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Invasive Alien Species Horizon Scanning in support of implementation of Regulation 1143/2014

Final Study Report

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Abstract

At the core of Regulation (EU) 1143/2014 is a list of invasive alien species of Union concern. An EU-level horizon scanning for species that can be added to this list was undertaken, aiming to derive at least 100 species likely to arrive, establish, spread and have an impact on native biodiversity or ecosystem services over the next ten years.

An updated methodology was put together, consisting of gathering species lists from global horizon scanning exercises and additional databases. These lists were refined, after which a rapid assessment of each species was undertaken, followed by consensus building to achieve a final list of prioritised species through an in-person workshop. This resulted in 165 species considered the most likely to enter or spread in the EU, with 57 of these presenting the highest threats to biodiversity.

Possible challenges to listing species under the Regulation were identified and discussed, such as insufficient or uncertain data, management feasibility or resource constraints, and push back by different stakeholders. Finally, 49 genera and six families were identified as taxonomic groups where a high number of invasive species would call for additional policy measures to prevent their negative impact on European biodiversity.

Resume

Au cœur du règlement (UE) n° 1143/2014 se trouve une liste d'espèces exotiques envahissantes préoccupantes pour l'Union. Un horizon scanning à l'échelle de l'UE a été mené pour identifier les espèces susceptibles d'être ajoutées à cette liste. Il visait à identifier au moins 100 espèces susceptibles d'arriver, de s'établir, de se propager et d'avoir un impact sur la biodiversité indigène ou les services écosystémiques au cours des dix prochaines années.

Une méthodologie actualisée a été élaborée, consistant à rassembler les listes d'espèces issues de les exercices d'horizon scanning mondiaux et de bases de données supplémentaires. Ces listes ont été affinées, puis une évaluation rapide de chaque espèce a été réalisée, suivie d'une recherche de consensus pour établir une liste finale d'espèces prioritaires lors d'un workshop en présentiel. Cela a abouti à une liste de 165 espèces considérées comme les plus susceptibles d'entrer ou de se propager dans l'UE, dont 57 présentent les menaces les plus importantes pour la biodiversité.

Les difficultés potentielles liées à l'inscription des espèces au Règlement ont été examinées, telles que l'insuffisance ou l'incertitude des données, la faisabilité de la gestion, les contraintes en matière de ressources et l'opposition

de différentes parties prenantes. Enfin, 49 genres et six familles ont été identifiés comme groupes taxonomiques où un nombre élevé d’espèces exotiques envahissantes nécessiterait des mesures politiques supplémentaires pour prévenir leur impact négatif sur la biodiversité européenne.

Executive Summary

The EU Biodiversity Strategy for 2030 aims to mitigate the impacts of invasive alien species (IAS) on native biodiversity, by strengthening the implementation of Regulation (EU) 1143/2014 on the prevention and management of IAS (EU IAS Regulation). A central component of this regulation is the establishment of a list of IAS of Union concern (also called Union list), which is updated periodically based on risk assessments conducted by the European Commission or Member States. The main aim of this project was to identify the IAS most likely to be introduced, establish, spread and have an impact on biodiversity or ecosystem services in the European Union (EU) over the next decade. These constitute potential candidate species for future risk assessment and subsequent listing as IAS of Union concern. More specific objectives of the project included revising the EU-level horizon scanning methodology (Task 1), undertaking a horizon scanning exercise to recommend at least 100 species across different taxonomic groups for future risk assessment (Task 2), addressing potential challenges in species listing (Task 3), and identifying taxonomic groups where additional policy measures might be needed due to the large number of potential invasive species (Task 4).

Task 1 – Update the horizon scanning methodology

The objective of Task 1 was to update the horizon scanning methodology developed and used in the previous EU-level horizon scanning exercise undertaken in 2014. This was done by first conducting a comprehensive literature review on horizon scanning exercises undertaken since 2015, which could inform methodological updates for the current horizon scanning exercise. The literature review process involved English language literature searches using standard search engines, as well as multi-language literature searches for IAS-specific horizon scans. Additionally, National Authorities and experts from various countries were contacted to retrieve any further relevant publications or reports that could inform this horizon scanning.

The search for IAS-specific horizon scans or related papers yielded a total of 74 relevant publications, 45 of these resulting from the English language searches, 20 from the multi-language searches, and nine obtained from National Authorities and additional experts. A review of the methodologies used in the horizon scanning studies for IAS revealed the consistent use of a stepwise approach, starting with the assembly of thematic groups and the compilation of species long lists. Due to the large number of potential IAS, mechanisms are developed to eliminate low risk species, while retaining those that could cause significant impacts on biodiversity, ecosystem services or human health. Species are often removed based on criteria like climate mismatch, lack of invasion history or duplication across regulatory frameworks.

The results of these searches contributed to refining the methodology of this horizon scanning exercise, by considering developments in horizon scanning

practices and incorporating new approaches to identifying and prioritising IAS risks. The updated methodology is largely similar to the one used in the previous EU-level horizon scanning, with the main changes being (1) the significant reliance on lists of species from previous horizon scans to compile the initial species long lists, (2) clearer criteria for defining "widely spread" species in the EU, and (3) the process used to refine species long lists, to some extent based on climate matching.

Task 2 – Perform a Horizon Scan

The horizon scanning process involved a series of systematic steps to identify species that can potentially pose a threat to EU biodiversity in a near future. Species were categorised into five thematic groups: plants, marine species, freshwater invertebrates, terrestrial invertebrates, and vertebrates. The methodology consisted of six key steps: (1) preparing long lists of species; (2) selecting and inviting experts; (3) refining the species lists; (4) gathering detailed information on species; (5) scoring species based on the likelihood of introduction, establishment, spread and impact; and (6) conducting an expert consensus workshop to finalise the list of prioritised species.

Step 1 entailed the creation of an extensive long list of species by consolidating data from various sources, which can be divided into three groups: previous horizon scanning exercises or related papers and reports, relevant IAS databases, and additional datasets provided by experts and National Authorities. The initial compilation of species from these sources yielded a total of 8,857 species, after removal of duplicates. This list was streamlined by ensuring the accuracy of scientific names using the GBIF (Global Biodiversity Information Facility) Backbone Taxonomy and removing synonyms and species with uncertain taxonomic status. The long list was then subjected to exclusion criteria, removing species that are, for example, native to the EU, considered widely spread in the EU, listed on the Union list or covered by any other EU Regulation (e.g. the Plant Health Directive). This resulted in a list of 5,076 species.

In Step 2, a total of 34 experts were invited to contribute to the following steps of the horizon scanning, with each expert specialising in one of the five thematic groups. These experts were all based in Europe, with 13 out of the 27 EU Member States being represented. The thematic groups each had one or two thematic lead(s) from the core project team, thus group sizes ranged from five to 12 experts.

In Step 3, in order to refine the long list of species, a climate matching exercise was undertaken for terrestrial species, which helped eliminate species unlikely to survive in EU climates. Aquatic species (both freshwater and marine) were excluded from the climate matching exercise, as this is currently not applicable to this environment. Based on this, a final long list of 4,053 species, 1,781 plants, 851 marine species, 112 freshwater invertebrates, 597 terrestrial invertebrates and 712 vertebrates, was passed on to the respective thematic groups. Thematic group leads, supported by the additional experts, streamlined these species lists further, by employing a variety of methods, for example looking for missed exclusion criteria and for potential lack of species impact. This resulted in a refined list of 667 species being shortlisted for scoring, 195 plants, 103 marine species, 28 freshwater invertebrates, 196 terrestrial invertebrates and 145 vertebrates.

In Steps 4 and 5, species were scored based on their likelihood of introduction, establishment, spread, and impact on biodiversity and ecosystem services in the EU. Each species was scored independently by at least two experts, using a 5-point scale for each criterion. An overall score was calculated for each species by multiplying the individual scores for each criterion, with a confidence level attributed to both each score and the overall score.

Under Step 6, an expert consensus workshop was held on 4th – 5th November 2024, in Brussels, Belgium. The workshop engaged the experts firstly with presentations of the work completed leading up to the workshop, including overviews of the various steps taken to compile and refine the species lists. Secondly, discussions within thematic groups were held to decide on the species to be put forward for the final consensus list. This led into discussions in plenary with all experts to reach overall consensus on the final list of species to prioritise for risk assessment. Lastly, thematic leads presented on taxa groups (genus and family level) which had been identified as having numerous candidate species for listing (see Task 4 below).

This overall process resulted in a final list of 165 risky species prioritised for risk assessment, divided into two groups: 57 species of very high risk, and 108 species of high risk, considered to be those with the highest likelihood of introduction, establishment, spread, and impact on biodiversity and ecosystem services in the EU in the next ten years. The remaining 457 species considered for the workshop, but not prioritised, were deemed of lower priority for risk assessment.

The vertebrates group represented the highest number of risky species, followed by plants, marine species, terrestrial invertebrates and freshwater invertebrates. The 57 species deemed of very high risk were predominantly marine and vertebrate species, with fewer plants and invertebrates. The risky species span eight phyla, 20 classes, 61 orders, and 99 families, with the most represented classes being Magnoliopsida for plants, Malacostraca for marine species and freshwater invertebrates, Insecta for terrestrial invertebrates, and Aves for vertebrates. The native regions of these species are diverse, with Eastern and Southeastern Asia and Northern America contributing the most, while regions such as Polynesia, Micronesia, and Melanesia contributing fewer terrestrial and freshwater species. For marine species, the Atlantic Ocean was the native region with the greatest number of risky species, followed closely by the Indo-Pacific Ocean and lastly the Pacific Ocean.

The main pathways of introduction recorded for the risky species were "Escape from Confinement" and "Transport – Stowaway". Plants are mainly introduced through horticultural escapes, while marine species often enter through ballast water and hull fouling. Freshwater invertebrates and vertebrates primarily escape from captivity (as aquarium species or pets, respectively) or, for vertebrate species, from public displays like zoos. Terrestrial invertebrates typically spread via unintended pathways, such as contaminants on commercial nursery material. In terms of the impacts caused by these risky species, competition with native species was by far the most commonly recorded impact, followed by predation and disease transmission. Marine and vertebrate species seem to cause significant disruption to ecosystem services, while plants and vertebrates primarily affect species and habitats of conservation priority. Nearly half of the risky species are already present in the EU in the wild, with a distribution that is considered very limited, with others also existing in captivity or cultivation.

Task 3 – Identify possible challenges to listing

Task 3 focused on identifying potential challenges to listing species as IAS of Union concern under the EU IAS Regulation. These challenges were broadly categorised as scientific, management, and socio-economic and political challenges.

Scientific challenges are related to the complexities and uncertainties associated with each species. Issues such as the lack of robust scientific evidence for species impact, gaps in ecological and biological knowledge, uncertainty regarding pathways of introduction and spread, and biosystematics and taxonomic uncertainty make it difficult to ascertain with confidence some species attributes, complicating the risk assessment process.

Management challenges involve the feasibility of implementing control measures for species, especially in cases where management techniques are unavailable, costly, or difficult to execute. Furthermore, differences in national policies and resources may lead to disagreements between EU Member States, complicating collaborative management efforts and the decision to list certain species.

Socio-economic and political challenges are primarily driven by the costs and economic implications of listing species. The financial burden associated with preventing, monitoring and managing IAS may deter some Member States from supporting the listing of certain species, especially when resources are limited. Economic interests of different stakeholders, such as those linked to agriculture, forestry, or the ornamental/pet trade, can also create opposition to listing species, as restrictions on trade may impact these sectors. Public resistance can further complicate listing, particularly when species hold cultural or aesthetic value, or when the ecological impacts of the species are not immediately visible to the public.

Task 4 – Identify taxonomic groups that could be invasive, but where the great number of species that are candidate for listing would call for additional measures

The main objective of Task 4 was to identify at least seven genera or families that contain a large number of species potentially eligible for listing under the EU IAS Regulation and to propose supporting policy measures to address the capacity limitations of the listing process.

A total of 49 genera and six families were identified across the five thematic groups. In the marine environment, where 13 genera were put forward, key introduction pathways, such as ballast water, hull fouling and aquaculture, require more stringent management, with the potential to strengthen linkages to policies like the International Convention for the Control and Management of Ships' Ballast Water and Sediments, and the Marine Strategy Framework Directive. For vertebrates, 11 genera and five families were identified, with species introduced via the pet trade being a significant concern. Policy recommendations include strengthening biosecurity, regulating the trade of high risk species and improving surveillance at entry points. For terrestrial invertebrates, six genera and one family were highlighted, with genera such as *Achatina* and *Apis* raising concerns due to their capacity for rapid spread, and measures like better coordination with Plant Health Authorities being proposed. For freshwater invertebrates, seven genera were identified, with ornamental trade and aquaculture being the primary pathways of introduction that need to be addressed. In plants, 12 genera were noted, with ornamental trade identified as the main pathway of introduction. Policy measures suggested included regulating ornamental trade of entire genera, rather than individual species, to prevent species substitutions in trade, as well as promoting the development and use of voluntary codes of conduct for nurseries.

Conclusions

The current horizon scanning exercise identified 165 IAS as high risk threats to EU environments over the next decade, based on their likelihood of introduction, establishment, spread, and impact on biodiversity and ecosystem services. These species are recommended for prioritisation in developing risk assessments under the EU IAS Regulation. Many of the identified species are already present in the EU, albeit in limited areas, underscoring the urgency of proactive management before they become widespread. Additionally, it is important to highlight the need for effective biosecurity protocols for those species that are currently held in confinement. Furthermore, although a number of priority species were identified and highlighted, attention should also be paid to lower priority species, which could also pose significant future risks.

Challenges faced while undertaking this exercise included the fact that some data providers sometimes contain incorrect and often incomplete data, as well as the difficulty in dealing with a very large geographical scale and substantial numbers of species. Recommendations for improving future horizon scans include developing a comprehensive and standardised process for species scoring, greater stakeholder engagement, and exploring more automated methods for continuous monitoring of potential threats. Finally, due to the unpredictability associated with the process of biological invasions, it is possible that species that have not been considered in this horizon scanning will be introduced into the EU in the future. However, the ultimate ambition is for the findings of this exercise to prompt immediate action to prevent the introduction or spread of the prioritised species, which is essential to ensure the EU's capacity to address biological invasions.

Sommaire

La stratégie de l'UE en faveur de la biodiversité à l'horizon 2030 vise à atténuer les impacts des espèces exotiques envahissantes (EEE) sur la biodiversité indigène, en renforçant la mise en œuvre du règlement (UE) n° 1143/2014 relatif à la prévention et à la gestion des EEE. Un élément central de ce règlement est l'établissement d'une liste des EEE préoccupantes pour l'Union (également appelée liste de l'Union), mise à jour périodiquement sur la base des évaluations des risques menées par la Commission européenne ou les États membres. L'objectif principal de ce projet était d'identifier les EEE les plus susceptibles d'être introduites, de s'établir, de se propager et d'avoir un impact sur la biodiversité ou les services écosystémiques dans l'Union européenne (UE) au cours de la prochaine décennie. Ces espèces constituent des candidates potentielles pour une future évaluation des risques et une inscription ultérieure sur la liste des EEE préoccupantes pour l'Union. Les objectifs plus spécifiques du projet comprenaient la révision de la méthodologie d'horizon scanning au niveau de l'UE (Tâche 1), la réalisation d'un exercice horizon scanning pour recommander au moins 100 espèces dans différents groupes taxonomiques pour une future évaluation des risques (Tâche 2), la résolution des difficultés potentielles liées à l'inscription des espèces (Tâche 3) et l'identification des groupes taxonomiques où des mesures politiques supplémentaires pourraient être nécessaires en raison du grand nombre d'espèces potentiellement invasives (Tâche 4).

Tâche 1 – Mise à jour de la méthodologie d'horizon scanning

L'objectif de la tâche 1 était de mettre à jour la méthodologie d'horizon scanning développée et utilisée lors du précédent exercice d'horizon scanning mené à l'échelle de l'UE en 2014. Pour ce faire, une analyse documentaire exhaustive des horizon scanning menés depuis 2015 a été réalisée, afin d'éclairer les mises à jour méthodologiques de l'exercice actuel. Cette analyse bibliographique comprenait des recherches bibliographiques en anglais à l'aide de moteurs de recherche standard, ainsi que des recherches bibliographiques multilingues pour les horizon scanning spécifiques aux EEE. Par ailleurs, les autorités nationales et les experts de différents pays ont été contactés afin de recueillir d'autres publications ou rapports pertinents susceptibles d'éclairer cet horizon scanning.

La recherche d'horizon scanning spécifiques aux EEE ou d'articles connexes a permis de recenser 74 publications pertinentes, dont 45 issues des recherches en anglais, 20 des recherches multilingues et neuf obtenues auprès des autorités nationales et d'autres experts. L'examen des méthodologies utilisées dans les études d'horizon scanning des EEE a révélé l'utilisation systématique d'une approche par étapes, commençant par la constitution de groupes thématiques et la compilation de listes exhaustives d'espèces. Compte tenu du grand nombre d'EEE potentielles, des mécanismes sont élaborés pour éliminer les espèces à faible risque, tout en conservant celles susceptibles d'avoir des impacts significatifs sur la biodiversité, les services écosystémiques ou la santé humaine. Les espèces sont souvent éliminées sur la base de critères tels que l'inadéquation climatique, l'absence d'historique d'invasion ou la duplication des cadres réglementaires.

Les résultats de ces recherches ont contribué à affiner la méthodologie de cet exercice d'horizon scanning, en tenant compte des évolutions des pratiques d'horizon scanning et en intégrant de nouvelles approches pour identifier et hiérarchiser les risques liés aux EEE. La méthodologie mise à jour est largement similaire à celle utilisée dans le précédent horizon scanning au niveau de l'UE, les principaux changements étant (1) le recours important aux listes d'espèces issues des horizon scanning précédents pour compiler les listes longues initiales d'espèces, (2) des critères plus clairs pour définir les espèces « largement répandues » dans l'UE, et (3) le processus utilisé pour affiner les longues listes initiales d'espèces, dans une certaine mesure en fonction de l'adéquation climatique.

Tâche 2 – Réalisation d'un horizon scanning

Le processus d'horizon scanning a consisté en une série d'étapes systématiques visant à identifier les espèces susceptibles de constituer une menace pour la biodiversité de l'UE dans un avenir proche. Les espèces ont été classées en cinq groupes thématiques : plantes, espèces marines, invertébrés d'eau douce, invertébrés terrestres et vertébrés. La méthodologie s'est articulée en six étapes clés : (1) préparation de longues listes d'espèces ; (2) sélection et invitation d'experts ; (3) affinement des listes d'espèces ; (4) collecte d'informations détaillées sur les espèces ; (5) notation des espèces en fonction de leur probabilité d'introduction, d'établissement, de propagation et d'impact ; et (6) organisation d'un workshop de consensus par les experts pour finaliser la liste des espèces prioritaires.

L'étape 1 a consisté à créer une longue liste exhaustive d'espèces en consolidant des données provenant de diverses sources, qui peuvent être divisées en trois groupes : exercices d'horizon scanning antérieurs ou articles et rapports connexes, bases de données d'EEE pertinentes et ensembles de données supplémentaires fournis par les experts et les autorités nationales. La compilation initiale des espèces à partir de ces sources a donné un total de 8.857 espèces, après suppression des doublons. Cette liste a été simplifiée en garantissant l'exactitude des noms scientifiques grâce à la taxonomie de base de GBIF (Global Biodiversity Information Facility) et en supprimant les synonymes et les espèces dont le statut taxonomique est incertain. La liste longue a ensuite été soumise à des critères d'exclusion, supprimant les espèces qui sont, par exemple, indigènes dans l'UE, considérées comme largement répandues dans l'UE, inscrites sur la liste de l'Union ou couvertes par tout autre règlement de l'UE (par exemple, le Règlement Santé des Végétaux). Cela a abouti à une liste de 5.076 espèces.

Lors de l'étape 2, 34 experts ont été invités à contribuer aux étapes suivantes de l'horizon scanning, chaque expert étant spécialisé dans l'un des cinq groupes thématiques. Ces experts étaient tous basés en Europe, 13 des 27 États membres de l'UE étant représentés. Chaque groupe thématique était dirigé par un ou deux responsables thématiques issus de l'équipe principale du projet, la taille des groupes variait donc de cinq à douze experts.

L'étape 3 a consisté à affiner la liste longue des espèces, en vérifiant la compatibilité climatique des espèces terrestres, ce qui a permis d'éliminer les espèces peu susceptibles de survivre sous les climats de l'UE. Les espèces aquatiques (d'eau douce et marines) ont été exclues de cet exercice, car celui-ci n'est actuellement pas applicable à ces environnements. Sur cette base, une liste longue finale de 4.053 espèces, dont 1.781 plantes, 851 espèces marines, 112 invertébrés d'eau douce, 597 invertébrés terrestres et 712 vertébrés, a été transmise aux groupes thématiques respectifs. Les responsables des groupes thématiques, soutenus par des experts supplémentaires, ont affiné ces listes d'espèces en utilisant diverses méthodes, notamment la recherche de critères d'exclusion non respectés et d'un éventuel manque d'impact sur les espèces. Cela a permis d'affiner la liste de 667 espèces présélectionnées pour la notation : 195 plantes, 103 espèces marines, 28 invertébrés d'eau douce, 196 invertébrés terrestres et 145 vertébrés.

Aux étapes 4 et 5, les espèces ont été notées en fonction de leur probabilité d'introduction, d'établissement, de propagation et de leur impact sur la biodiversité et les services écosystémiques dans l'UE. Chaque espèce a été notée indépendamment par au moins deux experts, selon une échelle de 5 points pour chaque critère. Une note globale a été calculée pour chaque espèce en multipliant les notes individuelles de chaque critère, un niveau de confiance étant attribué à chaque note et à la note globale.

Dans le cadre de l'étape 6, un workshop de consensus par les experts s'est tenu les 4 et 5 novembre 2024 à Bruxelles, en Belgique. Les experts ont d'abord présenté les travaux préparatoires, notamment un aperçu des différentes étapes de compilation et d'affinement des listes d'espèces. Ensuite, des discussions au sein des groupes thématiques ont eu lieu afin de déterminer les espèces à inclure dans la liste finale consensuelle. Ces discussions ont ensuite abouti à des discussions en séance plénière avec tous les experts afin de parvenir à un consensus général sur la liste finale des espèces à prioriser pour l'évaluation des risques. Enfin, les responsables thématiques ont présenté les groupes de taxons (genre et famille) identifiés comme comptant de nombreuses espèces candidates à l'inscription (voir tâche 4 ci-dessous).

Ce processus global a abouti à une liste finale de 165 espèces à risque prioritaires pour l'évaluation des risques, divisées en deux groupes : 57 espèces à très haut risque et 108 espèces à haut risque, considérées comme celles présentant la plus forte probabilité d'introduction, d'établissement, de propagation et d'impact sur la biodiversité et les services écosystémiques dans l'UE au cours des dix prochaines années. Les 463 espèces restantes prises en compte pour le workshop, mais non prioritaires, ont été jugées moins prioritaires pour l'évaluation des risques.

Le groupe des vertébrés représente le plus grand nombre d'espèces à risque, suivi des plantes, des espèces marines, des invertébrés terrestres et des invertébrés d'eau douce. Les 57 espèces considérées comme à très haut risque sont principalement des espèces marines et vertébrées, avec une proportion plus faible de plantes et d'invertébrés. Les espèces à risque se répartissent en huit embranchements, 20 classes, 61 ordres et 99 familles, les classes les plus représentées étant les Magnoliopsida pour les plantes, les Malacostraca pour les espèces marines et les invertébrés d'eau douce, les Insecta pour les invertébrés terrestres et les Aves pour les vertébrés. Les régions d'origine de ces espèces sont diverses : l'Asie de l'Est et du Sud-Est et l'Amérique du Nord y contribuent le plus, tandis que des régions comme la Polynésie, la Micronésie et la Mélanésie y contribuent moins en espèces terrestres et d'eau douce. Pour les espèces marines, l'océan Atlantique est la région d'origine comptant le plus grand nombre d'espèces à risque, suivi de près par l'océan Indo-Pacifique et enfin par l'océan Pacifique.

Les principales voies d'introduction enregistrées pour les espèces à risque sont « Évasion de captivité» et « Transport – Passager clandestin ». Les plantes sont principalement introduites par des évasions horticoles, tandis que les espèces marines sont souvent introduites par les eaux de ballast et les biosalissures de coque. Les invertébrés et les vertébrés d'eau douce s'échappent principalement de captivité (comme espèces d'aquarium ou comme animaux de compagnie, respectivement) ou, pour les espèces vertébrées, de lieux d'exposition publique comme les zoos. Les invertébrés terrestres se propagent généralement par des voies non intentionnelles, telles que les contaminants présents sur le matériel de pépinière. Concernant les impacts causés par ces espèces à risque, la compétition avec les espèces indigènes était de loin l'impact le plus fréquemment enregistré, suivi par la prédation et la transmission de maladies. Les espèces marines et vertébrées semblent perturber considérablement les services écosystémiques, tandis que les plantes et les vertébrés affectent principalement les espèces et les habitats prioritaires pour la conservation. Près de la moitié des espèces à risque sont déjà présentes dans l'UE à l'état sauvage, avec une répartition considérée comme très limitée, d'autres étant également présentes en captivité ou en culture.

Tâche 3 – Identification des difficultés potentielles liées à l'inscription

La tâche 3 visait à identifier les difficultés potentielles liées à l'inscription des espèces comme EEE préoccupantes pour l'Union en vertu du règlement de l'UE sur les EEE. Ces difficultés ont été globalement classées comme étant d'ordre scientifique, de gestion, socio-économique et politique.

Les difficultés scientifiques sont liées à la complexité et aux incertitudes associées à chaque espèce. Des problèmes tels que le manque de preuves scientifiques solides concernant l'impact des espèces, les lacunes dans les connaissances écologiques et biologiques, l'incertitude concernant les voies d'introduction et de propagation, ainsi que l'incertitude biosystématique et taxonomique, rendent difficile la détermination fiable de certaines caractéristiques des espèces, ce qui complique le processus d'évaluation des risques.

Les difficultés de gestion concernent la faisabilité de la mise en œuvre de mesures de contrôle pour les espèces, en particulier lorsque les techniques de gestion sont indisponibles, coûteuses ou difficiles à mettre en œuvre. De plus, les différences entre les politiques et les ressources nationales peuvent entraîner des désaccords entre les États membres de l'UE, ce qui complique les efforts de gestion collaborative et la décision d'inscrire certaines espèces.

Les difficultés socio-économiques et politiques sont principalement liées aux coûts et aux implications économiques de l'inscription des espèces. La charge financière liée à la prévention, à la surveillance et à la gestion des EEE peut dissuader certains États membres de soutenir l'inscription de certaines espèces, notamment lorsque les ressources sont limitées. Les intérêts économiques de différentes parties prenantes, notamment celles liées à l'agriculture, à la foresterie ou au commerce des animaux de compagnie et d'ornement, peuvent également susciter une opposition à l'inscription d'espèces, car les restrictions commerciales peuvent impacter ces secteurs. La résistance du public peut compliquer davantage l'inscription, notamment lorsque les espèces ont une valeur culturelle ou esthétique, ou lorsque leurs impacts écologiques ne sont pas immédiatement visibles pour le public.

Tâche 4 – Identification des groupes taxonomiques potentiellement invasifs, pour lesquels le grand nombre d'espèces candidates à l'inscription nécessiterait des mesures supplémentaires

L'objectif principal de la tâche 4 était d'identifier au moins sept genres ou familles contenant un grand nombre d'espèces potentiellement éligibles à l'inscription au règlement de l'UE sur les EEE, et de proposer des mesures politiques d'accompagnement pour pallier les limites de capacité du processus d'inscription.

Au total, 49 genres et six familles ont été identifiés dans les cinq groupes thématiques. En milieu marin, où 13 genres ont été proposés, les principales voies d'introduction, telles que les eaux de ballast, les biosalissures de coque et l'aquaculture, nécessitent une gestion plus rigoureuse, avec le potentiel de renforcer les liens avec des politiques telles que la Convention internationale pour le contrôle et la gestion des eaux de ballast et sédiments des navires et la Directive-cadre « Stratégie pour le milieu marin ». Pour les vertébrés, 11 genres et cinq familles ont été identifiés, les espèces introduites via le commerce des animaux de compagnie étant une préoccupation majeure. Les recommandations politiques comprennent le renforcement de la biosécurité, la réglementation du commerce des espèces à haut risque et l'amélioration de la surveillance aux points d'entrée. Pour les invertébrés terrestres, six genres et une famille ont été identifiés. Des genres comme *Achatina* et *Apis* suscitent des inquiétudes en raison de leur capacité de propagation rapide. Des mesures, comme une meilleure coordination avec les autorités phytosanitaires, sont proposées. Pour les invertébrés d'eau douce, sept genres ont été identifiés, le commerce ornemental et l'aquaculture étant les principales voies d'introduction à traiter. Pour les plantes, 12 genres ont été recensés, le commerce horticole étant identifié comme la principale voie d'introduction. Les mesures politiques suggérées comprenaient la réglementation du commerce horticole de genres entiers, plutôt que d'espèces individuelles, afin d'empêcher les substitutions d'espèces dans le commerce, ainsi que la promotion de l'élaboration et de l'utilisation de codes de conduite volontaires pour le secteur horticole.

Conclusions

L'exercice d'horizon scanning actuel a identifié 165 espèces exotiques envahissantes (EEE) présentant un risque élevé pour l'environnement de l'UE au cours de la prochaine décennie, compte tenu de leur probabilité d'introduction, d'établissement, de propagation et de leur impact sur la biodiversité et les services écosystémiques. Il est recommandé de prioriser ces espèces dans le cadre des évaluations des risques pour le règlement européen sur les EEE. Nombre des espèces identifiées sont déjà présentes dans l'UE, bien que dans des zones limitées, ce qui souligne l'urgence d'une gestion proactive avant leur propagation. De plus, il est important de souligner la nécessité de protocoles de biosécurité efficaces pour les espèces actuellement détenues en captivité. Par ailleurs, bien que plusieurs espèces prioritaires aient été identifiées et mises en évidence, il convient également de prêter attention aux espèces moins prioritaires, qui pourraient également présenter des risques futurs importants.

Les difficultés rencontrées lors de cet exercice comprennent le fait que certains fournisseurs de données fournissent parfois des données erronées et souvent incomplètes, ainsi que la difficulté de traiter une très grande échelle géographique et un nombre important d'espèces. Les recommandations pour améliorer les analyses prospectives futures comprennent l'élaboration d'un processus complet et standardisé de notation des espèces, une plus grande implication des parties prenantes et l'exploration de méthodes plus automatisées pour une surveillance continue des menaces potentielles. Enfin, en raison de l'imprévisibilité du processus d'invasion biologique, il est possible que des espèces non prises en compte dans cet horizon scanning soient introduites dans l'UE à l'avenir. Cependant, l'objectif ultime est que les conclusions de cet exercice incitent à prendre des mesures immédiates pour prévenir l'introduction ou la propagation des espèces prioritaires, ce qui est essentiel pour garantir la capacité de l'UE à faire face aux invasions biologiques.

1. Project background, aims and team

The EU Biodiversity Strategy for 2030 includes the commitment to reduce the adverse impacts posed by invasive alien species (IAS) on native biodiversity. To achieve this, the European Commission (EC) aims to step up the implementation of Regulation (EU) 1143/2014 on the prevention and management of the introduction and spread of invasive alien species (hereafter EU IAS Regulation), which entered into force in 2015. The Regulation includes a set of measures to be taken by all EU Member States (MS), focusing on three main pillars: prevention; early detection and rapid response; and management of invasive alien species.

At the core of the EU IAS Regulation is a list of invasive alien species of Union concern. The species included on this list are subject to various restrictions, including on keeping, importing, selling, and breeding. The list of IAS of Union concern was firstly established through Commission Implementing Regulation (EU) 2016/1141 and further updated by Commission Implementing Regulations (EU) 2017/1263, (EU) 2019/1262 and (EU) 2022/1203, with more updates foreseen, including one in 2025. The establishment of the list of IAS of Union concern is based on species risk assessments that are proposed and developed by either the EC or MS, and these species will ultimately need to comply with the criteria for listing cf. Art 4(3) and 4(6) of the EU IAS Regulation.

Following from this, the aim of this Tender is to “scan the horizon” of various groups of species, in order to determine the best candidates for risk assessment, prior to their possible listing as IAS of Union concern. To date, the main source of species indicated as good candidates to be risk assessed has been Roy *et al*. (2015), a study commissioned by the EC on ‘IAS – Prioritising prevention efforts through horizon scanning’ undertaken in 2014 (further published as Roy *et al*., 2019a). However, many of the candidate species stemming from this 2014 horizon scanning exercise have already been dealt with, either having become IAS of Union concern or having been excluded from the listing process for various reasons. Moreover, ideally, to anticipate future invasive alien species problems, the identification of potential high impact species through horizon scans should be repeated at regular intervals (e.g. 5 - 10 years; e.g. O’Shaughnessy *et al*. 2023). As such, the abovementioned study needed to be updated, notably to consider new scientific evidence and knowledge that has since emerged. This will ensure that species selected to undergo a risk assessment suggested by the EC are more likely to meet the criteria required, and increase the likelihood that their listing will be supported by MS.

The main goal of the current horizon scanning exercise is to derive a list of IAS that are likely to arrive, establish, spread and have an impact on native biodiversity or associated ecosystem services in the EU over the next 10 years. In particular, the specific objectives of the study are to:

1. Revisit the horizon scanning methodology developed under Roy *et al*. (2015) and apply any necessary updates to it.
2. Provide a recommendation of at least 100 species to be risk assessed, covering six taxonomic groups: terrestrial and aquatic vertebrates, terrestrial and aquatic plants, and terrestrial and aquatic invertebrates.
3. Consider possible challenges for listing the species recommended to be risk assessed.
4. Investigate taxonomic groups where the great number of species would call for additional policy measures to prevent their negative impact on European biodiversity.

Taking the above into account, the work developed under this project was divided into four main tasks (Figure 1), which are described in more detail in the sections below:

- **Task 1:** Update the horizon scanning methodology,
- **Task 2:** Perform a horizon scanning,
- **Task 3:** Identify possible challenges to listing,
- **Task 4:** Identify taxonomic groups that could be invasive, but where the great number of species that are candidate for listing would call for additional measures.

This project was led by members of the IUCN Secretariat based both in Cambridge (UK) and Brussels (Belgium), and by an additional Core Expert Group composed of seven leading and experienced IAS experts based in six different European countries (Figure 2).

