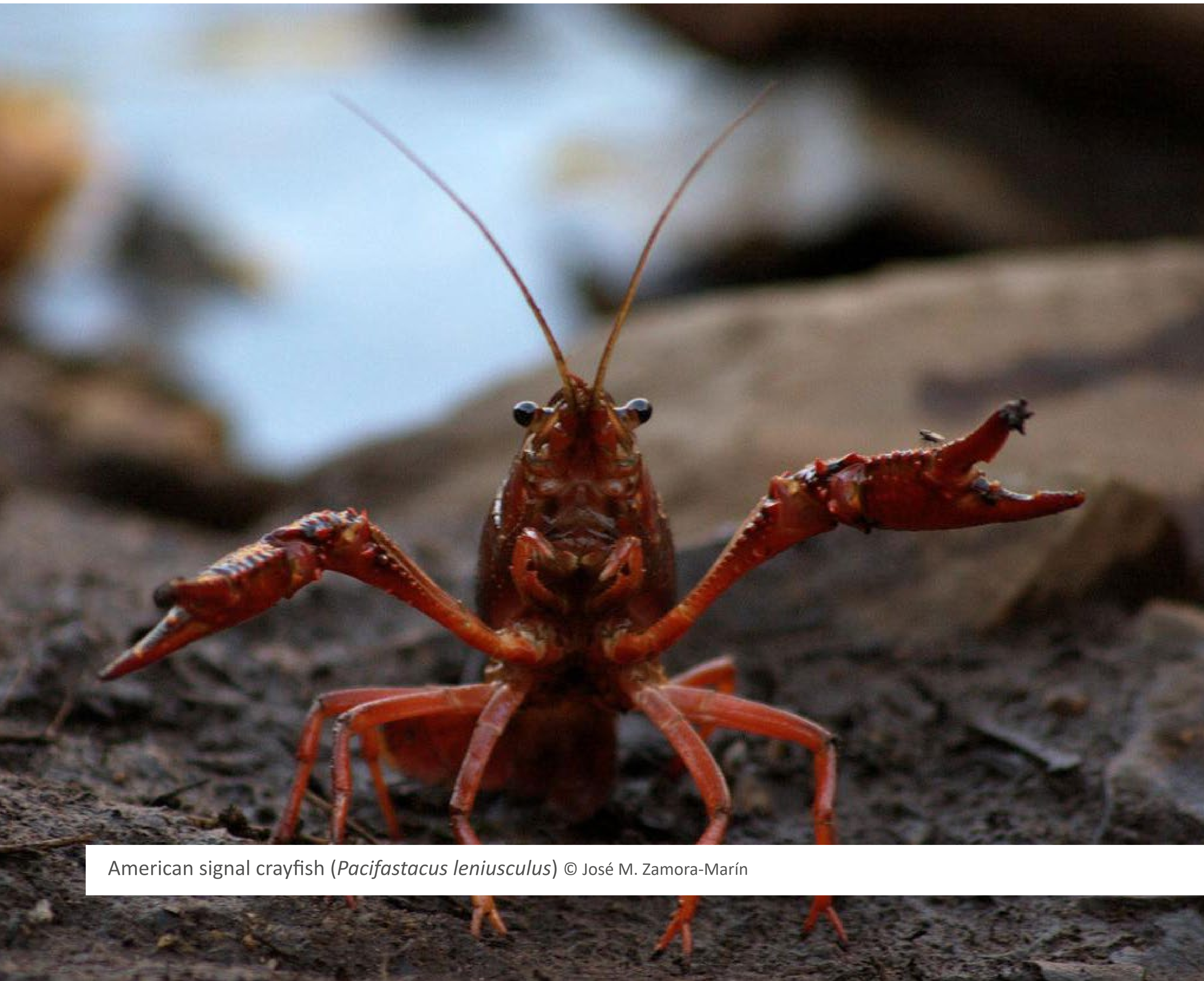

American signal crayfish (*Pacifastacus leniusculus*) © José M. Zamora-Marín

Acronyms and short-names

EASIN – European Alien Species Information Network

EU – European Union

EWRR – Early Warning and Rapid Response framework

IAS – Invasive Alien Species

IAS Regulation – 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

IUCN – International Union for Conservation of Nature

MS – Member State of the European Union

Portuguese National List of IAS – The National List of Invasive Species (Annex II, Decreto-Lei 92/2019).

SIBIC – Iberian Society of Ichthyology

Spanish Allochthonous List – List of non-native species capable of competing with native wild species, altering their genetic purity or ecological balances (related to R.D. 570/2020).

Spanish IAS catalogue – The Spanish Catalogue of Invasive Alien Species (Annex, R.D. 630/2013).

Water Framework Directive – Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy.

Executive Summary

Aim

Invasive Alien Species (IAS) are a primary driver of global change that threaten biodiversity, ecosystem services, and human health. It is estimated that the established IAS in Europe will increase in the next decades and, consequently, the Member States of the European Union need to provide evidence-based assessments of the risks posed by IAS to prioritise prevention and mitigation actions.

LIFE INVASAQUA European Project aims to provide information to help reduce the introduction and establishment of aquatic IAS, among others, by developing tools that will improve the management and Early Warning and Rapid Response (EWRR) for IAS in the Iberian Peninsula. The risk assessment carried out in the framework of this project will provide prioritized lists of IAS (Black list and Alert list) that could help Spain and Portugal in the implementation of the IAS Regulation.

Scope

The main objective is to provide transnational black list and alert list of invasive alien aquatic biota that may pose a threat to Iberian inland waters.

The geographical scope encompassess the continental areas of Spain and Portugal. The inland waters of the Balearic Islands and the Macaronesian islands belonging to Portugal and Spain are not included.

Assessment

LIFE INVASAQUA Project coordinated and supported a horizon scanning process with a group of 49 experts to identify issues, agree on methodologies and progress by consensus. The assessment was based on the data and knowledge of this group, who represented a large biological invasion expertise in the target taxa groups (estuarine invertebrates, freshwater invertebrates, plants and vertebrates) and with a track record of working in the interface of science and management.

We followed a structured step-based approach combining a systematic review of knowledge on IAS with the collaborative expert identification and consolidation. The outcoming black list and alert list are products of scientific consensus concerning species invasion status and risk, which is supported by relevant scientific information, and data sources.

Results

A total of 126 IAS were prioritised in the final black list (38 estuarine invertebrates, 26 freshwater invertebrates, 23 plants and 39 vertebrates) representing the 41.2% of alien taxa recorded in Iberian inland waters (Appendix A). Fishes (22 species) conformed as dominants in vertebrates which, together with molluscs (22) and crustaceans (18), were the most represented taxonomic groups. A top of 24 IAS had a very high risk of impact and, consequently, very high priority because they summarized the maximum values in the risk-assessment scoring process. Some IAS were consistenly highlighted as the worst currently recorded in the Iberian inland waters including, among others, the common carp (*Cyprinus carpio*), the largemouth bass (*Micropterus salmoides*), the red swamp crayfish (*Procambarus clarkii*), the zebra mussel (*Dreissena polymorpha*), the water hyacinth (*Eichhornia crassipes*) and the water fern (*Azolla filiculoides*).

The outcoming alert list included 89 IAS with a relevant risk of invasion in the Iberian Peninsula (22 estuarine invertebrates, 16 freshwater invertebrates, 23 plants and 28 vertebrates, see Appendix B). Eleven taxa were at the top of the list with higher scores and are consequently considered of very high priority. Some of those top potential taxa included the quagga mussel (*Dreissena rostriformis bugensis*), the marbled crayfish (*Procambarus virginalis*), the Amur sleeper (*Perccottus glenii*), and

the serpulid tubeworm (*Hydroides dirampha*). Indian swampweed (*Hygrophila polysperma*) and the Carolina fanwort (*Cabomba caroliniana*) were among the worst potential plants with a high probability of future introduction in the Iberian Peninsula.

Key conclusions

The resulting black list and alert list are important tools supporting the implementation of the IAS Regulation, and provide a factual basis for the review of its application. These prioritized lists of IAS will help the MS of Spain and Portugal in the establishment of a surveillance system of the key IAS and can foster transnational cooperation and coordination across borders or within shared biogeographical regions. This updated and shared information of IAS could also support IAS policies in multiple ways: providing a scientific basis for the update or development of future legislation; supporting restrictions in specific activities (e.g. species trade); prioritising surveillance, rapid response and mitigation actions. Ultimately, the black list and alert list provide valuable information for the implementation of other EU policies related to alien species, such as the Birds and Habitats Directives and the Marine Strategy and Water Framework Directives.

LIFE INVASAQUA Project has proved to be a good source of information of IAS within Spain and Portugal, but also extensible to other MS, supporting the IAS Regulation by engaging and creating synergies among knowledge building, management decision-makers and stakeholders. In this context, Spanish and Portuguese authorities responsible for implementing the IAS Regulation and several academic groups will be invited to check and validate the prioritized lists presented here.

Stone Moroko *(Pseudorasbora parva)* © CC BY-SA 3.0

1 Introduction and aims

1. Introduction and aims

1.1. Background

Biological invasions are one of the major drivers of global change that threatens biodiversity, ecosystem services, and human health (EEA 2012, Ricciardi *et al*. 2013, Simberloff *et al*. 2013, Early *et al*. 2016, IPBES 2019). Increasing rates of species introductions (Seebens *et al*. 2017), climate change (Gallardo *et al*. 2018) and other anthropogenic influences, such as globalisation as well as human-altered habitats, favour the establishment and spread of alien species (Didham *et al*. 2007, Hulme 2021). Alien species that, once introduced, establish populations, become abundant and spread in recipient non-native ecosystems are termed invasive alien species (IAS). They often cause biodiversity loss and disruption of ecosystem services, with impacts on human welfare, public health and the economy (Vilà *et al*. 2011, Jeschke *et al*. 2014, Tsiamis *et al*. 2020, Diagne *et al.* 2021, Vaz *et al*. 2021). Far from diminishing, their threat appears to be increasing and the number of established alien species from different taxonomic groups is unlikely to decrease in the near future. For instance, it is estimated that by 2050 established IAS in Europe will have increased by around 64% (Seebens *et al*. 2021). Urgent action on prevention strategies to avoid the entry of IAS into non-native ecosystems is therefore of paramount importance.

Aquatic environments (e.g. estuarine and inland waters) are particularly vulnerable to either accidental or deliberate IAS introductions (Strayer 2010, Flood *et al.* 2020 , Guareschi & Woods 2022) which often cause severe ecological impacts worldwide (Dudgeon *et al*. 2006, Gherardi 2007, Gallardo *et al*. 2016a). Economic costs of aquatic invasions are equally significant, with both damage and management costs estimated to be at least $23 billion per year (Cuthbert *et al.* 2021). Like the rate of increase in the number of alien species introductions, the number of aquatic IAS are also increasing rapidly and, in many cases, their spread rate too (Olden *et al*. 2022), particularly in the European inland waters (Nunes *et al*. 2015).

Recent studies estimate that there are almost 20,000 alien species in the world (Pyšek *et al.* 2020) and that approximately 70% of them (more than 14,000 alien taxa) are currently recorded in Europe sensu the European Alien Species Information Network (EASIN) (Katsanevakis *et al*. 2012). Several of them exhibit invasive behaviour and have a high impact on ecosystem functioning and biodiversity causing adverse effects on the environment (Katsanevakis *et al.* 2015) and irreversible economic losses (Haubrock *et al.* 2021, Zenni *et al*. 2021).