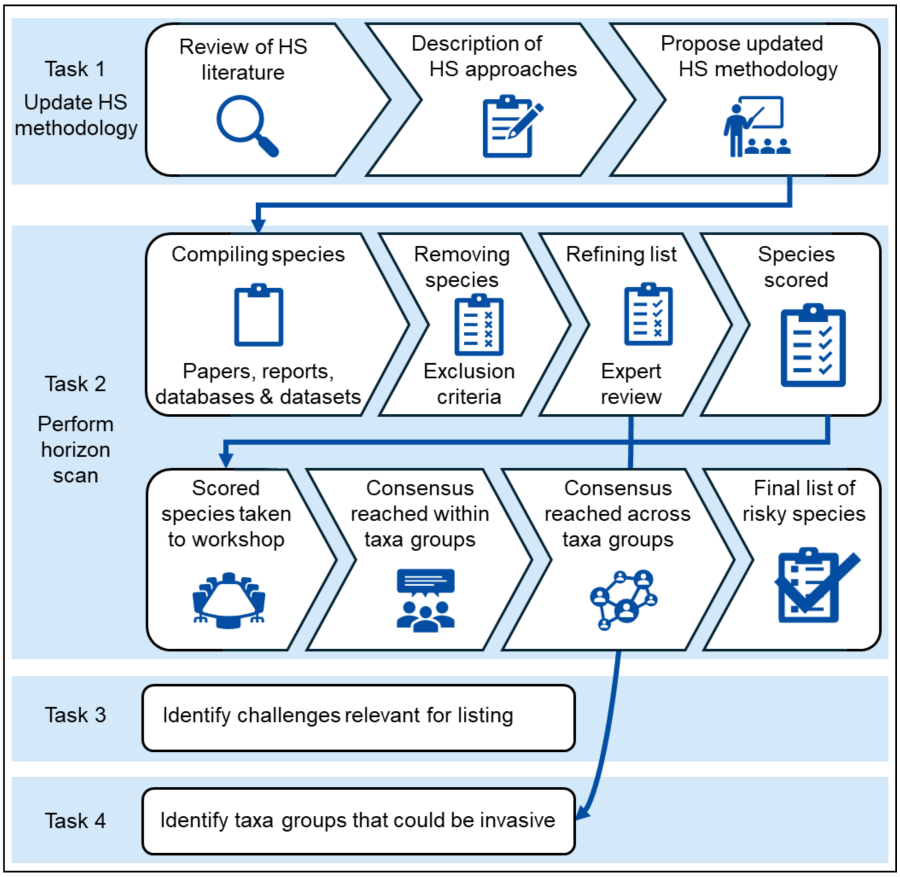

Figure 1. The four different tasks developed under this project. HS stands for Horizon Scanning.

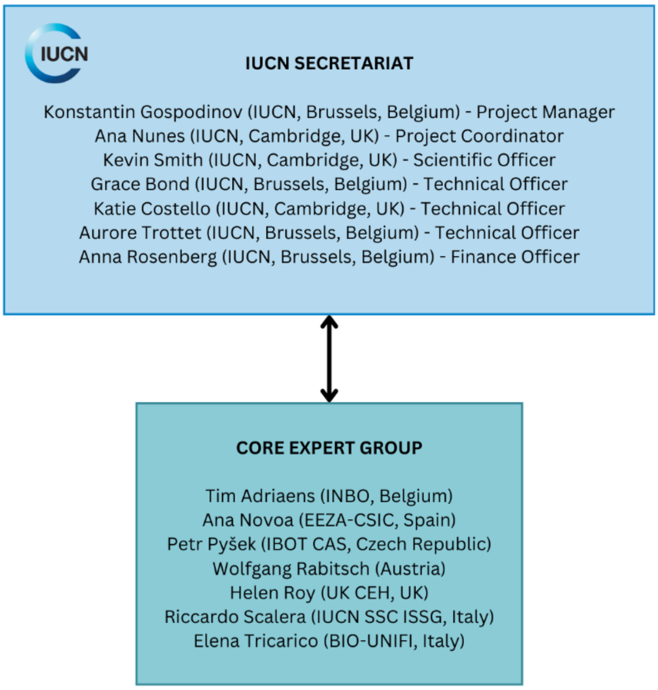

Figure 2. Project team structure.

2. Task 1 – Update the horizon scanning methodology

2.1. Task objective

The first task of this project aimed to produce an inventory of the literature relating to horizon scanning published since 2015, *inter alia* for invasive alien species (IAS), including scientific publications as well as policy-related reports or material. A further aim was to use the results stemming from this review to recommend appropriate updates to the horizon scanning methodology developed under Roy *et al*. (2015). This updated methodology was then to be applied to perform the current horizon scanning exercise.

2.2. Task 1. Part 1 – Literature review of horizon scanning methodologies

Taking the information provided by Roy *et al*. (2015) into consideration and using it as a baseline, potential developments in horizon scanning methodologies since 2015 that could be useful to suggest updates to the horizon scanning methodology to be used in this project were investigated. This was done by (i) conducting English-language literature searches through standard search engines for both general horizon scans and those focused on IAS, (ii) conducting multi-language literature searches using the linguistic skills of the project team for IAS-specific horizon scans and (iii) contacting National Authorities from various countries (in the EU and beyond), as well as additional experts, to retrieve any further relevant additional publications or reports also focused on IAS-specific horizon scans. These steps were also taken in order to retrieve as many lists of IAS generated by previous horizon scanning exercises as possible that could be used in this study. More specific details on the activities developed under each of these steps are discussed in the sub-sections below.

2.2.1. Literature searches for general horizon scanning exercises

Firstly, an English-language literature search on the topic of horizon scanning was done using the search engine ISI Web of Science (WoS). The temporal range of the search was from January 2015 – July 2024 (to account for pre-prints) but, as Roy *et al.* (2015) encompasses several publications dated from 2015 already, only documents published in 2015 that had not been addressed in that study were considered here.

In line with the methodology of Roy *et al.* (2015), ISI Web of Science was used as the starting point to capture information on potential developments of horizon scanning methods (or aspects of those) in different fields, which might be relevant for assessment and critical review. For this, in March – April 2024, a search using the general key search term "Horizon Scanning" (limited to the time range mentioned above) was carried out, retrieving 8,181 hits, most of which largely pertaining to the fields of 'Materials Science', 'Chemistry' and 'Physics'. A refinement of the search to the Research Area 'Environmental Sciences Ecology' still delivered 458 hits, many of which were not relevant to the general topic studied here (e.g. bacterial pathogens, robotics, laser scanning). As such, to further refine and improve the focus of the publications retrieved, and again similarly to what was done by Roy *et al.* (2015), the search was filtered to the Research Area 'Biodiversity Conservation', retrieving 77 hits. The abstracts of these 77 publications were screened and, for all cases which referred to a horizon scanning exercise, with potentially relevant methodological information, details were extracted from the corresponding papers using a pre-defined template (Table 1). Studies pertaining to the field of biological invasions that aimed to identify and/or prioritise issues of relevance to the field were incorporated in Table 1; however, publications with the aim of scanning and prioritising lists of potential IAS (i.e. IAS horizon scanning exercises) were deferred to Table 2, so that more exhaustive information could be retrieved from those (see details below).

Out of the 77 publications found, a total of 37 papers were deemed to be relevant horizon scanning exercises. However, out of those, 19 publications were horizon scanning exercises aimed at creating lists of potential priority IAS (all but two, of which were also retrieved through the more focused IAS-search described below), and therefore details on those publications are showcased in Table 2. Information on the remaining 18 relevant publications is compiled in Table 1 (Figure 3).

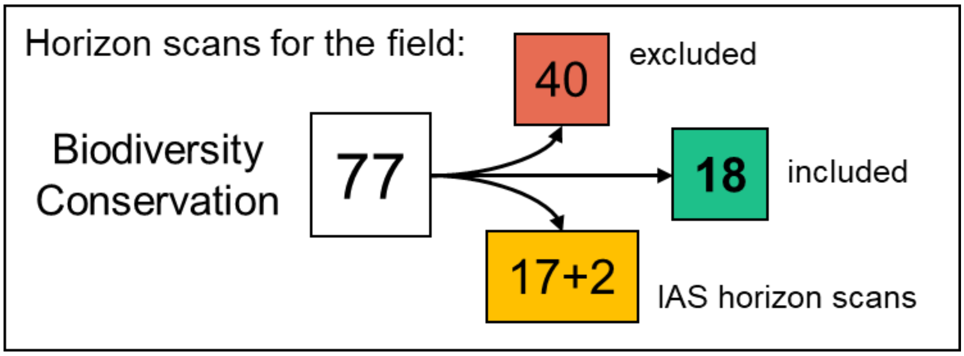

Figure 3. Number of horizon scanning scientific papers found in Web of Science for the Research Area 'Biodiversity Conservation' from January 2015 to July 2024.

2.2.2. Literature searches for IAS-focused horizon scanning exercises

As a large number of horizon scanning exercises have been performed at various scales for potential forthcoming IAS in Europe and around the world since 2015, in order to ensure that the methodologies of all these exercises were screened and captured in detail (as well as the species lists generated by those, if relevant; see Task 2 for more details), an additional and more focused search on these was performed. This search was done both by using Web of Science, as before, but additionally Google Scholar, for a more comprehensive retrieval of information. Furthermore, the search was done in English and in several other EU languages (see more information below). Beyond this, experts added any studies they deemed relevant to supplement the literature searches.

2.2.2.1. English language literature searches

In March – April 2024, a search in Web of Science using the key search terms "Horizon Scanning Alien Species", limited to the time range mentioned above (January 2015 – July 2024 to account for pre-prints) was performed, retrieving 59 results. A quick additional search using the search terms 'non-native' and 'non-indigenous' and 'introduced' was also performed but, as this retrieved less results, it was discarded.

The abstracts of the 59 publications were screened and, out of those, 26 were considered relevant for further analysis. For those, an assessment of their full texts was undertaken in order to retrieve details on the methodologies used, and on any different and potentially innovative methodological aspects, which were then captured through a different template shown below (Table 2). As mentioned above, two of the publications found through the general horizon scanning search (Hughes *et al*. 2020, Arianoutsou *et al*. 2023) were also analysed here and details on those added to Table 2.

As mentioned above, a supplementary search was performed on Google Scholar, using the same key search terms "Horizon Scanning Alien Species", again limited to the time range 2015 – 2024. The approach taken for Google Scholar, however, slightly differed to that used for Web of Science, due to the extremely high number of publications returned by this search engine. A search conducted in June 2024 considering the parameters outlined above returned 13,600 results. Given that analysing this number of publications was not feasible, and very likely would not lead to many additional relevant resources, a cap was placed on screening the titles of the first 10 pages of results obtained (100 records), to retrieve potential studies not captured through the Web of Science search.

Table 1. Horizon scanning (HS) publications pertaining to the Research Area 'Biodiversity Conservation' (other than for creating priority lists of IAS) from January 2015 to July 2024, extracted using Web of Science, here presented in chronological order.

Reference	Title	Main objective	Brief description of methods used	Aspects potentially relevant for update of HS methodology
Campbell *et al*. (2015)	**The next generation of rodent eradications: Innovative technologies and tools to improve species specificity and increase their feasibility on islands**	Identify the most promising technologies, techniques and approaches that might be applied to rodent eradications from islands.	(1) Innovation ideas gathered through interviews, literature searches and creative-thinking techniques; (2) review and selection by panel; (3) additional review and scoring against criteria; (4) additional identification of specialists, holding workshops or attend training sessions to develop ideas further.	- The use of interviews to gather expert knowledge. - Having a timeframe for the availability of promising techniques.
Kamp *et al*. (2016)	**Persistent and novel threats to the biodiversity of Kazakhstan's steppes and semi-deserts**	Assess current and emerging threats to steppe and semi-desert biodiversity in Kazakhstan and evaluate conservation research priorities.	(1) Initial list compiled through literature review, social networks, newspaper archives, expert knowledge and government statistics/documents; (2) experts list additional threats; (3) experts score final list against criteria; (4) scores for each criterion averaged and ranked in an interval scale; (5) threats featuring on either (or all) the lists compiled; (6) evaluate degree of agreement between rankers.	- The use of social network platforms to compile initial lists. - Considering the use of an interval, rather than an ordered categorical, scale. - Threats shortlisted for each criterion.

Reference	Title	Main objective	Brief description of methods used	Aspects potentially relevant for update of HS methodology
Roy *et al*. (2017)	**Alien Pathogens on the Horizon: Opportunities for Predicting their Threat to Wildlife**	Identify knowledge gaps, research priorities, and policy recommendations with respect to alien pathogens threatening wildlife.	(1) Horizon scanning workshop; (2) use of standard consensus methods as per Roy *et al*. 2014 (on which Roy *et al*. 2015 is largely based).	NA
Prescott *et al*. (2017)	**Political transition and emergent forest-conservation issues in Myanmar**	Identify the most important issues likely to affect forests in Myanmar over ten years.	(1) Experts submit relevant issues; (2) issues distilled, returned to experts for evaluation and submission of additional issues; (3) workshop: issues split into four sets and discussed by two groups of experts; (4) workshop: issues discussed by entire group and top 40 selected (but not ranked).	- Discussion of the same issues by two groups of experts. - No ranking of prioritised issues.
Dehnen-Schmutz *et al*. (2018)	**Alien futures: What is on the horizon for biological invasions?**	Identify the issues that may affect the future global and local management of biological invasions in the next 20 – 50 years and provide guidance for the prioritisation of actions/policies.	(1) Online survey to poll experts on the most important issues; (2) categorisation of issues into topics; (3) ranking of issues based on the number of respondents.	---

Reference	Title	Main objective	Brief description of methods used	Aspects potentially relevant for update of HS methodology
Gleason *et al*. (2018)	**Horizon Scanning: Survey and Research Priorities for Coastal and Marine Systems of the Northern Channel Islands, California**	Identify research and archiving priorities to enhance documentation of the past and present conditions of coastal and marine ecosystems of the northern Channel Islands, California.	(1) Inquiry focused on three questions; (2) workshop for participants to identify sources of information; (3) grouping sources into seven categories; (4) unclear how priorities were established.	- The use of historical data and/or archives to retrieve relevant information.
Rick *et al*. (2018)	**Horizon scanning: survey and research priorities for cultural, historical, and paleobiological resources of Santa Cruz Island, California**	Utilise research on Santa Cruz Island's past and present to help better prepare for the future and plan for forecast change.	(1) Hold two workshops focused on three main questions.	---
Bauer *et al*. (2019)	**The grand challenges of migration ecology that radar aeroecology can help answer**	Identify the most important challenges to overcome in order to gain understanding of migration ecology, which could be addressed using radar aeroecological and macroecological approaches.	(1) Expert workshop to compile list of challenges; (2) list circulated among 135 leading experts for prioritisation and scoring; (3) scores used to select the highest-ranked questions; (4) questions classified into themes; (5) post-hoc assessment of novelty/urgency of challenges.	- Challenges plotted along gradients of urgency and novelty (assessed post-hoc).
Cooke *et al*. (2020)	**Reframing conservation physiology to be more inclusive, integrative, relevant and forward-**	Explore ways in which conservation physiology can be more relevant to pressing	(1) Editorial Board members of *Conservation Physiology* generate a list of topics; (2) teams	---

Reference	Title	Main objective	Brief description of methods used	Aspects potentially relevant for update of HS methodology
	looking: reflections and a horizon scan	conservation issues of today, as well as more forward-looking to inform emerging issues and policies for tomorrow.	of two – four craft each section; (3) all co-authors edit/refine sections.	
Esmail *et al*. (2020)	**Emerging illegal wildlife trade issues: A global horizon scan**	Scan for significant emerging illegal wildlife trade issues.	(1) Open online platform used to remotely engage many contributors; (2) issues elicited from contributors and their networks; (3) initial list organised/anonymised by facilitators; (4) consolidated list circulated to assessors; (5) assessors score each issue based on criteria, these are ranked and top 45 are shortlisted; (6) opportunity to re-add issues not shortlisted through scoring; (7) each assessor assigned four – five issues to investigate, each issue examined by two – three people; (8) authors discuss issues via online forum and have second scoring round; 9) final top 20 ranked list produced; (10) facilitators rework 20 issues descriptions; (11) 12 external reviewers check issues relevance/descriptions	- The use of an open online platform (translated into 29 languages) to gather ideas from a very wide network of contributors. - Possibility of re-adding issues not shortlisted through scoring. - The use of an online forum for authors to discuss issues.
Wintle *et al*. (2020)	**Scanning horizons in research, policy and practice**	Describe approaches to horizon scanning exercises and provide case study examples.	Description of general and specific approaches to horizon scanning, outlining the main stages of the process and providing examples. (1)	- Evaluation of the horizon scanning process and

Reference	Title	Main objective	Brief description of methods used	Aspects potentially relevant for update of HS methodology
			Scoping; (2) gathering inputs; (3) sorting/clustering; (4) analysing/prioritising; (5) using the output; (6) evaluating the process.	engagement with various stakeholders for that process.
Gluszek *et al*. (2021)	**Emerging trends of the illegal wildlife trade in Mesoamerica**	Identify emerging trends of the illegal wildlife trade in Mesoamerica.	(1) Map and select experts; (2) expert elicitation through structured interviews; (3) first ranking of issues through online survey; (4) discussion through online focus group to refine issues; (5) second ranking through online survey.	- The use of persuasive writing techniques to improve response rates of experts. - The use of an online survey for experts to score and rank issues.
Evans and Drake (2022)	**A Data-driven Horizon Scan of Bacterial Pathogens at the Wildlife–livestock Interface**	Conduct a data-driven horizon scan of bacterial associations at the wildlife–livestock interface for cows, sheep, and pigs.	(1) Build a species interaction network of mammal-bacterium associations from three datasets; (2) compilation of data on various attributes of the mammals and bacteria in focus; (3) creation of covariates and assessment of collinearity; (4) use of machine learning model to estimate the propensity of each host-bacterium association (based on life-history traits and phylogenetic relationships); (5) performing sensitivity analyses to assess robustness of the findings.	- Calculation of species continental and habitat breadth. - The use of genus-level values/means to estimate life-history traits for which there is no species-level information.

Reference	Title	Main objective	Brief description of methods used	Aspects potentially relevant for update of HS methodology
Shiffman *et al*. (2022)	**The next generation of conservation research and policy priorities for threatened and exploited chondrichthyan fishes in the United States: An expert solicitation approach**	Create a list of research and policy priorities for chondrichthyan species of conservation concern in US waters.	(1) Identification of focal species based on criteria; (2) identification and contacting of experts; (3) gather priorities through a survey part 1; (4) combine and rephrase priorities; (5) experts comment on priorities and rank them through survey part 2.	---
Aldridge *et al*. (2023)	**Freshwater mussel conservation: A global horizon scan of emerging threats and opportunities**	Identify emerging threats and opportunities for addressing the global conservation of freshwater mussels over the next decade.	(1) Experts identify emerging topics; (2) Delphi approach with iterative rounds of voting: topics synopses anonymised, put in random order and ranked by experts; (3) average rank by synopsis circulated to experts; (4) online meeting to discuss topics; (5) experts re-rank topic synopses using same scoring criteria; (6) new average rank by synopsis circulated to experts; (7) new online meeting to discuss new rankings and collectively select highest ranked.	- Topics synopses assembled in random order before recirculated to experts. - Comparison of the average interquartile range in rankings for each synopsis in the two separate rankings.
Maasri *et al*. (2023)	**Wet-grassland breeding bird conservation in Germany: current status and future perspectives**	Identify the current strengths, weaknesses, future opportunities, and threats for wet-grassland breeding bird conservation across Germany.	(1) Online survey to collect experts' information and gather issues (for six months); (2) results summarised and distributed to experts; (3) online workshops for each region of Germany to discuss and finalise results.	---

Reference	Title	Main objective	Brief description of methods used	Aspects potentially relevant for update of HS methodology
Rowland *et al*. (2023)	**Setting research priorities for effective management of a threatened ecosystem: Australian alpine and subalpine peatland**	Undertake a research prioritisation process for Australian alpine and subalpine peatlands.	(1) Individual virtual interviews for experts to identify challenges; (2) information collated and arranged by theme; (3) virtual workshop1 with group discussions to review questions; (4) online survey1 to identify extra questions; (5) virtual workshop2 to review questions; (6) online survey2 for experts to vote top20; (7) questions divided into gold, silver and bronze; (8) gold and silver questions reviewed at workshop3 and refined through online survey3.	- Questions divided into gold, silver and bronze categories based on number of votes; gold questions automatically included, silver ones discussed and top ten included, bronze ones reviewed.
Williams *et al*. (2023)	**The future of fish and fisheries in Australia: prioritisation of research needs through a horizon scanning approach**	Identify the key research priorities for fish and fisheries research in Australia, across seven thematic fields of study.	(1) Literature searches and collation of organisational mailing lists to establish and invite experts; (2) participants submitted research questions through online survey; (3) similar entries combined and all questions classified into themes; (4) questions scored through a prioritisation online survey; (5) final prioritisation matrix averaged across participants to identify ten priority questions for each of the seven themes.	- The use of online surveys to engage with experts and undertake all steps of the exercise.

Indeed, screening of the first 100 entries in Google Scholar only returned 17 new publications considered relevant for further analysis and not yet captured through the previous search. In addition, towards the end of screening those 100 records, new publications were no longer being found, indicating that this was a suitable approach to take. Collectively, a total of 45 publications (26 WoS IAS + 17 Google Scholar IAS + 2 WoS general) referring to horizon scanning exercises performed for IAS was captured through these searches and their methodologies are explained in detail in Table 2 below (Figure 4).

2.2.2.2. Multi-language literature searches

Taking advantage of the fact that the project team members possess the capacity to work in multiple EU languages (in addition to English), additional multi-language literature searches were also conducted. The aim of these additional searches was both to look for different methodologies of interest, but also to gather information on lists of species at national/regional level that could be used to compile long lists of species for this study.

These searches were restricted to the linguistic capabilities of the project's team and consisted of focused searches for horizon scanning exercises on IAS. Also here, these were done using both Web of Science and Google Scholar, with the same key search terms as those mentioned above ("Horizon Scanning Alien Species"), but with the terms translated to the respective different languages in focus. The time range used was also the same as for the other searches, 2015 – 2024. The nine different EU languages for which the searches were performed are Bulgarian, Croatian, Czech, Dutch, French, German, Italian, Portuguese and Spanish. Table 3 lists these languages, alongside the specific members of the team of experts who conducted the searches for each of them. It is important to note that various experts struggled to translate the search terms into their languages, as often work performed on this area is published in English, so for some languages the term 'horizon scanning' was kept, as it is actually used as such in different languages.

All of the searches performed in Web of Science returned zero results for all of the nine languages, probably reflecting this search engine as not very inclusive for capturing publications in languages other than English. On the other hand, the searches performed using Google Scholar returned a variable number of results, ranging from zero in Czech to 15.100 in Portuguese (Table 3). For the latter, which is due to a very high number of scientific papers or reports published in Portuguese from Brazil, only the results stemming from the first 10 pages were investigated.

Different numbers of publications were screened through their abstracts for potential relevance in each language. One of those was found relevant in Croatian, German and Spanish, two in Italian and the largest number of relevant publications (45) was found in Dutch, illustrating a proportionally higher amount of work on horizon scanning and broad scale risk assessment in the Netherlands and Belgium in the time period considered (Figure 4). Further details on these publications, including brief details on their methodologies and other parameters of the exercises, are shown in Tables 4 and 12.

Table 2. Brief description of methods used and potential relevant/innovative methodological aspects of those since Roy *et al*. 2015 (and 2019a) for publications, at a global level, on IAS horizon scans performed from 2015 – 2024. Publications are presented in chronological order, per their source i.e. indicating if they were retrieved through the Web of Science (WoS) or Google Scholar (GS) English searches for IAS horizon scans, or through the general horizon scan search (WoS – gen HS). Environmental coverage refers to the type of ecosystem covered by the horizon scanning (freshwater FW, marine MAR, or terrestrial TERR). For more details from each of these publications, see Table 12.

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Gallardo *et al*. (2016)	**Trans-national horizon scanning for invasive non-native species: a case study in western Europe**	FW/TER/MAR	(1) Screen national and international lists of 'the worst' species to compile a meta-list of problematic invaders worldwide; (2) evaluate presence/absence of these problematic species in each the four countries concerned; (3) rank high-risk species INNS currently absent from all four countries (Alert List); and (4) identify the most problematic species present in at least one of the four countries (Black List).	To prioritise species on the Alert List, each species was assigned four risk scores based on (i) its likelihood of introduction, establishment and spread (invasive potential score), (ii) likelihood and magnitude of ecological impact, (iii) likelihood and magnitude of economic impact, and (iv) reversibility of the invasion (management difficulty score) by experts. Given the high numbers on the Black List, species were prioritised by dividing into four groups (terrestrial plants and fungi, terrestrial animals, freshwater organisms and marine organisms) and designing an online survey asking experts to select ten species from their group considered the most concerning in terms of current and/or potential environmental and socio-economic impacts. An interrater reliability	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
				(IRR) analysis was performed to assess consistency between voters.	
Karachle *et al*. (2017)	**Setting-up a billboard of marine invasive species in the ESENIAS area: current situation and future expectancies**	MAR	Approach for the ESENIAS region (East and South European Network for IAS). (1) List of invasive/potential invasive species drawn up, including invasive species present in the ESENIAS area, invasive species that had not yet exhibited invasive behaviour in ESENIAS countries and invasive species in European seas likely to invade ESENIAS countries; (2) species were classed for the ESENIAS region (from literature and expert judgement) as established, casual, invasive, unknown or expected; (3) factsheets were produced for the ten species considered of high importance using expert opinion. This was based on their expanding/invading character and existing data on invasion history.	Cryptogenic species were not considered. Not a significantly different methodology, but condensed in comparison to Roy *et al*. methodology.	WoS
Matthews *et al*. (2017)	**A new approach to horizon-scanning: identifying potentially invasive alien species and their**	FW/TER/MAR	Species lists were gathered based on climate matching to the target region. Risk classifications were then collected for each species (taken from different classification systems based on watchlists/black lists/alert lists, low/medium/high scores etc. - any different classification system can be included). These classifications were then harmonised by attributing a score of 1 (low risk), 2 (medium risk) or 3 (high risk) to the original classifications - this was based on interpretation, then verified using expert consultation and	Approach not comparable to Roy *et al*. (2015).	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
	introduction pathways		consensus during workshop. If there was debate, e.g. if the number of risk categories varied from the 1 – 3, the precautionary principle was applied and species assigned to the highest harmonised category. A single aggregated risk score was then derived, either by calculating the average of all harmonised risk scores for each species or by applying the maximum harmonised risk score which reflects a more precautionary approach (although application of the maximum score reduces the ability to discriminate between the highest risk species and other species, thereby greatly increasing the number of species classified as high risk which may stretch management resources). Uncertainty thresholds were set using an arbitrary method (see paper). High risk-low uncertainty species were then screened by experts on the following criteria: not recorded but will be able to reproduce in region, only in captivity in region and will be able to reproduce, limited distribution and able to reproduce. An inventory of origins, pathways and potential ecological impacts was then undertaken via literature search and the recorded impact types of the potential IAS were classified per introduction pathway and species group. The number of recorded impact types were ranked to identify priority IAS groups and introduction pathways – ranking was undertaken by frequency rather than severity.		