Recognising the need for a coordinated set of actions to prevent IAS introductions, to control their established populations, and to mitigate their impacts, the European Parliament and Council adopted the Regulation (EU) No 1143/2014 (hereafter referred to as the IAS Regulation), which entered into force in January 2015. This IAS regulation sets out rules to effectively address the IAS problem by seeking to prevent the entry of new IAS, building up an early warning and rapid response (EWRR) system, ensuring a prompt eradication of localised IAS populations and more efficiently managing IAS that become established and spread (Genovesi *et al*. 2015, Reaser *et al.* 2020). The IAS Regulation aims to firstly address the negative impact of IAS on biodiversity and ecosystem services, while negative effects on the economy and on human health are considered as aggravating factors. In fact, IAS accumulated costs probably reach €20 billion per year to the European Member States (MS) (Tsiamis *et al*. 2017). Furthermore, according to a recent study (Haubrock *et al*. 2021), the total costs of IAS in European Member States amounted to €45.63 billion between 1960 and 2020, being mainly attributed to damage-losses and management, and affecting multiple sectors depending on the country (e.g. agriculture, administrations, forestry or fisheries). These figures are probably underestimated due to the difficulty of counting and monetising damages, as well as the availability of management records attributed to IAS costs.

A pivotal issue in the IAS Regulation is the development of a list of IAS of Union concern (i.e. Union List), including those taxa that are highly damaging to native biodiversity, and for which concerted action is required across the EU (Genovesi *et al*. 2015). This regulation not only emphasises minimising harm from established IAS, but also have a specific focus on identifying potential invaders (Roy *et al.* 2019). Thus, in this EU framework, developing prioritized lists of established taxa and/or potential taxa in any

MS (also in any biogeographical area) is essential to design proficient prevention protocols, to promote unequivocal prompt detection and rapid response, and to adjust current legislation (Bertolino *et al.* 2020, Wallace *et al*. 2020).

Horizon scanning is seen as critical for identifying and priorizating the most threatening IAS, recorded or potential taxa, so that their risk can be assessed for future listing and management actions prioritised (Gallardo *et al.* 2016b, Roy *et al*. 2019, Peyton *et al.* 2019, Czechowska *et al.* 2022, among others). Accordingly, this technical report presents a systematic consensus horizon scanning procedure to derive the Black list and Alert list of the Aquatic Alien Species of the Iberian Peninsula (hereafter referred to as black list and alert list). The **black list** (BOX 1) comprises alien taxa already introduced and established in at least Spain or Portugal that, according to the procedure, have shown to pose important risks to the environment, economy or human well-being. At the same time, the **alert list** (BOX 1) prioritizes those potential IAS that are likely to arrive, establish, spread and have an impact in the Iberian Peninsula in the coming decades.

Under the IAS Regulation, Spain and Portugal – as all Member States – must prevent the entry of alien species, contain their spread within their territories, enforce effective EWRR mechanisms to detect new introductions, and adopt management measures for those IAS that are already widespread. The black list of established and introduced alien species defined in the present technical report should be a key tool for improving and prioritizing IAS management actions. Similarly, the developed alert list provides a basis for prioritizing risk assessments of species not yet established in inland waters of both countries to comprehensively evaluate the threat posed by these taxa to Iberian biodiversity and ecosystems. Ultimately, the information included in this technical report can also be used to monitor the achievement of the target of the EU Biodiversity Strategy for 2030 to address IAS, but also for the implementation of other EU policies with requirements on alien species, such as the Birds and Habitats Directives, the Marine Strategy Framework Directive, and the Water Framework Directive.

1.2. Objectives of the List and purpose of the report

The horizon scan excercise and resulted lists have three main objetives:

- To provided transnational prioritised lists of IAS that may pose a threat to Iberian inland waters.
- To contribute to regional, national, and European IAS management strategy through provision of a black list and an alert list.
- To constitute reference tools for the decision-makers and stakeholders, in addition to facilitate communication, knowledge transfer and discussion between key groups involved in IAS management.

The assessment developed and the resulting lists provide the next main outputs:

- A summary report on a systematic and consensus-based horizon scanning procedure among experts to obtain prioritised black list and alert lists of aquatic IAS of the Iberian Peninsula, which also serve as a model for future projects with a similar thematic or geographic scope.
- A freely accessible database containing the descriptive data and summary of invasiveness for all aquatic IAS defined in the black list and alert list.
- At the same time, LIFE INVASAQUA has developed a website, with information in the form of factsheets, covering most of the blacklisted taxa as well as a platform aggregating and supplying species observation records in the inland waters' (https://eei.sibic.org/).

Finally, it should be noted that the aim of LIFE INVASAQUA, and thus its technical reports, is to promote collaboration and coordination with decision-makers and ensure data sharing and exchange within the Iberian Peninsula.

Brazilian waterweed (*Egeria Densa*) © By Lamiot (CC BY-SA 4.0).

2 Scope and assessment methodology

2. Scope and assessment methodology

2.1. Geographic scope

The geographical scope encompasses the continental areas of two EU Member States, Spain and Portugal. The estuarine and inland waters of the Balearic Islands and Macaronesia islands belonging to those countries (Madeira and the Azores, and Canary Islands) are not included.

2.2. Alien aquatic biota scope

The assessment and the resulting Lists followed the definition of **alien species** according to IAS Regulation (BOX 1) including species moved by human activities beyond the limits of their native geographic range into the Iberian Peninsula in which these do not naturally occur. Human-mediated transport allows these species to overcome fundamental biogeographic barriers that they would otherwise not be able to cross by natural dispersal. Some may be considered as **invasive alien species** (BOX 1) and therefore included in black and alert lists because they are able to form abundant populations and spread within non-native territories, often causing important negative ecological and socio-economic impacts in Iberian aquatic systems or because they may potentially incur these impacts (European Union 2014).

The horizon scanning process has innitially analysed the establishment and spread stages of the **alien aquatic biota** in the Iberian Peninsula, which includes alien organisms living in or depending on the aquatic environment at least during part of their life-cycles (BOX 1). Inland waters are aquatic-influenced environments located within land boundaries, including those located in coastal areas, even if adjacent to marine environments, and encompass most of the aquatic habitats included in **transitional waters** and **inland waters** as defined in the EU Water Framework Directive (BOX 1).

Of the full set of species compiled for horizon scanning (see section 2.3 for details), the alien species were divided into four target groups for the assessment: vertebrates, estuarine invertebrates, freshwater invertebrates, and plants. Vertebrates include aquatic and semi-aquatic organisms, invertebrates also consider semi-aquatic animals, and plants include submerged, floating and emergent aquatic plants which are mainly hydrophytes and helophytes. In addition, more detailed taxonomic information (Phylum, Class, Order and Family) were also specified (see Supplementary material). The native range was divided into Europe, Africa, Asia-temperate, Asia-tropical, Australasia, Pacific, North America and South America. Whenever a native distribution included more than one region (e.g. Europe, Asia-temperate and Asia-tropical), all regions were considered. Marine taxa (except those which commonly colonise estuarine or brackish waters) were not included in the assessment. All translocated species which are considered native in any part of the Iberian Peninsula (e.g. Iberian native species introduced in river basins outside of their native area) were also excluded from the assessment.

A unified framework for biological invasions recognises that the human-mediated invasion process can be divided into a series of stages: **transport, introduction, establishment, and spread** (BOX 1) (Blackburn *et al.* 2011). Consequently, specific management actions can be applied at different points of that invasion process (IUCN 2018, Kocovsky *et al.* 2018). For the species inclusion in the present horizon scanning process, the experts have assessed at which invasion stage of each recorded alien taxa at the Iberian geographical scale. This classification is not an easy task, as species are dynamic within the invasion framework and are expected to cross barriers, transit between stages, and/or simply fail to do either. Therefore, reference to the invasion status for certain species in the Iberian Peninsula should be temporally and spatially explicit.

Hence, the assessment classifies all taxa in four groups. Firstly, **potential taxa** are those that are not yet present in the natural environments of the Iberian Peninsula (i.e. transport and introduction stages). Secondly, **established species** are the ones occurring in inland waters where they already form self-sustaining populations in the wild, and are often abundant (Richardson *et al*. 2010, Blackburn *et al.* 2011). Thirdly, **uncertain taxa** are casual or already introduced species that have been recorded in the Iberian Peninsula but that are not clearly established or naturalized (even if successful reproduction may have been observed, their populations are not self-sustaining). Fourthly, under expert consensus, we consider as **cryptogenics** those species with unknown or unclear biogeographical history that cannot be ascribed as being native or alien to a territory (i.e. Iberian Peninsula) (IUCN 2020) or species of controversial origin (BOX 1).

BOX 1 – Glossary of Key Definitions

Alert list is a list of alien species not yet present in a territory or present only in introduction stage that pose risks to the invaded area and for which particular surveillance and monitoring efforts are recommended, in order to enhance prompt response in the case of arrival to the wild and spread. The list shall be communicated to the competent authorities (EEA 2010).

Alien Species are any live specimen of a species, subspecies or lower taxon of animals, plants, fungi or microorganisms introduced outside its natural range; it includes any part, gametes, seeds, eggs or propagules of such species, as well as any hybrids, varieties or breeds that might survive and subsequently reproduce (Regulation (EU) No 1143/2014). Common synonyms for alien species are: exotic, introduced, non-indigenous, or non-native species (Blackburn *et al*. 2011).

Alien aquatic biota is a collective term describing the alien organisms living in or depending on the aquatic environment at least during a part of its life-cycle (expert consensus).

Black list is a list of introduced and established alien species in the wild that, according to a sound risk assessment, pose risks to the environment, economy or human well-being. Species subject to a detailed risk assessment and which may be introduced via trade should be proposed for trade regulation to competent European and/or national scale. Lists of species found to be harmful through a rapid screening, shall be communicated to competent authorities of the countries concerned to prioritise responses (EEA 2010).

Cryptogenic is commonly applied to taxa for which their native or alien status in a target territory is unclear (IUCN 2020), i.e. "species of unknown (or controversial) biogeographical history which cannot be ascribed as being native or alien" (Richardson *et al.* 2010).

Early Warning and Rapid Response system for invasive alien species is defined as a framework aimed at responding to biological invasions, through a coordinated system of surveillance and monitoring activities, diagnosis of invading species, assessment of risks, circulation of information, reporting to competent authorities, identification and enforcement of appropriate responses (EEA 2010).

Established (naturalized) species means that it has been successfully introduced in natural, seminatural or man-made environments (e.g. reservoirs, ponds, etc.) "with self-sustaining populations for several life-cycles in the wild, individuals surviving and reproducing either in the location where it was introduced or at multiple sites" (Richardson *et al*. 2010, Blackburn *et al.* 2011).

Establishment stage in the invasion process includes taxa that have been recorded in the wild but are not clearly established or naturalized, even if successful reproduction of some of these species may have been observed but population are not self-sustaining.

Inland water means all standing or flowing water on the surface of the land, and all groundwater on the landward side of the baseline from which the breadth of territorial waters is measured (EU Water Framework Directive). In the present assessment, artificial water bodies such as reservoirs are included.

Introduction stage in the invasion process includes taxa that have been transported by human agency beyond limits of their native ranges, and are in cultivation, captivity or quarantine in a new non-native region (Richardson *et al.* 2010, Blackburn *et al.* 2011).

Invasive Alien Species (IAS) are alien species whose introduction or spread has been found to threaten or adversely impact upon biodiversity and related ecosystem services (Regulation (EU) No 1143/2014).