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Mayer *et al*. (2017)	**Naturalization of ornamental plant species in public green spaces and private gardens**	TER	(1) Inventoried garden-plant species and estimated their planting frequency in the public green spaces and private gardens of the city. Difficult to count number of plants per garden so when a species occurred it was assigned to one of three abundance classes by estimating the number of plants: (i) one – three plants (shoots in the case of clonal plants), (ii) four – 99 plants and (iii) >99 plants; (2) standardised taxon names, removed duplication, identified cultivars to the species from which they were derived (any of this that could not be done were removed); (3) assessed whether plants were naturalised somewhere in the world, naturalised in Germany or reported in the wild from the garden surrounds; (4) climate niche modelling to predict current and future climatic suitability in the risk assessment area, i.e. identify the garden-plant species that are currently not naturalised but likely to become so in the future, also identified that some had invasive potential.	Spread of horticulture plants. Premise is that public and private garden flora constitute an enormous pool of potential future invaders, for some the current environment permits naturalisation but under changing conditions and lag times others may spread and naturalise or become invasive.	WoS
Pili *et al*. (2017)	**Alien amphibians, a threat to Philippine biosecurity: Geographic risk assessment of the six alien**	FW/TER	(1) List of alien amphibians with a history of invasion elsewhere was compiled from databases; (2) climate matching using biome distribution modelling; (3) propagule pressure using trade and tourism data; (4) *Criteria 1* were alien species with a history of invasion, *Criteria 2* were those occurring in an area with climate match and *Criteria 3* were those which appeared in areas that had propagule pressure to the study region. An alien amphibian was categorised as	Different approach – no consensus workshop and High or Low risk based on the use of criteria. Emphasis on propagule pressure.	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
	frogs and horizon scanning for potentially invasive alien amphibians		High Risk if it fell into all three Criteria, Low Risk if it fell into *Criteria 1* and either *Criteria 2* or *Criteria 3* but not both.		
Carboneras *et al*. (2018)	**A prioritised list of invasive alien species to assist the effective implementation of EU legislation**	FW/TER/MAR	(1) Expert workshop to develop a decision tree to help identify potential species for risk assessment based on the criteria set out in Regulation 1143/2014. Discussions aimed to develop a set of biologically relevant questions to distinguish species potentially suitable for listing (e.g. reviewing databases, considering pathways of introduction, etc.); (2) building on the first workshop, a second workshop was held to create a template 'distribution x impact' matrix, with distribution corresponding to the current stage of a species' invasion curve in Europe and impact modelled on the EICAT guidelines; (3) species screening using desk-based searchers (databases and literature), focusing on species' impacts on biodiversity and ecosystem services; (4) based on their attributes and criteria developed in the workshops, species were assigned a priority category. In case of species with a major impact, those in the initial stages of invasions were prioritised over widespread ones.	Overall approach different to Roy *et al*. (2015). Distribution x impact matrix innovative.	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
Bayón & Vilá (2019)	**Horizon scanning to identify invasion risk of ornamental plants marketed in Spain**	TER	(1) Database of outdoor ornamental plants compiled from the catalogues of major Spanish nurseries, included fruit trees but not vegetables, excluded all indoor plants, archaeophytes, hybrids and uncertain taxonomy; (2) classified species according to their invasion status in Spain (not in the wild, casual, established or naturalised, invasive non-regulated in Spain or Europe or invasive regulated in Spain or Europe; (3) naturalised species that were invasive elsewhere were considered for impact assessment, casual and not in the wild species were screened or climatic suitability in Spain, those which were climatically suitable and invasive elsewhere were also considered for impact assessment; (4) for impact assessment, assigned binary (Y/N) scores to 11 ecological impact types (as per Blackburn *et al.*, 2014) plus four socioeconomic impact types – analysis in R programming; (5) societal interest analysis of Attention list species using Google Trends, plus invasions risk assessment for Attention list species, plus priority index for each species in the Attention list.	• Green list of seven species with no invasive potential. • Watch list with potentially invasive species with few potential impacts. • Uncertainty list with 161 species of known status but insufficient information to further categorise. • Data deficient list.	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Peyton *et al*. (2019)	**Horizon scanning for invasive alien species with the potential to threaten biodiversity and human health on a Mediterranean island**	FW/TER/MAR	(1) Determination of composition and scope of thematic groups; (2) preliminary consultation between experts within four thematic groups (plants, freshwater animals, terrestrial animals and marine species), excluding microorganisms; (3) consensus-building across the thematic groups.	Participants were instructed to include a species if they had any doubt regarding its allocation; brackish species, for example, were considered by more than one group, with information pooled during the plenary sessions.	WoS
Roy *et al*. (2019a)	**Developing a list of invasive alien species likely to threaten biodiversity and ecosystems in the European Union**	FW/TER/MAR	(1) Preliminary longlists in thematic groups were collated using structured literature searches and expert knowledge; (2) experts within thematic groups scored each species for their separate likelihoods of (i) arrival, (ii) establishment, (iii) spread and (iv) magnitude of potential negative impact on biodiversity. A timeframe for arrival, establishment, and impact within ten years was set for scoring. A confidence interval was assigned to each score but was not used formally within the consensus building across thematic groups; (3) during the workshop the thematic groups were asked to restrict their lists to a total of 20 – 30 top-ranked species. All the species lists from across the thematic groups were then collated into a single list. All participants were then invited to review, consider and refine the rankings of all	Paper based on Roy *et al*. (2015) report.	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
			species through plenary discussion. The end result was an agreed ranked list of potential IAS derived through discussion and broad consensus.		
Roy *et al*. (2019b)	**Prioritising Invasive Non-Native Species through Horizon Scanning on the UK Overseas Territories**	FW/TER/MAR	(1) Preliminary longlists were collated using structured literature/database searches and expert knowledge; (2) experts within thematic groups scored each species for their separate likelihoods of (i) arrival, (ii) establishment, and (iii) magnitude of potential negative impact on biodiversity or ecosystems, economies, or human health. A timeframe for arrival, establishment, and impact within ten years was set for scoring; (3) consensus building within the workshop. During the workshop the scores from each expert within a thematic group were compiled, and discussions led to an overall agreed impact and confidence score, this included information on pathways of arrival.	Aligned to Roy *et al*. (2014) on arrival, establishment and impact.	GS
Swart & Robinson (2019)	**Horizon scanning for alien predatory crabs: insights from South Africa**	MAR	(1) From a list of 56 alien predatory crabs records globally, authors excluded those with a native range including South Africa (SA), those present in the region and those occurring at depths over 60 m; (2) species without a potential pathway of introduction (based on literature) were removed; (3) compared the temperature in the realised range with that in each of the four SA coastal ecoregions, when a bioregion was too cold/warm to support a species it was excluded from	Final species list was ranked using EICAT framework. The minimum and maximum sea surface temperatures (SSTs) of the realised range of each species, as well as that for the four South African ecoregions, were extracted from NASA Earth Observations (NEO) data. Minimum and maximum SSTs were chosen, rather than mean	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
			the list; (4) the final crab species was ranked from highest to lowest using the EICAT system.	SSTs, because it is more likely that species will be constrained by the extreme conditions in new regions, rather than their average environmental states.	
Tsiamis *et al*. (2019)	**Prioritizing marine invasive alien species in the European Union through horizon scanning**	MAR	(1) Species lists compiled based on published literature, databases and expert opinion – species absent from or with a limited distribution in EU marine waters were targeted. The definition of 'limited distribution' was based on expert judgement but, in most cases, it corresponded to presence in up to five EU countries; (2) basic information was assembled for each species included in the HS assessment: general taxonomic group, functional group, native range, current presence in European seas and in EU countries, and most likely primary introduction pathway; (3) species were scored for their likelihood of arrival, establishment, spread, and impact in EU waters on a 1 – 4 scale with high, medium or low confidence; (4) a consensus workshop ranked 267 species, including a subset of 26 prioritised species. These species are considered to be mainly introduced by shipping (fouling and ballast water), via the Suez Canal, and aquaculture activities. The 26 priority species were also scrutinised in terms of feasibility of their management.	As per Roy *et al*. (2015). Seven thematic marine taxonomic groups taking into account the known number of alien species per group occurring in Europe's seas – (i) microalgae and foraminiferans, (ii) macrophytes, (iii) polychaetes, (iv) molluscs, (v) arthropods and ascidians, (vi) fishes, (vii) bryozoans, cnidarians and remaining taxonomic groups. Cryptogenic species excluded.	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Bertolino *et al*. (2020)	**A framework for prioritising present and potentially invasive mammal species for a national list**	TER	(1) Lists of species. The initial list was built upon information collected from GRIIS, GISD, and CABI, and integrated with occasional reports from available scientific literature. The web was also scanned to identify those species that are traded in Italy and which could potentially escape from captivity; (2) assessment form (the scoring of the species) evaluating taxonomy, presence/absence, likelihood of arrival into the country or escape from confinement, likelihood of establishment and spread, either natural or human aided (with subsequent releases), with a scoring system ranging from 1 (low likelihood) to 5 (high likelihood); degree of potential impact on social and economic activities, human health and biodiversity, scoring from 1 (low) to 5 (high), effectiveness and acceptability of prevention and control measures (scoring 1 – 5, with 5 indicating a species easier to manage); (3) thorough bioclimatic models (looking at the climate suitability in Italy); (4) expert-based assessment; (5) prioritised lists of non-native mammals.	The scoring is detailed but the basic approach to scoring each component is similar to Roy *et al*. (2015). The standardised focus on species in trade which could potentially escape is interesting. Used EICAT and SEICAT. In Step 2 the effectiveness of management strategies was evaluated also, by taking into account the ease of species identification in the field. The feasibility of eradication was assessed for the prioritisation list only and it was considered low for those species with a wide introduction range and high for localised species. Prioritisation was also based on the estimated costs for the management of established species, on potential side effects of eradication methods (e.g. potential impacts on native species), on the social acceptability of eradication and control methods and on the estimated costs connected with the environmental restoration following the management intervention.	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Clarke *et al*. (2020)	**Identifying potentially invasive non-native marine and brackish water species for the Arabian Gulf and Sea of Oman**	MAR (& brackish)	(1) List generated using a combination of literature searches and predictions by the CABI Horizon-Scanning tool; (2) refined the list to ensure no species were present in the risk assessment area; (3) reviewed aquaculture in the area (i.e. those NNS being used by the industry or being reviewed for future use, but not yet recorded as present outside of cultivation); (4) applied the Aquatic Species Invasiveness Screening Kit.	Use of the CABI horizon scanning tool for longlists. Application of the Aquatic Species Invasiveness Screening Kit (AS-ISK). No workshop in this study.	GS
Hughes *et al*. (2020)	**Invasive non-native species likely to threaten biodiversity and ecosystems in the Antarctic Peninsula region**	FW/TER/MAR	(1) Establishment of thematic groups; (2) thematic groups compiled long-lists using systematic literature review, databases, grey literature and expert knowledge. Only species considered absent were included; (3) species were scored (1 – 5) within groups with respect to arrival, establishment and magnitude of impact on biodiversity in a ten year timeframe, a confidence interval (low-high) was included as a guide; (4) consensus workshop to collate the species into a single ranked list.	Scoring as per Roy *et al*. (2014).	WoS - gen HS
Lucy *et al*. (2020)	**Horizon scan of invasive alien species for the island of Ireland**	FW/TER/MAR	(1) Preliminary consultation between groups of experts in freshwater/marine/terrestrial – experts received a group-relevant list derived from species identified as High Risk in the GB horizon scan, the previous Invasive Species Ireland horizon scan, a marine list, non-native species Application based Risk Analysis for Ireland and species not established	Scoring based on Roy *et al*. (2014) Impact on biodiversity was assessed by considering the following parameters: 1. Dispersal potential 2. Colonisation of high conservation value habitats	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
			in Ireland pursuant to Regulation EU 1143/2014 at the time. Additional suggestions were included; (2) consensus building among and between expert groups based on the probability of arrival, establishment/spread and impact on biodiversity. The main deviation from the Roy *et al*. methodology was in reducing the number of expert groups to three habitats, and focusing on pathways appropriate to the island of Ireland.	3. Adverse impacts on native species: a) Predation/herbivory b) Competition c) Transmission of pathogens and parasites to native species d) Genetic effects 4. Alteration of ecosystem functions: a) Modification to nutrient cycling b) Physical modifications to the habitat c) Modifications of natural successions d) Disruption of food webs	
Peyton *et al*. (2020)	**Horizon Scanning to Predict and Prioritize Invasive Alien Species With the Potential to Threaten Human Health and Economies on Cyprus**	FW/TER/MAR	(1) Longlists derived from a previous horizon scan conducted by same author(s), with additional species from literature and databases; (2) focus on human health and economy. Experts were asked to score each potential IAS within their thematic group for their separate likelihoods of: (i) arrival, (ii) establishment, (iii) magnitude of the potential negative impact on human health or economies. Quantification of the impact score on human health and economy were performed using a scoring scheme modified from the SEICAT system. Only primary impacts were considered; for example, should a person be absent from work because they were ill from a mosquito-borne infection, this would only be considered within human health impacts, but not economic impact; (3) then a two-day consensus workshop. Two final, ranked lists	Focus was human health and economies yet overall scoring approach as per Roy *et al*. (2014). SEICAT.	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
			produced (one for impacts on human health and one for economy).		
Adhikari *et al.* (2021)	**Assessment of the Spatial Invasion Risk of Intentionally Introduced Alien Plant Species (IIAPS) under Environmental Change in South Korea**	TER	(1) Ten alien plant species introduced intentionally in South Korea were selected based on their rapid range expansion, their degree of invasion into natural ecosystems, and the availability of minimum species occurrence records; (2) assessors quantified the spatial distribution area and invasion risk of these intentionally introduced alien plants (IIAPs) using a species distribution model with a maximum entropy approach under different levels of environmental change in South Korea; (3) classified the IIAPS into groups according to their spatial distribution and invasion potential (to prioritise control and management strategies). Estimated three categories of spatial invasion risk — low, moderate, and high — across the country and existing provinces.	The focal species are all already present in the risk assessment area, but this demonstrates a quantitative way of estimating spread – almost a mix of horizon scanning and risk assessment, because the authors do observe that the approach can be used to identify small populations detected in non-target areas that are likely to become sources for future expansion.	WoS
Goldsmit *et al.* (2021)	**Screening for High-Risk Marine Invaders in the Hudson Bay Region, Canadian Arctic**	MAR	(1) Species gathered from published and grey literature were pre-screened to only include those which could tolerate the thermal range and were linked to shipping (i.e. an anthropogenic transport route to the high Arctic); (2) species were ranked using the semi-quantitative Canadian Marine Invasive Screening Tool (CMIST) to identify AIS of potential concern to the region. This screening level risk assessment tool uses documented information to answer 17 questions related to the likelihood and impact of invasion; (3)	Use of the risk assessment tool CMIST (Canadian Marine Invasive Screening Tool) which uses 17 questions related to likelihood and impact of invasion.	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
			distribution of High Relative Risk (HRR) species richness among ecoregions was calculated and plotted on a global map. Both known native and invaded ranges were included to evaluate the number of HRR species in each source ecoregion.		
Adriaens *et al.* (2022)	**Assessment of current and future invasive plants in protected dune habitats of the Atlantic coastal region**	TER	(1) Used a data driven approach to find habitat-focused dune species using GRIIS plus lists from a published paper and an unpublished study; (2) excluded species partly native to the EU and excluded synonyms; (3) harvested post-1950 occurrences using GBIF and included only those taxa which had at least one occurrence in the target region; (4) Circulated these longlists to experts for quality control, addition of any species missed and scoring (1 = ecological impact unknown, 2 = no relevant ecological impact, 3 = (potential) ecological impact). For species marked with a 3, experts were asked to flag potential habitats and mechanisms by which species might have an impact. These species were taken forward to the workshop; (5) workshop scoring was based on the framework 'Introduction × Establishment × Spread × Impact = Overall score' with low, medium or high confidence. Also conducted an exercise on feasibility of management for every species.	The approach differs in the data-driven workflow for drafting the longlist of species, by using the Global Biodiversity Information Facility (GBIF). The workshop attendants were asked to rank the feasibility of management by selecting one of several options. Scoring as per Roy *et al.* (2015).	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
Czechowska *et al.* (2022)	**Horizon scanning to identify and prioritize high-risk alien species**	FW/TER/MAR	(1) Online search to identify peer-reviewed articles focusing on HS for IAS which may threaten Europe, metadata compiled for each; (2) horizon IAS were checked against Union concern and Member State concern list(s) and any species listed were excluded from further analysis; (3) further exclusions based on defined criteria (e.g. listed under other legislation, cryptogenic, etc.,); (4) added species to the EASIN catalogue and geodatabase, added information on taxonomy environment and pathways; (5) selected ten species for risk assessment.	Used peer-review articles only. In compiling lists, grouped species by criteria e.g. amenability to prevention and early eradication. Species excluded based on the premises: •Regardless the extent of their current distribution in EU, their potential management is unrealistic due to specific species traits (e.g. planktonic organisms, microscopic dinoflagellates). •Their correct identification is extremely difficult or requires the use of molecular tools, also when confusion with similar species is very high. •Inclusion on Union list would not effectively prevent/mitigate/minimise adverse impacts.	GS
Guilder *et al.* (2022)	**Threats to UK freshwaters under climate change: Commonly traded aquatic ornamental species and**	FW	(1) Identified commonly-traded ornamental species using expert elicitation (making use of data from the Ornamental Aquatic Trade Association and the Fish Health Inspectorate), eBay retailer search and Google search; (2) organisms not identified to species level were removed, as were species already present in UK waters and species listed on legislative positive or negative lists; (3) species distribution models undertaken to estimate climate suitability for each	This horizon scanning approach was focused on the potential parasites and pathogens associated with non-native ornamental fishes and invertebrates found in trade (so not on the potentially invasive nature of the fish or invertebrate species).	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
	their potential parasites and pathogens		species under current and future conditions; (4) out of 233 ornamental species identified as traded in the UK, 24 were screened, via literature search, for potential parasites and pathogens (PPPs) due to their increased risk of survival and establishment under climate change.		
Kendig *et al.* (2022)	**Scanning the horizon for invasive plant threats using a data-driven approach**	TER/FW	(1) Used the CABI horizon scanning tool to generate long lists; (2) identified taxa that were growing in at least one climate that matched the target region, were not naturalised in the area, not on a local/national noxious weed list, naturalised outside of their native ranges and historically weedy; (3) selected the top 100 most globally common taxa for further assessment – the largest number of taxa that nine assessors could evaluate given 20 hours of assessment time each (40 for one assessor). Global commonness was the proxy for propagule pressure and establishment; (4) scoring based on likelihood of arrival, establishment and negative impacts (environmental, socioeconomic and human health) from 1 – 5 plus confidence ratings; (5) review and consensus building workshop.	Scoring similar to Roy *et al.* (2014). Use of the CABI horizon scanning tool for longlists. Checking against noxious weed lists so as not to duplicate. Calculating assessor hours to determine number of taxa it was feasible to assess. Rapid risk assessment designed to take less than two hours per taxon - Arrival: current distribution, availability for purchase, history of invasion in other regions, presence of a plausible arrival pathway. - Establishment: Distribution and number of records within matching Köppen-Geiger zones, ecological properties of taxon and target habitats. - Impacts: Rubric modified from Invasive Species Environmental Impact Assessment protocol, EICAT and SEICAT.	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Kenis *et al*. (2022)	**Horizon scanning for prioritising invasive alien species with potential to threaten agriculture and biodiversity in Ghana**	TER	(1) Preliminary horizon scanning using the CABI horizon scanning tool then added species, particularly those that do not occur yet in Africa but are listed as quarantine pests by the National Plant Protection Organisation (NPPO) or species that had recently spread rapidly across other continents but not yet in Africa; (2) definition of a scoring system; (3) scoring of species was modified from Roy *et al*. 2019a to be 'Likelihood of entry × likelihood of establishment × (magnitude of socio-economic impact + magnitude of environmental impact)'; (4) consensus workshop (5) post workshop adjustments.	Scoring modified from Roy *et al*. (2019a). Use of the CABI horizon scanning tool for longlists. Considering species that were listed as quarantine pests and species that were rapidly spreading across other continents even if not identified using the CABI tool.	WoS
Mulema *et al*. (2022)	**Prioritization of invasive alien species with the potential to threaten agriculture and biodiversity in Kenya through horizon scanning**	TER	(1) Preliminary horizon scanning, mostly using CABI horizon scanning tool with some additions from experts; (2) description of the scoring system; (3) scoring of species; (4) consensus workshop; (5) finalising the ranked list.	Scoring modified from Roy *et al*. (2019a). Use of the CABI horizon scanning tool for longlists.	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Osunkoya *et al*. (2022)	**Horizon scan for incoming weeds into Queensland, Australia**	TER	(1) Used Biosecurity Queensland's compiled list of horizon weeds (~230 species) as a starting point; (2) reviewed the pest management plans of all 72 local government areas in the state for emerging species; (3) cross-checked the list with introduced species in Australia; (4) presented the list to stakeholders; (5) reviewed the grey and scientific literature for the global distributions of listed weeds; (6) predicted the potential distribution of listed species in QLD; (7) combined data on realised/potential distribution of the weeds worldwide and in QLD, and their (perceived) impacts to generate a prioritised list and actions required; (8) examined the feasibility of eradication.	Different approach – emphasis on (what appear to be) desk-based searches, reviews and cross-checks – no workshop. Categorised and graphed species by 16 'impact types' and considered impacts to be Positive (1), Negative (-1), or Neutral (0). Listed the top 25 species worthy of management action.	GS
Arianoutsou *et al*. (2023)	**HELLAS-ALIENS. The invasive alien species of Greece: time tends, origin and pathways**	FW/TER/MAR	(1) Establishment of thematic groups; (2) species lists combined (no exact detail provided on how), excluded cryptogenic species; (3) species were scored within groups with respect to arrival, establishment, spread and magnitude of impact on biodiversity in a ten-year timeframe; (4) consensus workshop which selected the 29 species with the highest score.	Scoring as per Roy *et al*. (2015).	WoS – gen HS
Cano-Barbacil *et al*. (2023)	**Identification of potential invasive alien species in Spain**	FW/TER/MAR	(1) Determining the composition and scope of the thematic groups; (2) building a preliminary list of species within each thematic group (preliminary longlists derived from CABI horizon scanning tool), performing a rapid evaluation and compiling a preliminary consensus list within groups.	Paper states that the approach largely followed Roy *et al*. (2019a). *The scoring was based on likelihood of arrival, establishment and impact, which would actually be Roy et al. 2014.*	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
	through horizon scanning		Regarding initial screening – due to the very long lists obtained for plants and terrestrial invertebrates, species were ranked according to their "degree of invasion" (i.e. number of occurrences globally that are considered "invasive") thus selecting the 200 taxa with a higher degree of invasion. These lists were completed with species that were included in previous HS conducted in Europe and Spain and with those IAS listed in Spanish and European regulations; (3) establishing a general consensus and ranked list of potential IAS across thematic groups (scoring based on likelihood of arrival, establishment, and impact on biodiversity and ecosystems).	Use of the CABI horizon scanning tool for longlists. Shortening longlists by ranking species according to their degree of invasion (the number of occurrences globally that are considered invasive).	
Dawson *et al.* (2023)	**Horizon scanning for potential invasive non-native species across the United Kingdom Overseas Territories**	FW/TER/MAR	(1) Preliminary longlists were collated using structured literature/database searches and expert knowledge, and included species that were not present as established alien species on a focal Overseas Territory (OT) but may have been present already on other OTs; (2) experts within thematic groups scored each species for their separate likelihoods of (i) arrival, (ii) establishment, and (iii) magnitude of potential negative impact on biodiversity or ecosystems, economies, or human health for each OT. A timeframe for arrival, establishment, and impact within ten years was set for scoring. A confidence interval was assigned to each score. During the workshop the scores from each expert within a thematic group were compiled, and discussions led	Scored on likelihoods of (i) arrival, (ii) establishment, and (iii) magnitude of potential negative impact on biodiversity or ecosystems, economies, or human health. Approach therein as per Roy *et al.* (2014).	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
			to an overall agreed impact and confidence score; (3) consensus building within the workshop(s). the end result produced three agreed ranked lists of species with the potential to arrive, establish and pose a threat to biodiversity and ecosystems, economies, or human health on the territory.		
Dobrzycka-Krahel and Medina-Villar (2023)	**A New Horizon-Scanning Tool to Identify Potential Aquatic Invasive Alien Species Introduced into the Baltic Sea by Shipping**	FW/MAR	Approach tailored towards marine species: (1) climatic matching of aquatic species that can utilise shipping; (2) division into taxonomic groups; (3) screening under the criterion that it is a species not yet recorded in the Baltic Sea but will be able to reproduce there; (4) inventory of the origins and environments (based on salinity to see is it freshwater, brackish or marine) of the list of potential IAS; (5) prioritisation as per Roy *et al*. 2015 based on the probability of establishment, spread and impact of each species (each invasion stage assigned a probability value of 1 – 5, then these values were multiplied and ordered from highest to lowest).	Scoring similar to Roy *et al*. (2015, 2019a) but used establishment, spread and impact (not arrival).	WoS
Gilles Jr. *et al*. (2023)	**Risk of invasiveness of non-native fishes can dramatically increase in a**	FW	(1) Species were selected based on whether they were (i) already present in the RA area or (ii) not yet reported in the RA area but likely to enter in the future; (2) risk identification was undertaken using the Aquatic Species Invasiveness Screening Kit, whereby the assessor must provide for each question a response, confidence level and justification.	Use of the CABI Horizon Scanning tool. Application of the Aquatic Species Invasiveness Screening Kit (AS-ISK).	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
	changing climate: The case of a tropical caldera lake of conservation value (Lake Taal, Philippines)		Scores < 1 suggest a “low risk” of the species being or becoming invasive in the risk assessment area, whereas scores ≥ 1 indicate a “medium risk” or a “high risk”. The distinction between medium and high risk was defined using a calibrated threshold obtained by Receiver Operating Characteristic (ROC) curve analysis. An additional ad hoc threshold was used to distinguish a “very high risk” category.; (3) *a priori* categorisation of species required for ROC curve analysis was fitted (using global databases to assess invasiveness).		
Hill *et al.* (2023)	**Narrowing the Horizon: Using Known Invasives and Propagule Pressure to Focus Risk Screening Efforts on Potential Invasives**	MAR	(1) This study selected family Pomacentridae (damselfishes) to screen due to their high representation in trade coupled with the establishment of one member of the family in the study region; (2) 424 species within the family – too many to screen so species with the highest numbers in trade were selected and some species added through expert opinion; (3) a bioprofile for each species was created, containing information on the biology, ecology, geography, invasion history, and human use of the species as well as sections including expert opinion on potential risks; (4) the Aquatic Species Invasiveness Screening Kit was applied.	Application of the Aquatic Species Invasiveness Screening Kit (AS-ISK). Approach taxonomically-restricted and based on pathway. Authors reasoned that horizon scanning resources can become 'somewhat evenly spread over numerous species, many of which will not be classified as hazards' and proposed '…narrowing the focus to taxonomic groups that contain known invaders within priority pathways.'	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Lieurance *et al*. (2023)	**Identifying invasive species threats, pathways, and impacts to improve biosecurity**	FW/TER/MAR	(1) Assembled a panel of experts, this team was later expanded to fill emerging knowledge gaps; (2) developed a candidate list of taxa for assessment using the CABI horizon scanning tool. Species were removed based on climate mismatch, taxa being already present, lacking invasion or naturalisation history or other thematic-group specific criteria. Additional taxa from databases were added; (3) completed rapid risk assessments using the scoring system of likelihood of arrival within the next ten years (A), establishment (E), and negative impacts (I). Each category scored 1 – 5, (A x E x I = SCORE), plus confidence interval and peer review, (4) built consensus among experts on final rankings within a workshop (5) Collected additional data, e.g. pathways of introduction, after consensus to further detail the threat posed by ranked species.	Scoring as per Roy *et al*. (2014).	GS
McCulloch-Jones *et al*. (2023)	**Early detection of alien fern species through the consultation of horticultural catalogues**	TER	(1) Horticultural trade catalogues (e-commerce and on the ground) were consulted to develop species lists (noted that the representation of ferns and their invasion status in plant species inventories is generally poor); (2) Google Maps used to search for traders, followed by Google Search; (3) recorded mode and scale of trade, trade in native and alien species and species of concern.	Spread of horticulture plants/species in trade.	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
Mulema *et al.* (2023) [Preprint]	**Prioritizing nematode species likely to be introduced and threaten agriculture, biodiversity, and forestry in Zambia: A Horizon Scanning Approach** *****[This is a preprint]*****	TER	(1) A preliminary selection of nematode species that had not yet been reported as present in Zambia was conducted using the CABI horizon scanning tool; (2) the list was manually assessed to remove pests that do not affect value chains and pests represented by their genera instead of species names; (3) scoring was done by subject matter experts (SMEs) during the consensus workshop following the formula 'Likelihood of entry x likelihood of establishment x (magnitude of socio-economic impact + magnitude of impact on biodiversity)'. The likely pathway of arrival and associated confidence levels were used to help focus discussions on the possibility of entry and establishment but did not contribute to the overall score. The scoring system was based on the Roy methodology, however Roy *et al.* (2019a) assessed the likelihood of arrival, establishment, spread, and magnitude of potential negative impact on biodiversity and ecosystem services whereas in this assessment, the likelihood of entry (arrival), establishment, and potential magnitude of socioeconomic impact and potential magnitude of impact on biodiversity were assessed. The likelihood of spread was not considered because once an alien species arrives ashore, exponential spread within and between countries in sub-Saharan Africa has been observed.	Scoring modified from Roy *et al.* (2019a). (*Excluded spread, actually slightly closer to 2014 methodology*). Use of the CABI horizon scanning tool for longlists.	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
Oficialdegui *et al.* (2023)	**A horizon scan exercise for aquatic invasive alien species in Iberian inland waters**	FW	(1) Systematic review, working groups and preliminary lists compiled. Comparable assessments at national and international scales were used, and lists from previous horizon scan exercises plus Iberian inventories of aquatic IAS; (2) discrimination and taxa status definition; (3) expert ranking of alien taxa; (4) preliminary risk assessment and IAS prioritisation using the following criteria: Invasive potential, Ecological impact, Management difficulty, Economic and human health impact, Acceptability of management. Each category was given a score from 0 – 4 (plus confidence level) so the max. score was 20. Species of ≥ 15 were high priority; (5) consensus-building across expert groups. Lastly, there was a comparison exercise between the final lists and the list of Union concern, Spanish IAS catalogue, Portuguese national list and Spanish list of allochthonous species.	Making a 'concern' list of recorded species and an 'alert' list of potential species. *The technical report from LIFE Invasaqua (Oliva-Paterna et al., 2022) is linked to this – methodology and results the same, so not duplicated here*.	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
O'Shaughnessy *et al*. (2023)	**Horizon scanning for potentially invasive non-native marine species to inform trans-boundary conservation management – Example of the northern Gulf of Mexico**	MAR	(1) An initial list of marine species with physiological tolerances that matched the conditions of the northern Gulf of Mexico was developed using existing lists, databases and the CABI horizon scanning tool; (2) species on this list were cross-checked to determine whether they were already reported as established in the risk assessment area; if it was determined that they were already established, then they were removed; (3) habitat suitability was assessed using the online tool AquaMaps which produces computer-generated predicted global distribution maps for marine species (using depth, temperature, salinity and primary production). If the risk assessment area was deemed unsuitable habitat the species was removed from the list; (4) expert judgement was used to further refine the lists – assessors reviewed the likelihood of these species being introduced, becoming established, and causing ecological and/or socio-economic harm within the northern Gulf of Mexico over the next decade to help sub-select species for a full risk screening; (5) risk screening for the final subset was undertaken using the Aquatic Species Invasiveness Screening Kit.	Initial scoring (prior to the AS-ISK) used similar criteria to Roy *et al.* (2014). Assessing habitat suitability using the online tool AquaMaps. Application of the Aquatic Species Invasiveness Screening Kit (AS-ISK).	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
Sarakatsani *et al.* (2023) [Preprint]	**PeMoScoring: a rapid screening of emerging threats caused by invasive plant pests ***[This is a preprint]*****	TER	PeMoScoring for plant pests (named after an abbreviation of pest and monitoring). (1) Scanning of media and scientific sources using the IT platform of the Medical Information System (MEDISys) developed by the (JRC). This is an automated surveillance system that was initially developed for public health; (2) further selection of these automatically-retrieved-articles was manually performed. This selection was based on specific criteria, which differ depending on the status of the pest in the EU legislation; (3) as an example, four insect species were selected for scoring. Pests eligible to the PeMoScoring, in the EU horizon scanning context, have to fulfil the following conditions: a) they can cause damages to plant species of economic relevance to the EU, b) they should be able to enter the EU territory by at least one commodity not banned for import into the EU or by natural spread from non-EU territories. PeMoScoring is composed of 15 criteria including: data about the pest (host range, distribution, spread mechanisms including vectors transmission, type of damages), data about host plants (distribution and surface area covered by the hosts in the area under assessment), data about the European specific scenario (trade pathways prohibited by the EU legislation, suitability of European climate, availability of detection and control measures).	Not a comparable horizon scanning. The PeMoScoring model is a strong tool, but developed at present for plant pests.	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Trajanovski *et al*. (2023)	**Aquatic Invasive Alien Species in Lake Ohrid: Horizon Scanning and Assessment with Aquatic Species Invasiveness Screening Kit**	FW	Selected six IAS, three already established and three potentials from the surrounding area. Selection of the potential IAS for assessment was based on three criteria: (i) an elevated level of invasiveness and impact on a global scale; (ii) presence in the geographical proximity (horizon countries) and (iii) climate similarity between the horizon area and the RA area. Applied the Aquatic Species Invasiveness Screening Kit (AS-ISK) tool, composed of 49 questions that examine the impact of an alien species from a biogeographical, biological and economic point of view. The combination of these three types of impact produces a Basic Risk Assessment (BRA) score. Six further questions define the Climate Change Assessment (CCA) of the species, describing the potential effects of future climate change on the risk of the species' introduction, establishment, dispersal and socio-economic impacts. The combination of BRA and CCA scores give the species the final level of invasiveness.	Scoring based on application of the Aquatic Species Invasiveness Screening Kit (AS-ISK).	WoS
Tshikhudo *et al*. (2023) [Preprint]	**Horizon scanning for invasive arthropods with the potential to threaten crop production industry in**	TER	(1) Developed a candidate list for assessment using the CABI horizon scanning tool; (2) species with a full datasheet in the CPC but not in the ISC were excluded; (3) subject matter experts (SMEs) reviewed the list and removed species already present in the target region; (4) SMEs scored species (Likelihood of entry × likelihood of establishment × (magnitude of socio-economic impact +	Scoring as per Roy *et al*. (2014). Use of the CABI horizon scanning tool for longlists.	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
	South Africa *[This is a preprint]*****		magnitude of environmental impact)) and the confidence in the entire score was expressed as low, medium, or high.		
Cottier-Cook *et al.* (2024)	**Horizon scanning of potential threats to high-Arctic biodiversity, human health and the economy from marine invasive alien species: A Svalbard case study**	MAR	(1) Selection of expert group; (2) production of preliminary lists of marine IAS using literature searchers, databases and expert knowledge; (3) prioritisation of species (scoring based on arrival, establishment and impacts on biodiversity, economies and human health); (4) consensus approach.	Scoring approach based on Roy *et al.* (2014). Positive impacts, particularly economic, were discussed, but not included, since the main aim was to highlight the high-risk species with the greatest negative impacts.	WoS
Jones *et al.* (2024)	**Can gardeners identify 'future invaders'?**	TER	Perhaps not a comparable horizon scanning, because the premise of the paper is that 'Ornamentals confined to gardens and those which have already naturalised, but are not yet shown to be invasive, represent a 'pool' of species with invasive potential – 'future invaders'. This identified nine species of concern, but these had already escaped from gardens (the paper does note it would be very important to identify them before escape). However, there is no information on how widely spread these species are, so in	Spread of horticulture plants. Interesting citizen science approach which makes use of surveys.	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
			theory the time for prevention could already have passed. A three-step approach. (1) Two surveys were conducted – a scoping survey asking gardeners to identify up to three ornamental plants invading/taking over their garden and follow-up survey at the RHS Chelsea flower show providing a drop-down and asking participants to select the main ornamental invading/taking over their garden; (2) the 'future invaders' were prioritised by looking at domestic and global naturalised and invasive status of each taxon, using GRIIS and GLoNAF; (3) priority assigned to the reported taxa which had already escaped gardens but are not yet invasive, although they have an invasive status globally.		
Mulema *et al*. (2024a)	**Rapid risk assessment of plant pathogenic bacteria and protists likely to threaten agriculture, biodiversity and forestry in Zambia**	TER	(1) Preliminary selection of pests that had not been reported as present in Zambia using the CABI Horizon Scanning Tool. This generated a list of pest species that are not yet reported in the selected 'area at risk' (Zambia), but reported in specified "source areas" (such as trading partner countries); (2) the list was manually assessed to remove pests that do not affect value chains and pests represented by their genera instead of species names; (3) the final list was subject to risk assessment by subject matter experts (SMEs). The risk scoring system used was based on that described by Roy *et al*. (2019a). Roy *et al*. (2019a) assessed the likelihood of arrival, establishment, spread and magnitude of potential negative impact on biodiversity and ecosystem	Scoring modified from Roy *et al*. (2019a). (*Excluded spread, actually slightly closer to 2014 methodology)*. Use of the CABI horizon scanning tool for longlists.	WoS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
			services, whereas in this assessment, the likelihood of entry (arrival), establishment and potential magnitude of socio-economic impact and potential magnitude of impact on biodiversity were assessed.		
Mulema *et al*. (2024b) [Preprint]	**Prioritizing plant parasitic nematodes and Mollusca that are likely to be introduced and threaten agriculture, forestry, and biodiversity in Zambia: A horizon scanning approach ***[This is a preprint]*****	TER	(1) A preliminary selection of species that had not yet been reported as present in Zambia was conducted using the CABI horizon scanning tool; (2) the list was manually assessed to remove pests that do not affect value chains and pests represented by their genera instead of species names; (3) scoring was done by subject matter experts (SMEs) during the consensus workshop. A 5-score system for the four parameters (entry, establishment; socio-economic and biodiversity impact) was used, where a score of 1 indicated that an organism was unlikely to enter or establish, or minimal impact and a score of 5 indicated that an organism was very likely to enter or establish or have a major economic or environmental impact. Associated confidence intervals were assigned. Scoring followed the formula 'Likelihood of entry x likelihood of establishment x (magnitude of socio-economic impact + magnitude of impact on biodiversity)'. The scoring system was based on the Roy methodology, however Roy *et al*. (2019a) assessed the likelihood of arrival, establishment, spread, and magnitude of potential negative impact on biodiversity and ecosystem services whereas in this assessment, the likelihood of entry	Scoring modified from Roy *et al*. (2019a). (*Excluded spread, actually slightly closer to 2014 methodology*). Use of the CABI horizon scanning tool for longlists.	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
			(arrival), establishment, and potential magnitude of socioeconomic impact and potential magnitude of impact on biodiversity were assessed.		
Wyman-Grothem *et al*. (2024)	**Scanning the Horizon for Potential Nonnative Aquatic Plant and Algae Arrivals to the Pacific Northwest**	FW	(1) Assembled a group of aquatic invasive species (AIS) researchers and managers working in the Pacific Northwest and asked them to provide input on the scope and focus of the regional horizon scan based on their knowledge of the region and AIS threats; (2) identified the most likely geographic sources of organisms to the Pacific Northwest within the pathway and taxonomic scope selected by the advisory group. Watercraft inspection data were combined with climate matching analyses to identify "top donor regions" from which submerged or floating aquatic plants (non-marine) were most likely to arrive. Species lists generated from GBIF and the US Geological Survey BISON database; (3) asked advisory group for conditions and characteristics to use in prioritising species and obtained information on species' occurrences, traits and human uses from databases/sorted species into priority tiers depending on the advisory group recommendations. Individual species risk screening was conducted on a subset of priority species using the US Fish and Wildlife Service (USFWS) Ecological Risk Screening Summary (ERSS) tool. The ERSS methodology classifies a species as high risk to the contiguous United States if it has a documented history of	Conducting climate matching on a subset of priority species under future RCP conditions to estimate future establishment. Use of the Ecological Risk Screening Summary Tool.	GS

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
			establishment and harm to native species, the ecosystem, human health, or the economy outside its native range and if the USFWS Risk Assessment Mapping Program (RAMP) climate match of the species' current range to the contiguous United States shows > 5 % of target climate stations scoring 6 or higher out of 10. To estimate future establishment potential under a changing climate, ERSS climate change supplements were also written for the subset of priority species. As with current climate matching, future climate matching was conducted with RAMP.		

Table 3. Results of the multi-language literature searches performed for nine languages using Google Scholar, alongside the experts who conducted them. The number of articles screened refers to those which abstracts were read in order to gauge their relevance. For Portuguese, only the first 100 hits were checked.

Language	Team Member	N articles found	N articles screened	N articles relevant	Search terms used
Bulgarian	Konstantin Gospodinov	6	6	0	инвазивни видове хоризонт сканиране
Croatian	Konstantin Gospodinov	4	4	1	skeniranje horizonta invazivnih vrsta
Czech	Petr Pyšek	0	0	0	horizon scanning nepůvodních druhů
Dutch	Tim Adriaens	45	45	15	horizon scan invasieve soorten uitheemse soorten
French	Aurore Trottet*	40	20	0	analyse de l'horizon espèces envahissantes espèces exotiques
German	Wolfgang Rabitsch	527	1	1	horizon scan invasive arten
Italian	Riccardo Scalera/ Elena Tricarico	2	2	2	horizon scanning specie introdotte/horizon scanning specie aliene/horizon scanning specie esotiche
Portuguese	Ana Nunes	15.100	6	0	exploração do horizonte espécies exóticas
Spanish	Ana Novoa	2	2	1	"Exploración del Horizonte" AND "Especies Exóticas"

* Initial team member who left IUCN and, therefore, was not further involved in the project

2.2.2.3. Retrieving information from National Authorities and expert knowledge

In order to potentially retrieve any additional information on horizon scanning exercises, or species long lists, not captured through the literature searches performed above, the project team asked the DG ENV IAS team from the EC to contact representatives from National Authorities (NA) from the various EU MS. The aim was to gather information on horizon scanning studies that might have been performed at a national/regional level, but that were not made publicly available, or not easily accessible. For this, the request consisted of asking for any information on unpublished horizon scanning exercises performed for their MS or region, grey literature and/or any relevant datasets (e.g. in the form of Excel files) to be made available, if possible. However, no information was gathered in this way.

Additionally, with the intent of contacting Authorities from countries outside the EU, in Europe and beyond, the project team reverted to their network of existing contacts to establish quick communications with representatives of specific countries. The only information retrieved in this way was that provided by the Ministry of Environment of Japan regarding the process to develop lists of IAS in Japan (and said lists). In this process, species are evaluated by a group of experts who, based on 15 detailed evaluation items, score species that are the most threatening. As such, this work involves some components of, or those that are similar to, horizon scanning, despite not being a full horizon scanning exercise.

Finally, all project team experts were asked to suggest and add any outstanding publications on horizon scanning of IAS that they were aware of, including by consulting their own experts' networks, details of which were also added to Table 4 (Figure 4).

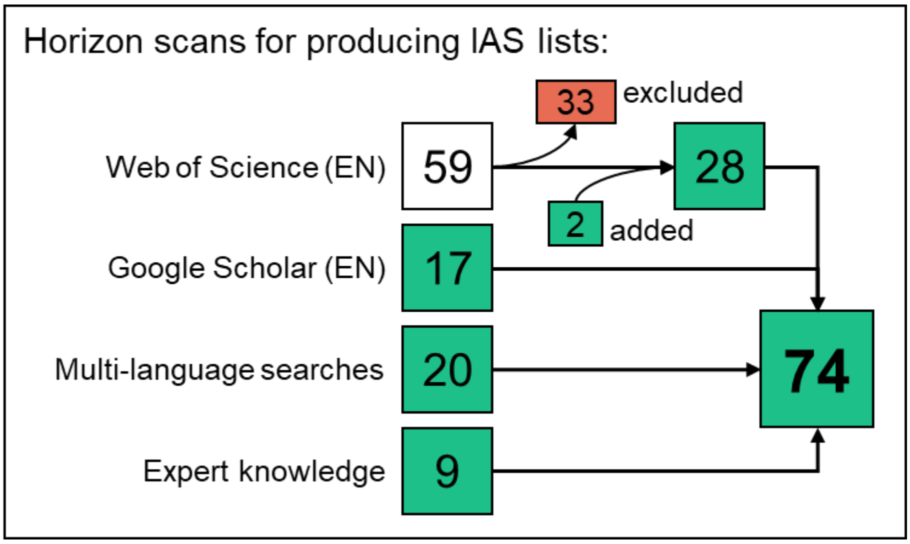

Figure 4. Number of horizon scans specifically targeted at producing IAS lists (or other relevant publications) retrieved through various search engines and expert knowledge.

2.2.3. Detailed review of horizon scanning methodologies based on the English language literature searches

Upon reviewing the methodologies described within the 45 publications retrieved through the English language literature searches, it was evident that the horizon scanning exercises for IAS followed a logical, stepwise process. As a general rule, the composition and scope of thematic groups were first assembled and species longlists compiled. There were recurring patterns in the development of these lists, for example just under one quarter (22.2 %) of the 45 studies used the CABI Horizon Scanning Tool[1] to generate preliminary longlists. These longlists were complemented by standardised literature reviews, databases and expert opinion. It was frequently noted that this approach will lead to high numbers of potential IAS – too high to realistically assess. Assessors had therefore to develop a mechanism to remove low-risk species, while retaining species capable of causing impacts (e.g. biodiversity and related ecosystem services, socioeconomic, or human health impacts), and which have a (potentially) high-risk of arrival and establishment. In general, species may be removed based on climate mismatch, lack of invasion or naturalisation history, or other thematic-group specific criteria (Lieurance *et al*., 2023). Checks for synonyms were conducted to further eliminate unnecessary duplication. Cryptogenic species and species which are duplicated across other regulatory frameworks, for example noxious weed lists (Kendig *et al*., 2022) were also excluded.

With regards to climate (or habitat) matching, to determine whether a species is likely to establish in the area in focus, there was a degree of variation as to whether this step was conducted at a longlist or shortlist stage. Regardless, the different studies used different tools and analyses to perform these matching exercises, for example biome distribution modelling as per Pili *et al*. (2017), or predicted global distributed maps (via the online tool AquaMaps) as per O'Shaughnessy *et al*. (2023).

When considering a species' invasion or naturalisation history, there were again different options available to thematic groups. For example, Cano-Barbacil *et al*. (2023) ranked species according to their 'degree of invasion' – i.e. the number of occurrences globally that are considered invasive, thus selecting taxa with a higher degree of invasion. Alternatively, assessors may apply a basic scoring system such as '1 = ecological impact unknown, 2 = no relevant ecological impact, 3 = (potential) ecological impact', with higher scoring species taken forward to the next stages (Adriaens *et al*., 2022).

[1] https://www.cabi.org/HorizonScanningTool

Table 4. Brief description of methods used and different/potential relevant methodological aspects of those since Roy *et al*. 2015 (and 2019a) for publications retrieved through the multi-language searches on IAS horizon scans performed from 2015 – 2024, as well as those gathered through expert knowledge. Environmental coverage refers to the type of ecosystem covered (all, FW, MAR, TERR). For more details from each of these publications, see Table 12.

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Lensink *et al*. (2015)	**Alien species on the Dutch Wadden Sea Islands**	FW/TER	Considers 300 aliens for the Wadden and identifies 47 black list species. Also, identifies which ones are problematic to achieve conservation goals of Natura2000 and which predator introductions would be a disaster for the island's ecology.	Scores 110 alien species present on the Wadden with ISEIA and calculates risk score for protected habitats based on their presence on those.	Multi-language search (Dutch)
Rougoor *et al*. (2015)	**Landbouw-gerelateerde infectieziekten: verkenning van risico's in praktijk en lacunes in beleid. Deel B: Analyse**	TER	Risk screening for agriculture-related pathogens from a one health perspective.	Uses a published risk assessment for scores (Giessen, J. van der, A. van de Giessen, M. Braks (eds.) (2010) Emerging Zoonoses: early warning and surveillance in the Netherlands. RIVM-rapport 330214002).	Multi-language search (Dutch)
Verbrugge *et al*. (2015)	**Expertpanelbeoordeling van (potentiële) risico's en managementopties van invasieve exoten in Nederland: Inhoudelijke input voor het Nederlandse**	FW/TER/MAR	Expert assessments of impact on biodiversity, ecosystems and ecosystem services for 152 alien species in the Netherlands. Includes additional proposals by experts of species that could be put forward for inclusion on the Union list.	It considers manageability of species on top of impacts on biodiversity using a developed protocol which considers the distribution of a species and the costs of removal/control.	Multi-language search (Dutch)

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
	standpunt over de plaatsing van soorten op EU-verordening 1143/2014				
Leuven *et al*. (2016)	**Exotische biomassagewassen: oplossing of probleem?**	TER	Dutch article that refers to a RA for biomass plants. Identifies *Arundo donax* and *Spartina pectinata* as high risk and 5 other species as medium risk (*Miscanthus sacchariflorus, Asclepias syriaca, Symphytum* x *uplandicum, Andropogon gerardii, Fallopia sachalinensi*s var. *igniscum* candy).	Uses ISEIA for assessing the potential impact (so in essence the same as Roy *et al*. method). It also considers which species are already out into the environment.	Multi-language search (Dutch)
Pergl *et al*. (2016)	**Black, Grey and Watch Lists of alien species in the Czech Republic based on environmental impacts and management strategy**	TER/FW	Screening of alien plants and animals classified according to risk and feasibility of management.		Expert knowledge
Lensink *et al*. (2018)	**Exoten op de Nederlandse Waddeneilanden**	MAR	Article discussing high impact alien species found on one or more Wadden Islands in the period 2005 – 2014 and identifying 47 alien species as 'black list' or 'watch list' according to the ISEIA protocol. Identification of 29 high risk species and 18 potentially high risk species including species that represent a major threat to reaching Natura2000 targets.	Use of ISEIA for ecological impact assessment.	Multi-language search (Dutch)

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Pieters *et al*. (2018)	**Risico's van de sierteeltketen als introductieroute voor invasieve exoten**	FW/TER	Assesses the extent to which ornamental trade and horticulture contribute to the introduction, spread and establishment of IAS in the Netherlands, and what (potential) risks these species pose for nature, public health and other socioeconomic interests.	Includes alien biocontrol agents and contaminants of ornamental plants; uses a translation table of impact categories.	Multi-language search (Dutch)
Weber *et al*. (2018)	**Deutsche botanische Gärten als mögliche Quelle invasiver Pflanzenarten – eine Bewertung der Lebendsammlungen**	TER	Living collections of plants in botanical gardens were evaluated according to hardiness and invasiveness elsewhere; 30 species were found that have not yet established, have caused significant ecological damages in other countries and have a hardiness zone of 7 or lower.	Not a horizon scanning.	Expert knowledge
Englmaier & Münch (2019)	**Potenziell verwilderungsfähige Gräserarten aus dem Zierpflanzen- und Saatguthandel: Steht die nächste Invasionswelle vor der Türe?**	TER	Based on a recent catalogue of alien grasses, and recently added species in trade, a selection of species is given with the potential to establish in Austria in the future. Criteria have been species traits (reproduction and dispersal, hardiness) and expert opinion.	Not a horizon scanning.	Expert knowledge
Lazzaro *et al*. (2019)	**Towards alien plant prioritization in**	TER/FW	The authors present the methods used to prioritise species already present in Italy for the national list.	Not a horizon scanning.	Expert knowledge

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al.* 2015 (and 2019a)	Source
	Italy: methodological issues and first results				
Adriaens *et al.* (2020)	**Invasieve Exoten in Vlaanderen: toestand en beleidsaanbevelingen Achtergrondrapport bij het Natuurrapport 2020**	FW/TER/MAR	Contains descriptions of valuable conservation habitats and problematic aliens including some novel species.	Not a horizon scanning.	Multi-language search (Dutch)
Bertolino *et al.* (2020)	**A framework for prioritising present and potentially invasive mammal species for a national list**	TER	The authors present the framework used to prioritise species already present and absent in Italy for the national list. Application of the approach used within the LIFE ASAP for the national list including all taxa (see Monaco *et al.* 2020).	Use of equations for invasiveness (impacts + spread) and manageability to have different rank classes and cross the classes of invasiveness and manageability to identify the priority species to list.	Expert knowledge
De Knijf *et al.* (2020)	**Exotische rivierkreeften in België-Een (k) nijpend probleem?**	FW	Article on the state of the art for alien and invasive crayfish in Belgium, with recommendations on how to tackle invasions, including the proposal to draft an alert list through horizon scanning.	Not a horizon scanning.	Multi-language search (Dutch)
Molfini *et al.* (2020)	**A preliminary prioritized list of Italian alien terrestrial invertebrate species**	TER	The authors present the methods used to prioritise species already present in Italy for the national list.	Not a horizon scanning.	Expert knowledge

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Monaco *et al*. (2020)	**Risultati dell'horizon-scanning e proposta per un elenco di specie esotiche invasive di rilevanza nazionale**	TER/FW/MAR	The authors produced a list of already present and potential invasive alien species for Italy for all taxa to be prioritised, screening the scientific and grey literature, international databases and considering experts' opinion. Approach developed within the LIFE ASAP project and used at national level for all taxa and environments.	Use of equations for invasiveness (impacts + spread) and manageability to have different rank classes and cross the classes of invasiveness and manageability to identify the priority species to list.	Expert knowledge
Thunnissen *et al*. (2020)	**Risicobeoordeling van uitheemse landplatwormen**	FW	Identifies 29 planarians including species not present in The Netherlands.	Combines climatic suitability with Harmonia+ assessments in four domains (environment, plant health, animal and human health).	Multi-language search (Dutch)
Lemmers *et al*. (2021)	**Risks and management of alien freshwater crayfish species in the Rhine-Meuse river district**	FW	Scientific article describing results of first-line risk assessments for alien crayfish of the Rhine-Meuse River district including also a standardised assessment of the feasibility of six pre-defined control strategies.	Use of Harmonia+ assessments, supported by literature search using a backward snowballing technique to acquire relevant literature. Standardised method for management feasibility assessment.	Multi-language search (Dutch)
Lorenzoni *et al*. (2021)	**Deliverable A13: List of IAS and Prioritized IAS for Umbria (Italy)**	TER/FW	The authors use the same approach of the LIFE ASAP project adapted at regional scale (for details, please see Monaco *et al*. 2020 above).	Uses the approach of LIFE ASAP adapted at regional scale.	Multi-language search (Italian)

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
Radočaj *et al*. (2021)	**Horizon scanning of potentially invasive non-native fish species for Croatia and Slovenia**	FW	Use of the CABI Horizon Scanning Tool to generate species lists. Information on pathways of introduction and ecological impacts was collected using specific databases and scientific literature.	Methodology not described in detail.	Multi-language search (Croatian)
Thunnissen *et al*. (2021)	**Risicoscan van exotische mierensoorten in Nederland**	TER	Identifies alien ant species that have been introduced in the Netherlands or that can be expected based on establishment in surrounding countries or areas with a similar climate.	Twenty-one species were assessed using the Harmonia+ protocol including two horizon scan species that currently do not occur in the Netherlands (*Monomorium trageri* and *Plagiolepis invadens* do not yet occur in the Netherlands, but are expected to survive in the Dutch climate).	Multi-language search (Dutch)
Adriaens *et al*. (2022)	**Assessment of current and future invasive plants in protected dune habitats of the Atlantic coastal region - Including management accounts of selected species for the LIFE DUNIAS project (LIFE20 NAT/BE/001442)**	TER/FW	Risk screening of alien plants in the European Atlantic coastal area using a combination of available scientific evidence and a moderated process to capture expert knowledge.	Data driven workflow for drafting longlist using GRIIS checklists and calculating occupancy in different countries; considers plants and bryophytes with records in the area, encompassing potential sleeper weeds as well as established high-impact IAS. It evaluates the impact specifically on protected Annex I habitats under the NATURA2000	Expert knowledge

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
				regime; risk scores were combined with distribution data to identify emerging, high-impact invaders	
Branquart *et al*. (2022)	**Belgian alert lists of alien aquatic plants and crayfish**	FW/TER	Alert list of potentially invasive crayfish and aquatic and riparian plants for conservation action in LIFE RIPARIAS, three-step screening: (1) longlist of alien species available on the Belgian market for ornamental purposes (nurseries, garden centres and aquarium shops) harvested from wholesaler's catalogues (2) climate matching (3) assessments with Harmonia+. Longlist of 202 alien plants and 36 alien crayfish currently present in the Belgian commerce.	Use of information from commercial wholesaler catalogues for drafting longlist. Climate matching with Belgian climate (using a GBIF based workflow) was used to select candidates for detailed assessments. Shortlisted species were assessed in detail using Harmonia+ (D'hondt *et al*. 2015, 2025).	Expert knowledge
D'hondt and Adriaens (2022)	**Advies over de opmaak van een lijst van voor het Vlaamse Gewest zorgwekkende invasieve uitheemse soorten**	FW/TER/MAR	Advice on potentially relevant species and methodology for drafting a list of national concern for Belgium. Contains list of all alien species on national lists in Europe (Denmark, Estonia, France, Ireland, Lithuania, Poland, Slovakia, Spain), and a list of species with risk assessment for Belgium.	Use of Harmonia+ assessments.	Multi-language search (Dutch)
Lorenzoni *et al*. (2022)	**A consensus-building based prioritization and horizon scanning of alien freshwater fish to predict the potential**	FW	The authors were part of the group conducting the exercise within the LIFE ASAP project (for details, please see Monaco *et al.* 2020 above). This is only an abstract.	Uses the approach of LIFE ASAP.	Multi-language search (Italian)

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
	threats to native fish biodiversity				
Oliva-Paterna *et al*. (2022)	**Lista negra y lista de alerta de especies exóticas invasoras acuáticas de la Península Ibérica (2022)**	FW	The authors reviewed the literature and organised workshops with 60 experts, which resulted in prioritising 126 invasive species among all the invasive species registered in continental waters in the Iberian Peninsula (41.2 % of all registered invasive species), according to their potential impacts.	Scoring of the species included their potential economic impacts and impacts on human health, management feasibility, and whether society would support or oppose the management.	Multi-language search (Spanish)
Thunnissen *et al*. (2022a)	**Risicoscan van uitheemse zoetwatermollusken in Nederland**	FW	Identifies 70 present and expected (potentially) invasive alien molluscs for the Netherlands.	Includes a list of 39 non-established alien molluscs in aquarium trade (so used trade data), uses a "harmonised risk score" based on a table that translates risk scores from all kinds of scoring systems into low, medium and high impact.	Multi-language search (Dutch)
Thunnissen *et al*. (2022b)	**Risk screening and management of alien terrestrial planarians in The Netherlands**	TER	Article version of the Dutch risk screening report (Thunnissen *et al*., 2020).		Multi-language search (Dutch)

Reference	Title	Environ. coverage	Brief description of methods used	Potential relevant/innovative aspects since Roy *et al*. 2015 (and 2019a)	Source
van Riel *et al*. (2023)	**Horizonscan voor nieuwe invasieve uitheemse soorten in Nederland, update 2022**	FW/TER/MAR	Update of the 2014 horizon scanning for The Netherlands, identifies 195 high risk species. Combines information on distribution, species in trade and captivity (zoos etc.) and risk assessments on top of expert judgement.	Uses a system of harmonising scores from other horizon scanning methods into low/medium/high risk (Annex 3). Use of distribution data to select species with limited occurrence in the territory, use of data on captive populations in zoos or private collections.	Multi-language search (Dutch)
Steen *et al*. (2024)	**Invasieve uitheemse soorten onder klimaatwijziging. Een beheergids van prioritaire invasieve planten voor De Vlaamse Waterweg nv**	FW	Longlist was produced using GRIIS Belgium, a study on aquatic plants in trade, the RIPARIAS alert list and the CABI HS tool. Because plants from GRIIS observed since 2010 were selected also sporadically occurring plant species were considered besides “true HS” species. Methodologically the study used a simple climate matching tool (with a cut-off on % climate match) to break the longlist down into a workable selection. Impact was derived from the Global Plant Invaders database, ISEIA, and a selection of traits linked to invasiveness using the TRY database.	Climate matching, data driven, invasiveness assessment based on global invader database and trait databases.	Multi-language search (Dutch)

These elimination processes led to shortlists with manageable numbers of higher priority species and, once the shortlists were confirmed, the thematic groups generally engaged in a detailed scoring exercise. To facilitate scoring, defined ecological characteristics were collected for each species, specifically the functional group, native range, current presence/absence in the risk assessment area, most likely pathway(s) of introduction, and type of impact. There are of course many further aspects which may be incorporated into a scoring system, so the exact determination of information to collate was at the discretion of the assessors. For example, Lucy *et al*. (2020) gave weighting to the potential colonisation risk of high value conservation habitats.

When conducting the scoring exercise, over half of papers screened (51.1 %) used the methodology (or a variation thereof) employed in the previous EU-level horizon scan (Roy *et al*., 2015). In this methodology, an overall risk score for each species was calculated as the product of the individual scores (1 – 5) for arrival, establishment, spread and impact on biodiversity. With a four-criterion, five-point scoring system, this produces a maximum score of 625 (Roy *et al*., 2015, 2019a). A confidence interval of low, medium or high was assigned to each score. Another option is to simply consider the product of the scores for likelihood of arrival, establishment and impact (excluding spread), leading to a maximum score of 125, again with a confidence interval (Roy *et al*., 2014).

The essential role of expert knowledge within the scoring process becomes evident when understanding how experts assign a quantitative score for arrival, establishment and spread, as these metrics rely on robust pathway information alongside a detailed knowledge of the species' life history strategy. This can be a complex exercise, for example, a modified version of the Roy *et al*. (2015) methodology described 'spread' as the likelihood of arrival in the risk assessment area or escape from captivity if already present × likelihood of establishment × [(likelihood of natural spread + likelihood of human assisted spread)/2], giving a maximum value of 125 (Bertolino *et al*., 2020). A defined timeframe was frequently suggested for arrival, for example within the next ten years (Roy *et al*., 2019a).

The metric used to assess and score a species' impact differed slightly, as this did depend on whether the thematic groups were focusing on environmental, socio-economic or human-health impacts. However, there are existing guidelines to determine the exact type of impact, including the IUCN Environmental Impact Classification for Alien Taxa (EICAT), which categorises impacts into 12 mechanisms, and the Socio-Economic Impact Classification of Alien Taxa (SEICAT) in which impacts are considered as constituents of human well-being (Bacher *et al*., 2018; IUCN, 2020). These mechanisms, (listed below), may be used in an original or modified form to facilitate impact scoring (Bertolino *et al*., 2020; Peyton *et al*., 2020, Kendig *et al*., 2022).

While the Roy *et al*. (2015) methodology was frequently employed, there were other risk-scoring tools available, particularly for aquatic invasive species. These included the semi-quantitative Canadian Marine Invasive Screening tool (CMIST), in which assessors answered 17 questions related to the likelihood and impact of invasion

(Goldsmit *et al*., 2021) or the Aquatic Species Invasiveness Screening Kit (AS-ISK). The AS-ISK is composed of 49 questions that examine the impact of an alien species from a biogeographical, biological and economic point of view. The combination of these three types of impact produces a Basic Risk Assessment (BRA) score. Six further questions define the Climate Change Assessment (CCA) of the species, describing the potential effects of future climate change on the risk of the species' introduction, establishment, dispersal and socio-economic impacts. The combination of BRA and CCA scores give the species the final level of invasiveness. This AS-ISK was used in 11.1 % of studies overall, but when considering horizon scans for aquatic species only (marine and freshwater, no terrestrial component) the proportion using the AS-ISK rose to 35.7 %.

In some cases, the assessors scored the acceptability or difficulty of species management (e.g. Oficialdegui *et al*., 2023). Indeed, Bertolino *et al*. (2020) evaluated the effectiveness of management strategies by considering the ease of species identification in the field. Prioritisation within this study was partly based on the estimated costs for the management of established species, on the potential side effects of eradication methods (e.g. potential impacts on native species), on the social acceptability of eradication/control methods and on the estimated costs connected with the environmental restoration following the management action.

Regardless of the precise scoring mechanism used within the thematic groups, upon completion of the preliminary scoring exercises experts would adopt a consensus approach (often in workshop form) so that the species lists from across the thematic groups could be collated into a single, ranked list. Within these workshops, participants were invited to review, consider and refine the rankings of all species through plenary discussion. It is possible that feasibility of management may be discussed at this stage also, as per Adriaens *et al*. (2022), whereby experts were asked to rank the feasibility of management as a final step in the workshop according to a predetermined eight-point scale.

While the explanation above details the more common horizon scanning process, there were of course methodologies available which differ from the pattern of (i) compiling longlists, (ii) refining the lists based on specific criteria, (iii) expert scoring of species (iv) workshop or similar ranking exercise. For example, Carboneras *et al*. (2018) used an expert workshop to develop a decision tree to help identify potential species for risk assessment based on the criteria set out in Regulation 1143/2014. These discussions aimed to develop a set of biologically relevant questions to distinguish species potentially suitable for listing, which then led to a second workshop designed to create a template 'distribution x impact' matrix (with distribution corresponding to the current stage of a species' invasion curve in Europe and impact modelled on the EICAT guidelines). Species were screened using desk-based searches (databases and literature), focusing on species' impacts on biodiversity and ecosystem services. Species were then assigned a priority category based on the criteria developed in the workshops. In cases of species with a major impact, those in the initial stages of invasions were prioritised over widely spread ones.

There was a further trend evident, particularly for (potentially) invasive alien plants, whereby authors assessed those species currently growing in private gardens and/or public green spaces (Mayer *et al*., 2017). One such study asked gardeners to identify ornamental plants they felt were 'taking over' their garden, thus listing a pool species with invasive potential. The authors then used a follow-up survey to identify the dominant species. These 'future' invaders were prioritised by looking at the domestic and global naturalised and invasive status of each taxon using the Global Register of Introduced and Invasive Species (GRIIS) and Global Naturalized Alien Flora (GloNAF) databases. Priority was assigned to taxa which had already escaped gardens, but were not yet considered invasive within the risk assessment area, although they held invasive status globally (Jones *et al*., 2024). Alternatively, researchers may screen species in horticultural trade catalogues, to assess their potential for invasive behaviour (Bayón & Vilá, 2019).

The above information provides a broad overview of the horizon scanning methodologies for IAS and demonstrates that, despite some differences in the specificities, there was a general trend of refining significant quantities of information into concise, peer-reviewed lists through an expert elicitation process. There is one caveat which is particularly evident for those conducting a horizon scan at a broad spatial scale, namely that the initial pool of species in longlists is challenging to condense. This is due, in part, to the often many matching habitats and/or climatic variables in the region of interest that may allow a species to arrive, establish and spread. There was an acknowledgement of this in one study, whereby the authors noted that horizon scanning resources can become, 'somewhat evenly spread over numerous species, many of which will not be classified as hazards'. In this particular study the authors proposed a taxonomically-restricted approach, focusing on taxonomic groups that contain known invaders within priority pathways (Hill *et al*., 2023).

While this taxonomic approach may benefit a study on a smaller spatial scale, at the EU level it is not necessarily feasible to limit the taxonomic scope of a horizon scan due to the high volumes of inter and intra EU trade, travel and transport, all of which may facilitate the movement of IAS. To counter this, assessors working at EU level (or indeed at any regional level) must prepare a detailed methodology in advance and ensure that all experts involved are confident in the proposed scoring and ranking system. This will ensure that the final prioritised list is robust, allowing managers and policy makers to focus on prevention of introductions, or on rapid eradication as soon as a new species is detected in the risk assessment area. This proactive, early intervention response will facilitate the core tenet of IAS management, namely that prevention is more cost effective and ecologically effective than long-term management.

2.3. Task 1. Part 2 – Update the horizon scanning methodology

This section refers to the ultimate goal of this task, which was to produce an updated version of the horizon scanning methodology developed by Roy *et al*. (2015), in order to create a list of IAS that are likely to arrive, establish, spread and have an impact on biodiversity or associated ecosystem services across the EU in the next ten years. Following the review of the various horizon scanning methodologies used both to prioritise various themes/issues (related to 'Conservation Biology') and those undertaken to prioritise lists of IAS with the potential to arrive and establish in new areas (collated and summarised in Section 2.2. above), as well as considering expert knowledge, an adapted version of Roy *et al*.'s (2015) methodology is presented here. The suggested revised methodology is largely similar in structure to the one developed by Roy *et al*. (2015), with the main changes referring to:

- how the initial species long lists have been gathered, here taking advantage of all previous horizon scans performed globally;
- the manner of defining which species are considered widely spread in the EU and should therefore not be included in this exercise;
- the process used to refine species long lists, here to some extent based on climate matching.

The revised methodology also envisages retrieval of some additional information on aspects related to Task 4 of this project. This updated horizon scanning methodology was used in the implementation of 'Task 2: Perform a horizon scanning'.

2.3.1. Scope of the Horizon Scanning

The geographical scope of the horizon scanning exercise was originally determined as the territory of the EU, i.e. the 27 EU MS, excluding the EU outermost regions and EU Overseas Countries and Territories. The six originally defined taxonomic groups to be covered by the exercise were: terrestrial and aquatic vertebrates, terrestrial and aquatic invertebrates, and terrestrial and aquatic plants. It was also stated that the 100 species suggested to be prioritised for risk assessment did not need to have balanced representation across the different habitats and taxonomic groups, e.g. a final list of most risky species could be composed of many more plant than animal species, if appropriate.

After deliberations within the project team, it was decided that, for all taxonomic groups, aquatic species would be separated into freshwater and marine. It was also deemed appropriate to deal with all the marine species as a single group, rather than separating vertebrates, invertebrates and plants, given that often experts working in this environment tackle a multitude of taxonomic groups simultaneously. Furthermore, a similar approach of addressing all species together was deemed more appropriate also for the vertebrates and plants groups. As such, the current horizon scanning study exercise was performed considering five different taxonomic groups (hereafter called 'thematic groups'), as presented in Table 5.

Table 5. Thematic groups of the current horizon scanning exercise and respective lead experts from the project team.

Initial thematic groups	Expert leads	Final thematic groups
Terrestrial vertebrates	Riccardo Scalera	Vertebrates
Freshwater vertebrates	Tim Adriaens	
Terrestrial invertebrates	Wolfgang Rabitsch	Terrestrial invertebrates
Freshwater invertebrates	Elena Tricarico	Freshwater invertebrates
Terrestrial plants	Petr Pyšek	Plants
Freshwater plants	Ana Novoa	
Marine animals and plants[2]	Katie Costello	Marine

Species considered for inclusion in this horizon scanning were only those known to be alien to mainland EU territory (i.e. not native in any part of it), acknowledging that the EU does not encompass all of Europe. Furthermore, species which have had Risk Assessments (RA) produced at the EU level before but that, for various reasons, were not listed as IAS of Union concern, were also taken into account. In addition, the exercise included not only 'true horizon scanning' species in the sense of those not present at all in the EU territory, but also species considered to have very limited distribution in the EU (see more details on this in Section 2.3.3.). Overall, with the exception of species that satisfy any of the exclusion criteria outlined below, species that were considered for inclusion in this horizon scanning exercise include, among others, those that:

- are present in countries, regions or waters adjacent or physically connected to the EU;
- are found in trade or have other active pathways of introduction into the EU, or are present in areas having strong trade and/or travel links with the EU;
- are found only in confined environments in the EU, with a risk of escaping or being released in the near future;

[2] Including macroscopic algae, as this group has proven problematic in the marine environment.

- are present in regions that have climatic conditions comparable to any region in the EU.

2.3.2. Exclusion criteria

Similarly to those in Roy *et al*. (2015) and extended here, a variety of criteria on species that were excluded from the current horizon scanning exercise, some of which related to exclusion criteria set out in the EU IAS Regulation (Art. 2), are outlined below:

- Species changing their natural range without human intervention, in response to changing ecological conditions and climate change (Art. 2(a)), unless these species originate from populations that are non-native;
- Genetically modified organisms as defined in point 2 of Article 2 of Directive 2001/18/EC (Art. 2(b));
- Pathogens that cause animal diseases (Art. 2(c)) and other microorganisms (e.g. bacteria, viruses, fungi, protozoa, diatoms, dinoflagellates) (Art. 2(f,g));
- Harmful organisms listed in Annex I or Annex II to the Plant Health Directive 2000/29/EC (Art. 2(d)), which has been repealed and replaced by Regulation (EU) 2016/2031[3]; as such, this refers to harmful organisms listed in Annexes II, III and IV of Commission Implementing Regulation (EU) 2019/2072[4];
- Species listed in Annex IV to Regulation (EC) No 708/2007[5] when used in aquaculture (Art. 2(e));
- Species that are native to any part of the EU territory (excluding the EU outermost regions and EU Overseas Countries and Territories);
- Species listed as of Union concern, as per the EU IAS Regulation[6];
- Species which have had Risk Assessments (RA) produced at the EU level recently, are currently being proposed to be listed, or for which a RA will be performed soon;
- Cryptogenic species (i.e. species of uncertain or unknown origin, for which it is not possible to reliably determine whether they are introduced or native to a region);
- Taxa that are members of unresolved species complexes or that cannot be reliably separated from other closely related taxa, cultivars and hybrids;
- Species that are considered as widely spread in the EU (see details under Section 3.1.2 below);

[3] https://eur-lex.europa.eu/eli/reg/2016/2031/oj

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02019R2072-20220714&qid=1667573350824

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32007R0708

[6] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02016R1141-20220802&from=EN

- Species having adverse impacts only on economic activities (e.g. agriculture, horticulture, timber production) or human health and wellbeing, unless these impacts are in addition to impacts on native biodiversity or ecosystem services.

2.3.3. Methodological steps

Considering all the above, the project team developed a tiered six-step methodology combining the use of a modified Delphi-approach and consensus expert elicitation to undertake the present EU-level horizon scanning exercise. The methodology, largely relying on expert knowledge, aimed to be comprehensive and, at the same time, as standardised as possible, for easy replication across the thematic groups and at any point in the future. The six different steps, which are described in detail in the sections below, were:

1. Preparation of long lists of IAS;
2. Selection and invitation of experts for each thematic group;
3. Checking and refining of species long lists;
4. Gathering information for species in refined lists;
5. Scoring species – rapid assessment of likelihood of introduction, establishment, spread and impact (to allow preliminary ranking of species);
6. Expert consensus workshop – review scores and refine species rankings across all groups.

2.3.3.1. Step 1 – Preparation of long lists of IAS

The first step of the horizon scanning consisted of compiling and merging various species lists of IAS that may have a high risk of arrival, establishment and spread in the EU in the coming years, which formed the baseline of this study. For this, a variety of relevant sources were used to compile species long lists, followed by a step consisting of clearing these lists from species that were out of the scope of the exercise, as much as possible, based on the exclusion criteria mentioned above.

2.3.3.1.1. Merging various species lists and removing name duplicates

In order to compile species long lists for each of the thematic groups to be tackled in this study, lists of IAS that have been previously produced with a similar aim or lists that align with the goal of this exercise were retrieved, combined and crosschecked. Firstly, information was extracted from lists resulting from previous IAS horizon scanning exercises undertaken in the EU and beyond between 2015 and 2024 (or other relevant papers/reports), as per the literature review undertaken in Section 2.2.2. Secondly, targeted species lists were extracted from selected EU and global databases whose data was deemed most relevant for this study. Finally, specific data sources with species lists provided by experts from the project's team or their networks were used and merged with the others.

A master long list of species was put together by merging all the IAS lists compiled (each described in more detail in Section 3.1.; see also Tables 12 and 13 further below). The lists were initially filtered for the exclusion criteria easily addressed, such as removal of microorganisms, hybrids, etc., with most of the exclusions undertaken under the section just below. In addition, at this stage, all identified duplicate species names were removed, as much as possible, with an additional step of further removal of any possible inaccurate scientific names or synonyms by matching those to the GBIF Backbone Taxonomy.

At this stage, species were also categorised into each of the five thematic groups under focus, as accurately as possible. All the information on species attributes that could be extracted from the initial lists (e.g. on taxonomy, pathways of introduction and spread, native range) was kept, in order to inform, and be used in, subsequent steps of the horizon scanning exercise.

2.3.3.1.2. Removal of species considering exclusion criteria

After the master long list was compiled based on the data sources mentioned above, the list was further filtered taking into account all the pre-defined exclusion criteria, as comprehensively as possible. Some of these criteria had already been addressed through the filtering of lists in the previous section, and the remaining ones were addressed during this step (e.g. species considered widely spread in the EU; see Section 3.1.2). However, the refinement of some of these exclusion criteria (e.g. species native to the EU) was only possible to fully address at later stages of the horizon scanning, as they relied on expert knowledge and the retrieval of information from open data repositories.

2.3.3.2. Step 2 – Selection and invitation of experts for each thematic group

Given the subsequent steps of this horizon scanning, namely the expert elicitation and consensus exercise undertaken, an important step was the selection and invitation of a number of experts to participate in the refinement, scoring and ranking of lists of species before and during the workshop (see more details in sections below). As mentioned above, for this horizon scanning five main thematic groups were considered and so, in order to guarantee robustness in the expert elicitation exercise, it was decided that each of these groups should have a minimum of three additional specialist experts identified and invited to participate. For this, each of the core team members leading the different groups was asked to suggest the names of at least three experts at the forefront of research in what concerns those specific IAS groups, prioritising those that have previous experience in horizon scanning exercises. An attempt was made to have a wide representation of as many EU MS as possible across the entire expert team, and to keep gender balance in mind.

2.3.3.3. Step 3 – Checking and refining species long lists

As it was anticipated that the initial long lists generated for each taxonomic group under step 1 would have a very high number of species, there was a need to further filter these lists to reduce numbers before specific species information was retrieved and the species were scored. At the same time, as it was also entirely possible that some relevant species might not have been captured in the initial lists, it was also necessary to allow for additional species to be integrated into these lists. This step then consisted of streamlining the initial long lists prepared for each thematic group, both by removing species potentially out of scope of the exercise or deemed not relevant for various reasons (e.g. no impact on biodiversity), while also adding new potentially impactful species that might have been missed. Differences in the final methodological approaches taken by the different thematic groups were captured.

2.3.3.3.1. Removal of species from long lists

Regarding the removal of species from the long list, as a first step, the project core team decided to perform a climate matching exercise for all terrestrial and freshwater species in the long list, to define potential cut-offs for removing species from each of the different thematic groups (see Step 3, Section 3.3.1 below). This exercise was also used to assist assessing likelihood of species establishment at a later stage. For the climate matching, a data-driven procedure was applied, which involved calculating the proportion of climatic overlap of each species based on worldwide species GBIF distribution data. Based on the percentage of climatic match with EU climates, species for which the percentage overlap with any of the EU climates was below a certain threshold (see more details under Step 3, Section 3.3.1 below) could potentially be removed – but this was left to the discretion of each group lead. Due to the difficulty in running climate matching for the marine environment, this approach was not considered for those species.

Group leads and the invited experts further assessed the relevance of species to be included in the horizon scanning exercise again, considering those that might have been missed in previous steps due to the exclusion criteria mentioned above. Furthermore, they were also asked to indicate species that did not belong to their thematic group and should be moved to another.

Finally, in order to further refine the lists, a variety of additional steps were taken by the thematic group leads in consultation with their invited experts, such as: removing certain groups of species either not deemed problematic or difficult to deal with (e.g. identification issues); performing a quick species relevance check similar to what was done by Adriaens *et al*. (2022), based on documented evidence of species impacts on native biodiversity or associated ecosystem services; using information from additional databases to understand if and how species show invasive behaviour and exclude those that did not fit the pre-defined criteria.

2.3.3.3.2. Addition of species to long lists

The addition of new species to the lists was based on a quick retrieval of information from limited sources, such as databases, publications, reports, social media, etc., but largely reliant on experts' knowledge and experience. For this, each thematic group lead and their additional experts:

- Looked for, and inspected, literature that was not captured in step 1, including publications or reports not specifically focusing on horizon scanning exercises, but looking at IAS that threaten biodiversity and that might arrive to the EU in the near future;
- Searched for potential additional data sources, such as lists of species found in trade in the EU that are not yet present in the wild or that have limited distribution, or species present in the EU only within confined environments;
- Searched for any type of useful information possible to retrieve from social media or other platforms, such as X, Facebook and citizen science apps.

2.3.3.4. Step 4 – Gathering information for species in refined lists

In order to inform the expert-led exercise of scoring species from the refined lists according to different criteria (step 5 of this horizon scanning), detailed information regarding each of those species needed to be gathered first (or at the same time). As mentioned before, some of the species lists retrieved from previous horizon scans during step 1 contained varied species information attached to them, which was kept and provided to experts, so that it could be used here.