Potential taxa are alien species not yet present in a territory but already present in transport or introduction invasion stage, or taxa occurred in nearby territories, i.e. with a high risk of invasion in that territory.

Transitional waters are bodies of surface water in the vicinity of river mouths that have a partly saline character as a result of their proximity to coastal waters, but are substantially influenced by freshwater flows (EU Water Framework Directive).

Transport stage in the invasion process includes taxa transported by human agency beyond limits of their native ranges (Richardson *et al*. 2010, Blackburn *et al*. 2011). The concept includes for example taxa involved in intercontinental movement into a new region primarily as a result of global commerce and travel.

Spread stage in the invasion process includes taxa clearly introduced in the wild which are already naturalized and established, i.e. "species with self-sustaining populations in the wild" (Richardson *et al.* 2010, Blackburn *et al.* 2011). The concept involves established, naturalized or widespread invasive species.

2.3. Assessment and species screening

Information on alien species present in the Iberian Peninsula and potential taxa to be introduced is often scattered across various sources, including scientific and grey literature, online and offline databases, regional and national competent authorities, etc. For this technical report, we followed a participatory procedure with experts to identify issues, agree on methodologies and progress by consensus. The LIFE INVASAQUA Project coordinated the process and supported channels of communication or discussion spaces in the expert´s workshops and online-meetings. The assessment was a shared process with those developed both to update the inventory of 306 alien species already recorded in the inland waters (Oliva-Paterna *et al*. 2021a) and to establish an inventory of 272 alien taxa not yet present, but included in the transport or in the introduction stage of the invasion process at the Iberian level (Oliva-Paterna *et al*. 2021b).

Three workshops and six online-meetings were held from January 2019 to October 2020. These events mainly focused on developing the criteria for screening and species inclusion, discussion on the process, voting the worst species, risk scoring and agreement about the final lists. Finally, the data and results were edited, and outstanding questions were solved through communication by email with experts.

A total of 60 experts in conservation biology from Spain and Portugal took part in the first steps of the process (Steps 1 and 2) to obtain lists of recorded and potential taxa of alien species (Oliva-Paterna *et al.* 2021a and 2021b).

Experts participants at the 1st Iberian Lists of aquatic IAS. LIFE INVASAQUA Workshop. June 2019, Málaga, Spain. ©LIFE INVASAQUA.

We followed a structured step-based approach (BOX 2) combining alien invasive knowledge with the collaborative expert identification and consolidation. Participants were experts in the field of biological invasions, many of them specialised in Mediterranean environments, and covered a range of different taxa and biome types with an excellent track record of work or research at the science-management interface (see appendix List of Author's affiliations).

Step 1. Systematic review, working groups and compilation of preliminary lists

Scientific literature, technical reports, IAS databases and other web sources were systematically screened to obtain preliminary lists. Several regional and national competent authorities and some scientists supported the compilation by providing inventories on taxa (Oliva-Paterna *et al*. 2021a and 2021b).

Experts were allocated to working groups based on their expertise, covering all taxa in each of the main environments (vertebrates, estuarine invertebrates, freshwater invertebrates, and plants) (see group description in section 2.2). Each group had at least two co-leaders (i.e. researchers with relevant expertise in invasion biology) to coordinate or to resolve doubts in the taxa inclusion process (e.g. some brackish species were considered by more than one group).

The task of compiling the preliminary lists was divided into thematic work groups and taxonomically. Each expert in the thematic groups was responsible for reviewing the preliminary lists. Over a period of six months, the experts completed this initial exercise by e-mail and online-meetings.

Lists of recorded species generated from previous scientific studies in the Iberian Peninsula were circulated to all working groups (e.g. García-Berthou *et al*. 2007, Cobo *et al*. 2010, Chainho *et al*. 2015, Anastácio *et al*. 2019, Muñoz-Mas & García-Berthou 2020). Complementarily, comparable assessments in others geographical areas, at national or international levels, and lists from previous horizon scanning exercises were discussed (e.g. Almeida *et al.* 2013, Roy *et al.* 2014, Gallardo *et al*. 2016b, Carboneras *et al.* 2018, Roy *et al*. 2019, Nentwig *et al*. 2018, Peyton *et al*. 2019, among others).

Step 2. Discrimination and taxa status definition.

The experts collected additional information to assess the invasion stage and thus to define the status of each recorded taxa (i.e. established, uncertain or cryptogenic) or potential taxa.

Consensus building across the working groups took place at an intermediate online-meeting where lists of recorded and potential alien taxa were established. Including macroalgae and fungi that were not initially the target of the present assessment, a total of 306 alien taxa were listed as recorded in Iberian inland waters and 272 alien taxa were identified as potential invaders (Oliva-Paterna *et al.* 2021a, 2021b). The resulting lists were the result of scientific consensus on the invasion status of species based on relevant literature and data sources (for more information, see Oliva-Paterna *et al.* 2021a, 2021b). The four thematic groups of IAS for the next steps (vertebrates, estuarine invertebrates, freshwater invertebrates, and plants) totalled 275 recorded taxa (**recorded alien list** in BOX 2) and 260 potential taxa (**potential alien list** in BOX 2).

Step 3. Expert ranking of alien taxa – Selection of worst taxa

As a first step in prioritisation, we conducted an expert poll consultation. According to Burgman *et al.* (2014) and Gallardo *et al.* (2016b), the voting system synthetises expert perception in an efficient manner and represents a rapid, cost-effective method to rank taxa.

For each list separately (recorded and potential alien taxa), the experts selected the 10 worst alien taxa from their thematic group of expertise, i.e. those they considered most worrying in terms of their impacts (current and/or potential) on biodiversity, socio-economy, and human health in the Iberian Peninsula. For each thematic group, between 12 and 14 sets of votes were obtained from the experts (12 for in vertebrates, 12 for estuarine invertebrates, 14 for freshwater invertebrates, and 13 for plants). The score given to each species was the number of votes received (from 0 to 10).

Note that this does not mean that taxa receiving no votes are risk-free, but simply considered lower priority than others with a high number of votes.

Four preliminary lists where taxa are ranked by number of votes were compiled, one for each of the four target groups (vertebrates, estuarine invertebrates, freshwater invertebrates, and plants). The experts group reached consensus and the taxa voted by at least 25% of the experts in each target group formed the **lists of worst alien species** (worst lists in BOX 2). These ranked worst species were subsequently used in the risk assessment in step 4.

Step 4. Risk assessment and priorization by scoring of top IAS

The worst recorded species (worst list of 126 taxa in BOX 2) and also the worst of taxa not yet recorded (worst list of 89 taxa in BOX 2) in each thematic group was evaluated by scoring (Table A). According to the consensus opinion of experts, all taxa included in these preliminary worst taxa lists can be considered invasive.

In order to rank the most damaging IAS, each taxon on these lists (i.e. potential and recorded lists) has been assigned a score (from 0 to 4, see below) for five categories to indicate the likelihood and magnitude of threat posed to biodiversity, economy and human well-being in the Iberian Peninsula (Table A).

The risk scoring of this step was thereby adapted from Molnar *et al*. (2008) and Gallardo *et al*. (2016b).

The five categories summarised important features of the invasion process:

- **(A1) Geographic extent in the Iberian Peninsula (only for recorded taxa)**: as an approximation to the range of distribution of the species in the Iberian Peninsula.

- **(A2) Invasive potential in the Iberian Peninsula (only for potential taxa)**: as an approach to the future potential establishment and spread around the Iberian inland waters based on their ecological preferences, vectors and pathways.

- **(B) Ecological impact**: effects on Iberian species and ecosystems.

- **(C) Management difficulty**: a simple approach to the potential difficulties of management, control and eradication (mainly technical and/or related to ecological factors such as the dispersal potential of the target taxa).

- **(D) Economic and human health impacts**: all economic sectors are valid, but the assessment mainly focused on those most related to aquatic systems, such as agriculture, aquaculture, water industry and infrastructure (e.g. flood control, hydropower, etc.), or recreation activities (e.g. navigation, water sports, fishing/angling, etc.). Impacts on human health (e.g. disease transmission, poisoning, toxicity, allergies, etc.) were also assessed.

- **(E) Acceptability of management**: social acceptability of management strategies refers to significant problems that might arise from opposition, disapproval or resistance by citizens, interest groups, stakeholders or private sectors. This does not include regulatory or legal barriers, which are considered under practicality (C).

Because the likelihood and magnitude of biological invasion effects are context-dependent, experts were asked to assume a worst-case scenario for voting (step 3) and scoring (step 4). For the recorded taxa, this was the current extent and, under a virtual situation where preventive measures failed, the potential extent within the Iberian Peninsula; for potential taxa, it is the largest area that could potentially (most likely) be reached in the Iberian Peninsula.

Between 3 and 6 different experts assessed and scored each taxon in the worst taxa lists. All five categories of the risk assessment (Table A) were considered equally important. Thus, the total score given to a taxon was equal to the sum of the five categories, with a maximum score of 20 points for a taxon that is widespread or highly likely to be introduced, that has high ecological, economic and health impact, and whose management is very complicated and poorly accepted by society at large. The taxa with a scoring value equal or more than 15 were included in the top of the lists as having a very high priority and risk of impact for the Iberian inland waters.

Over a 4-months period, the experts completed this step by compiling a spreadsheet template that included the values of the scoring categories and useful supporting information to determine the confidence level of each score (see Appendix A). In addition, the main pathways of introduction and spread, as well as native origin of the taxa was collected. Guidance to incorporate data was provided to the experts (Appendix A).

Step 5. Final expert consensus

Consensus among the working groups took place in a final online-meeting (and subsequent emailing) where experts had the opportunity to revise the final black list and alert list and, specifically, check the final score of each alien species (or taxa).

BOX 2 – Structured stepwise approach of the assessment followed for the identification and prioritization aquatic IAS

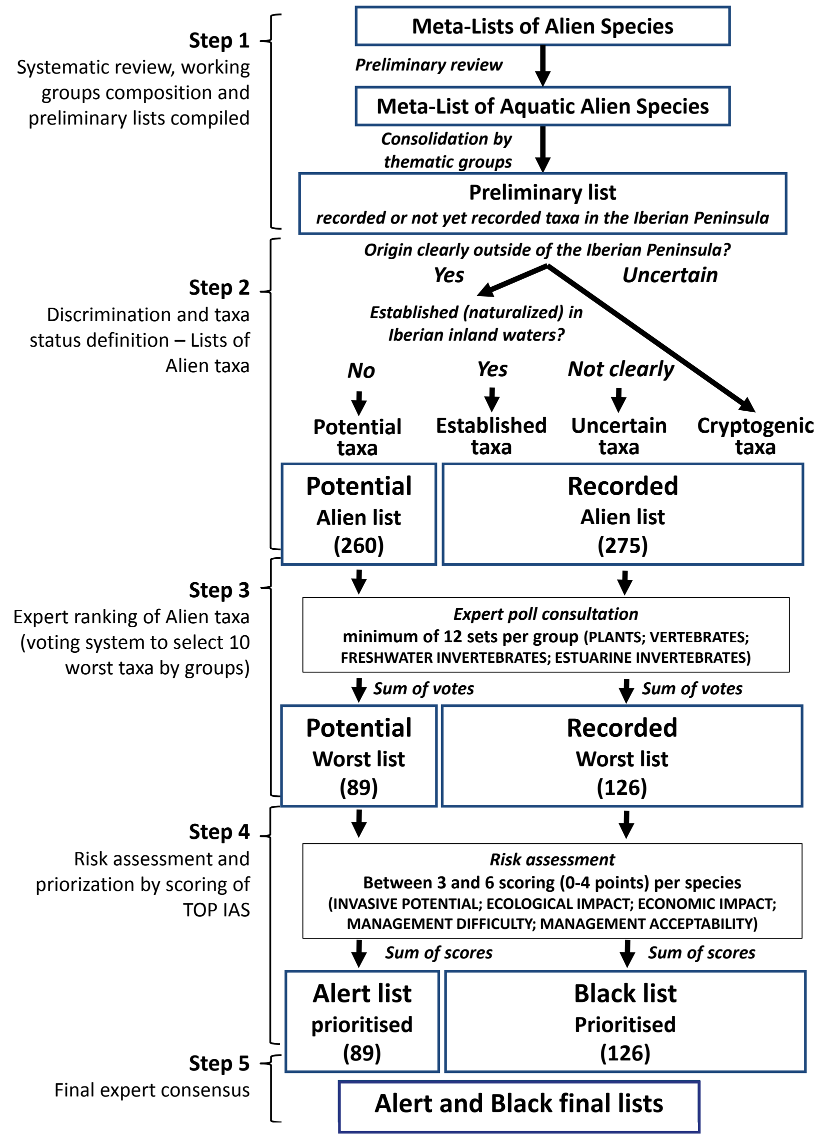

Table A. Guidelines used by the experts in the black list and alert list scoring process. Five risk scores were assigned for each taxa (A1 and A2 were specific to black and alert lists, respectively). Based on Molnar *et al.* (2008) and Gallardo *et al.* (2016b).