Various information sources were screened and species-specific information was retrieved from a variety of databases, scientific publications and their supplements, grey literature and other data sources deemed relevant. The specific fields of information retrieved by experts in order to be able to score species are detailed below. In addition, with the aim of gathering information for Task 4 of the project – '*Identify taxonomic groups that could be invasive but where the great number of species that are candidate for listing would call for additional measures*' –, information on families or genera with high numbers of species identified in these lists was also noted down during this step.

For each species in the refined list of each thematic group, the following core information was assembled in a pre-prepared Excel spreadsheet shared with all the experts:

- Scientific name

- Taxonomy (Phylum, Class, Order, Family)
- Native range
- Invaded range
- Presence in the EU
- Pathways of introduction and spread
- Percentage/area of potential establishment in the EU
- Negative impacts on biodiversity and associated ecosystem services

2.3.3.4.1. Native and invaded range

Due to the intrinsic differences between ecosystems, the native and invaded range of terrestrial/freshwater and marine species was recorded using different schemes. For the former, the United Nations geoscheme[7], a system which divides 248 countries and territories in the world into six continental regions and 22 geographical subregions, was used. Both the continental region and the geographical subregion were recorded for each species (Table 6).

For marine species, due to the large connectivity and consequent difficulty in strictly separating these environments, the major world oceans were used to record the native range of species (Pacific, Atlantic, etc.), with a further subcategorisation loosely based on the United Nations Maritime Zones and Maritime Delimitation[8] (e.g. Baltic Sea, Mediterranean Sea, Red Sea, South-East Asia, South Pacific, West Africa).

Table 6. Categories used to record the native and invaded range (both continental region and geographic subregion) of terrestrial and freshwater species in this horizon scanning exercise.

Continental region	Geographical subregion
Africa	Northern Africa
	Eastern Africa
	Middle Africa
	Southern Africa
	Western Africa

[7] https://en.wikipedia.org/wiki/United_Nations_geoscheme

[8] https://www.un.org/Depts/los/LEGISLATIONANDTREATIES/subregionsandseas.htm

Continental region	Geographical subregion
Americas	Caribbean
	Central America
	South America
	Northern America
Asia	Central Asia
	Eastern Asia
	South-eastern Asia
	Southern Asia
	Western Asia
Europe	Eastern Europe
	Northern Europe
	Southern Europe
	Western Europe
Oceania	Australia and New Zealand
	Melanesia
	Micronesia
	Polynesia

2.3.3.4.2. Presence in the EU

For each species, it was noted if the species is currently present in the EU. Information on the presence or absence of species in the EU was initially provided to the experts based on distribution data retrieved from GBIF. Additionally, in case a species was present, it was indicated in which EU countries the species is present and in how many 50 km x 50 km EU grid cells. Given that species in ≥ three 50 km grid cells were considered widely spread in the territory and were not taken into account here, the number of grid cells for each species was either zero, one or two (see more details in Section 3.1.2 and in Delva *et al.*, 2025). Experts were asked to double check the information provided by GBIF and to correct it, if applicable and possible; in cases where there was uncertainty regarding the presence of a species in the EU, the status was marked as 'uncertain'. Species only present in captivity or cultivation, but not present in the wild, were marked as 'not present in the EU'. Species for which there have been casual records, but that are not established in the wild, were marked as 'present in the EU'.

2.3.3.4.3. Pathways of introduction and spread

Pathways of introduction and spread through which each species has been introduced into, or has spread to, different regions where it is not native, as well as other active pathways through which the species could arrive to the EU (if applicable), were also recorded. At a first stage, for all species in the refined lists, this was done rather coarsely, based on the high-level categories of the pathways scheme outlined by the CBD[9] and also used for the reporting obligations under the EU IAS Regulation (Release in Nature; Escape from confinement; Transport – contaminant; Transport – stowaway; Corridor; Unaided; see also IUCN, 2018; Table 7).

At a later stage of the exercise (post-workshop), for the 167 risky species put forward for potentially being risk assessed, pathways of introduction and spread were further refined in accordance with the detailed pathways categories from the scheme mentioned above (Table 7). For many species, multiple pathways of introduction and/or spread are relevant, therefore an attempt was made to capture all of those, as much as possible.

Table 7. High-level and detailed categories of pathways of introduction and spread (with respective codes) through which species can be introduced and/or spread in the EU according to the CBD pathways scheme.

High-level pathways categories	Detailed pathways categories	Detailed pathways codes
Release in Nature	Biological control	BC
	Erosion control/dune stabilization (windbreaks, hedges, …)	EC
	Fishery in the wild (including game fishing)	F
	Hunting	H

[9] https://www.cbd.int/doc/meetings/sbstta/sbstta-18/official/sbstta-18-09-add1-en.pdf

High-level pathways categories	Detailed pathways categories	Detailed pathways codes
	Landscape/flora/fauna “improvement” in the wild	L
	Introduction for conservation purposes or wildlife management	Cons
	Release in nature for use (other than above, e.g., fur, transport, medical use)	R
	Other intentional release	Other
Escape from Confinement	Agriculture (including Biofuel feedstocks)	Ag
	Aquaculture/mariculture	Aq
	Botanical garden/zoo/aquaria (excluding domestic aquaria)	BZA
	Pet/aquarium/terrarium species (including live food for such species)	Pet
	Farmed animals (including animals left under limited control)	Farm
	Forestry (including afforestation or reforestation)	For
	Fur farms	FF
	Horticulture	Hort
	Ornamental purpose other than horticulture	Orn
	Research and ex-situ breeding (in facilities)	Res
	Live food and live bait	Live
	Other escape from confinement	Other escape
Transport – Contaminant	Contaminant nursery material	CNM
	Contaminated bait	Bait
	Food contaminant (including of live food)	Food
	Contaminant on animals (except parasites, species transported by host/vector)	Con Anim

High-level pathways categories	Detailed pathways categories	Detailed pathways codes
	Parasites on animals (including species transported by host and vector)	Par Anim
	Contaminant on plants (except parasites, species transported by host/vector)	Con Plant
	Parasites on plants (including species transported by host and vector)	Par Plant
	Seed contaminant	Seed
	Timber trade	TT
	Transportation of habitat material (soil, vegetation,…)	THM
Transport – Stowaway	Angling/fishing equipment	Ang
	Container/bulk	Container
	Hitchhikers in or on airplane	Air
	Hitchhikers on ship/boat (excluding ballast water and hull fouling)	Ship
	Machinery/equipment	Mach
	People and their luggage/equipment (in particular tourism)	Lug
	Organic packing material, in particular wood packaging	Org
	Ship/boat ballast water	Ballast
	Ship/boat hull fouling	Hull
	Vehicles (car, train, …)	Veh
	Other means of transport	Other Transport
Corridor	Interconnected waterways/basins/seas	Water
	Tunnels and land bridges	Tun

High-level pathways categories	Detailed pathways categories	Detailed pathways codes
Unaided	Natural dispersal across borders of invasive alien species that have been introduced through pathways 1 to 5	Nat
Unknown	Unknown	Unknown

2.3.3.4.4. Percentage/area of potential establishment in the EU

The climate matching exercise showing the potential future distribution of species in the EU was also used to assist in the process of scoring the likelihood of species establishment in the EU (in the subsequent step). The suitability of EU climate zones for each species was calculated as the percentage of the species' global GBIF occurrence records that fell within these zones, with a correction for the surface area of each climatic zone present in Europe (see more specific details in Step 3, Section 3.3.1 below). These percentages for each species were provided to all experts in a pre-filled Excel spreadsheet, along with maps showing areas suitable for establishment of each species under current and future climate scenarios (see Delva *et al.*, 2025). This was done also for species that are already present in the EU, in order to understand in which areas these species may further establish under current or future climate conditions.

As mentioned before, due to the limited possibilities of running climate matching for species in the marine environment, this approach was not considered for those species. As such, in that case, an expert-based approach was taken, through which experts assessed the high-level Marine Strategy Framework Directive (MSFD) subregions[10] (excluding non-relevant regions) in which the potential establishment of each species is predicted. This was based on previous histories of invasion, ecological and life-history characteristics of the species, temperature and salinity profiles and other relevant features, and was mostly captured at the high-level subregions (or in more detailed subregions, where possible; Table 8).

Table 8. MSFD high-level and detailed subregions considered to record marine species potential establishment under current and future climate scenarios.

High-level MSFD subregions	Detailed MSFD subregions
Baltic Sea	Baltic Sea
North-east Atlantic Ocean	Greater North Sea, including the Kattegat and the English Channel

[10] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX%3A52020SC0062

High-level MSFD subregions	Detailed MSFD subregions
	Celtic Seas
	Bay of Biscay and the Iberian Coast
Mediterranean Sea	Western Mediterranean Sea
	Adriatic Sea
	Ionian Sea
	Central Mediterranean Sea
	Aegean-Levantine Sea
Black Sea	Black Sea

2.3.3.4.5. Negative impacts on native biodiversity or associated ecosystem services

Information on all the types of potential and/or realised negative impacts exerted by each IAS on native biodiversity (at all levels of organisation) was recorded, following the impact mechanisms outlined by EICAT (IUCN, 2020), with minor adaptations (Table 9). However, here, those impacts can refer both to negative effects imposed on native species, similarly to EICAT's scheme, but also to adverse impacts on habitats and ecosystems (see more details under step 5, Table 10 below).

In case information was available, a brief description of any potential or observed negative impacts exerted by each species on ecosystem services was also registered. For this, a simplified version of the 'Ecosystem services classification (CICES V5.1[11])' used under the framework of producing risk assessments for species considered for inclusion in the Union list was used, but only for reference, as each of the specific impact categories therein was not registered by experts (Annex I).

Additionally, when information was readily available, negative impacts exerted on species of conservation importance, for example endemic species, species that are considered threatened according to the IUCN Red List of Threatened Species[12] (Vulnerable, Endangered or Critically Endangered), or on protected habitats of conservation importance (e.g. Natura 2000, Habitats Directive), were also indicated.

[11] https://cices.eu/resources/

[12] https://www.iucnredlist.org/

Table 9. Different types of impact recorded for each IAS considered in this horizon scanning exercise. Under the negative impact on native biodiversity, ten different impact mechanisms were taken into account, in line with those established by the IUCN EICAT scheme.

Impact type	Impact mechanism
Negative impact on native biodiversity	1. Competition
	2. Predation
	3. Hybridisation
	4. Transmission of disease
	5. Parasitism
	6. Poisoning/toxicity
	7. Biofouling or other direct physical disturbance
	8. Grazing/herbivory/browsing
	9. Chemical, physical, structural impact on ecosystem
	10. Indirect impacts through interactions with other species
Negative impact on ecosystem services	N/A
Negative impact on species and habitats of conservation importance	N/A

2.3.3.5. Step 5 – Scoring species – rapid assessment of likelihood of introduction, establishment, spread and impact

All the species-specific information described under step 4 was gathered in view of performing a scoring exercise similar to a rapid risk analysis, in which the likelihood of introduction, establishment, spread and impact of each species was scored. This scoring information was inserted into the same pre-prepared Excel spreadsheet mentioned above, which was circulated to all additional experts together with some supporting documents, to facilitate this process. Additional resources, as deemed necessary, were shared among members of each thematic group (coordinated by group leads) and several online meetings were held, to ensure the scoring process ran smoothly.

Each expert was responsible for independently scoring a certain number of species. As most thematic groups had to score a high number of species, a minimum of two experts within each group scored each species. Experts from each thematic group were asked to score each species separately for their likelihood of arrival, establishment and spread on a 5-point scale, ranging from 1 (= very low likelihood) to 5 (= very high likelihood). Additionally, experts also scored the potential or realised negative impact of species on biodiversity and associated ecosystem services in the EU (Table 10). Given the nature of the scoring process relying largely on expert judgement, each score was also attributed an attached confidence level (high, medium, low; Table 11) which, together with the scores attributed to each criterion, aimed mostly at providing guidance for the species to prioritise.

Following the scoring of each species by different experts, group leads compiled and collated the scoring (and other) information from all experts within their thematic group. This was followed by discussions between various experts of the group, with the aim of reaching consensus on the final scores of each species (especially for species for which experts had very disparate initial scores). Species for which consensus could not be easily reached were scrutinised during the workshop.

2.3.3.5.1. Likelihood of introduction

To rapidly assess and score the likelihood of introduction of each species both into the EU and into the environment, experts considered various aspects based on data or knowledge, namely:

- Number and type of pathways through which the species could be introduced into the EU and/or enter the environment, e.g. ornamental trade, natural dispersal, transported as a contaminant (CBD pathways scheme mentioned above; IUCN, 2018);
- How likely the species is to survive and reproduce through the pathway(s) of introduction, considering its life-history characteristics and ecology;
- How likely the species is to escape the pathway and enter the environment;
- Species present in trade/captivity in the EU, potentially their volume, likelihood of escape and overall popularity on Google (and other platforms);
- Register of any previous casual occurrence of the species in the EU;
- Species present in regions/waters adjacent or physically connected to the EU;
- Number of regions the species has invaded outside the EU.

1 = species extremely unlikely to be introduced in the EU in the next ten years.

5 = species extremely likely (certain or near certain) to be introduced in the EU in the next ten years.

* Species already present in the EU were scored similarly to the others, as they do not necessarily have a higher current and future likelihood of introduction into the EU (and so as to not inflate their scores).

2.3.3.5.2. Likelihood of establishment

To rapidly assess and score the likelihood of establishment of each species (i.e. species reproducing and having a self-sustaining population), different aspects were considered based on data or knowledge, namely:

- For terrestrial and freshwater species, areas in the EU where the species can potentially establish based on current and future climate. This was aided by the provision to all experts of summary maps resulting from the exercise mentioned above showing the potential distribution of each species in the EU based on current and future climate matching (Delva *et al.*, 2025);
- For marine species, number and type of MSFD subregions in which the species can potentially establish;
- Availability of habitats used by the species in the EU;
- Biology and life-history characteristics of the species (e.g. adaptability of the species, reproductive biology and tolerance to a range of environmental conditions);
- Physiological constraints on establishment or biotic resistance of the habitats (e.g. presence of competing species).

1 = species extremely unlikely to establish in the EU in the next ten years.

5 = species extremely likely (certain or near certain) to establish in the EU in the next ten years; species already established in the EU were scored 5.

2.3.3.5.3. Likelihood of spread

To rapidly assess and score the likelihood of spread of each species (the expansion of their geographical distribution, either by autonomous dispersal or human-mediated spread), various aspects were considered based on data or knowledge, namely:

- Number and type of pathways through which the species can spread in the EU;
- Likelihood of human-assisted spread;
- History of spread in other invaded regions;
- Population ecology of the species, especially the reproductive potential and dispersal ability.

1 = species extremely unlikely to spread in the EU in the next ten years.

5 = species extremely likely (certain or near certain) to spread widely in the EU in the next ten years.

2.3.3.5.4. Likelihood of impact on native biodiversity or associated ecosystem services

To assess and score the impact of each species on native biodiversity or associated ecosystem services, a scheme was produced by the core project team based on a combination of the IUCN EICAT impact categories (IUCN, 2020), the impact scoring scheme used by Roy *et al*. (2015) and the impact framework used for scoring magnitude of impacts for EU Risk Assessments (European Commission and Umweltbundesamt GmbH, 2022) (Table 10). Based on the impacts that species have had elsewhere, or could potentially have, the type and magnitude of impacts they might have in the EU was extrapolated. For species already in the EU, some impacts might already have been recorded, which was reflected through a high level of confidence (Table 11).

Only one impact score number (from 1 – 5) was attributed to each species, combining the negative impacts on native biodiversity and associated ecosystem services. As such, this score reflects the effects caused by all potential impact mechanisms exerted by the species (as described in Table 9 above) and was given in line with the most severe impacts under any of those mechanisms and types of impact.

Table 10. Impact scoring system used to assess each species' negative impacts on native biodiversity and ecosystem services.

Impact Score	Impact on native biodiversity	Impact on Ecosystem Services
Minimal = 1	Local population decline OR no significant ecosystem change.	No services affected.
Minor = 2	Local population loss OR localised reversible ecosystem change.	Local and temporary, reversible effects to one or few services.
Moderate = 3	Regional population decline or loss, no extinction OR regional reversible ecosystem change.	Measurable, temporary, regional and reversible effects on one or several services.
Major = 4	Regional irreversible population loss or extinction of single species OR regional irreversible, or widespread and reversible, ecosystem change.	Regional and irreversible or widespread and reversible, effects on one or several services.
Massive = 5	Widespread population loss or extinction of several species OR widespread, irreversible ecosystem change	Widespread and irreversible effects on one or several services.

2.3.3.5.5. Confidence levels

As mentioned above, due to the largely expert knowledge-based nature of the scoring exercise, it was deemed fundamental to attribute a confidence level to each of the four different criteria scored for each species (likelihood of arrival, establishment and spread, and environmental impact; Table 11). These confidence levels were mostly used as aids to guide the consensus building exercise and later the ranking of species.

Table 11. Detailed description of the three different levels of confidence attributed to each of the four scored categories.

Confidence level	Guidance
High	There is direct relevant scientific evidence/data to support the scoring.
	The interpretation of data/information is straightforward.
	Data/information are reliable, not controversial or contradictory and are from reputable sources.
Medium	There is some evidence/data to support the scoring.
	The interpretation of data/information is to some extent ambiguous.
	Data/information are not entirely reliable, with some ambiguities and contradictions.
Low	There is no direct evidence/data to support the scoring.
	Evidence is poor and difficult to interpret, being ambiguous or contradictory.
	Data/information are not from reputable sources, being speculative and/or based on broadscale observations or opinions.

2.3.3.5.6. Overall score of each species

An overall score for each species was calculated as the product of the (unweighted) individual scores for likelihood of arrival, establishment, spread and environmental impact, with a maximum possible overall score of 625. Based on their overall scores, species from the different thematic groups were then ranked to aid in the prioritisation of species to be risk assessed, with rankings generally used for guidance, and not as absolute values (see more details in Section 3.5 below).

Introduction × Establishment × Spread × Impact = Overall score

[1 – 5] × [1 – 5] × [1 – 5] × [1 – 5] = [1 – 625]

2.3.3.6. Step 6 – Expert consensus workshop

The expert consensus workshop took place on 4th – 5th November 2024, in Brussels, Belgium. The main objectives of the workshop were for all the experts from the various thematic groups (group leads and additional experts) to meet in person, streamline and achieve consensus on the individual and overall scores of their species, and discuss the final ranking of species within and across the different groups. Discussions first took place within each thematic group through five different breakout groups, which was followed by plenary discussions among all groups. Different opinions were discussed among all participants until a consensus was reached on a final list of species considered the most likely to be introduced, establish, spread and have an impact on EU biodiversity or associated ecosystem services in the coming ten years. The various parts of the expert workshop are described in detail under Task 2 below (Section 3.4).

3. Task 2 – Perform a Horizon Scanning

3.1. Step 1 – Preparation of long lists of IAS

The first step of this horizon scanning consisted of putting together a long list of species deemed potentially relevant for this exercise by compiling and merging various lists of IAS from different sources. These lists were then cleared of species which were out of the scope of the exercise, based on the exclusion criteria mentioned above (Figure 5; see Section 2.3.2).

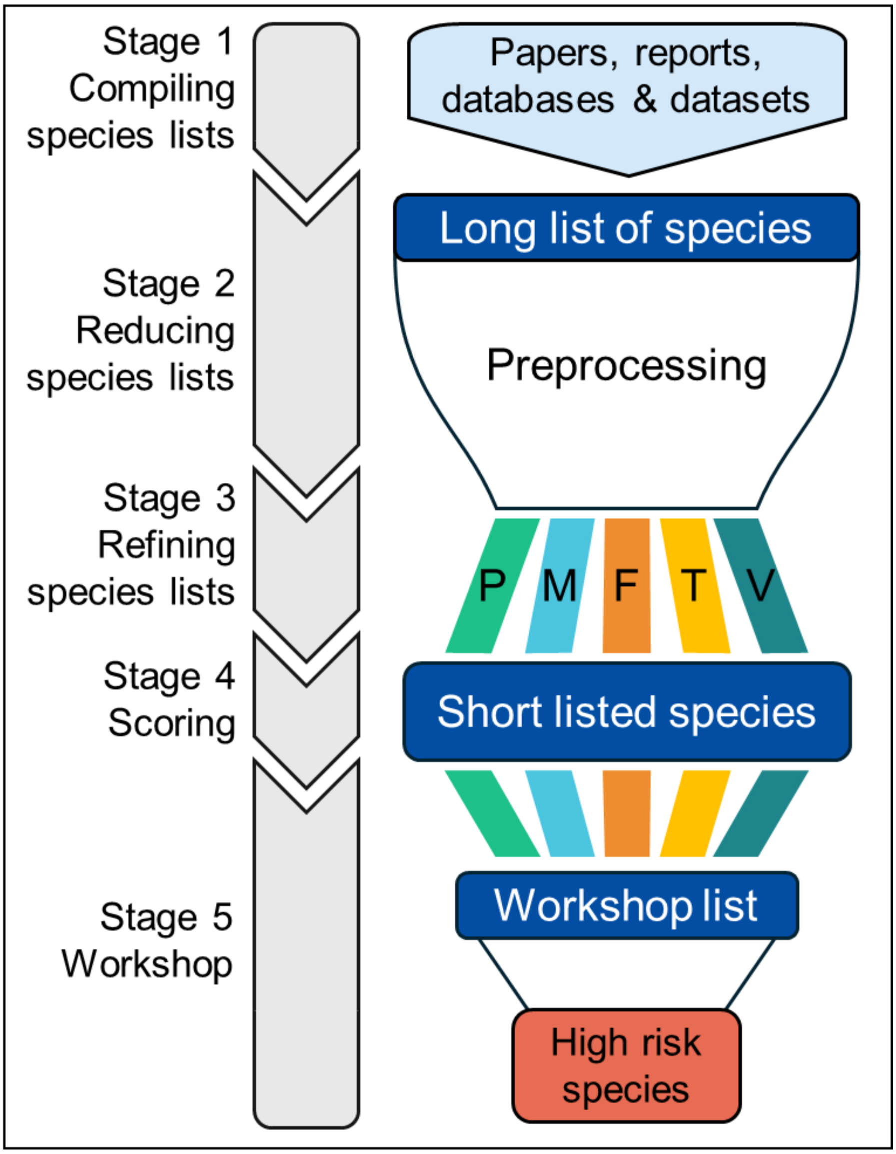

Figure 5. Figure outlining the steps followed performing the horizon scan. The letters refer to the thematic groups, P: plants, M: marine, F: freshwater invertebrates, T: terrestrial invertebrates, V: vertebrates.

3.1.1. Merging various species lists and removing name duplicates

A master long list of species was created by merging lists of IAS extracted from a variety of sources deemed relevant for this horizon scanning. These can be divided into three groups: (1) previous IAS horizon scanning exercises in the EU and beyond, and additional relevant papers/reports compiled through the literature searches performed in Task 1 (English, multi-language and expert knowledge); (2) EU and global databases containing relevant lists of IAS; (3) additional datasets/sources provided by the project team and national authorities. Each of these three types of sources is described more specifically in the sections below, with further details on each source and the numbers of species found in each of them shown in Tables 12 and 13. All duplicate species scientific names identified were immediately removed from these lists (Figure 9). This list represents a valuable resource for future horizon scanning exercises and its provision will reduce future workloads in compiling and standardising this information from a variety of sources.

3.1.1.1. Information retrieved from previous IAS horizon scans and other papers/reports compiled in Task 1

- <u>Species lists from horizon scans and other papers/reports within the EU.</u> The available lists of species stemming from horizon scanning exercises performed either at a national or regional level within the EU were examined and, if relevant, retrieved (Table 12). Additional lists of species generated by other publications from within the EU and deemed of relevance for the current study were also checked and, where appropriate, incorporated. After examination, species lists were retrieved from a total of 32 sources (out of 45), with a cumulative total of 4,505 species compiled (Table 12 and Table 13). For most sources, the lists extracted were not the initial long lists of species compiled, but the 'final' refined lists of species considered a priority or deemed most risky in the areas in focus (more details in Table 13).
- <u>Species lists from horizon scans and other papers/reports beyond the EU.</u> Taking into account the Köppen-Geiger climate classification (Cui *et al*., 2021), in principle the species under consideration for this EU-level horizon scanning can invade from any continent in the world, except from large areas with tropical and desert climates. As such, lists of species generated by horizon scanning exercises undertaken for countries/regions outside the EU (including European and non-European countries) were considered, as long as the climate of these regions (partly) matched that of any EU region. Given this, the only exceptions were the horizon scans for Ghana and Antarctica (Hughes *et al*., 2020; Kenis *et al*., 2022), which were not included due to largely non-matching climate (Table 12). Some of the IAS in the lists that were included were native and/or widely spread in the EU, but a precautionary inclusive approach was used at this stage, with further exclusion criteria and quality control applied later. In this case, species lists were retrieved from a total of 19 out of 27 examined sources, with a total of 1,704 species compiled (Table 12 and Table 13).

Table 12. Data sources screened for the compilation of species lists retrieved from previous IAS horizon scans and other papers/reports compiled in Task 1 through the Web of Science or Google Scholar English language searches (WoS/Scholar EN), multi-language searches, or through expert knowledge (Expert). Details of each publication screened and the species lists within are showcased. For the cases in which the lists of species were not used, reasons for excluding those are indicated.

Reference	Geographic coverage	Environ. coverage	Taxonomic coverage	Species list included	Available information					Reason for excluding species lists	Source
					Pathway	Impact	Species scores	Species status	Native Range		
Horizon scans and other papers/reports within the EU											
Lensink *et al*. (2015)	Netherlands	FW/TER	All taxa	Yes	No	No	Yes		No		Expert
Rougoor *et al*. (2015)	Netherlands	TER	Infectious diseases	NA						No species lists	Expert
Verbrugge *et al*. (2015)	Netherlands	TER/FW/MAR	All taxa	Yes	No	No	Yes	No	No		Expert
Gallardo *et al*. (2016)	Western Europe	TER/FW/MAR	All taxa	Yes	No	No	Yes	Yes	Yes		WoS/Scholar EN
Leuven *et al*. (2016)	Netherlands	TER	Plants	Yes	No	No	No	Yes	No		Expert
Pergl *et al*. (2016)	Czechia	TER/FW	Plants and animals	Yes	No	Yes	No	No	No		Multi-language
Karachle *et al*. (2017)	Eastern and Southern European countries with marine borders	MAR	All taxa	Yes	No	No	No	Yes	No		WoS/Scholar EN

Reference	Geographic coverage	Environ. coverage	Taxonomic coverage	Species list included	Available information					Reason for excluding species lists	Source
					Pathway	Impact	Species scores	Species status	Native Range		
Matthews *et al.* (2017)	Europe & Netherlands	TER/FW/MAR	All taxa	Yes	No	No	No	No	No		WoS/Scholar EN
Mayer *et al.* (2017)	Germany	TER	Plants	Yes	No	No	No	Yes	Yes		WoS/Scholar EN
Carboneras *et al.* (2018)	EU/Europe	TER/FW/MAR	All taxa	Yes	Yes	Yes	No	Yes	No		WoS/Scholar EN
Lensink *et al.* (2018)	Netherlands	FW/TER		No	No	No	Yes	Yes	No	Species included in Lensink *et al.* (2015)	Expert
Pieters *et al.* (2018)	Netherlands	FW/TER	Plants	No							Expert
Weber *et al.* (2018)	Germany	TER	Plants	Yes	No	No	No	Yes	Yes		Multi-language
Bayón & Vilá (2019)	Spain	TER	Plants	Yes	No	No	Yes	Yes	Yes		WoS/Scholar EN
Englmaier & Münch (2019)	Austria	TER	Plants	No						Catalogue of grass neophytes used in gardening	Multi-language
Lazzaro *et al.* (2019)	Italy	TER/FW	Plants	No						Species already present and being considered for National lists	Multi-language
Peyton *et al.* (2019)	Cyprus	TER/FW/MAR	All taxa	Yes	Yes	Yes	Yes	Yes	Yes		WoS/Scholar EN

Reference	Geographic coverage	Environ. coverage	Taxonomic coverage	Species list included	Available information					Reason for excluding species lists	Source
					Pathway	Impact	Species scores	Species status	Native Range		
Roy *et al*. (2019a)	European Union	TER/FW/MAR	All taxa	Yes	No	No	No	No	No		WoS/Scholar EN
Tsiamis *et al*. (2019)	Europe	MAR	All taxa	Yes	Yes	No	Yes	Yes	Yes		WoS/Scholar EN
Adriaens *et al*. (2020)	Belgium (Flanders)	TER/FW/MAR	All taxa	NA						No species lists	Expert
Bertolino *et al*. (2020)	Italy	TER	Mammals	Yes	No	No	Yes	Yes	No		WoS/Scholar EN; Multi-language
De Knijf *et al*. (2020)	Belgium	FW	Crayfish	NA						No species lists	Expert
Lucy *et al*. (2020)	Ireland	TER/FW/MAR	All taxa	Yes	Yes	No	Yes	No	Yes		WoS/Scholar EN
Molfini *et al*. (2020)	Italy	TER	Inverts	No						Species already present and being considered for National lists	Multi-language
Monaco *et al*. (2020)	Italy	TER/FW/MAR	All taxa	Yes	No	No	Yes	Yes	No		Multi-language
Peyton *et al*. (2020)	Cyprus	TER/FW/MAR	All taxa	No						Species prioritised for impacts on human health and economy	WoS/Scholar EN

Reference	Geographic coverage	Environ. coverage	Taxonomic coverage	Species list included	Available information					Reason for excluding species lists	Source
					Pathway	Impact	Species scores	Species status	Native Range		
Thunnissen *et al*. (2020)	Netherlands	FW	Planaria	No						Report for Thunnissen *et al*. (2022b)	Expert
Lemmers *et al*. (2021)	Netherlands	FW	Crayfish	NA						No species lists	Expert
Lorenzoni *et al*. (2021)	Umbria (Italy)	TER/FW	All taxa	Yes	No	No	Yes	No	No		Expert
Radočaj *et al*. (2021)	Croatia and Slovenia	FW	Fish	Yes	Yes	Yes	No	Yes	No		Expert
Thunnissen *et al*. (2021)	Netherlands	TER	Ants	Yes	Yes		Yes	Yes	Yes		Expert
Adriaens *et al*. (2022)	Dune habitats of the Atlantic coastal region	TER	Plants	Yes	No	No	Yes	Yes	No		WoS/Scholar EN; Multi-language
Branquart *et al*. (2022)	3 river basins in Belgium	TER/FW	Plants	Yes	No	Yes	Yes	Yes	No		Multi-language
Czechowska *et al*. (2022)	EU	TER/FW/MAR	All taxa	Yes	No	No	No	No	No		Multi-language
D'hondt & Adriaens (2022)	Belgium (Flanders)	TER/FW/MAR	All taxa	Yes	No	No	No	No	No		Expert
Lorenzoni *et al*. (2022)	Italy	FW	Fish	No						No species list	Expert

Reference	Geographic coverage	Environ. coverage	Taxonomic coverage	Species list included	Available information					Reason for excluding species lists	Source
					Pathway	Impact	Species scores	Species status	Native Range		
Oliva-Paterna *et al.* (2022)	Iberian Peninsula	FW	Plants and animals	No						Report for Oficialdegui *et al.* (2023)	Expert
Thunnissen *et al.* (2022a)	Netherlands	FW	Molluscs	Yes	No	No	Yes	No	No		Expert
Thunnissen *et al.* (2022b)	Netherlands	TER	Planaria	Yes	No	Yes	Yes	Yes	No		Expert
Arianoutsou *et al.* (2023)	Greece	FW/TER/MAR	All taxa	Yes	No	No	Yes	Yes	No		Multi-language
Cano-Barbacil *et al.* (2023)	All Spanish territories	TER/FW/MAR	All taxa	Yes	No	No	Yes	No	No		WoS/Scholar EN
Dobrzycka-Krahel & Medina-Villar (2023)	Baltic sea	FW/MAR	Plants and animals	Yes	No	No	No	No	Yes		WoS/Scholar EN
Oficialdegui *et al.* (2023)	Iberian Peninsula	FW	Plants and animals	Yes	Yes	No	Yes	Yes	Yes		WoS/Scholar EN
van Riel *et al.* (2023)	Netherlands	TER/FW/MAR	All taxa	Yes	No	No	No	Yes	No		Expert
Steen *et al.* (2024)	Belgium (Flanders)	FW	Plants	Yes	No	No	No	No	No		Expert
Horizon scans and other papers/reports beyond the EU											
Pili *et al.* (2017)	Philippines	TER/FW	Amphibians	Yes	No	No	Yes	No	No		WoS/Scholar EN

Reference	Geographic coverage	Environ. coverage	Taxonomic coverage	Species list included	Available information					Reason for excluding species lists	Source
					Pathway	Impact	Species scores	Species status	Native Range		
Swart & Robinson (2019)	South Africa	MAR	Crabs	Yes	No	No	No	No	No		WoS/Scholar EN
Roy *et al*. (2019b)	15 United Kingdom Overseas Territories	TER/FW/MAR	All taxa	No						Report for Dawson *et al*. (2023)	WoS/Scholar EN
Clarke *et al*. (2020)	Arabian Gulf and Sea of Oman	MAR (& brackish)	All taxa	Yes	Yes	No	Yes	Yes	No		WoS/Scholar EN
Hughes *et al*. (2020)	Antarctic Peninsula	FW/TER/MAR	All taxa	No						Very little climate overlap with EU	WoS/Scholar EN
Adhikari *et al*. (2021)	South Korea	TER	Plants	No	NA	NA	NA	NA	NA	Already introduced species and does not assess impacts	WoS/Scholar EN
Goldsmit *et al*. (2021)	Canadian Arctic	MAR	All taxa	Yes	No	No	Yes	No	No		WoS/Scholar EN
Guilder *et al*. (2022)	United Kingdom	FW	Fish and invertebrates	Yes	No	No	No	No	No		WoS/Scholar EN
Kendig *et al*. (2022)	Florida, USA	TER/FW	Plants	Yes	Yes	Yes	Yes	No	Yes		WoS/Scholar EN
Kenis *et al*. (2022)	Ghana	TER	Arthropods and pathogens	No						No climate overlap with EU	WoS/Scholar EN

Reference	Geographic coverage	Environ. coverage	Taxonomic coverage	Species list included	Available information					Reason for excluding species lists	Source
					Pathway	Impact	Species scores	Species status	Native Range		
Mulema *et al.* (2022)	Kenya	TER	Inverts and pathogens	Yes	Yes	No	Yes	Yes	No		WoS/Scholar EN
Osunkoya *et al.* (2022)	Queensland, Australia	TER	Plants	Yes	No	No	No	Yes	No		WoS/Scholar EN
Dawson *et al.* (2023)	United Kingdom Overseas Territories	TER/FW/MAR	All taxa	Yes	Yes	Yes	Yes	No	No		WoS/Scholar EN
Gilles Jr *et al.* (2023)	Lake Taal, Philippines	FW	Fish	Yes	No	No	Yes	Yes	No		WoS/Scholar EN
Hill *et al.* (2023)	Florida, USA	MAR	Fish	Yes	No	No	Yes	Yes	Yes		WoS/Scholar EN
Lieurance *et al.* (2023)	Florida, USA	TER/FW/MAR	All taxa	Yes	Yes	Yes	Yes	No	Yes		WoS/Scholar EN
McCulloch-Jones *et al.* (2023)	Canada, USA, Great Britain, Ireland, South Africa, Australia, New Zealand	TER	Plants (ferns)	No						Did not score species or assess their risk	WoS/Scholar EN
Mulema *et al.* (2023) [Preprint]	Zambia	TER	Nematodes	Yes							WoS/Scholar EN
O'Shaughnessy *et al.* (2023)	Northern Gulf of Mexico	MAR	All taxa	Yes	No	No	Yes	Yes	No		WoS/Scholar EN

Reference	Geographic coverage	Environ. coverage	Taxonomic coverage	Species list included	Available information					Reason for excluding species lists	Source
					Pathway	Impact	Species scores	Species status	Native Range		
Sarakatsani *et al.* (2023) [Preprint]	NA	TER	Plant pests	NA						No species lists	WoS/Scholar EN
Trajanovski *et al.* (2023)	Lake Ohrid (North Macedonia and Albania)	FW	All taxa	No						Only six species either established or on Union list	WoS/Scholar EN
Tshikhudo *et al.* (2023) [Preprint]	South Africa	TER	Arthropod pest species	Yes	Yes	No	Yes	Yes	No		WoS/Scholar EN
Cottier-Cook *et al.* (2024)	Svalbard archipelago (Norway)	MAR	All taxa	Yes	Yes	Yes	Yes	No	No		WoS/Scholar EN
Jones *et al.* (2024)	Britain	TER	Plants	Yes	No	No	No	No	No		WoS/Scholar EN
Mulema *et al.* (2024a)	Zambia	TER	Bacteria and protists	No						Only bacteria and Protista species	WoS/Scholar EN
Mulema *et al.* (2024b) [Preprint]	Zambia	TER	Mollusca and plant parasitic nematodes	Yes	Yes	No	Yes	Yes	No		WoS/Scholar EN
Wyman-Grothem *et al.* (2024)	Pacific Northwestern United States	FW	Plant and algae	Yes	No	No	No	No	No		WoS/Scholar EN

3.1.1.2. Information retrieved from EU and global databases

- CABI Horizon Scanning Tool (CABI, 2024). This tool helps identify and categorise species that might, in the future, enter a particular geographic area of interest from another geographic area. It uses CABI data to generate a list of species that are not recorded as present in a specified selected 'area at risk', but that are reported from the 'source areas' chosen, which can be geographic areas with similar climates to the 'area at risk' or neighbouring areas (or selected trading partners in the premium version). It is of note that these lists rely on the data available in the CABI Compendia which, as for any database, might not be complete or up to date. As the list generated only includes species that are not recorded as present in the EU, native species to the area are excluded; however, this also means that species present in the EU will not be accounted for in this list. Overall, the attributes of the list generated by the CABI Horizon Scanning Tool and merged with the other lists were:
    - *area at risk:* EU (27 Member States); *source areas:* all climate zones from geographic areas with matching climates to the EU (346 areas); *organism type:* plants, vertebrates, invertebrates; however, due to the high number of species initially generated (5,761), the option *'only show known invasive species'* was selected, significantly decreasing the number of species to 1,924 (Table 13).
- European Alien Species Information Network (EASIN, 2024). Given its scope and the large amount of data available, EASIN can provide very valuable lists of species, including for horizon scanning exercises. More specifically, the list of species from EASIN that was merged with the other lists here was the following, taking all exclusion criteria into account:
    - species not native to any part of the EU, that have been recorded in European countries or in close neighbouring countries from the EU/Europe, but that are not present in any EU Member State. This generated a list of 961 species (Table 13).
- European and Mediterranean Plant Protection Organisation (EPPO). EPPO holds relevant lists of pest species that are very useful to this EU-level horizon scanning exercise, and were therefore combined with the other species lists, as follows:
    - species in the EPPO A1 and A2 Lists (EPPO, 2024a) – lists of species recommended for regulation as quarantine pests. The EPPO A1 List contains pests that are absent in the EPPO region (which goes beyond the EU) and the EPPO A2 List contains pests that are not widely distributed in the EPPO region. A total of 270 species from these lists were added (Table 13).
    - species in the EPPO Alert List and previously listed species (EPPO, 2024b) – pests on the Alert List may present a phytosanitary risk for the EPPO region, for various reasons: e.g. pests which are new to science, new outbreaks recorded in the EPPO region or in other parts

of the world, or reports of rapid spread. Taking these lists into consideration, an additional 218 species were added to the long list (Table 13).
    - species in the EPPO List of invasive alien plants or in the Observation List of invasive alien plants (EPPO, 2024c) – the former refers to species absent or present in the EPPO region, with a high potential for spread, posing an important threat to plant health and/or the environment and biodiversity (and eventually having other type of detrimental impacts) in the EPPO region; the latter refers also to species absent or present in the EPPO region which, through a prioritisation process, are assessed as presenting a medium risk and species for which not enough information is available to make an accurate assessment. This generated a list of 80 invasive alien plants that were added to the long list (Table 13).