(A1) Geographic extent in the Iberian Peninsula	
0	Unknown or deficient data (not enough information to determine score).
1	Single location.
2	Local ecosystem or sub-ecoregion (e.g. sub-basin, small basin).
3	Ecoregion (e.g. a great basin, a freshwater ecoregion sensu Abell *et al.* 2008).
4	Multi-ecoregions (e.g. some basins, more than one freshwater ecoregion).
(A2) Invasive potential to the Iberian Peninsula	
0	Unknown or deficient data (not enough information to determine score).
1	Very unlike future introduction because of its ecological preferences, vectors and pathways of spread.
2	Likely introduction of propagules but unlikely establishment of wild populations because of environmental constraints – probably difficult to spread.
3	Likely introduction and establishment in the long-term because of suitable environmental conditions and/or high propagule pressure – spread could be easy.
4	Very likely introduction and establishment in the short-term because of suitable environmental conditions, closeness to invaded regions, suitable vectors and pathways - high potential of spread.
(B) Ecological impact	
0	Unknown or deficient data (not enough information to determine score).
1	Little or no disruption, when it causes minor levels of impacts showing no reduction in performance of individuals in the native biota.
2	Disrupts single species with little or no wider ecosystem impacts.
3	Disrupts multiple species, some aquatic habitats, some wider ecosystem function, and/or keystone species or species with conservation value.
4	Disrupts entire ecosystem processes with wider abiotic-influences and it causes irreversible community changes.
(C) Management difficulty	
0	Unknown or deficient data (not enough information to determine score).
1	Invasion process is easily reversible with no ongoing management actions (eradication).
2	Invasion process is reversible with some difficulty and/or can be controlled with periodic management.
3	Invasion process is reversible with difficulty and/or can be controlled with significant ongoing management.
4	Invasion process is irreversible and/or cannot be controlled or contained.
(D) Economic and human health impacts	
0	Unknown or deficient data (not enough information to determine score).
1	Little or no economic impact.
2	Affects one economic sector (agriculture, aquaculture, water industries, recreation, infrastructure, and human health) with little or no wider economic impacts.
3	Affects multiple economic sectors (agriculture, aquaculture, water industries, recreation, infrastructure, and human health), requiring periodic investment to control damage.
4	Affects multiple and/or key economic sectors (agriculture, aquaculture, water industries, recreation, infrastructure, and human health), requiring ongoing significant investment to control damage.
(E) Acceptability of management	
0	Unknown or deficient data (not enough information to determine score).
1	No social visibility, total or very acceptable because social support.
2	Acceptable or moderate, no important conflicts or only with one social sector.
3	Unacceptable, potential conflicts with multiple social sectors (e.g. public opinion, stakeholders, animal welfare groups, waterbody users).
4	Very unacceptable, potential conflicts with multiple key sectors and the general public.

3 Results

3. Results

3.1. Black list.

A total of 126 IAS were included in the final black list: 30.9% of vertebrates (39 taxa), 50.8% of invertebrates (64 taxa: 38 estuarine and 26 freshwater), 18.3% of plants (23 taxa) (Figure A) (see Appendix A for full database). Of all blacklisted IAS, we identified 105 taxa (83.3%) clearly established or naturalized in the estuarine and continental aquatic systems, most of them in both countries, whereas the remaining 21 taxa were defined as having an uncertain status (see Appendix A). Of the total of 306 alien taxa initially listed as recorded in the inland waters of the Iberian Peninsula (Oliva-Paterna *et al.* 2021a), only 41.2% were included in this final black list.

A top of 24 species were categorised as having a very high priority or risk of impact for Iberian inland waters by achieving highest scores (equal to or higher than 15; Figure A). The rest of taxa were categorised as high (92 taxa) or medium (10 taxa), with no species classified as low impact (Figure A). The detailed information with the total number of evaluated taxa is in Appendix A.

Among the IAS that received the highest category were 11 vertebrates, 7 invertebrates (3 estuarine and 4 freshwater) and 6 plants (Table B). However, all taxa ranked during the process were considered to be of relevance to the entire Iberian Peninsula. The most prominent IAS consistently highlighted as the worst in the Iberian inland waters were the common carp (*Cyprinus carpio*), the largemouth bass (*Micropterus salmoides*), the red swamp crayfish (*Procambarus clarkii*), the zebra mussel (*Dreissena polymorpha*), the water hyacinth (*Eichhornia crassipes*) and the water fern (*Azolla filiculoides*), among others (Table B).

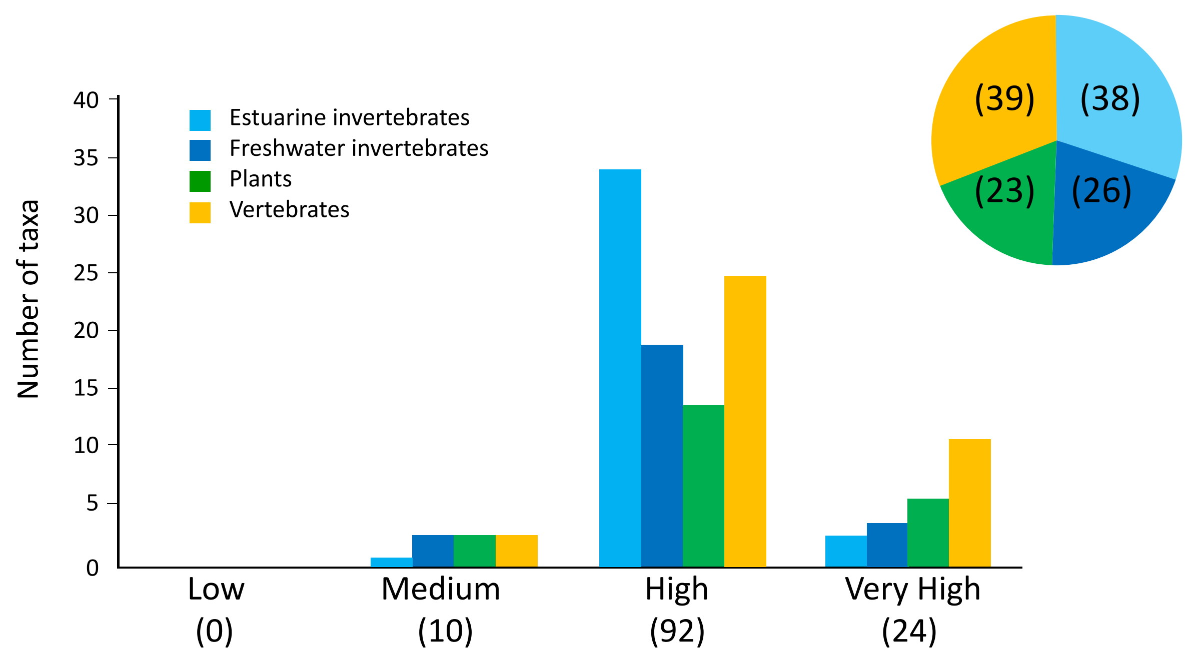

Figure A. Number of taxa included in the black list ranked as low, medium, high or very high risk of impact by de horizon scanning process. Colours represent the target groups (estuarine invertebrates, freshwater invertebrates, plants and vertebrates) and numbers in brakets the total taxa per group (top right insert) and per category (main plot) included in the black list.

Table B. The top of 24 IAS included in the black list and evaluated by experts as having a very high risk of impact for the Iberian inland waters (scoring value ≥ 15). The full blacklist is available in Appendix A. The common name, native range, and score value (mean ± standard error of three to six independent sets of scores from the expert assessment) are shown.

Top IAS included in the Black list				
Target-group	**Taxa**	**Common name**	**Native range**	**Score**
Vertebrates	*Cyprinus carpio*	Common carp	Eur, As	18.2 ± 0.4
	Micropterus salmoides	Largemouth bass	NAm	17.2 ± 0.4
	Sander lucioperca	Pike-perch	Eur, As	16.3 ± 0.6
	Gambusia holbrooki	Eastern mosquitofish	NAm	16.2 ± 0.7
	Silurus glanis	Wels catfish	Eur, As	16.2 ± 0.4
	Esox lucius	Pike	Eur, As, NAm	16.0 ± 0.3
	Pseudorasbora parva	Topmouth gudgeon	As	15.8 ± 0.4
	Alburnus alburnus	Bleak	Eur	15.8 ± 0.6
	Neovison vison	American mink	NAm	15.4 ± 0.7
	Branta canadensis	Canada goose	NAm	15.2 ± 0.8
	Procyon lotor	Raccoon	NAm	15.0 ± 1.3
Estuarine Invertebrates	*Ficopomatus enigmaticus*	Tubeworm	Pac, Aus	16.0 ± 0.7
	Magallana gigas	Pacific oyster	Pac, As	16.0 ± 0.9
	Callinectes sapidus	Atlantic blue crab	NAm, SAm	15.2 ± 0.7
Freshwater Invertebrates	*Procambarus clarkii*	Red swamp crayfish	NAm	18.7 ± 0.6
	Dreissena polymorpha	Zebra mussel	As, Eur	17.3 ± 0.3
	Pacifastacus leniusculus	Signal crayfish	NAm	17.3 ± 0.9
	Corbicula fluminea	Asian clam	As, At	17.0 ± 0.4
Plants	*Eichhornia crassipes*	Water hyacinth	SAm	16.7 ± 0.7
	Azolla filiculoides	Water fern	NAm, SAm	16.2 ± 0.2
	Ludwigia grandiflora	Water primrose	NAm, SAm	15.8 ± 0.5
	Salvinia natans	Floating fern	NAm, SAm	15.7 ± 1.2
	Salvinia molesta	Kariba weed	SAm	15.4 ± 1.1
	Spartina densiflora	Denseflower cordgrass	NAm	15.3 ± 1.1

Native range: Eur, Europe; As, Asia-temperate; At, Asia-tropical; Aus, Australasia; Pac, Pacific; NAm, North America; SAm, South America.

Taxonomic approach

The 126 aquatic taxa included in the Black list belonged to 11 phyla divided into 34 classes. The most represented taxa in the black list were Chordata 35.7% (45 taxa), followed by Arthropoda 17.5% (22 taxa), Mollusca 17.5% (22 taxa), and Magnoliophyta 15.9% (20 taxa) (Figure B). At a lower taxonomic level, the most numerous group of the taxa listed were fishes (Actinopterygii), bivalves (Bivalvia), angiospermas (Angiospermae) and crustaceans (Malacostraca); see further details in Appendix A of Oliva-Paterna *et al.* 2021a). . In general, the majority of phyla included established taxa, with the exception of the vertebrates that comprised of 11 uncertain taxa.

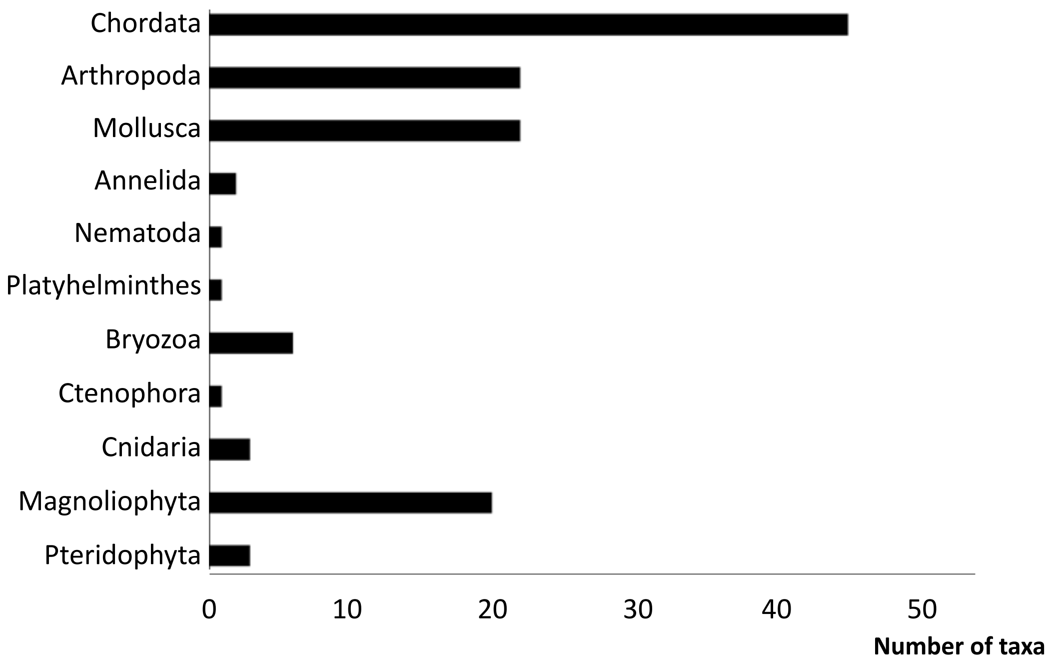

Figure B. Histograms showing the number of taxa/species included in the black list by taxonomic group (phylum/division).

With regards to alien animals present in Iberian inland waters, fish (Actinopterygii) comformed the largest group of vertebrate taxa (56.4%), with 22 species blacklisted. Most of the invertebrates blacklisted were molluscs and crustaceans, with 22 species in each phylum (34.4%). Gastropoda and Bivalvia were the classes representing the totality of the former, and Malacostraca the dominant group of the latter. Due to the difficulties involved in the study of aquatic invertebrates (e.g., misidentification of some species), and despite the growing scientific interest in biological invasions in recent decades, there is still a significant knowledge gap on alien invertebrates and some functional groups in the Iberian inland waters.

The black list included submerged, floating and emergent aquatic plants, which fall into the categories of hydrophytes and helophytes. However, due to their high invasive potential, taxa that tolerate flooding and that are able to grow with part of their vegetative structure submerged or floating were also considered. Considering the aquatic plants present in Iberian inland waters, Magnoliophyta was clearly dominant among the blacklisted plants (87.0%), with 20 taxa listed (13 Magnoliopsida and 7 Liliopsida).

Native range and Pathways of introduction

Regarding the native range of the 126 IAS included in the black list, most of taxa were native to North America (46.0%, 58 taxa) and temperate Asia (31.7%, 40 taxa), followed by those from the Pacific region (21.4%, 27 taxa) (Figure C), which hosts the native range of many estuarine invertebrate species present in the Iberian Peninsula. Taxa with native ranges in Africa (10 taxa) were less represented, and there were no vertebrates native to Australia or South America. It should be noted that there was an important group of invasive taxa partly native to the European continent (19 taxa) which are currently not a priority focus of the IAS Regulation at EU level, although they are highly problematic invaders in their non-native areas, particularly in the Iberian Peninsula (e.g. wels catfish, *Silurus glanis*, or zebra mussel, *Dreissena polymorpha*).

The taxa included in the black list have been able to reach the Iberian Peninsula through multiple pathways, 48.8% were related to more than on introduction pathway in Supplementary material. Escape from confinement and release into the wild were the two main pathways of introduction for IAS present in the Iberian Peninsula. The former was especially relevant to vertebrates and plants, while the latter was mainly attributed to vertebrates. As for invertebrates, freshwater IAS came to Iberian inland waters through release, escape, as contaminants and stowaways in roughly equal parts; however, the latter two pathways of introduction were mostly used by estuarine IAS. Other pathways of introduction, such as through corridors or unaided, were less relevant for the 126 IAS on the blacklist. (Figure C).

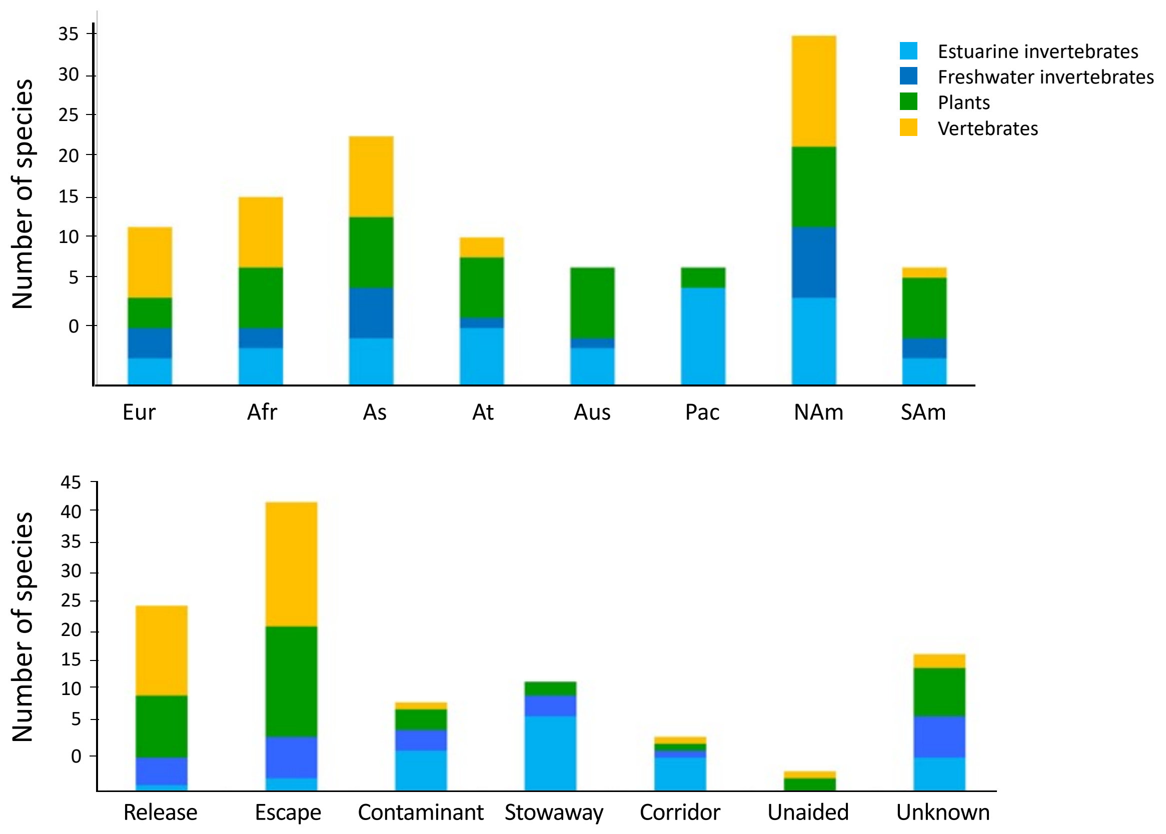

Figure C. Number of taxa/species across the four target groups included in the black list by native origin (upper panel) and pathways of introduction (lower panel). Colours in histograms represent the target groups (vertebrates, estuarine invertebrates, freshwater invertebrates, plants). Native range: Eur, Europe; As, Asia-temperate; At, Asia-tropical; Aus, Australasia; Pac, Pacific; NAm, North America; SAm, South America.

3.2. Alert list.

The final alert list comprised 89 IAS with remarkable risk of invasion in the Iberian Peninsula which were 31.5% vertebrates (28 taxa), 42.6% invertebrates (38 taxa: 22 estuarine and 16 freshwater) and 25.2% plants (23 taxa) (Table C and Figure D) (Appendix B). They represent 34.9% of potential taxa not yet present in Spain and Portugal (Oliva-Paterna *et al.* 2021b).

Only 10 IAS reached the maximum category with a score equal to or higher than 15 (Table C). They were considered as being at very high risk of introduction through the Iberian inland waters and, consequently, capable of potentially cause severe impacts in the coming decades. The remaining taxa were identified as having high (61 taxa), medium (15 taxa) or low (3 taxa) risk of the invasion to the Iberian Peninsula (Appendix B). Notably, none of the plants and only one vertebrate (Amur sleeper, *Perccottus glenii*) were classified as very high, even though most of them (12 plants and 27 vertebrates) were categorized as highly likely to be introduced. Specific information on the total number of potential taxa evaluated can be found in Appendix B.

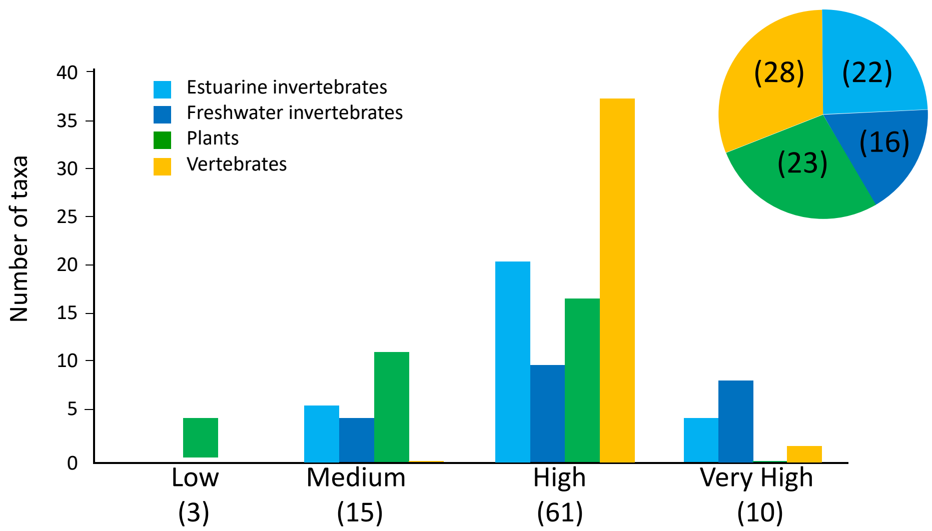

Figure D. Number of taxa included in the alert list ranked as low, medium, high or very high risk of invasion and impact by de horizon scanning process. Colours represent the target groups (estuarine invertebrates, freshwater invertebrates, plants and vertebrates) and number in brakets shows the total taxa per group (insert) and per risk category (main plot) included in the alert list.