3.1.1.3. Information retrieved from additional datasets/sources provided by the team and national authorities

- <u>List of alien squirrel species in trade (Adriaens, unpub. data).</u> This list collated by INBO experts and added here (Table 13) included a total of 47 squirrel species found in trade in the EU (based on expert knowledge, internet searches, e-commerce platforms, zoo registries, CITES trade database, published records of alien squirrels presence in the wild, positive lists of mammals, etc.). It was compiled in the framework of a broad scale risk assessment.
- <u>List of invasive ornamental plants in Belgium (Belgian NSSIAS, unpub. data).</u> This list collected by the Belgian National Scientific Secretariat on Invasive Alien Species (NSSIAS) was composed of alien plants present in trade in Belgium based on 21 catalogues of wholesalers. The list was narrowed down to only keep species that are not solely an agricultural pest or human health issue (via the Global Compendium of Weeds) and that have been identified as potentially invasive or having environmental impact. The drafting of this list was performed in the framework of setting up a code of conduct for the horticultural sector in Belgium, as part of the action plans to tackle unintentional species introductions under the EU IAS Regulation. This resulted in the addition of 666 species to the long list of species (Table 13).
- <u>List provided by the Japanese Government (Japan Government, 2015).</u> This consisted of a list of alien species identified as those that may cause damage to Japan's ecosystems and were therefore prioritised for preventing introduction or establishment in Japan. This resulted in the addition of 99 species being added to the long list (Table 13).
- <u>List of alien insect species.</u> Clarke and McGeoch (2023) analysed environmental impacts for 352 alien insect species worldwide, which were all added here.

- List of horizon scanning species for Scotland (Roy *et al*., 2023). The long list of 171 invasive non-native species not yet established in Scotland, but likely to establish and impact Scottish biodiversity within the next ten years, was added here (Table 13).
- List of alien ant species. Wong *et al*. (2023) provided a long list of 520 alien ant species, 50 of which are established indoors only and 309 of which are established outdoors worldwide. These two latter lists combined (359 species) were added to the long list (Table 13).
- List of ornamental crayfish. Olden & Carvalho (2024) retrieved a list of 60 crayfish species used in ornamental trade worldwide, 15 of which were highlighted as having non-native ranges, and therefore added to this exercise (Table 13).

Table 13. Information sources used in the compilation of a species long list, number of species in each of the individual lists used, and total cumulative number of species after merging the different sources. The cumulative number of species presented excludes obvious duplicates and considers only a few exclusion criteria (e.g. microorganisms removed). Brief details of each of the species' lists retrieved are shown, although it was not always clear to determine whether a long or short list was being retrieved from the source. For more detailed information on each of the sources mentioned, please refer to Table 12.

Short reference	Brief details of the lists retrieved	N species retrieved	Total N species
Horizon scans and papers/reports within the EU			
Lensink *et al*. (2015)	Only the species that were risk assessed	47	4,505
Verbrugge *et al*. (2015)	Lists from Appendices 1 and 5	154	
Gallardo *et al*. (2016)	Short list	80	
Leuven *et al*. (2016)	Possibly long list	52	
Pergl *et al*. (2016)	Watch list	52	
Karachle *et al*. (2017)	Possibly short list	160	
Matthews *et al*. (2017)	Short list	89	
Mayer *et al*. (2017)	List of species alien to Germany	954	
Carboneras *et al*. (2018)	Long list	991	
Weber *et al*. (2018)	Lists from Appendices 1 and 2	405	

Short reference	Brief details of the lists retrieved	N species retrieved	Total N species
Bayón & Vilá (2019)	Attention, Watch, Uncertainty and Data deficient lists	681	
Peyton *et al.* (2019)	Short list	225	
Roy *et al.* (2019a)	Short list	248	
Tsiamis *et al.* (2019)	Long list	282	
Bertolino *et al.* (2020)	Long list	211	
Lucy *et al.* (2020)	Short list	182	
Monaco *et al.* (2020)	Lists from Appendix 7	386	
Lorenzoni *et al.* (2021)	Horizon scanning short list	43	
Radočaj *et al.* (2021)	Short list	25	
Thunnissen *et al.* (2021)	Only the species that were risk assessed	21	
Adriaens *et al.* (2022)	Short list	235	
Branquart *et al.* (2022)	Final alert list	13	
Czechowska *et al.* (2022)	Short list	85	
D'hondt & Adriaens (2022)	Short list	99	
Thunnissen *et al.* (2022a)	Only the species that were risk assessed	30	
Thunnissen *et al.* (2022b)	Only the species that were risk assessed	22	
Arianoutsou *et al.* (2023)	Species added after the horizon scan	15	
Cano-Barbacil *et al.* (2023)	Long list	1063	
Dobrzycka-Krahel & Medina-Villar (2023)	Long list	27	
Oficialdegui *et al.* (2023)	Alert short list	89	
van Riel *et al.* (2023)	Possibly short list	278	

Short reference	Brief details of the lists retrieved	N species retrieved	Total N species
Steen *et al*. (2024)	Possibly long list	160	
		Cumulative total	4,505
Horizon scans and papers/reports beyond the EU			
Pili (2017)	Short list	168	1,704
Swart & Robinson (2019)	Long list	56	
Clarke *et al*. (2020)	Extant and Horizon lists	119	
Goldsmit *et al*. (2021)	Ranked list	31	
Guilder *et al*. (2022)	Long list	233	
Kendig *et al*. (2022)	Short list	99	
Mulema *et al*. (2022)	Possibly short list	79	
Osunkoya *et al*. (2022)	Short list	25	
Dawson *et al*. (2023)	Short list	178	
Gilles Jr *et al*. (2023)	Possibly long list	45	
Hill *et al*. (2023)	Short list	11	
Lieurance *et al*. (2023)	Short list	460	
Mulema *et al*. (2023) [Preprint]	High risk species	58	
O'Shaughnessy *et al*. (2023)	Short list	138	
Tshikhudo *et al*. (2023) [Preprint]	Short list	96	
Cottier-Cook *et al*. (2024)	Long list	88	
Jones *et al*. (2024)	Short list	30	
Mulema *et al*. (2024b) [Preprint]	Short list	9	
Wyman-Grothem *et al*. (2024)	Long list	123	

Short reference	Brief details of the lists retrieved	N species retrieved	Total N species
		Cumulative total	5,747
EU and global databases			
CABI (2024)	Only species considered invasive	1924	3,061
EASIN (2024)	Species present in neighbouring countries	961	
EPPO (2024a)	A1 and A2 lists	270	
EPPO (2024b)	Alert List and previously listed species	218	
EPPO (2024c)	EPPO List and Observation List of invasive alien plants	80	
		Cumulative total	7,987
Datasets/sources provided by the team and national authorities			
Adriaens (unpub. data)	Squirrels in trade	47	1,640
Belgian NSSIAS (unpub. data)	Ornamental plants in trade in Belgium	666	
Japan Government (2015)	IAS that may cause damage to Japan's ecosystems	99	
Clarke & McGeoch (2023)	Short list	352	
Roy *et al*. (2023)	Long list	171	
Wong *et al*. (2023)	Short list	359	
Olden & Carvalho (2024)	Only species with non-native ranges	15	
		Cumulative total	8,857

As per Table 13, after merging all the individual lists of species potentially relevant for this horizon scanning exercise stemming from the three types of sources mentioned above, and removing obvious duplicates, the initial long list comprised of 8,857 species (Table 13, Figure 9).

Following from this, in order to further remove species with possibly inaccurate scientific names or that were synonyms of other species (and to ensure that the scientific names in the long list were accurate), a series of standardisation steps were undertaken using the GBIF: (1) scientific names of all species in the long list were matched to the GBIF Backbone Taxonomy; (2) scientific names of species for which no match was found were verified by the project team, corrected and rematched to GBIF; (3) synonyms were converted to their associated accepted species scientific names, subspecies or variety; (4) lower-level taxa, such as subspecies and varieties, were scaled up to the species level. Out of the 8,857 species, 561 were removed through this taxonomic standardisation (Figure 9).

3.1.2. Removal of species considering exclusion criteria

As much as possible, the long list of species was further reduced through the application of all exclusion criteria that had not yet been addressed. Firstly, this referred to the exclusion of:

- Any harmful organisms listed in Annexes II, III and IV of Commission Implementing Regulation (EU) 2019/2072[13] out of a total of 326 species;
- Any species listed in Annex IV to Regulation (EC) No 708/2007 when used in aquaculture (Art. 2(e))[14] out of a total of 10 species;
- Any of the 88 species listed as of Union concern, as per the EU IAS Regulation[15] and all their identified synonyms;
- Any species that have had Risk Assessments (RA)[16] produced at the EU level recently (are currently being proposed to be listed), or for which a RA is ongoing, out of a total of 48 species. It was agreed by the project team and the EC that species which have had RA produced not recently and that, for different reasons, have not been listed as of Union concern (37 species), were to be included in this exercise, but highlighted at a later stage (and not included in the final prioritised list).

Secondly, species native to any part of the EU territory (excluding the EU outermost regions and EU Overseas Countries and Territories) were excluded through the use of data gathered from specific databases, or collected via expert networks, as follows:

- EASIN. Any alien species (plants, vertebrates, invertebrates) native to any part of the EU out of a total of 886 species;
- CABI Invasive Species Discovery Tool.[17] Any alien species (plants, vertebrates, invertebrates) native to any part of the EU out of a total of 376 species;

[13] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02019R2072-20220714&qid=1667573350824

[14] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32007R0708

[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32007R0708

[16] For a full list of RA species see here: https://circabc.europa.eu/w/browse/ed95cea1-4f6a-4a3b-b27d-b2bfb8288c42

[17] https://www.cabidigitallibrary.org/journal/cabicompendium/isdt#/

- IUCN Red List of Threatened Species[18]. Any species (plants, vertebrates, invertebrates) native to at least one EU Member State, or to the Mediterranean or Black Sea out of a total of 11,866 species;
- Species native to Belgium. Any species native to Belgium, as indicated on the '*List of species observed in Belgium'* (Swinnen *et al*., 2024), out of a total of 15,994 species;
- Plant species native to the EU. Any plant species native to at least one EU Member State, according to a list of alien species native to Europe crosschecked by experts from Masaryk University, Czechia (Axmanová, unpub. data).

These two steps of species exclusions resulted in a total of 1,557 species being removed from the long list, resulting in a list comprised of 6,739 species (Figure 9).

Removal of widely spread species

Thirdly, species that were considered as widely spread in the EU were also removed from the long list. As mentioned above, only species currently absent from the EU, or present in the EU but considered not widely spread, were taken into account for this horizon scanning exercise. Based on Art. 3(16) of the EU IAS Regulation, 'widely spread' refers to "*IAS whose population has gone beyond the naturalisation stage, in which a population is self-sustaining, and has spread to colonise a large part of the potential range where it can survive and reproduce*". However, it is not clear at which stage a species can be considered widely spread, as this can depend on various factors, such as the species itself, its rate of spread, and the context of the ecosystem that it has invaded. Given this, it did not seem possible to establish a standard threshold from when species become widely spread in the EU.

As such, for the purposes of this exercise, occurrence data of each of the 6,739 species in the long list in all EU MS and their Exclusive Economic Zone (to account for the marine environment), was retrieved. Occurrence data were downloaded from GBIF considering the following seven criteria[19]:

i. occurrence records were required to be presences;
ii. these presences had to have associated coordinates;
iii. to avoid occurrence records with misleading location information, records of fossil specimens and those of living specimens from zoos and botanical gardens were excluded;
iv. records with default geospatial issues were excluded;
v. records which displayed coordinate uncertainties higher than 50 km were excluded;

[18] https://www.iucnredlist.org/

[19] This download can be revisited using GBIF download key "0033551-240906103802322". Please note that the download initially included 6751 species (as 12 native plant species were still included at the time of processing). These were manually removed afterwards and were not included in further steps.

vi. records which were observed before 1980 were excluded. This temporal restriction was applied, as alien plants often experience a lag phase of 40 years on average before becoming invasive and widespread (Robeck *et al*., 2024);

vii. only records observed within the EU and its associated Exclusive Economic Zones (EEZs) were included (Figure 6).

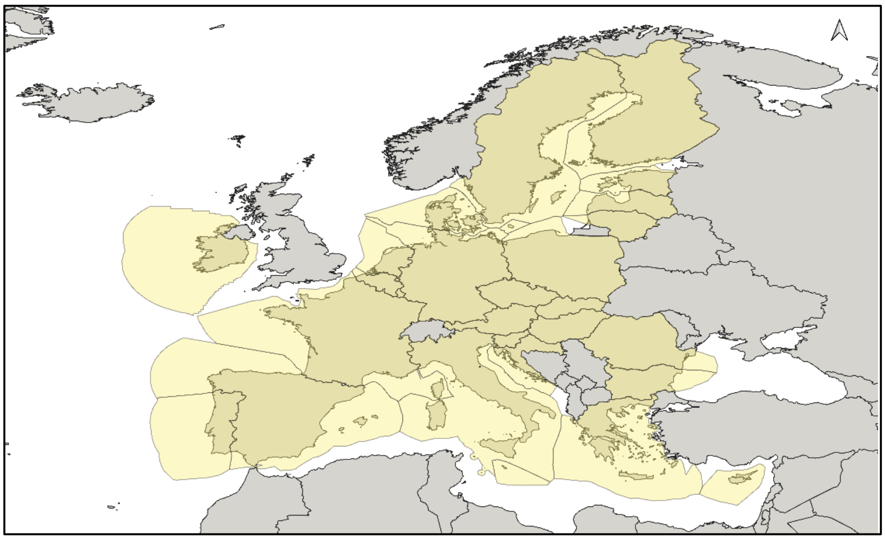

Figure 6. Area from which occurrence records within the EU and its associated Exclusive Economic Zones were downloaded.

To avoid including records with unreliable coordinates, occurrence points were removed within a radius of 50 m around capitals, country centroids, known biodiversity institutions, and the GBIF headquarters in Copenhagen, or within a radius of 0.5 decimal degrees around the so-called 'null island' (i.e., the location at zero degrees latitude and zero degrees longitude). In addition, to avoid taxonomic uncertainties, we excluded records with any of the following identification verification statuses: unverified, unvalidated, not validated, under validation, not able to validate, control could not be conclusive due to insufficient data, 0, uncertain, unconfirmed, *douteux*, *invalide*, *non réalisable*, verification needed, probable, unconfirmed-not reviewed, and validation requested.

To calculate the occupancy of each species in the EU, the resulting occurrence records were projected on a grid with a resolution of 50 km x 50 km. Grid cells were considered occupied by a species when it was observed in the respective cell during at least two distinct years (Figure 7). Based on the occupancy data gathered for all the different species (Figure 8), an occupation of three or more grid cells was established as the cut-off threshold to define a widely spread species. Therefore, only species that occupied zero, one or two grid cells were kept, resulting in the removal of 1,663 species from the long list, which at this stage ended up having a total of 5,076 species.

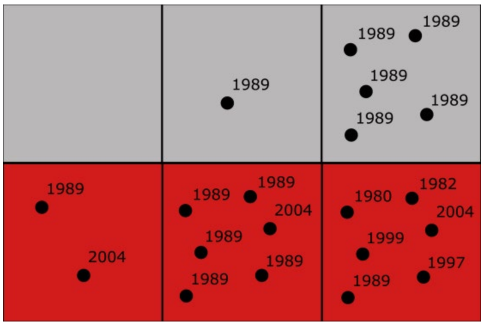

Figure 7. Example of situations in which grid cells were considered occupied (red) or not occupied (grey). Black dots indicate occurrence points, while numbers indicate the associated year of observation.

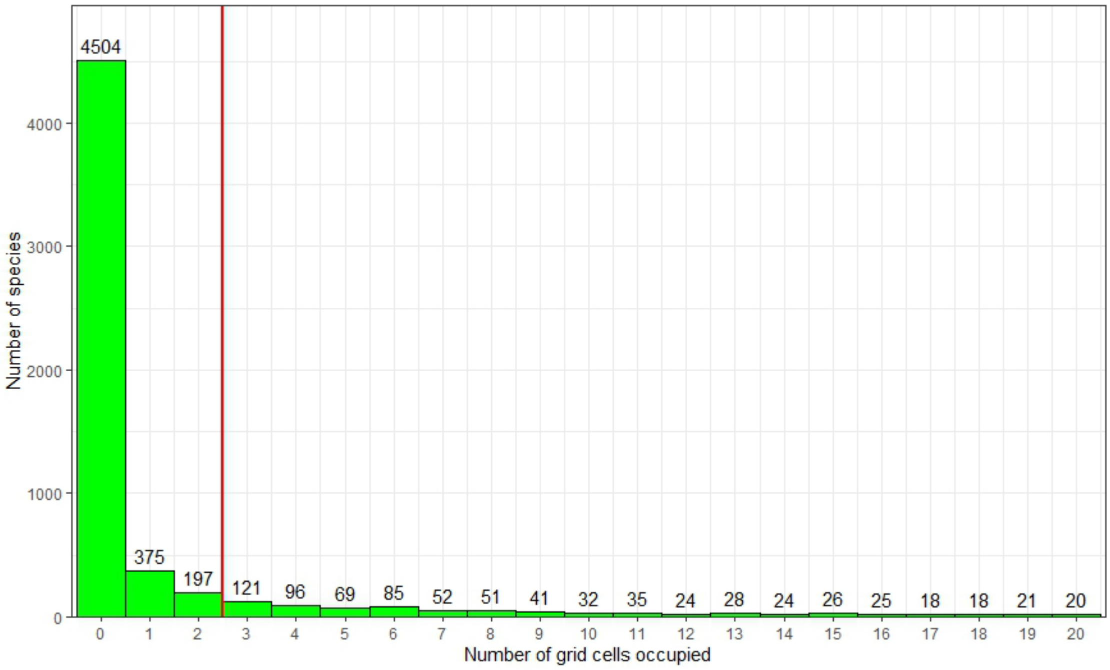

Figure 8. Number of species in the long list occupying 0-20 grid cells in the EU. For better visualisation, only species occupying up to 20 grid cells are shown.

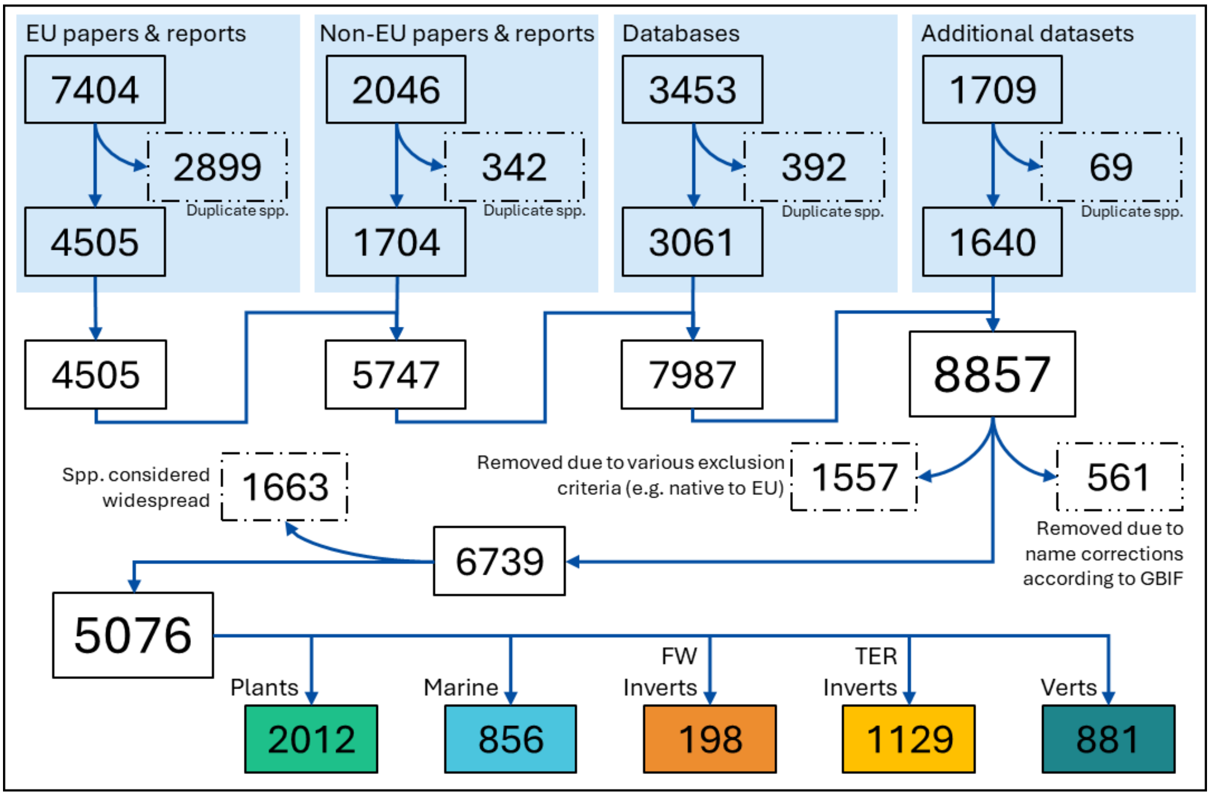

Figure 9. Number of species resulting from the various iterations of Step 1 of this horizon scanning exercise (Preparation of long lists of IAS), considering both the merging of various species lists and the removal of species considering duplicates and the exclusion criteria.

3.2. Step 2 – Selection and invitation of experts for each thematic group

A total of 34 additional invited experts, whose CVs were approved by the EC, were invited to contribute to the next steps undertaken for this horizon scanning, under each of the five thematic groups: ten additional experts for the plants' group, five for the marine group, four for the freshwater invertebrates, five for the terrestrial invertebrates (plus one expert from the core project team), and ten for the vertebrates (Table 14). Considering that each group had one or two thematic leads, group sizes ranged between five and 12 experts. The majority of the additional experts were based in the EU, more specifically in 13 out of the 27 EU MS, with six experts based in the UK. As the project consensus workshop took place in Brussels, a relatively high number of these experts (nine) were based in Belgium (from INBO), with representation in most of the thematic groups (Table 14).

Table 14. Names, countries and affiliations of the additional experts from each of the five thematic groups who participated in the horizon scanning expert elicitation exercise.

Thematic group	Expert lead(s)	Names of experts	Country	Affiliation
Plants	Ana Novoa & Petr Pyšek	Giuseppe Brundu	IT	University of Sassari
		Franz Essl	AT	University of Vienna
		Wayne Dawson	UK	University of Liverpool
		Jodey Peyton	UK	CEH
		Bram D'hondt	BE	INBO
		Wouter Van Landuyt	BE	INBO
		Elizabete Marchante	PT	University of Coimbra
		Zarah Pattison	UK	University of Stirling
		Johan van Valkenburg	NL	NVWA
		Frédérique Steen	BE	INBO
Marine animals & plants	Katie Costello	Ruth O'Riordan	IE	University College Cork
		Stelios Katsanevakis	EL	University of the Aegean
		María Altamirano Jeschke	ES	University of Malaga
		Agnese Marchini	IT	University of Pavia
		Sergej Olenin	LT	Klaipeda University
Freshwater invertebrates	Elena Tricarico	Francisco J. Oficialdegui	CZ	University of South Bohemia
		David Aldridge	UK	University of Cambridge
		Belinda Gallardo	ES	Instituto Pirenaico de Ecología, CSIC

Thematic group	Expert lead(s)	Names of experts	Country	Affiliation
		Kevin Scheers	BE	INBO
Terrestrial invertebrates	Wolfgang Rabitsch	Jakovos Demetriou	EL	University of Athens
		Jiří Skuhrovec	CZ	Crop Research Institute
		Imogen Cavadino	UK	Forest Research
		Cristina Preda	RO	Ovidius University of Constanta
		Jasmijn Hillaert	BE	INBO
		*Helen Roy**	UK	UK CEH
Vertebrates	Riccardo Scalera & Tim Adriaens	Tom Evans	DE/UK	Freie Universität Berlin
		Sandro Bertolino	IT	University of Turin
		Wojciech Solarz	PL	Polish Academy of Sciences
		Diederik Strubbe	BE	INBO
		Fleur Petersen	BE	INBO
		Hugo Verreycken	BE	INBO
		Rui Rebelo	PT	University of Lisbon
		Emili García-Berthou	ES	University of Girona
		Teun Everts	BE	INBO
		Pieterjan Verhelst	BE	INBO

* Part of the core project team.

3.3. Steps 3, 4 and 5 – Checking and refining species long lists, gathering information and scoring species

Starting from the long list of 5,076 species assembled through Step 1 of this horizon scanning, this step consisted of streamlining the lists of species from each of the five thematic groups to be later scored, both by removing a large number of non-relevant species and by adding potentially relevant species that might have been missed from the initial lists. Firstly, in an attempt to standardise the process as much as possible, a climate matching exercise was undertaken for species in the long list to help define cut-offs for potentially removing species, which was followed by each of the five thematic groups taking various tailored approaches to reduce their long species lists.

3.3.1. Climate matching to potentially reduce species long lists

Out of the 5,076 species taken forward from the previous step, some of those were identified from the beginning as marine species and immediately not considered for this process, as climate matching is not yet applicable to marine species. For the remaining species, the suitability of EU climatic zones for each species was assessed by calculating the percentage of the species' global occurrence records that fell within these zones. To this end, global occurrence records for each of the species were downloaded from GBIF for the period 1901 – present, using the same selection criteria mentioned in Section 3.1.2 regarding retrieval of species occurrence data (except for the temporal and spatial criterion).

Further filtering was conducted as previously mentioned (i.e., based on a radius around certain locations and the record's identification verification status), with the addition of an extra filtering step that removed species for which more than 50 % of records fell in the ocean. As these were considered marine species, they were also discarded from the climate matching process. Note that some of these species may, however, be terrestrial species for which the majority of records fell close to the coastline. In any case, considering this and the above, a total of 854 species were identified as being marine, and therefore not considered for climate matching (Figure 11).

Out of the remaining 4,222 species taken forward for climate matching, for 529 of these no climate matching was possible as all records were removed during the filtering steps, or they displayed a 0 % climate match with all EU climatic zones. For 467 other species, climate-matching was based on 20 records or less, which is unlikely to give an informative indication of the species' preferred climatic range. As such, in both cases, it was decided that these 996 species could be removed from the long list due to a lack of information on their global distribution, or due to it being unlikely that they will establish under current and future EU climatic conditions (Figure 11). Regardless, a list of these 996 species was provided to the thematic groups (named 'no data' list; Supplementary Material 1; Nunes *et al.*, 2025), in order for them to assess if any of these species was worth being added to their final list of species to score.

Climate matching consists of calculating the percentage of species' global occurrence records that fall within specific climatic zones, thereby assessing the potential suitability of these zones for the species under study. For example, if 50 % of a species' records fall within climatic zone Cfb (temperate oceanic climate), the species has a 50 % match with this zone. In this exercise, we calculated the match with Köppen-Geiger climatic zones, which are based on temperature and precipitation values (Rubel & Kottek, 2010). Each Köppen-Geiger zone is indicated by a maximum of three letters, with the first letter indicating the main climatic class (A: equatorial climates, B: arid climates, C: warm temperate climates, D: snow climates, and E: polar climates), the second letter indicating the precipitation class (f: fully humid, m: monsoonal, s: summer dry, S: steppe, W: desert, w: winter dry) and the third letter indicating the temperature class (a: hot summer, b: warm summer, c: cool summer, d: extremely continental, F: polar frost, h: hot arid, k: cold arid, T: polar tundra).

Climate matching was initially performed for all 3,226 terrestrial and freshwater species in the long list. However, given that the climatic zones used here were grouped by precipitation classes, the results should be interpreted with extra caution for freshwater organisms, as their distribution may be less likely constrained by precipitation gradients compared to terrestrial organisms. As a result, the freshwater invertebrates group decided to not use climate matching results to reduce their species list, and the plants and vertebrates' groups also dismissed these for their aquatic species (see more details in Section 3.3.2 below).

Additionally, climate matching was performed for 245 species present in three to five EU grid cells, according to GBIF distribution data (Figure 11, Supplementary Material 1; Nunes *et al.*, 2025). These were part of the 1,663 species considered widely spread in the EU and therefore previously removed from the long list (Figure 9), so the aim was to inform thematic groups in case some of those species with limited distribution were deemed relevant to be re-added to the long list.

Overall, occurrence records were associated with their respective climatic zone during the period of observation (with time periods for which Köppen-Geiger classifications were available being 1901 – 1925, 1926 – 1950, 1951 – 1975, 1976 – 2000, and 2001 – 2025 under A1FI). Note that forecasted data were used for the period 2001 – 2025, as part of this period lies in the future. Using these data, the climate matching percentage with each climatic zone was calculated and an overall climate matching percentage with EU climate was deduced by summing up the climate matching percentages of all zones that will be present in the EU in the near future (2026 – 2050) under high-emission scenario A1FI (Figure 10).

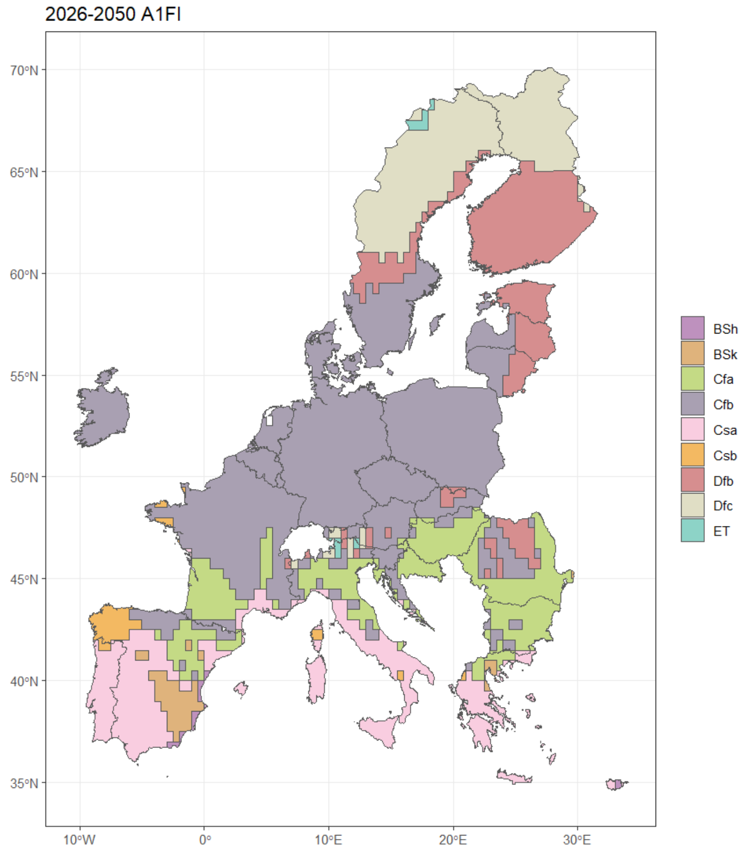

Figure 10. Climatic zones predicted to be present in the EU under high emission scenario A1FI in 2026 – 2050.

While the 'percentage of climate match with the EU' metric gives a good indication as to whether the predicted EU climate for 2026 – 2050 will be suitable for a species, it does not take into account the surface area of suitable climatic zones. For example, a species may have a 100 % climate match with climatic zone ET, but this zone occupies very little surface area in the EU (Figure 10). To address this, we constructed an index that considers both the percentage climate match with each EU zone, as well as the surface area of that zone, which was standardised based on the maximum value according to the following equations:

$$Weighted\ EU\ climate\ match = \sum_{i=1}^{n} A_i \frac{CM_i}{100}$$

With *i* indicating the different future climate zones in the EU, *n* indicating the total number of climate zones (n = 9 for the EU), A_i being the surface area of zone *i*, and CM_i indicating the climate matching percentage of climate zone *i*.