Among the IAS listed in the highest risk category (i.e. very high), six were freshwater invertebrates, three estuarine invertebrates and one vertebrate (Table C). Some of the species that in this category included the quagga mussel (*Dreissena rostriformis bugensis*), the marbled crayfish (*Procambarus virginalis*), the amur sleeper (*Perccottus glenii*), and the serpulid tubeworm *Hydroides dirampha* (Table D). The water fern (*Azolla mycrophylla*), the Indian swampweed (*Hygrophila polysperma*) or the Carolina fanwort (*Cabomba caroliniana*) were some of the plants with the highest risk values in the scoring (Appendix B).

Table C. The top 10 IAS included in the alert list with a very high risk of invasion and impact to the Iberian inland waters (scoring value ≥ 15) in the near future. The common name, native range, and score value (mean ± standard error of three to six independent sets of scores from the expert assessment) are shown.

Top IAS included in the Alert list				
Target-group	**Taxa**	**Common name**	**Native Range**	**Score**
Vertebrates	*Perccottus glenii*	Amur sleeper	As	15.2 ± 0.5
Estuarine Invertebrates	*Hydroides dirampha*	Serpulid tubeworm	Aus	15.7 ± 1.3
	Perna viridis	Asian green mussel	As, At, Pac	15.3 ± 0.3
	Rhopilema nomadica	Nomad jellyfish	As, At, Afr, Pac	15.0 ± 0.0
Freshwater Invertebrates	*Dreissena rostriformis bugensis*	Quagga mussel	As, Eur	17.0 ± 0.5
	Procambarus virginallis	Marbled crayfish	NAm	16.2 ± 1.1
	Pomacea gigas	Apple snail	SAm	15.3 ± 0.8
	Aedes aegypti	Yellow fever mosquito	Afr	15.2 ± 1.1
	Faxonius virilis	Virile crayfish	NAm	15.2 ± 1.0
	Faxonius rusticus	Rusty crayfish	NAm	15.0 ± 0.2

Native range: Eur, Europe; Afr, Africa; As, Asia-temperate; At, Asia-tropical; Aus, Australasia; Pac, Pacific; NAm, North America; SAm, South America.

Taxonomic approach

At the level of major groups, the number of species reflected in the Alert list was lower than in the Black list (see above). Taxa included in the Alert list belonged to 7 phyla divided into 15 classes. Of the total taxa, 32.6% were Chordata (29 taxa), 23.6% Magnoliophyta (21 taxa), 20.2% Arthropoda (18 taxa) and 15.7% Mollusca (14 taxa) followed by Annelida, Pteridophyta and Cnidaria to a lesser extent (Figure E). The most important class in numerical terms was again fish (Actinopterygii), followed by Malacostraca and Liliopsida (see Suplementary material in Oliva-Paterna *et al.* 2021b).

The number of crustaceans and molluscs present here is lower than expected according to the data presented in the preliminary list of potential aquatic alien taxa of the Iberian Peninsula (Oliva-Paterna *et al.* 2021b). This fact could indicate a certain bias in the Alert list towards the vertebrate group.

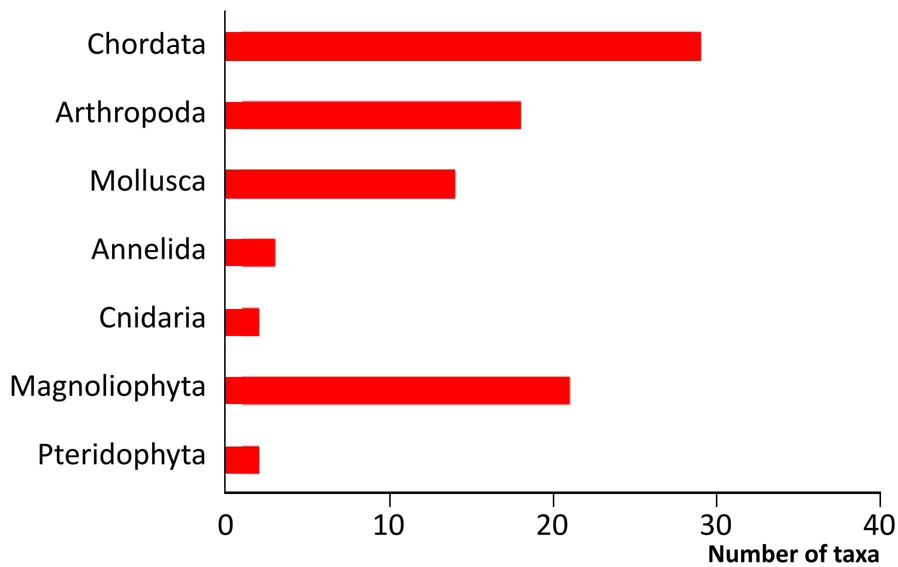

Figure E. Histograms showing the number of taxa/species included in the alert list by taxonomic group (phylum).

Similar to the black list, fish (Actinopterygii) constituted the most important taxomic group with 25 taxa, 89.3% of the vertebrate taxa included in the alert list. The majority of invertebrates were crustaceans (15 species, 39.5% of listed invertebrates) and molluscs (14 species, 36.8% of listed invertebrates). Malacostraca was the dominant group among the former, and Gastropoda and Bivalvia accounted for the totality of the latter. The dominant among plants were angiosperms, with 12 Liliopsida and 9 Magnoliopsida.

Native range and Pathways of introduction

The native ranges of most taxa that could potentially be introduced to the Iberian Peninsula in the near future were North America (39.3%, 35 taxa) and temperate Asia (28.1%, 25 taxa) (Figure F). However, other regions such as Africa (21.3%, 19 taxa) and European regions outside the Iberian Peninsula (18.0%, 16 taxa) were also relevant. The Australiasian and South American regions were considered as a relevant potential source of invasive alien plants, and the Pacific region specifically for estuarine invertebrates. The alert list did not include vertebrates from neither Australasia nor the Pacific regions. As with the black list, it is important to note that there were a significant number of taxa partly native to Europe that are potentially invasive to Iberian inland waters and, consequently, may generate negative impacts and should be considered in future European IAS policies.

Many of the taxa included in the alert list could reach the Iberian Peninsula through multiple pathways, 42.7% were related to more than one introduction pathway (Supplementary material). Similar to the black list, escape from confinement and release into the wild were the two most prominent pathways of introduction for IAS belonging to the alert list, followed by stowaway and contaminant. While the first two were especially relevant for vertebrates and plants, the latter two were mainly attributed to invertebrates, and estuarine invertebrates in particular (Figure F). Surprisingly, for many taxa likely to be introduced in the future, their pathways of introduction remain unknown so far. Therefore, there is an urgent need to continue providing knowledge on the pathways of introduction of those species that are likely to be introduced and cause damage to the ecosystems of the Iberian Peninsula in order to implement successful biosecurity actions.

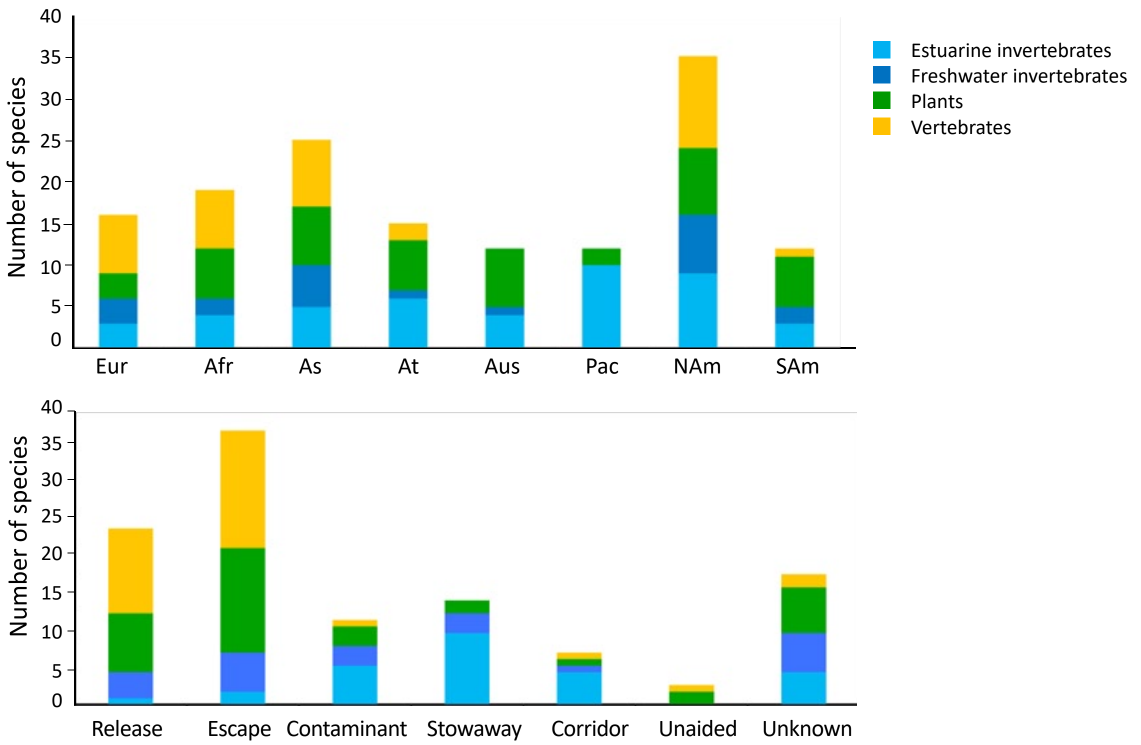

Figure F. Number of taxa/species across the four target groups included in the alert list by native origin (upper panel) and CBD pathways of introduction (lower panel). Colours in histograms represent the target groups (vertebrates, estuarine invertebrates, freshwater invertebrates, plants). Native range: Eur, Europe; As, Asia-temperate; At, Asia-tropical; Aus, Australasia; Pac, Pacific; NAm, North America; SAm, South America.

4 Recommendations and needs for update

4. Applied conclusions and recommendations

4.1. Horizon scanning as a tool for prioritisation

LIFE INVASAQUA Project has proven to be a good source of information to support the implementation of the IAS Regulation, providing factual basis for the review of regional enforcement. The information provided by INVASAQUA's horizon scanning process is essential to support decision making on IAS that affect -or have the potential to do so- the Iberian inland waters, and to ensure an optimal use of the resources invested in prevention and early detection of potential invaders (see e.g. Roy *et al*. 2019). However, given the increase in the number of alien species that are and will likely be introduced in the coming decades (Seebens *et al*. 2017, 2021), it is essential to regularly review and update the outcoming black list and alert list.

Horizon scanning processes have recently played a central role in environmental and conservation practice related to IAS (Gallardo *et al*. 2016b, Roy *et al*. 2019, Peyton *et al*. 2019, among others). They are considered essential components of IAS control and management (Shine *et al*. 2010), as they help to prioritise mitigation and prevention measures, identify possible pathways of introduction, and provide information for early response in specific areas. The primary objective of a horizon scanning exercise is to identify possible IAS that are on the verge of being introduced, and investigate their potential pathways of introduction in order to improve biosecurity measures. Horizon scanning usually follows a structured process of simplification from a larger set of data to carve out the most risky IAS and relevant details about them.

The development of the INVASAQUA's horizon scanning process was based on a systematic compilation of IAS of concern for the Iberian Peninsula and independent expert consultation. This procedure was designed to provide an unbiased, cost-effective a rapid screening of the risk associated with the introduction and impacts of potential and recorded invasive taxa in the Iberian inland waters.

Compared to other European risk analyses, we employed a relatively quick and easy risk scoring system that combined several elements of the invasion process and management. We conducted a transnational process including a broad group of taxa (vertebrates, estuarine invertebrates, freshwater invertebrates, and plants) and considering both their ecological and economic impacts, including those on infrastructure and human health. Additionally, the social acceptability of the taxon's management, which is a key aspect in its regional management, was also considered in the scoring. However, the INVASAQUA's horizon scanning process is not a substitute for other comprehensive and robust risk analyses on target IAS that countries need to develop or are already developing.

The prioritisation of IAS may be influenced by the experts involved in the horizon scanning process. To minimize this, a diverse and moderately large group of 49 participants from different groups of expertise, as well as a simple and clear criteria set out in the prioritization, helped to reduce the potential impact of that source of uncertainty in this exercise developed by INVASAQUA.

4.2.Black list and Alert list as key elements for IAS management

There is an urgent need to provide evidence-based assessments of the risks posed by IAS to prioritise action in several European geographic regions such as the Iberian Peninsula. The INVASAQUA's horizon scanning underpins IAS policies in many ways: informing legislation; providing justification for restrictions in trade or other human activities; prioritising surveillance procedures, rapid responses and mitigation actions.

The outcoming lists are expected to help Spain and Portugal support the implementation of the IAS Regulation by engaging and creating synergies between knowledge building and management. Black and alert listing of recorded and potential IAS, respectively, can help to identify priority taxa for management. For example, informing on biosecurity policies regarding the introduction pathways of IAS, mitigating the impacts caused by the most damaging IAS, raising stakeholders' awareness and improved communication for citizens about the current and emerging threats in the Iberian inland waters. These prioritised lists may be critical for the coordinated and unified efforts involving transnational strategic actions for the management of IAS in Iberian inland waters.

The risk assessments carried out in the framework of LIFE INVASAQUA will also provide evidence to inform whether the target species included in the black list and alert list should be considered for inclusion in the Spanish and Portuguese national IAS catalogues or even in the Union List under the IAS Regulation (last update 2022). It is noteworthy that only 22.2% (28 taxa) and 13.5% (12 taxa) of the IAS included in the present black list and alert list, respectively, are included in the current List of Invasive Alien Species of Union concern (the Union List) which is the core of the IAS Regulation. Although it is understandable that the national IAS regulations do not necessarily include all the alien species recorded in the Iberian inland waters, the Spanish IAS catalogue and the Portuguese National List of IAS only include 52.4% and 50.0%, respectively, of the taxa included in the INVASAQUA's black list. In the case of the alert list, the Spanish IAS catalogue lists only include 11.9% (15 taxa) and the Portuguese National List of IAS only 12.7% (16 taxa) of the taxa identified here. Finally, the Spanish Allochthonous List, which is focused on potential species, reflects the highest percentage of taxa included in the lists of this study (69.8% of the black list and 75.3% of the alert list) (Figure G).

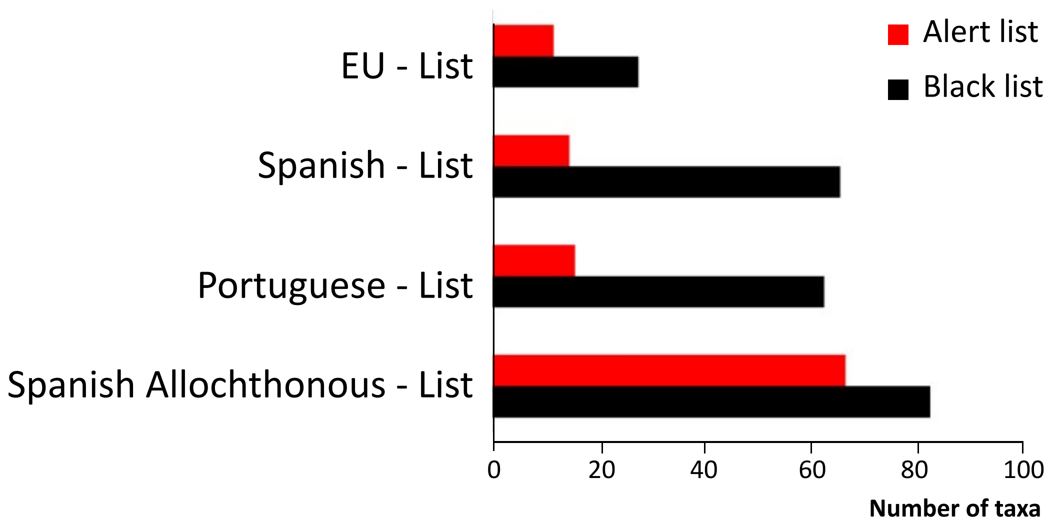

Figure G. Histograms shows the number of taxa of the black list (colour black) and alert list (colour red) that are included in the list of invasive alien species of Union concern under the IAS Regulation (EU – List), in the Spanish IAS catalogue (Spanish – List), in the Portuguese National List of IAS (Portuguese – List) and in the Spanish Allochthonous List (Spanish Allochthonous – List).

Impacts, risk perception and the management capacity of a particular region, such as the Iberian Peninsula, may change depending on the stage of the invasion process of each IAS. Thus, prioritized black and alert lists need to be re-evaluated to reflect progress in knowledge and new suitable management options.

Finally, the identification and prioritisation of IAS can facilitate a better understanding for the public and engage society in terms of biodiversity conservation. In fact, black and alert lists developed by LIFE INVASAQUA also aim to stimulate and support research, monitoring, management and control actions at local and regional level.

The resulting lists are part of a wider initiative within the LIFE INVASAQUA project, which aims to assess the status of the vast majority of Iberian aquatic alien species. By compiling information on populations, ecology, habitats and recommended management measures for several aquatic IAS, this initiative will provide key resources for decision-makers, environmental managers, NGOs, and other stakeholders in implementing actions. The outputs of this initiative can be applied to inform policy, and to identify priority IAS to be included in monitoring and research programmes, as well as to identify priority areas for management plans.

All the information generated by the LIFE INVASAQUA is freely available on its Websites (http://www.lifeinvasaqua.com/; https://eei.sibic.org/; https://ibermis.org/), and/or through different technical reports.

Final recommendations:

- Use the black list and alert list to support inform reviews and implementation of relevant European, National and Regional legislation.
- Improve the requirements of the EU, National and Regional management agencies for the reporting of risk analyses, occurrences and invasion status of all listed species.
- Conduct basic and applied biological research for the listed IAS, especially those with a high or very high risk and that may have a greater need for control and management to minimise their impacts.

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Appendix A

Black list of aquatic invasive alien taxa recorded in Iberian inland waters

List of IAS included in the black list by target groups (vertebrates, estuarine invertebrates, freshwater invertebrates and plants). Taxa are ordered by score value (mean of three to six independent sets of scores from the expert assessment, standard error included) in each target group.

More information about taxa (synonyms, native geographic range, pathways of introduction, inclusion in IAS Regulation and key literature references) are included in the supplementary database.

ESTUARINE INVERTEBRATES				
Scientific name	Score	S.E.	No. of expert scorings	Order in group
Ficopomatus enigmaticus	16,00	0,71	4	1
Magallana gigas	16,00	0,91	4	2
Callinectes sapidus	15,20	0,73	5	3
Hydroides elegans	14,67	1,33	3	4
Ruditapes philippinarum	14,50	0,50	4	5
Amphibalanus improvisus	14,20	0,80	5	6
Austrominius modestus	14,00	0,00	3	7
Bugula neritina	14,00	0,58	3	8
Microcosmus squamiger	14,00	0,58	3	9
Mnemiopsis leidyi	14,00	0,58	3	10
Magallana angulata	13,75	0,85	4	11
Didemnum vexillum	13,67	2,60	3	12
Acartia (Acanthacartia) tonsa	13,00	1,00	3	13
Styela plicata	13,00	1,35	4	14
Mya arenaria	12,67	2,33	3	15
Ocinebrellus inornatus	12,67	0,67	3	16
Penaeus japonicus	12,67	0,33	3	17
Artemia franciscana	12,33	0,88	3	18
Crepidula fornicata	12,33	1,20	3	19
Styela clava	12,33	2,03	3	20
Amphibalanus amphitrite	12,25	1,11	4	21
Botrylloides violaceus	12,00	2,65	3	22
Palaemon macrodactylus	12,00	0,71	4	23
Corella eumyota	11,67	1,20	3	24
Ensis leei	11,67	0,33	3	25
Watersipora scf. subtorquata	11,67	1,33	3	26
Mytilopsis leucophaeata	11,33	2,33	3	27
Amathia verticillata	11,00	2,31	3	28
Anadara transversa	11,00	2,08	3	29
Arcuatula senhousia	11,00	0,58	3	30
Blackfordia virginica	11,00	0,58	3	31
Tricellaria inopinata	11,00	1,58	4	32
Victorella pavida	11,00	1,73	3	33
Balanus trigonus	10,50	1,55	4	34
Bursatella leachi	10,00	2,00	3	35
Haloa japonica	10,00	1,00	3	36
Anadara kagoshimensis	6,00	2,27	4	37

FRESHWATER INVERTEBRATES				
Scientific name	Score	S.E.	No. of expert scorings	Order in group
Procambarus clarkii	18,67	0,61	6	1
Dreissena polymorpha	17,33	0,33	6	2
Pacifastacus leniusculus	17,33	0,99	6	3
Corbicula fluminea	17,00	0,37	6	4
Pomacea maculata	14,83	0,31	6	5
Lernaea cyprinacea	14,75	1,03	4	6
Aedes japonicus	14,60	1,03	5	7
Xenostrobus securis = Limnoperna fortunei	14,20	0,80	5	8
Aedes albopictus	14,00	0,32	5	9
Cordylophora caspia	14,00	0,77	5	10
Craspedacusta sowerbii	13,17	0,48	6	11
Potamopyrgus antipodarum	12,80	0,66	5	12
Eriocheir sinensis	12,75	0,95	4	13
Sinanodonta woodiana	12,60	1,12	5	14
Faxonius limosus	12,50	1,34	6	15
Rhithropanopeus harrisii	12,50	1,76	4	16
Anguillicoloides crassus	12,40	0,87	5	17
Cherax quadricarinatus	12,00	1,48	5	18
Argulus japonicus	11,80	2,03	5	19
Marissa cornuarietis	11,71	0,97	6	20
Cherax destructor	11,67	1,82	6	21
Physella acuta	11,50	1,20	6	22
Pectinatella magnifica	11,25	0,85	4	23
Gyrodactylus salaris	10,60	1,12	5	24
Melanoides tuberculata	9,75	0,90	6	25
Trichocorixa verticalis	9,40	1,47	5	26
Stenopelmus rufinasus	8,00	1,73	5	27