The standardised potential occupancy is then indicated by the following equation:

$$Standardised\ potential\ occupancy\ = \frac{Weighted\ EU\ climate\ match}{\max(Weighted\ EU\ climate\ match)} * 100$$

With max(*Weighted EU climate match*) being the maximum climate match across all species. This corresponds to a species that has a 100 % match with the climatic zone that occupies the largest surface area in the EU.

The percentage of species' standardised potential occupancy in the various EU climatic zones was divided into classes of 10 % increment, i.e. 0 – 10, 10 – 20, 30 – 40, etc. It was then suggested to thematic groups that species with less than 20 % match with EU climates (i.e. classes 0 – 10 and 10 – 20) could potentially be removed from their long lists of species, if deemed appropriate.

3.3.2. Approaches taken by thematic groups to reduce species long lists and score species

At this stage, considering the 3,226 species that were climate matched, the additional 854 marine species mentioned above, and the removal of 27 species due to missed exclusion criteria, a total of 4,053 species were left to be dealt with by the different thematic groups. These were 1,781 plants, 851 marine species, 112 freshwater invertebrates, 597 terrestrial invertebrates and 712 vertebrates (Figure 11).

A spreadsheet was put together with this long list and passed on to each thematic group lead for them, together with their additional experts, to streamline into a feasible number of species to score. The spreadsheet contained:

- all the species-specific information retrieved from papers and reports during Task 1 (e.g. on impacts, pathways, native range);
- the sources of information from which each species was originally retrieved;
- an indication of each species presence in the EU and, if present, in which Member State(s);
- the percentage of each species climate match, as well as the standardised potential occupancy of each species in the various EU climatic zones (for the species that underwent that process);
- an additional list of 996 species for which no reliable climate matching was possible due to various reasons (see above; named 'no data', Supplementary Material 1; Nunes *et al.*, 2025), that were hence removed from the long list, but which could be re-added on a case-by-case basis to the scoring lists of thematic groups;
- an additional list of the 1,663 species present in three or more EU grid cells considered widely spread in the EU (Supplementary Material 1; Nunes *et al.*, 2025), which were therefore removed from the long list, but for which a case-by-case decision about potentially re-adding them into the scoring lists of thematic groups could be taken.

Although ultimately similar, each thematic group developed a specific approach to reduce their long lists of species, which process is documented in detail in the sections below.

3.3.2.1. Plants

As mentioned above, the plants thematic group started with a long list of 1,781 species. One species, wrongly assigned to the marine thematic group, was transferred to this list, therefore, resulting in 1,782 species. Firstly, a total of 1,587 species were removed from the long list (Table 15), as follows:

1. A group of algae, hybrids, and other organisms that did not comply with the initial exclusion criteria, but had been missed, which resulted in the removal of 75 species.

2. Species with less than 20 % standardised potential occupancy in the EU, AND that were recorded in GloNAF as naturalised in less than 50 regions, AND that had less than 25 papers in WoS mentioning them as invasive species. This was done using a search in the title, abstract and keywords of scientific papers with the following search string: scientific name AND “alien species” OR “invasive species” OR “invasive plants” OR “invasive plant” OR “alien plants” OR “alien plant” OR “invasive shrubs” OR “invasive shrub” OR “alien shrubs” OR “alien shrub” OR “invasive trees” OR “invasive tree” OR “alien trees” OR “alien tree” OR “invasive herbs” OR “invasive herb” OR “alien herbs” OR “alien herb”. This resulted in 886 species being removed.

3. For species with less than 20 % standardised potential occupancy in the EU, AND that were recorded in GloNAF as naturalised in more than 50 regions, AND that had more than 25 papers in WoS mentioning them as invasive species, these were quickly checked by experts to see whether they could be risky, based on their potential to be introduced, become established and cause impacts in the EU. A total of 63 of those species were considered non-risky and were therefore removed.

4. Species with more than 20 % standardised potential occupancy in the EU, AND that were recorded in GloNAF as naturalised in fewer than ten regions, AND that had fewer than ten papers in WoS mentioning them as invasive species, which resulted in the removal of 563 species.

Following from the steps listed above, the resulting 195 species were put forward for scoring (Figure 11), each of them being individually scored by two experts. Of all scored species, those that were given a score of 200 or more by at least one of the experts, and at least 100 by both experts (= 43 species, 24 of which were scored as 200 or more by both experts) were selected to achieve initial scoring consensus before the workshop took place.

3.3.2.2. Marine

The marine thematic group began with a long list of 851 species, divided into 17 phyla. The group differed from the terrestrial thematic groups in that robust climate matching could not be conducted due to a lack of data. As such, 89 of these 851 species had initially been considered for the climate matching exercise (e.g. due to shoreline records) but instead were screened manually, to determine whether they could be removed instantly or required more discussion within the group. As the preparatory work progressed, 17 species were also passed over from other thematic groups (Table 15).

Step one: Reducing the long list to streamlined numbers

There was a total of 868 species composed of the initial long list and corrections sent from other groups. A stepwise approach was taken to narrow down which species should be taken forward for (potential) scoring:

1. Removal of instantly clear errors or obvious anomalies (e.g. species that slipped through the initial exclusion filters, often due to scientific name mismatches). For example:

- Species assigned to the thematic group incorrectly;
- Parasitic species (e.g. from Platyhelminthes, some parasitic copepods);
- (Borderline) microorganisms, while also conducting a rapid screen for impact.

2. Removal of selected species derived from just one original source (from the literature review compiled in Task 1 of this horizon scanning), provided that source was a horizon scan geographically well outside EU waters (and EU neighbouring waters). A sample of species from each publication was screened, to ensure they were acceptable to remove.

3. The database EASIN had provided a list of alien species across all environments which was adding high species numbers, due in part to the many records of alien species in the Mediterranean Sea. When a species appeared in this source only, it was rapidly screened for invasion history and impact. Many of the species were data deficient, with just early records of detection and no further information (in any geographic region). All species which appeared to warrant further consideration under the current horizon scan conditions were held, and the remainder removed.

4. Focus on the taxonomic groups with extremely high numbers e.g. Arthropoda and Annelida.

Arthropoda: More intensive screening of this phylum led to the removal of species based on various criteria, e.g. some partly native to EU waters, some microscopic (with rapid impact screen) and some already considered too widely spread.

Annelida: The representation of annelids was high (composed of 105 polychaetes). The recently published EU-level marine horizon scan by Tsiamis *et al*. (2019) was utilised here, as the authors had considered numerous polychaetes, scoring them based on arrival, establishment, spread and impact. Species which had been put through to the top quartile score were held for this present horizon scan (excluding those which were already widespread or already part of the RA process).

Additionally, selected polychaetes were removed based on recommendations from Tsiamis *et al*. (2019), usually due to complex taxonomy. Any polychaetes that were derived from a source separate from Tsiamis *et al*. (2019) were held, provided they had not already met any of the other exclusion conditions in the steps above. Three species that were not ranked highly by Tsiamis *et al*. (2019), but were identified in every other major source, were also held.

It should be noted that many species fulfilled more than one of the criteria in the four steps above, meaning they were removed for multiple reasons. Lastly, of the 17 species passed from other groups, none of them were taken forward to Step two.

Step two: Selecting the specific species to score

Upon completion of the steps listed above, the remaining 425 species underwent a rigorous review by all experts within the thematic group. Each expert reviewed the list and marked species with a binary 'one' or 'zero', with 'one' meaning the species should be scored and considered at the workshop, and 'zero' meaning the species should be excluded. When entering their selection, the experts also provided a brief note as to why this selection had been made. In cases where the species was marked with a 'one' to bring forward for scoring, experts were invited to enter their initials in a separate column, indicating that they would score that species.

As a final step, experts were invited to check the 13 species that had previously been risk assessed but not listed (for various reasons), and the 143 species considered 'Widespread' (present in ≥ three 50 km x 50 km EU grid cells; Supplementary Material 1; Nunes *et al.*, 2025) to confirm whether there were any species here they would like to include and score. Experts were also reminded periodically that if there was a species they considered important that was not present on any list, then they were welcome to include it for consideration.

In total, 103 species were selected for scoring (Figure 11), broken down into 100 species from the initial long list, two from the 'Widespread' list present in three and four EU grid cells, respectively (one of which had also been previously dismissed from the RA process), and one species added from expert opinion. Each species was scored by two experts, so that there were two scores per species, with approximately 30 species scored per expert. The expertise of the team was such that the different taxa and geographic areas were all accounted for.

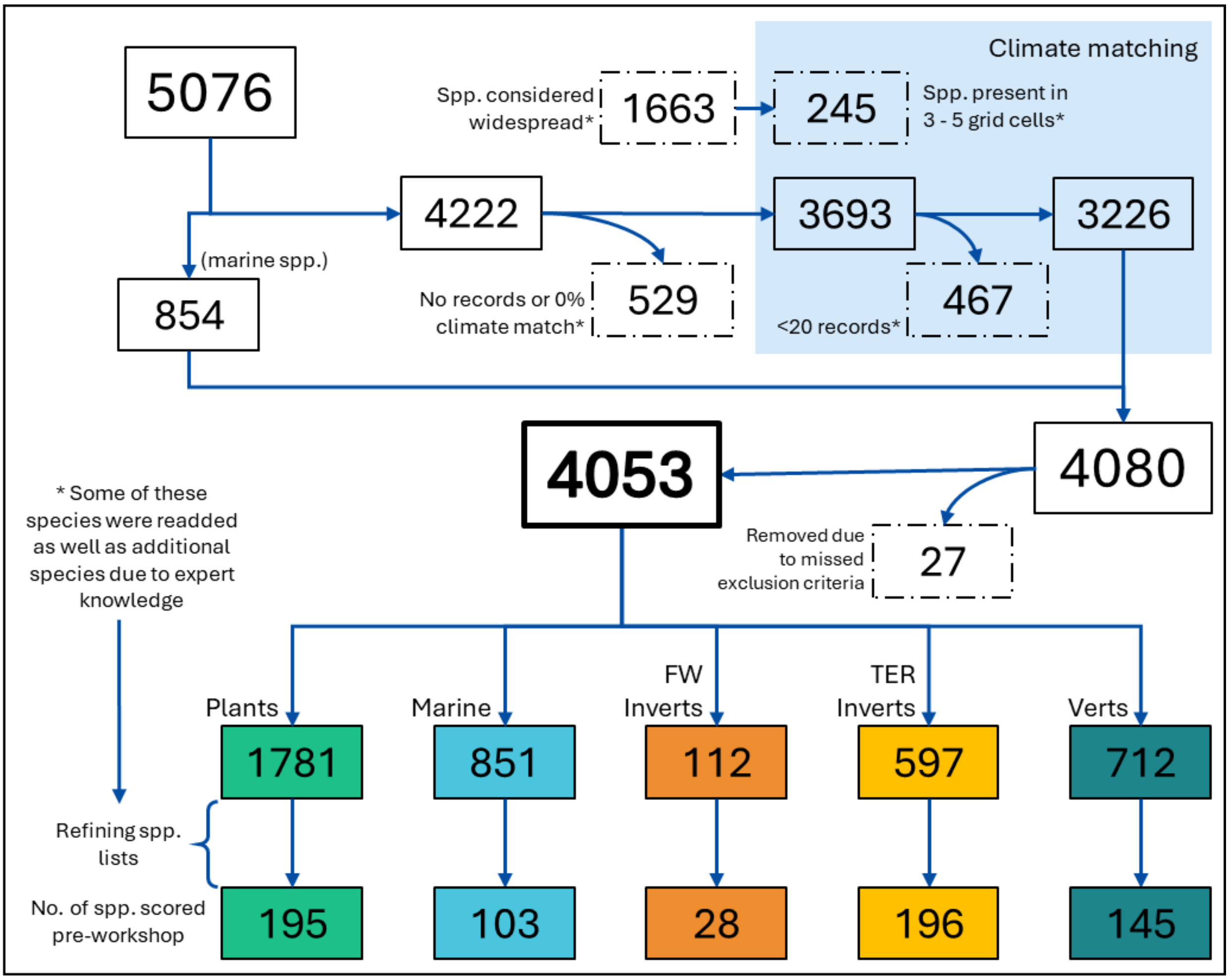

Figure 11. Number of species to be scored resulting from Step 3 of this horizon scanning exercise (Checking and refining species long lists) for each of the five thematic groups, considering both the removal and addition of species to the initial long lists.

3.3.2.3. Freshwater invertebrates

The initial long list of the freshwater invertebrates' group was the shortest of all thematic groups, with only 112 species to screen (Figure 11). Therefore, there was no need to remove species based on standardised potential occupancy in the EU, which, as mentioned above, was not entirely appropriate for aquatic species.

Firstly, the list of 50 widespread species (as per Supplementary Material 1; Nunes *et al.*, 2025) was double checked, but none of those species were re-added to the list to score. Two species, wrongly assigned to the marine group, were transferred to this list but were discarded and not taken forward for scoring. Following this, a total of 85 species were removed from the long list and one species was added (Table 15) in various steps, as described below:

1. Initial removal of 32 species: 14 of which were wrongly assigned to this group and were transferred to the marine group and 18 species which were partly European,

already regulated/or pathogens, cryptogenic, having likely been missed from the initial exclusion criteria.

2. The remaining species were then quickly checked for potential impacts to biodiversity, other missed exclusion criteria and additional features deemed relevant (see below). Based on this, a further 53 species were removed: 48 species with no reported impacts, already widespread in the EU, or that could potentially be outcompeted by other IAS already present in the EU (e.g. *Procambarus clarkii*, *Faxonius rusticus*); and five species having only impacts on human health (three species) or on economic activities (two species), but not on biodiversity or associated ecosystem services.

3. From the initial long list, 27 species were shortlisted. One species was added by the experts, based on an article showing high climatic suitability for Europe, the mollusc *Corbicula largillierti* (Reyna *et al.*, 2018; Table 15).

The final pre-workshop list was composed of 28 species to score. All five experts who were part of the thematic group independently scored all species, and then reconvened online to reach a consensus for the scores of each species. The species scores presented at the workshop were agreed and approved by all the experts.

3.3.2.4. Terrestrial invertebrates

The long list of terrestrial invertebrates initially included 597 species. Firstly, 175 species were removed, as considered (i) to be partly native to the EU, (ii) to be widespread or cryptogenic, (iii) to be economic pests only, e.g. for agriculture, forestry, ornamental plants, stored products or animal and human health, or (iv) to be regulated elsewhere (e.g. EPPO A1 and A2 and Alert Lists), resulting in a list of 422 remaining species to assess. Furthermore, one species was passed over to the marine group as it was wrongly allocated to this group (Table 15). Subsequently, 247 species with a 0 % – 20 % standardised potential occupancy in the EU were also removed, resulting in a list of 174 species. The 247 species removed due to low climate matching were screened to assess if any needed to be retained, which lead to two species being re-added to the list. Finally, 19 species were added based on expert opinion and recently published literature about their presence or relevance for the EU territory (Table 15). One species had been erroneously placed in another thematic group and was later transferred to this list. This process resulted in a list of 196 species taken forward for scoring. However, during the scoring, another 16 species were removed for similar reasons as those mentioned above, that had been overlooked during the first round. The final list of scored species therefore included 180 species. All chosen species were scored by at least two experts from this thematic group, with some, and particularly the top-ranked species, being scored by more than two, sometimes five experts.

3.3.2.5. Vertebrates

For the vertebrates group, initially a relevance check was conducted on the preliminary list of 196 mammals, 74 birds, 66 reptiles, 122 amphibians, and 254 freshwater fish (totalling 712 species, as per Figure 11). Two marine mammal species had been wrongly allocated to this group and were therefore moved to the marine group (resulting in 194 mammal species; Table 15). The methodology adopted to reduce the long list of species and scoring those was similar for all groups of vertebrate species, with some slight differences in the way the work was organised within the relevant groups of experts.

To ensure consistent progress and facilitate collaborative decision-making, the vertebrate group held various online meetings, including a preliminary panel meeting to illustrate the methodology, and meetings for focused discussion on the different vertebrate species groups. These sessions allowed the group to review findings, resolve uncertainties, and refine methodologies in real-time, fostering a clear consensus at each stage.

The first filtering step focused on climate and habitat matching, although the approaches adopted for the different groups of vertebrate species were slightly different (see below). Species considered widely spread in the EU (in more than three 50 km x 50 km squares; Supplementary Material 1; Nunes *et al.*, 2025) were generally excluded, but the list of excluded species was crosschecked by experts to identify any species that should still be considered (which resulted in some species being retained, see below).

Birds

To maintain steady progress and facilitate collaborative decision-making, weekly one-hour online meetings were conducted over one month. These sessions provided a platform for reviewing findings, addressing uncertainties, and ensuring a clear consensus at each stage. The process began with a relevance check on an initial list of 74 species, resulting in the retention of 61 species and the addition of *Rhea americana*, *Quelea quelea* and *Amazona amazonica* from the list of widespread species (Table 15). The first filtering step assessed climate and habitat suitability, leading to the exclusion of species unlikely to survive in Europe under current or projected conditions. The second filtering step targeted species with (a) no active introduction pathways, making transport to the EU highly improbable, and (b) no history of invasiveness elsewhere. This refinement ensured that only species with potential introduction risks were considered.

A total of 27 bird species remained and each species was independently scored by three assessors to enhance reliability and minimise bias. The likelihood of bird species introduction success was assessed using a combination of indicators, including species presence in zoological institutions, as documented on platforms such as Zootierliste.de, along with CITES listing, recent trade activity, prevalence in private aviaries, and online availability for purchase within the EU.

Mammals, amphibians and reptiles

Eleven species were added to the list (eight mammal, two reptile and one amphibian species) from either the list of widespread species, the list of species with no information, or due to expert opinion (Table 15). A panel of three experts then reviewed the shortlist of 393 species (202 mammal, 68 reptile, and 123 amphibian species), categorising them into three groups based on their knowledge and expertise: '0' – species unlikely to be introduced to the EU, establish populations, spread, and significantly impact native species; '1' – species that might pose a concern for the EU, but with a relatively low likelihood of being introduced, at least within the next ten years; and 'H' – species of high concern, warranting a more in-depth analysis for potential impacts within the EU. Only the species deemed high priority ('H'), which corresponded to a total of 69 species (40 mammals, 15 reptiles, and 14 amphibians), underwent scoring. To increase reliability and reduce bias, each species was scored independently by three assessors. Similarly to what was done for the bird species, information on mammal species presence in zoological institutions was gathered using platforms such as zootierliste.de, as these efforts provided a more nuanced understanding of the introduction potential for each of the mammal species. The experts then held an online meeting to discuss the scores and rankings, and address any inconsistencies, ultimately reaching a consensus. In preparation for the workshop, the list was double checked and the scores assessed collaboratively until the group reached full agreement.

Freshwater fish

For freshwater fish, one species was added from the widespread list (*Oncorhynchus gorbuscha*) and one species was added due to expert opinion (*Tridentiger bifasciatus*), resulting in an updated long list of 256 species (Table 15). Three experts went through the long list and, by consensus, 207 species were removed according to the following criteria:

- Species that were partly native to the EU, for instance Ponto-Caspian gobies that are native to at least some parts of Europe;
- Species that have already been introduced into the EU (e.g. early 1900s), but have not successfully established (e.g. some species of the Ictaluridae and Centrarchidae families);
- Species that only occur in the tropics;
- When multiple species of a genus were listed (e.g. species of the *Lepomis* genus), only those species that already had an invasion history were kept for scoring;
- Species that would have a low impact according to a previous horizon scan (e.g. Cano-Barbacil *et al*. 2023);

- Species with dubious taxonomic status (e.g. *Micropterus floridanus*, which seems to be *Micropterus salmoides*, already invasive in part of the EU).

The remaining species of freshwater fish (49 species) were scored by at least two of the three experts.

Table 15. Overview of the number of species added to, and removed from, the initial long list of species for each of the five thematic groups. The 'Final long list' column is the long list of species per group, taking into account the species that were moved between thematic groups.

Thematic group	Initial long list	Spp. passed on to other groups	Spp. received from other groups	Final long list	N spp. removed	Added from 'widely spread' list	Added from 'no info' list	Added from other sources	N spp. scored pre-workshop
Plants	1781	0	1	1782	1587	0	0	0	195
Marine	851	4	17	864	764	2	0	1	103
FW Inverts	112	14	2	100	73	0	0	1	28
TER Inverts	597	1	1	597	420	0	0	19	196
Verts	712	2	0	710	581	8	2	6	145
Total	4053	21	21	4053	3425	10	2	27	667

3.4. Step 6 – Expert consensus workshop

The expert consensus workshop took place on 4th – 5th November 2024, over one and a half days, in the Hendrik Consciencegebouw facilities of the Flemish Government, in Brussels (Belgium).

The main aim of the workshop was to produce a final list of at least 100 IAS likely to establish and have an impact on biodiversity across the EU in the next 10 years, using scientific information channelled through expert knowledge and consensus. This list will then be used to prioritise species selected for risk assessment, to ultimately be proposed for addition to the list of IAS of Union concern.

More specific goals of the workshop consisted of:

- Undertaking an expert-led consensus building exercise within and between the different thematic groups, by:

    - Reviewing species scores within thematic groups until a consensus was reached
    - Reviewing and refining the rankings of all species between groups through plenary discussion
    - Achieving consensus on a final list of at least 100 species for risk assessment, ranked in different priority categories
- Discussing possible challenges to the listing of certain species – corresponding to Task 3 of this project (which was not discussed due to lack of time)
- Discussing potential policy measures suggested for groups with a large number of IAS candidate for listing – corresponding to Task 4 of this project.

3.4.1. List of participants

Most project team members attended the workshop, with all seven core experts attending, and only three out of seven IUCN Secretariat members not able to attend (see Figure 2). All the additional experts mentioned in Table 14 above (and some extra ones) were invited to participate in the workshop and, out of those 33, only two could not attend (one of whom attended online). Overall, the workshop brought together 11 members of the project team, three additional IUCN Secretariat staff, 38 invited experts and four representatives of the EC, with a total of 56 participants (Table 16).

Table 16. List of workshop participants, with their role and affiliation indicated.

Name	Role and/or thematic group	Affiliation
Ana Nunes	Facilitator/note taker (project team)	IUCN (Cambridge, UK)
Tamryn Venter	Data manager/note taker	IUCN (Cambridge, UK)
Konstantin Gospodinov	Organising team (project team)	IUCN (Brussels, Belgium)
Grace Bond	Organising team/note taker (project team)	IUCN (Brussels, Belgium)
Vittorio Bellotto	Organising team/note taker	IUCN (Brussels, Belgium)
Valerie Verëll	Organising team/note taker	IUCN (Brussels, Belgium)
Daniel Nuijten	EC	DG ENV (Belgium)
Juan Pérez Lorenzo	EC	DG ENV (Belgium)
Leonardo Mazza	EC	DG ENV (Belgium)

Name	Role and/or thematic group	Affiliation
Katie Costello	IUCN/Marine (lead) (project team)	IUCN (Cambridge, UK)
Ruth O'Riordan	Marine	University College Cork (Ireland)
Stelios Katsanevakis	Marine	University of the Aegean (Greece)
María Altamirano Jeschke	Marine	University of Malaga (Spain)
Agnese Marchini	Marine	University of Pavia (Italy)
Sergej Olenin	Marine	Klaipeda University (Lithuania)
Ana Cristina Cardoso	EC/Marine	JRC (Italy)
Wolfgang Rabitsch	Terrestrial invertebrates (lead) (project team)	Environment Agency Austria (Austria)
Helen Roy	Facilitator/Terrestrial invertebrates (project team)	UK CEH (UK)
Jakovos Demetriou	Terrestrial invertebrates (remote)	University of Athens (Greece)
Cristina Preda	Terrestrial invertebrates	Ovidius University of Constanta (Romania)
Jasmijn Hillaert	Terrestrial invertebrates	INBO (Belgium)
Jiří Skuhrovec	Terrestrial invertebrates	Crop Research Institute (Czechia)
Imogen Cavadino	Terrestrial invertebrates	Forest Research (UK)
Riccardo Scalera	Vertebrates (co-lead) (project team)	IUCN ISSG (Italy)
Tim Adriaens	Vertebrates (co-lead) (project team)	INBO (Belgium)
Tom Evans	Vertebrates	Freie Universität Berlin (Germany)
Sandro Bertolino	Vertebrates	University of Turin (Italy)
Wojciech Solarz	Vertebrates	Polish Academy of Sciences (Poland)
Fleur Petersen	Vertebrates	INBO (Belgium)
Diederik Strubbe	Vertebrates	INBO (Belgium)

Name	Role and/or thematic group	Affiliation
Hugo Verreycken	Vertebrates	INBO (Belgium)
Rui Rebelo	Vertebrates	University of Lisbon (Portugal)
Emili García-Berthou	Vertebrates	University of Girona (Spain)
Teun Everts	Vertebrates	INBO (Belgium)
Pieterjan Verhelst	Vertebrates	INBO (Belgium)
Elena Tricarico	Freshwater invertebrates (lead) (project team)	BIO-UNIFI (Italy)
Francisco J. Oficialdegui	Freshwater invertebrates	University of South Bohemia (Czechia)
David Aldridge	Freshwater invertebrates	University of Cambridge (UK)
Belinda Gallardo	Freshwater invertebrates	Instituto Pirenaico de Ecología, CSIC (Spain)
Kevin Scheers	Freshwater invertebrates	INBO (Belgium)
Ana Novoa	Plants (co-lead) (project team)	EEZA-CSIC (Spain)
Petr Pyšek	Plants (co-lead) (project team)	IBOT CAS (Czechia)
Elizabete Marchante	Plants	University of Coimbra (Portugal)
Zarah Pattison	Plants	University of Stirling (UK)
Frédérique Steen	Plants	INBO (Belgium)
Johan van Valkenburg	Plants	NVWA (Netherlands)
Giuseppe Brundu	Plants	University of Sassari (Italy)
Wayne Dawson	Plants	University of Liverpool (UK)
Jodey Peyton	Plants /note taker	UK CEH (UK)
Bram D'hondt	Plants	INBO (Belgium)
Wouter Van Landuyt	Plants	INBO (Belgium)
Sander Devisscher	Additional participant	INBO (Belgium)
Soria Delva	Additional participant	INBO (Belgium)

Name	Role and/or thematic group	Affiliation
Arnaud Jacobs	Additional participant	Belgian National Scientific Secretariat on IAS (Belgium)
Jane Reniers	Additional participant	Belgian National Scientific Secretariat on IAS (Belgium)
Quentin Groom	Additional participant	Meise Botanic Garden (Belgium)

3.4.2. Agenda

A workshop agenda was prepared by the project team and circulated to all participants one week prior to the workshop. The agenda aimed at giving sufficient time for participants to discuss and achieve consensus on the scoring and ranking of the lists of species both within and between groups, as well as allowing for time for general discussions around Tasks 3 and 4 of the project. However, due to slight delays and time constraints during the workshop, the agenda had to be adapted and ultimately, in consultation with representatives from the EC, Task 4 (large groups of species) was prioritised to the exclusion of Task 3 (challenges to listing). The final workshop agenda is showcased in Table 17.

Table 17. Workshop agenda as it took place. A few modifications from the original agenda were implemented on site, in response to the need for additional time for each of the thematic groups to refine and reach consensus on their species scores.

Time	Description
Monday, 4th November	
09:00	Coffee and registration
09:30	Welcome (Daniel Nuijten, Konstantin Gospodinov)
09:40	Aims of the workshop (Ana Nunes)
09:45	Brief overview of the project (Ana Nunes, Soria Delva) - Task 1, Part 1 – Literature review on horizon scanning - Task 2, Part 2 – Methodology for horizon scanning
09:55	Overview of methodology and high-ranking species – Marine species (Katie Costello)
10:05	Overview of methodology and high-ranking species – Plants (Ana Novoa)

10:15	Overview of methodology and high-ranking species – Vertebrates (Tim Adriaens and Riccardo Scalera)
10:25	Overview of methodology and high-ranking species – Freshwater invertebrates (Elena Tricarico)
10:35	Overview of methodology and high-ranking species – Terrestrial invertebrates (Wolfgang Rabitsch)
10:45	COFFEE BREAK
11:10	Discussions within thematic groups to refine scores and rankings (in breakout rooms)
13:00	LUNCH
14:00	Discussions within thematic groups to refine scores and rankings (in breakout rooms)
15:30	COFFEE BREAK (compilation of lists by data manager)
16:00	Initial overview of rankings from all thematic groups (Helen Roy, Tamryn Venter)
17:00	Nibbles & drinks
18:30	Close of the day
Tuesday, 5th November	
09:00	Brief recap of ranked list and reflections from previous day (Ana Nunes)
09:15	Review of rankings from all thematic groups (Helen Roy, Tamryn Venter)
09:30	Final review of at least 100 species prioritised for risk assessment (Helen Roy, Tamryn Venter)
10:30	COFFEE BREAK
11:00	Task 4 – Identifying taxonomic groups that could be invasive, but where the great number of species that are candidate for listing would call for additional measures (each of the thematic leads)
12:15	Next steps and potential outputs (Ana Nunes)
12:30	Final considerations and close (Ana Nunes, Daniel Nuijten, Konstantin Gospodinov)
12:45	LUNCH
14:00	END

3.4.3. Implementation of the workshop

Day 1

The first day of the workshop started with a short presentation by Konstantin Gospodinov (IUCN) presenting the project team and running through the agenda for the one and a half days of the workshop. This was followed by a welcome to all participants by Daniel Nuijten, representative of DG ENV from the European Commission. The workshop then turned to the more technical aspects, with Ana Nunes (IUCN) outlining the specific goals of the project and workshop. This helped provide a foundation for the coming days, by reminding participants of what was to be achieved.

Ana Nunes then continued to provide an overview of the project, highlighting the four different tasks to be implemented, as mentioned above. A more detailed approach of Task 1 of the project was then presented, first focusing on the literature review of horizon scanning exercises undertaken (in particular those for IAS), and then reiterating the scope and outlining the steps of the updated methodology of the current horizon scanning. This was followed by a presentation from Soria Delva (INBO) deep diving into the more technical aspects of both the methodology used to define which species were considered widely spread in the EU (and therefore removed from the exercise), and the climate matching exercise that was undertaken to help thematic leads reduce their long list of species (as described in the sections above).

The morning session then moved on to the delivery of presentations by each thematic group lead on the steps taken to reduce and refine their long lists of species (as described in Section 3.3.2 above) and the preliminary lists of high-ranking species of each group based on the initial scoring done pre-workshop. These presentations were instrumental to inform the other thematic group leads and additional experts of the slightly adapted methodologies used, and especially of the range of scores of the different high-ranking species presented as being key for prioritisation. This was helpful to guide discussions and assist in reviewing species scores in the breakout group discussions that followed. In addition, a short question-and-answer session followed these presentations, where some points regarding the exercise, which were important to take into account for the breakout group discussions, were clarified.

Konstantin Gospodinov (IUCN) explained where and how breakout groups would occur, also indicating the project team member that would be taking notes of the discussions held in each of the breakout rooms. As such, after a short coffee break, the participants spent the remainder of the morning session of Day 1 in five breakout groups, one for each of the thematic groups, to collaboratively refine the scores and rankings of their species, aiming for final consensus within groups (Figure 12 and Figure 13). Some groups also used this opportunity to add species to their lists, as relevant, or to remove species which, after further in depth research, met one or more of the exclusion criteria, e.g. were found to be widely spread, native to the EU, or having taxonomic complexities (Figure 16). In order to keep the final list of species focused and somewhat limited in numbers, thematic groups were asked to, from their species scored pre-workshop, select those that they considered fundamental to put forward for the final horizon scanning list and to reach scoring consensus for those (without limiting this to a specific number of species). These within-group species scores were later used to guide the between-group species rankings, which were discussed among all workshop participants until group consensus was reached.

Figure 12. Freshwater invertebrates' thematic group in their breakout group session.

After the lunch break, which provided an opportunity for informal discussions and networking, the afternoon started with the various breakout groups reconvening and within-group discussions continuing, in order to give participants additional time to refine, finalise and achieve consensus on their species scores and rankings. Detailed discussions points and decisions made within each of the five breakout groups were captured by notetakers. Of note, is the decision of the marine group to further remove some species from the marine list due to information mobilised during the scoring process relating to cryptic taxonomy or the fact that they are too widely spread. The freshwater invertebrates group also decided to reconsider two additional species of molluscs from the 'no data' list (*Pila scutata* and *Anentome helena*).

After the coffee break, the data manager (Tamryn Venter, IUCN), supported by the facilitators and thematic leads, compiled the various lists of species scored and ranked by each thematic group that were considered essential to put forward for the final list into a single combined list. At this initial stage, the combined list consisted of 292 species (see Figure 16 below). The facilitator (Helen Roy) presented the initial overview of the list to all workshop participants, briefly summarising the results of the species rankings which resulted from merging all species scores. The list was slowly shown to participants, in order to give them a chance to look at the top-ranking species from different thematic groups. All workshop participants were given the opportunity to raise questions and comment on this list, and some experts were invited to justify their scores in comparison to those of other groups.

Figure 13. Terrestrial invertebrates thematic group in their breakout group session.

Day 1 of the workshop ended with a draft list of prioritised species, for which a cut off seemed to be a score of around 192, showing a relatively good representation of the different thematic groups. This combined list was shared with all workshop participants for reflection before reconvening the following day.

Day 2

The second day of the workshop lasted only half a day. It started with a brief reflection on what was discussed and achieved in the previous day by Ana Nunes. This was followed by Helen Roy taking the stage to recap and summarise the rankings of species in the list of prioritised species as discussed the day before, while outlining the main goals for the day.

Based on this, the facilitators suggested for the thematic groups to briefly reconvene, to make sure there were no additional relevant species that would be disregarded if the list of prioritised species was to have a cut off at a score of 192. It was also suggested that each group should look for species with high impact and high establishment likelihood (even if the likelihood of introduction was low), to make sure that all species deemed the most risky were captured. Following from this, some species were rescored and consequently reranked, and some were considered for review at the genus level (under Task 4).

When the plenary resumed, some thematic leads and additional experts were asked to explain to other workshop participants the scores given to some of their prioritised species. Questions were also asked about some species that were either ranking low in the list or not present in the list at all. A species from the marine thematic group that ranked high, *Perna viridis*, was mentioned as having been previously risk assessed and so, as initially agreed with the European Commission, it was removed from the prioritised list. In addition, it was noticed that quite many prioritised vertebrate species were scoring/ranking relatively high in the list and that, on the contrary, plant species were scoring/ranking perhaps lower than expected. As such, the facilitator suggested for these thematic groups to quickly reconvene again during the coffee break to revise some of their species' scores. This process resulted not only in some species from these thematic groups being rescored, but also in a number of plant species being added to the prioritised list.

The subsequent discussions were mostly focused on establishing a top priority number of species out of the prioritised longer list of species, although some species also ended up being re-scored during this process (Figure 14).