PLANTS				
Scientific name	Score	S.E.	No. of expert scorings	Order in group
Eichhornia crassipes =Pontederia crassipes	16,67	0,67	3	1
Azolla filiculoides	16,25	0,25	4	2
Ludwigia grandiflora	15,80	0,49	5	3
Salvinia natans	15,67	1,20	3	4
Salvinia molesta	15,40	1,08	5	5
Spartina densiflora	15,33	1,12	6	6
Myriophyllum aquaticum	14,40	0,81	5	7
Egeria densa	14,20	0,73	5	8
Spartina alterniflora	13,50	0,50	4	9
Ludwigia peploides subsp. *montevidensis*	13,00	1,34	5	10
Nymphaea mexicana	12,67	1,33	3	11
Elodea canadensis	12,60	1,33	5	12
Crassula aquatica	12,33	0,88	3	13
Lagarosiphon major	12,33	2,96	3	14
Myriophyllum heterophyllum	12,00	1,96	4	15
Alternanthera philoxeroides	11,67	1,45	3	16
Bacopa monnieri	11,20	1,69	5	17
Hydrocotyle ranunculoides	11,00	1,22	4	18
Pistia stratiotes	11,00	1,00	3	19
Ludwigia repens	10,33	3,48	3	20
Hydrocotyle bonariensis	9,80	1,83	5	21
Rotala indica	8,25	2,29	4	22
Hydrocotyle verticillata	6,50	1,89	4	23

VERTEBRATES				
Scientific name	Score	S.E.	No. of expert scorings	Order in group
Cyprinus carpio	18,20	0,37	5	1
Micropterus salmoides	17,17	0,40	6	2
Sander lucioperca	16,33	0,61	6	3
Gambusia holbrooki	16,20	0,73	5	4
Silurus glanis	16,20	0,37	5	5
Esox lucius	16,00	0,26	6	6
Pseudorasbora parva	15,83	0,40	6	7
Alburnus alburnus	15,80	0,58	5	8
Neovison vison	15,40	0,68	5	9
Branta canadensis	15,25	0,85	4	10
Procyon lotor	15,00	1,29	4	11
Carassius auratus	14,83	0,40	6	12
Lepomis gibbosus	14,67	0,42	6	13
Oncorhynchus mykiss	14,60	0,51	5	14
Perca fluviatilis	14,60	0,68	5	15
Trachemys scripta	14,50	0,29	4	16
Ictalurus punctatus	14,25	0,75	4	17
Salvelinus fontinalis	14,00	0,58	4	18
Ameiurus melas	13,80	1,07	5	19
Myocastor coypus	13,67	0,49	6	20
Fundulus heteroclitus	13,60	0,51	5	21
Scardinius erythrophthalmus	13,50	0,87	4	22
Carassius gibelio	13,25	0,48	4	23
Ondatra zibethicus	13,25	0,85	4	24
Threskiornis aethiopicus	13,00	0,55	5	25
Xenopus laevis	12,80	1,46	5	26
Rutilus rutilus	12,75	0,63	4	27
Pelophylax kl. grafi	12,50	0,87	4	28
Pelodiscus sinensis	12,33	0,67	3	29
Lithobates catesbeianus	12,20	0,58	5	30
Chelydra serpentina	12,00	0,95	5	31
Misgurnus anguillicaudatus	12,00	0,41	4	32
Oxyura jamaicensis	11,60	0,24	5	33
Alopochen aegyptiacus	11,50	0,65	4	34
Pseudemys concinna	11,50	0,65	4	35
Chrysemys picta	11,00	0,41	4	36
Leuciscus idus	9,50	1,04	4	37
Mauremys aff. sinensis	8,80	2,48	5	38
Acipenser baerii	8,20	1,53	5	39

Red-eared slider (*Trachemys scripta*) © Javier Murcia Requena

Appendix B

Alert list of potential aquatic invasive alien taxa with a significant risk of invasion in Iberian inland waters

List of IAS included in the alert list by target groups (vertebrates, estuarine invertebrates, freshwater invertebrates and plants). Taxa are ordered by score value (mean of three to six independent sets of scores from the expert assessment, standard error included) in each target group.

More information about taxa (synonyms, native geographic range, pathways of introduction, inclusion in IAS Regulation and key literature references) are included in the supplementary database.

ESTUARINE INVERTEBRATES				
Scientific name	Score	S.E.	No. of expert scorings	Order in group
Hydroides dirampha	15,67	1,33	3	1
Perna viridis	15,33	0,33	3	2
Rhopilema nomadica	15,00	0,00	4	3
Urosalpinx cinerea	14,25	1,44	4	4
Gammarus tigrinus	13,67	0,88	3	5
Spirorbis marioni	13,67	2,40	3	6
Phyllorhiza punctata	13,50	0,87	4	7
Brachidontes pharaonis	13,33	2,73	3	8
Rangia cuneata	12,60	1,44	5	9
Cercopagis pengoi	12,33	1,67	3	10
Portunus segnis	12,33	1,45	3	11
Botrylloides giganteum	12,00	2,65	3	12
Hemigrapsus aff. *takanoi*	12,00	1,15	3	13
Homarus americanus	11,67	1,67	3	14
Anadara aff. *inaequivalvis*	11,00	2,08	3	15
Spondylus spinosus	11,00	2,31	3	16
Dikerogammarus aff. *haemobaphes*	10,33	1,20	3	17
Hemimysis anomala	10,33	1,20	3	18
Mytilopsis adamsi	9,67	2,67	3	19
Marenzelleria neglecta	9,33	0,88	3	20
Megabalanus coccopoma	9,33	0,67	3	21
Crepidula onyx	7,33	2,19	3	22

FRESHWATER INVERTEBRATES				
Scientific name	Score	S.E.	No. of expert scorings	Order in group
Dreissena rostriformis bugensis	17,00	0,55	5	1
Procambarus virginalis	16,17	1,11	6	2
Pomacea gigas	15,25	0,75	4	3
Aedes aegypti	15,20	0,80	5	4
Faxonius rusticus	15,50	0,98	6	5
Faxonius virilis	15,17	1,17	6	6
Aedes koreicus	14,33	1,76	3	7
Cipangopaludina chinensis	14,00	0,77	6	8
Potamocorbula amurensis	13,80	2,22	5	9
Anopheles quadrimaculatus	13,17	2,14	6	10
Dikerogammarus villosus	13,00	0,45	6	11
Planorbella trivolvis	11,00	1,08	4	12
Triops longicaudatus	11,00	1,10	5	13
Cherax tenuimanus	9,80	1,77	5	14
Potamon ibericum	8,83	1,58	6	15
Gillia altilis	6,50	1,31	6	16

PLANTS				
Scientific name	Score	S.E.	No. of expert scorings	Order in group
Azolla microphylla	12,40	1,89	5	1
Hygrophila polysperma	12,40	1,03	5	2
Cabomba caroliniana	12,33	1,76	3	3
Crassula helmsii	12,33	0,88	3	4
Hydrilla verticillata	12,25	2,50	4	5
Salvinia auriculata	12,25	1,03	4	6
Spartina anglica	12,20	0,97	5	7
Gymnocoronis spilanthoides	11,00	0,91	4	8
Pontederia cordata	10,40	1,69	5	9
Elodea nuttallii	10,00	1,00	3	10
Halophila stipulacea	10,00	1,96	4	11
Zostera japonica	10,00	1,52	5	12
Nymphaea lotus	8,40	2,42	5	13
Aponogeton distachyos	7,50	1,32	4	14
Elodea callitrichoides	7,40	2,42	5	15
Vallisneria nana	7,33	3,48	3	16
Lemna turionifera	7,00	3,79	3	17
Nelumbo nucifera	6,75	2,69	4	18
Myriophyllum verrucosum	6,50	1,19	4	19
Hydrocotyle sibthorpioides	6,20	1,93	5	20
Ottelia alismoides	4,17	1,35	6	21
Potamogeton epihydrus	3,50	1,76	4	22
Hydrocotyle moschata	3,33	2,03	3	23

VERTEBRATES				
Scientific name	Score	S.E.	No. of expert scorings	Order in group
Perccottus glenii	15,20	0,58	5	1
Lates niloticus	14,80	0,73	5	2
Castor canadensis	14,67	0,80	6	3
Ctenopharyngodon idella	14,60	0,51	5	4
Channa argus	14,33	0,71	6	5
Clarias gariepinus	14,25	0,75	4	6
Oreochromis mossambicus	14,20	0,37	5	7
Neogobius melanostomus	14,00	0,77	6	8
Lepomis cyanellus	13,80	0,92	5	9
Clarias batrachus	13,75	0,48	4	10
Rhodeus amarus	13,75	1,55	4	11
Micropterus dolomieu	13,67	0,43	6	12
Gambusia affinis	13,40	0,75	5	13
Xiphophorus hellerii	13,33	0,88	3	14
Ameiurus nebulosus	13,20	1,02	5	15
Rhinella marina	13,00	0,82	4	16
Coptodon zillii	12,80	0,37	5	17
Nyctereutes procyonoides	12,75	1,70	4	18
Sander vitreus	12,75	0,25	4	19
Oncorhynchus aff. *gorbuscha*	12,50	1,19	4	20
Barbus barbus	12,40	1,12	5	21
Hypophthalmichthys molitrix	12,40	1,36	5	22
Hemichromis fasciatus	12,00	0,58	3	23
Squalius cephalus	11,75	0,85	4	24
Morone aff. *americana*	11,60	0,75	5	25
Ponticola aff. *kessleri*	11,50	1,94	4	26
Leuciscus leuciscus	10,80	0,97	5	27
Proterorhinus semilunaris	10,20	1,80	5	28

Abstract

An important goal of LIFE INVASAQUA is to develop tools that will improve management and increase the efficiency of the Early Warning and Rapid Response (EWRR) framework for Invasive Alien Species (IAS) in the Iberian Peninsula. Horizon scanning for high risk IAS is basic when implementing measures to reduce new invasions and to focus efforts on the species already recorded. We developed a transnational horizon scanning exercise focused on inland waters of Spain and Portugal in order to provide a black list of current established aquatic IAS and an alert list of potential aquatic IAS that may pose a threat to aquatic ecosystems and socio-economic sectors in the future. We followed a structured 5-steps approach for horizon scanning that combined existing evidence about IAS with an expert scoring of prioritized taxa. A total of 126 IAS were prioritised in the final black list, representing the 41.2% of alien taxa recorded in Iberian inland waters. The top 24 species had a very high risk of impact because they obtained the maximum values in the risk-assessment scoring process. Moreover, the alert list included 89 IAS with a relevant risk of invasion in the Iberian Peninsula in the future, resulting in 11 taxa on the top with a very high risk of invasion.

The resulting black list and alert list are important tools supporting the implementation of the IAS Regulation. Ultimately, the information included can be used for monitoring the achievement of the target of the EU Biodiversity Strategy for 2030 for combatting IAS, and also for the implementation of other EU policies with requirements on alien species, such as the Birds and Habitats Directives, and the Marine Strategy and Water Framework Directives.

WHAT IS LIFE INVASAQUA?

A European project that seeks to tackle aquatic invasive alien species in Spain and Portugal by increasing public and stakeholder awareness. It will contribute to improve IAS management and reduce their environmental, societal, economic and health impacts through information campaigns and the exchange of successful management solutions and practices.

HOW WILL IT BE ACHIEVED?

Creating priority lists of IAS and strategic management guidelines at the Iberian level to support and facilitate the implementation of the EU Regulation. Implementing training and information campaigns with key stakeholders. Developing communication and awareness activities through volunteering campaigns, citizen science, events with students or travelling exhibits across the Iberian Peninsula.

Coordination

UNIVERSIDAD DE MURCIA

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