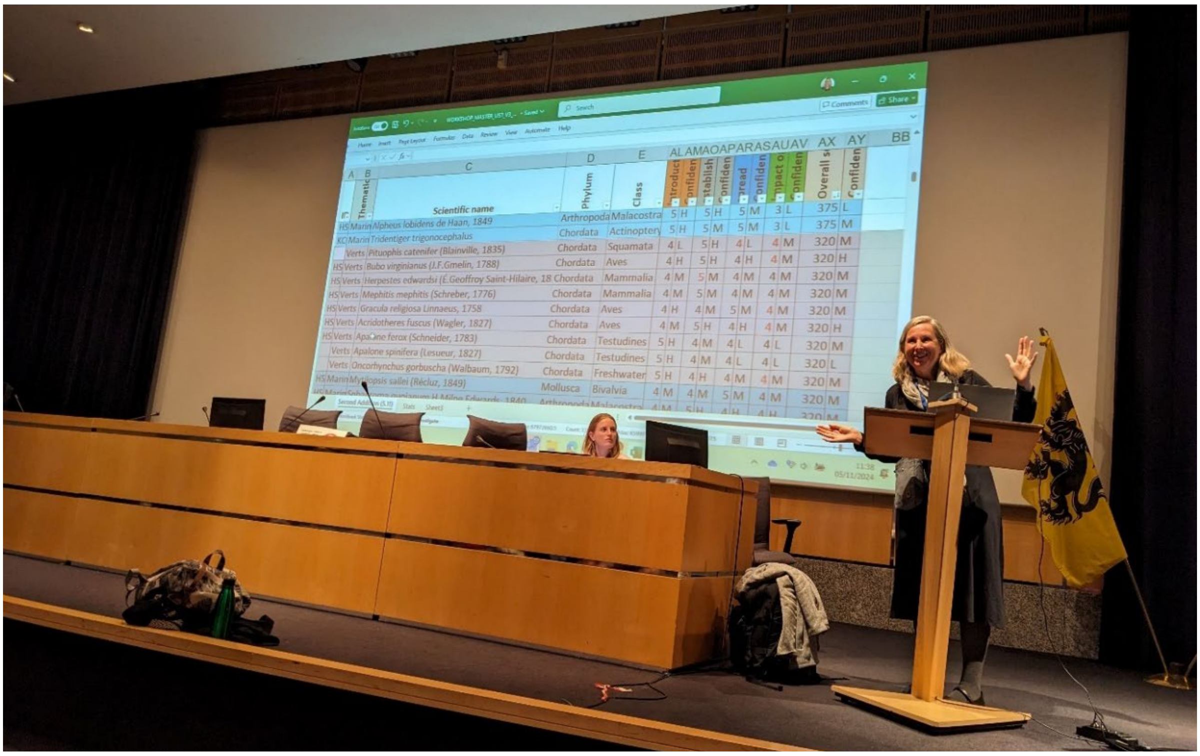

Figure 14. Consensus between all workshop participants is agreed on a final list of species prioritised for future risk assessment, featuring Helen Roy (facilitator) and Tamryn Venter (data manager).

During this overall process, some species potentially scoring less than others were moved up in the ranking (sometimes without change in scores), as they were deemed of very high priority and therefore should feature in the top part of the list. Naturally, this was only done in case there was full consensus among all workshop participants. After much discussion and questions, all workshop participants agreed on a consensus list of 169 prioritised species, with a Top 55 most damaging species that were agreed to not be ranked, but yet presented in alphabetical order (Figure 14).

The next part of the workshop addressed Task 4 of the project; 'Identify taxonomic groups that could be invasive, but where the great number of species that are candidate for listing would call for additional measures'. This session comprised six presentations, a brief one delivered by the facilitator Ana Nunes on the main aims of the task, followed by five presentations, one by each of the different thematic leads. For this, each of the groups had identified the taxonomic groups (at genus or family level) that they considered having a large number of species that may require additional measures.

Figure 15. All participants at the IAS EU-level horizon scanning workshop, held on 4-5 November 2024, in Brussels.

The final part of the workshop consisted of outlining the next steps for the project work and some final considerations. It was mentioned that the final project report would be produced and shared with all workshop participants for comments and approval. Representatives from the EC and IUCN thanked all the experts for the time and effort dedicated to the project, and the Flemish Government for hosting the workshop, upon which the meeting was closed (Figure 15).

3.4.4. Issues raised by thematic groups at the workshop

During the implementation of the workshop, a number of important points were raised by different thematic groups, some of which are worth highlighting here, as follows:

- It is particularly difficult to deal with species for which there is not much information available, for example on distribution and life-history. This is especially common in what concerns the lack of robust or consistent information on impacts of IAS on biodiversity and ecosystem services.
- Scoring of species is challenging at times and hard to standardise even within thematic groups, e.g. it can be hard to decide if to give a 4 for likelihood of impact with high confidence or an impact score of 5 with low confidence.
- The scale at which the impacts of certain IAS on biodiversity is assessed seems to be very relevant and particularly delicate in the case of vertebrates. For example, many IAS which belong to this group (e.g. birds, snakes and mammals), may have a significant impact on species confined to island ecosystems, while on the mainland the evidence of their impact may be less obvious. This has a large influence on how species' impacts are scored, given that the scheme used here looks at population decline/loss at various scales (local, regional and widespread; see Table 10 above). For example, if the gopher snake (*Pituophis catenifer*) was be introduced to a (snakeless) Mediterranean island, it would potentially devastate native fauna and lead to irreversible impacts such as multi-species extinction, but on continental landmasses the impacts would be much lower. Another example is *Mephitis mephitis*, the striped skunk, which scored 5 for impact based on its potential for ecological impacts on islands (e.g. Balearics).
- For some species, taxonomic uncertainties can complicate the work of experts, so in these cases it would be important to contact, or have access to, specific taxonomic expertise to clarify these issues. This was the case for *Neocaridina denticulata* and *N. davidi* in the freshwater invertebrates' group, which might be two different species.

3.5. Results beyond the expert consensus workshop

As mentioned above, the outcome of the workshop was a list of 169 species prioritised for risk assessment, with a Top 55 species identified as of highest concern and a remaining 114 species also of high risk. However, shortly after the workshop, the project team realised there were two marine species (*Eriocheir hepuensis* and *Eriocheir japonica*) that had been agreed by all workshop participants to be moved up to the Top 55, which ended up being missed from that Top 55 list. As such, they were later incorporated, changing the highest concern list to a Top 57.

Additionally, it was also later realised that two additional species present in the list of prioritised species (*Bison bison* and *Micropterus dolomieu*) were in a similar situation to that described for *Perna viridis* above (in Section 3.4.3). As such, given that these species have previously been risk assessed in consideration for addition to the list of Union concern, they were downgraded from the prioritised list to the list of ‘remaining species’ (see more details below). Further checks of the prioritised list of species resulted in two other species being completely removed from the list, as it was realised that one of them (*Sciurus anomalus*) is native to Lesbos (Greece) and the other is a feral horse (*Equus ferus*) – feral (native) mammals (e.g. sheep, goats, dogs, cats, cattle, horses) being excluded from this exercise.

This overall process resulted in a final list of 165 species considered to represent a very high (Top 57) or high (108 species) risk in what concerns their likelihood of introduction, establishment, spread and impact on biodiversity and ecosystem services in the EU in the next ten years, that therefore should be prioritised for risk assessment (Figure 16). For all these 165 species (hereafter called ‘risky species’), full consensus was reached within and between the different thematic groups on their individual components and overall scores, which are shown, alongside many other details (presence in the EU, pathways of introduction and spread, impacts, etc.), in Supplementary Material 2 (Tabs ‘Top 57 Species’ and ‘High Risk Species’; Nunes *et al.*, 2025). For the Top 57 (also called ‘very high risk’ species), as mentioned above, due to the difficulty in ranking each of these species in a meaningful way, it was agreed by all workshop participants that these species would be presented in this report in alphabetical order (Table 18). For the 108 ‘high risk’ species, as described in Section 3.4.3, a score of 192 was deemed the general cut off to keep species in the prioritised list.

All the 457 ‘remaining’ species from the total initial number of species considered for the workshop were deemed of low priority for risk assessment (Figure 16). For some of these species, consensus on scores was reached within groups, while for others this was not achieved. A list of all these species shown in alphabetical order, within each of the thematic groups, can be found in Supplementary Material 2 (Tab ‘Remaining Species’; Nunes *et al.*, 2025).

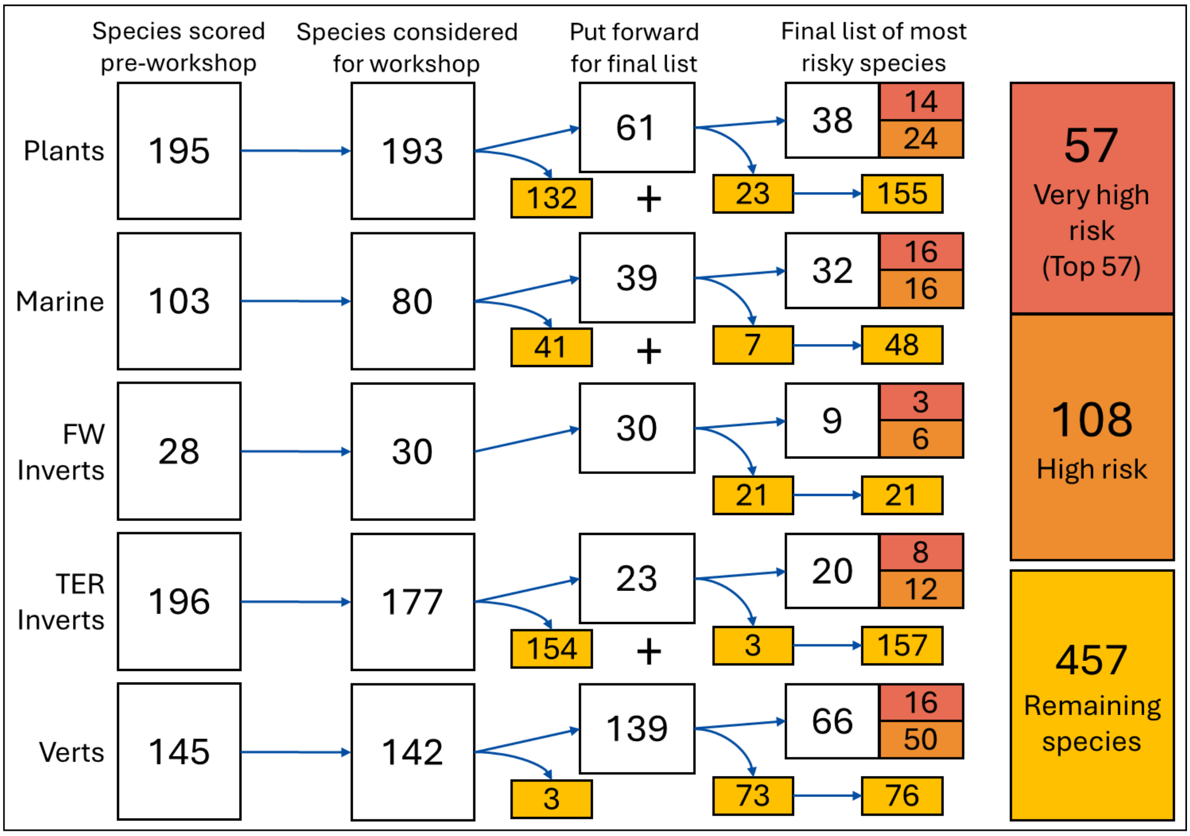

Figure 16. Number of species of each thematic group scored pre-workshop, those considered for the workshop, how many of those were put forward for the final prioritised list and how many feature in the list of most risky species (very high risk and high risk). The 'high risk' species are those that scored equal to, or above 192, with some exceptions.

Table 18. Top 57 list of species considered as having a very high risk of arrival, establishment, spread and impact on biodiversity or associated ecosystem services across the EU in the next 10 years. It was agreed by all workshop participants to present this list in alphabetical order, and not according to their rank. Verts – Vertebrates; TERR Inverts – Terrestrial Invertebrates; FW Inverts – Freshwater Invertebrates.

Thematic Group	Scientific name	Phylum	Class	Order	Family
Plants	*Acacia decurrens* Willd.	Tracheophyta	Magnoliopsida	Fabales	Fabaceae
Verts	*Acridotheres fuscus* (Wagler, 1827)	Chordata	Aves	Passeriformes	Sturnidae
Marine	*Actaea savignii* (H.Milne Edwards, 1834)	Arthropoda	Malacostraca	Decapoda	Xanthidae
Marine	*Alpheus lobidens* de Haan, 1849	Arthropoda	Malacostraca	Decapoda	Alpheidae
Plants	*Ampelopsis glandulosa* (Wall.) Momiy.	Tracheophyta	Magnoliopsida	Vitales	Vitaceae
TERR Inverts	*Apis florea* Fabricius, 1787	Arthropoda	Insecta	Hymenoptera	Apidae
TERR Inverts	*Australoplana sanguinea* (Moseley, 1877)	Platyhelminthes	Turbellaria	Tricladida	Geoplanidae
Plants	*Baccharis spicata* (Lam.) Baill.	Tracheophyta	Magnoliopsida	Asterales	Asteraceae
Marine	*Balanus glandula* Darwin, 1854	Arthropoda	Maxillopoda	Sessilia	Balanidae
TERR Inverts	*Brachymyrmex patagonicus* Mayr, 1868	Arthropoda	Insecta	Hymenoptera	Formicidae
TERR Inverts	*Brephulopsis cylindrica* (Menke, 1828)	Mollusca	Gastropoda	Stylommatophora	Enidae
Verts	*Bubo virginianus* (J.F.Gmelin, 1788)	Chordata	Aves	Strigiformes	Strigidae
Marine	*Callinectes bocourti* A.Milne-Edwards, 1879	Arthropoda	Malacostraca	Decapoda	Portunidae

Thematic Group	Scientific name	Phylum	Class	Order	Family
Marine	*Callinectes exasperatus* (Gerstaecker, 1856)	Arthropoda	Malacostraca	Decapoda	Portunidae
Marine	*Callinectes marginatus* (A.Milne-Edwards, 1861)	Arthropoda	Malacostraca	Decapoda	Portunidae
Verts	*Callosciurus prevostii* (Desmarest, 1822)	Chordata	Mammalia	Rodentia	Sciuridae
Marine	*Cancer irroratus* Say, 1817	Arthropoda	Malacostraca	Decapoda	Cancridae
Marine	*Caulerpa chemnitzia* (Esper) J.V.Lamour.	Chlorophyta	Ulvophyceae	Bryopsidales	Caulerpaceae
Plants	*Cenchrus purpureus* (Schumach.) Morrone	Tracheophyta	Liliopsida	Poales	Poaceae
Marine	*Codium arabicum* Kuetz.	Chlorophyta	Ulvophyceae	Bryopsidales	Codiaceae
Marine	*Codium parvulum* (Bory ex Audouin) P.C.Silva	Chlorophyta	Ulvophyceae	Bryopsidales	Codiaceae
FW Inverts	*Corbicula largillierti* (R.A.Philippi, 1844)	Mollusca	Bivalvia	Venerida	Cyrenidae
Plants	*Cotoneaster glaucophyllus* Franch.	Tracheophyta	Magnoliopsida	Rosales	Rosaceae
Verts	*Elaphe schrenckii* Strauch, 1873	Chordata	Reptilia	Squamata	Colubridae
Verts	*Elaphe taeniura* (Cope, 1861)	Chordata	Reptilia	Squamata	Colubridae
Marine	*Eriocheir hepuensis* Dai, 1991	Arthropoda	Malacostraca	Decapoda	Varunidae
Marine	*Eriocheir japonica* (De Haan, 1835)	Arthropoda	Malacostraca	Decapoda	Varunidae
Marine	*Galaxaura rugosa* (J.Ellis & Sol.) J.V.Lamour.	Rhodophyta	Florideophyceae	Nemaliales	Galaxauraceae
Marine	*Geukensia demissa* (Dillwyn, 1817)	Mollusca	Bivalvia	Mytilida	Mytilidae

Thematic Group	Scientific name	Phylum	Class	Order	Family
Verts	*Graptemys geographica* (Lesueur, 1817)	Chordata	Reptilia	Testudines	Emydidae
Plants	*Harrisia martinii* (Labour.) Britton	Tracheophyta	Magnoliopsida	Caryophyllales	Cactaceae
Plants	*Hedychium coronarium* J.Koenig	Tracheophyta	Liliopsida	Zingiberales	Zingiberaceae
Marine	*Hemigrapsus penicillatus* (De Haan, 1835)	Arthropoda	Malacostraca	Decapoda	Varunidae
Verts	*Herpestes edwardsi* (É.Geoffroy Saint-Hilaire, 1818)	Chordata	Mammalia	Carnivora	Herpestidae
TERR Inverts	*Limicolaria aurora* (J. C. Jay, 1839)	Mollusca	Gastropoda	Stylommatophora	Achatinidae
TERR Inverts	*Linepithema angulatum* (Emery, 1894)	Arthropoda	Insecta	Hymenoptera	Formicidae
FW Inverts	*Macrobrachium nipponense* (De Haan, 1849)	Arthropoda	Malacostraca	Decapoda	Palaemonidae
Plants	*Murdannia keisak* (Hassk.) Hand.-Mazz.	Tracheophyta	Liliopsida	Commelinales	Commelinaceae
TERR Inverts	*Nylanderia fulva* (Mayr, 1862)	Arthropoda	Insecta	Hymenoptera	Formicidae
Verts	*Oreochromis mossambicus* (Peters, 1852)	Chordata	Actinopterygii	Perciformes	Cichlidae
Verts	*Oreochromis niloticus* (Linnaeus, 1758)	Chordata	Actinopterygii	Perciformes	Cichlidae
Verts	*Pantherophis guttatus* (Linnaeus, 1766)	Chordata	Reptilia	Squamata	Colubridae
Verts	*Pelophylax shqipericus* (Hotz, Uzzell, Günther, Tunner & Heppich, 1987)	Chordata	Amphibia	Anura	Ranidae
FW Inverts	*Procambarus alleni* (Faxon, 1884)	Arthropoda	Malacostraca	Decapoda	Cambaridae
TERR Inverts	*Pseudomyrmex gracilis* (Fabricius, 1804)	Arthropoda	Insecta	Hymenoptera	Formicidae

Thematic Group	Scientific name	Phylum	Class	Order	Family
Verts	*Pycnonotus aurigaster* (Vieillot, 1818)	Chordata	Aves	Passeriformes	Pycnonotidae
Verts	*Rattus tanezumi* (Temminck, 1845)	Chordata	Mammalia	Rodentia	Muridae
Plants	*Rumex sagittatus* Thunb.	Tracheophyta	Magnoliopsida	Caryophyllales	Polygonaceae
Plants	*Sagittaria platyphylla* (Engelm.) J.G.Sm.	Tracheophyta	Liliopsida	Alismatales	Alismataceae
Plants	*Salvinia minima* Baker	Tracheophyta	Polypodiopsida	Salviniales	Salviniaceae
Plants	*Schizachyrium scoparium* (Michx.) Nash	Tracheophyta	Liliopsida	Poales	Poaceae
Verts	*Sciurus lis* Temminck, 1844	Chordata	Mammalia	Rodentia	Sciuridae
Plants	*Solanum seaforthianum* Andrews	Tracheophyta	Magnoliopsida	Solanales	Solanaceae
Plants	*Spirodela punctata* (G.Mey.) C.H.Thomps.	Tracheophyta	Liliopsida	Alismatales	Araceae
Verts	*Tridentiger bifasciatus* Steindachner, 1881	Chordata	Actinopterygii	Perciformes	Gobiidae
Marine	*Tridentiger trigonocephalus* (Gill, 1859)	Chordata	Actinopterygii	Gobiiformes	Oxudercidae
Verts	*Xiphophorus hellerii* Heckel, 1848	Chordata	Actinopterygii	Cyprinodontiformes	Poeciliidae

3.6. Analysis of risky species

This section presents a brief analysis of some of the attributes of the 165 risky species considered to be of high, or very high risk, in this horizon scanning exercise. The vertebrates thematic group had the greatest number of species considered risky, followed by plants, then marine, terrestrial invertebrates and, lastly, freshwater invertebrates (Figure 17). Regarding the Top 57 very high risk species, the marine and vertebrates thematic groups had the greatest number of species (both having 16 species), followed by plants, then terrestrial invertebrates and freshwater invertebrates (Figure 17).

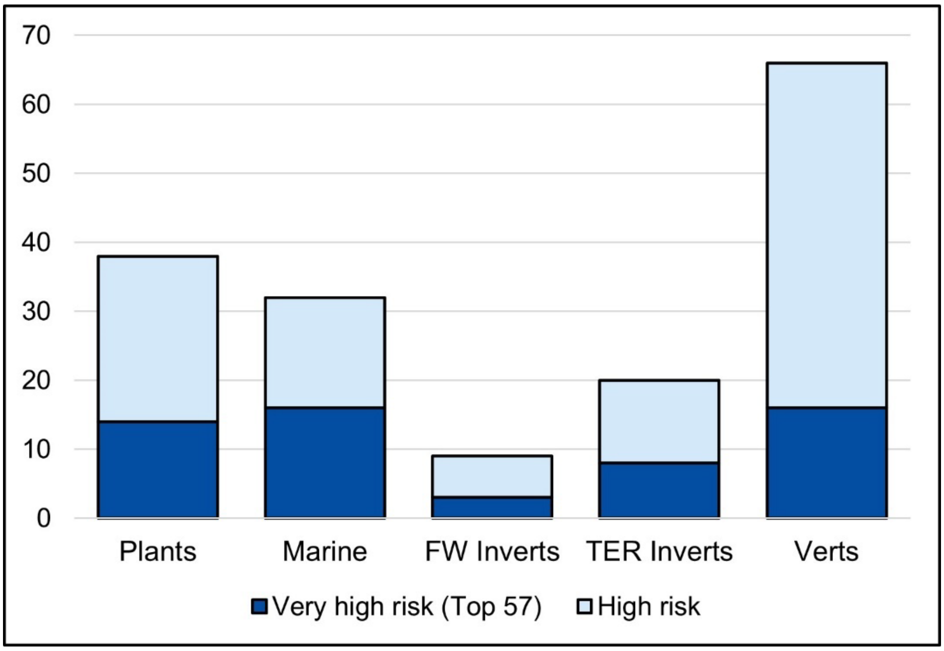

Figure 17. Number of species in each thematic group that were agreed by consensus as of high, or very high, risk of arriving, establishing, spreading and having an impact on biodiversity or associated ecosystem services across the EU in the next ten years.

3.6.1. Taxonomy

The taxonomy of the 165 risky species consists of eight phyla, 20 classes, 61 orders, and 99 families. The classes with the greatest number of species per thematic group are Magnoliopsida for plants, Malacostraca for marine and freshwater invertebrates, Insecta for terrestrial invertebrates, and Aves for vertebrates. As expected, for some aquatic species, there is an overlap in classes of species represented from the vertebrates, marine and freshwater invertebrates groups (Figure 18).

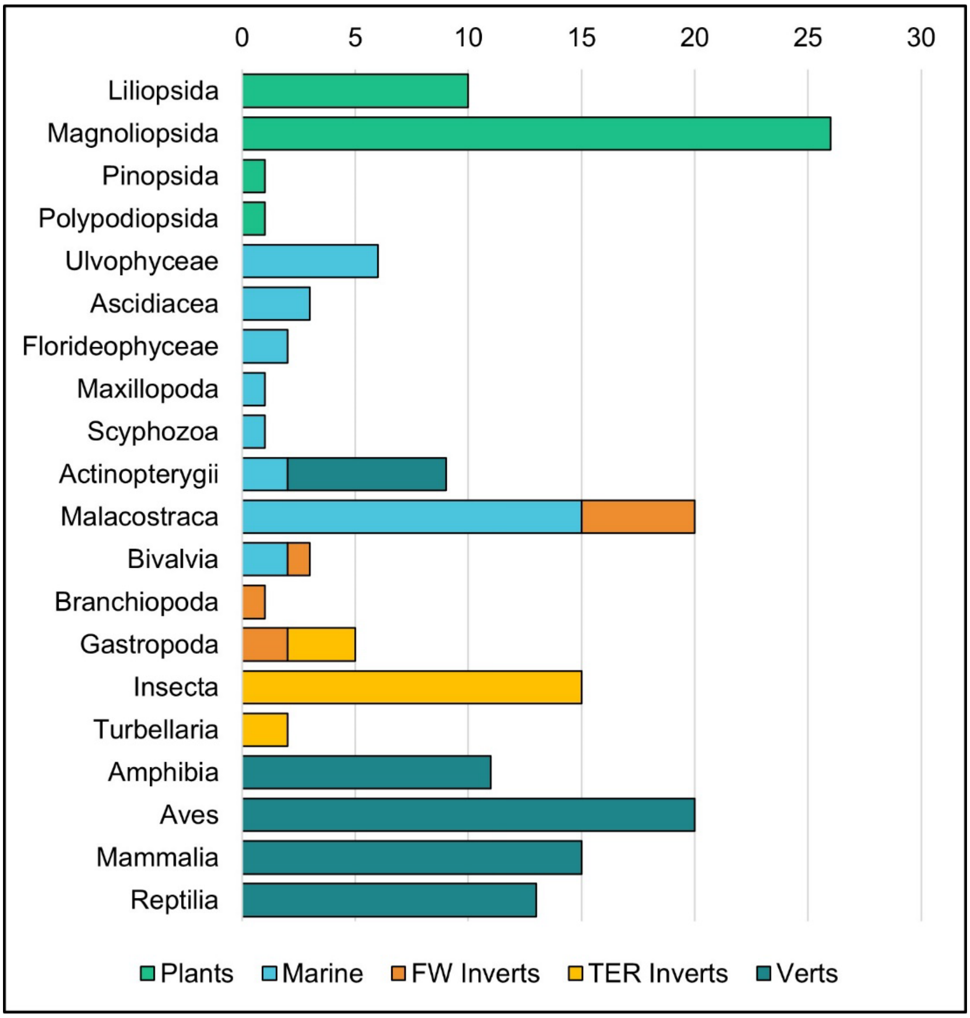

Figure 18. Number of risky species per Class, colour coded per thematic group.

3.6.2. Native areas

Terrestrial and freshwater species

The region from which the highest number of risky species are native to is Eastern Asia (37 species), followed by Southeastern Asia (26 species) and Northern America (23 species) (Figure 19). Regions with the lowest number of native risky species (excluding European regions) were the Oceania regions of Polynesia (no species), Micronesia (no species) and Melanesia (two species), as well as the Caribbean region (three species) and Middle Africa (four species). Three of the risky species are native to Europe (outside of EU MS), the ghost slug *Selenochlamys ysbryda*, the land snail *Brephulopsis cylindrica* and the Albanian water frog *Pelophylax shqipericus*. When considering only the Top 57 species, the regions with the highest number of native species are Eastern Asia and South America (both ten species each), followed by Central America (eight species). Note that species can be native to more than one region, thus the numbers quoted here and in the figure will exceed the total number of risky species.

Overall, Asia and the Americas were the continents with the greatest number of risky species native to them. Vertebrate species were largely native to Asia, as were freshwater invertebrates. Plants were largely native to Asia and the Americas, and terrestrial invertebrates largely native to the Americas (Figure 19).

Marine species

The regions used to describe a species' native range were based upon major oceanic basins. The Atlantic Ocean was the native region with the greatest number of risky species (13 species), followed closely by the Indo-Pacific Ocean (12 species), and lastly the Pacific Ocean (eight species) (Figure 19). Again, noting that species can have more than one native area, thus the numbers quoted here and in the figure, exceed the total number of risky marine species. The Tropical and Western Atlantic regions, the Western Indo-Pacific region, and the North and Northwest Pacific regions, respectively, were the regions within these larger oceanic areas to which a higher number of risky species were native.

When considering only the Top 57 species, all three oceanic regions were fairly equally represented, with six, six, and five species being native to the Atlantic, Indo-Pacific, and Pacific Oceans, respectively.

3.6.3. Pathways of introduction and spread

The current and potential future pathways through which the risky species could be introduced into, or spread in the EU spanned 32 out of the 45 categories of the pathways scheme outlined by the CBD (see also IUCN, 2018). The 'Escape from Confinement' category had the greatest potential to introduce species, followed by the category 'Transport – Stowaway' (Figure 20). The pathway that could introduce the greatest number of species into the EU, which falls under the 'Escape from Confinement' category, is the 'Pet' pathway, i.e. species that escape from confinement, where they are kept as pets, in aquariums or terrariums. The pathway that could introduce the second greatest number of species, which was less than half the number of species in the 'Pet' pathway, is the 'Botanical garden/zoo/aquaria' pathway, referring to species that escape from confinement where they are kept for public display in botanical gardens, zoos, or aquaria.

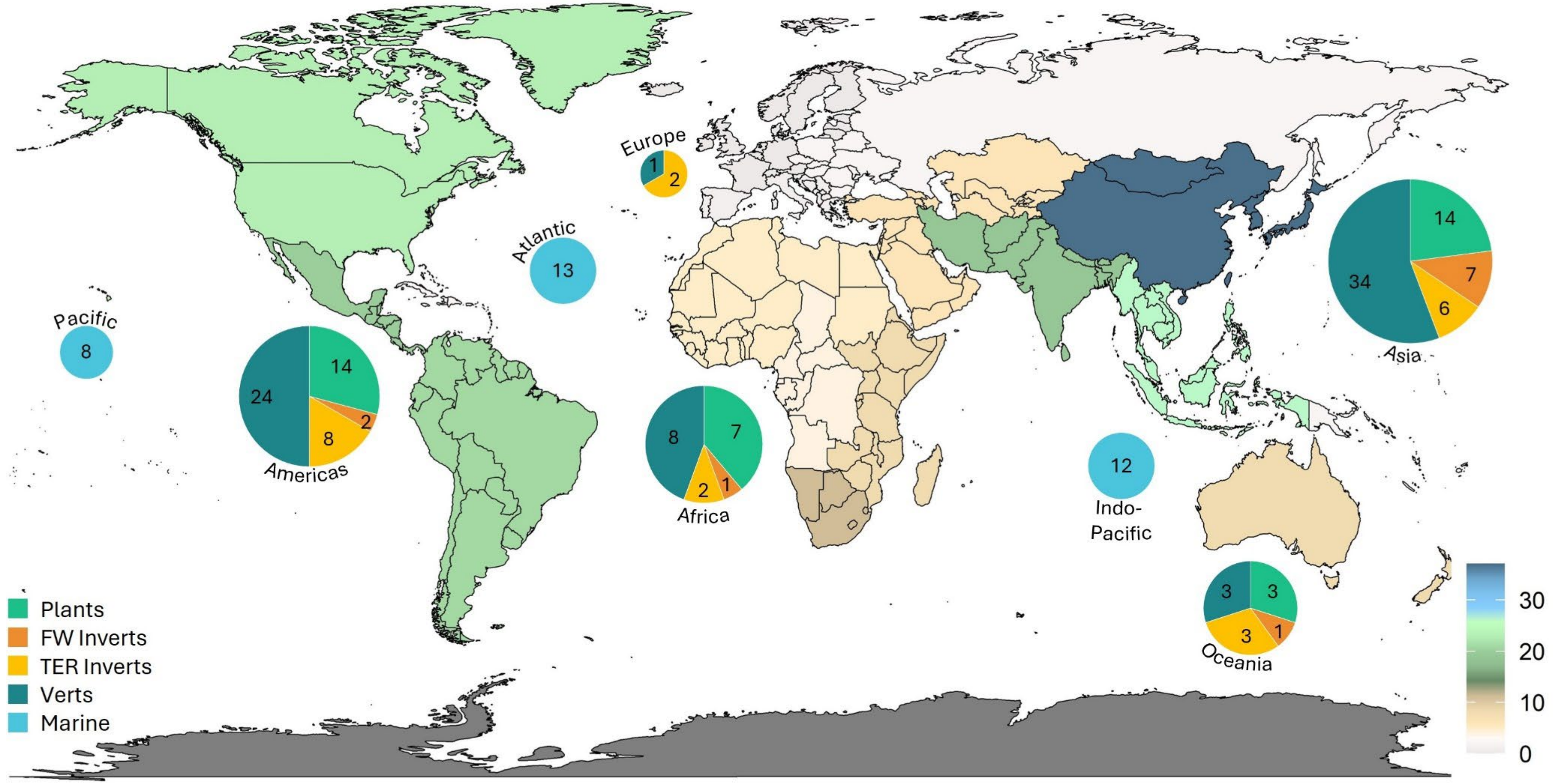

Figure 19. Overall number of species native to a specific region shown in the map (legend on the right). The number of species per the thematic group native to each continent and ocean is shown in the pie charts (legend on the left). The pie charts are roughly sized according to the total number of species native to each continent/ocean. Species can be native to more than one region, thus the numbers will exceed the total number of risky species (n=165). Furthermore, in some cases, the continent a species is native to could be identified, but the specific region was unknown, thus the numbers between the native continents and native ranges may not necessarily align.

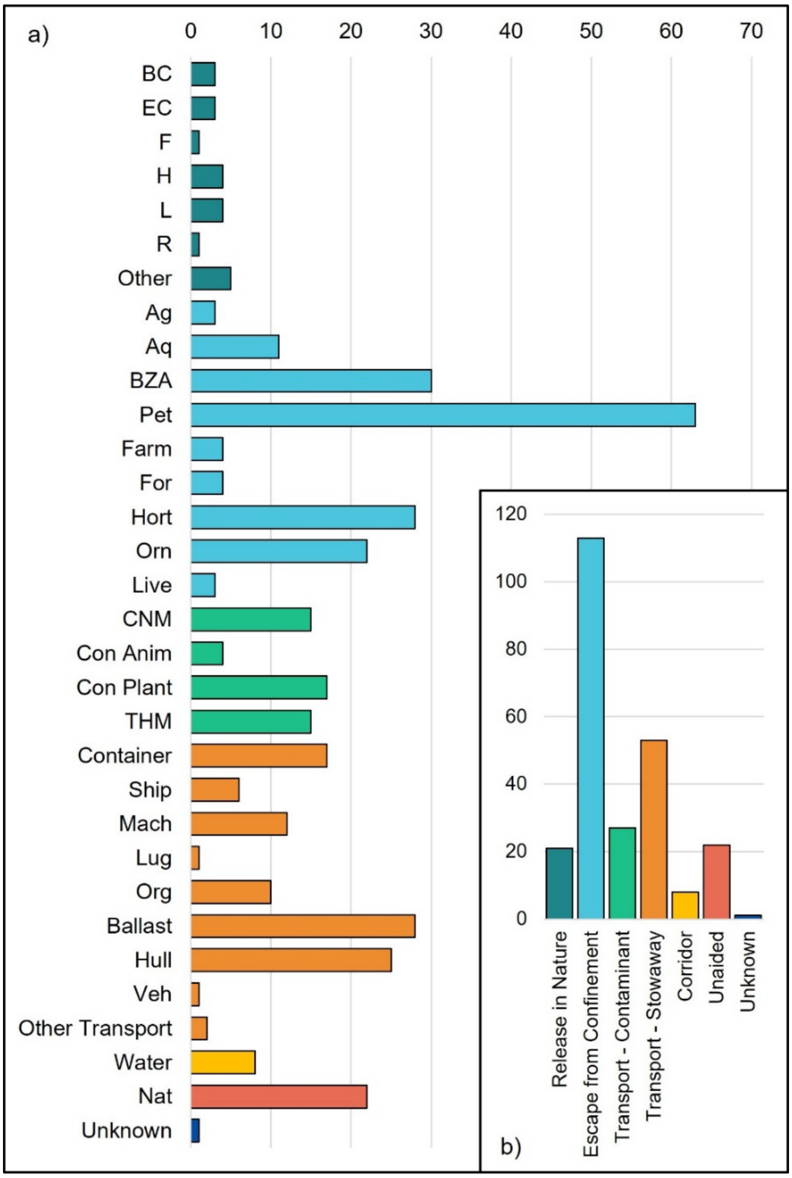

Figure 20. Number of risky species that could be introduced into, or spread within the EU via (a) the detailed CBD pathways categories and (b) the high level CBD pathways categories. Each species can have more than one pathway, thus the total number of pathways exceeds the total number of species. BC: Biological control, EC: Erosion control, F: Fishery in the wild, H: Hunting, R: Release in nature for use, Other: Other intentional release, Ag: Agriculture, Aq: Aquaculture/mariculture, BZA: Botanical garden/zoo/aquaria, Pet: Pet/aquarium/terrarium species, Farm: Farmed animals, Hort: Horticulture, Orn: Ornamental purpose other than horticulture, Live: Live food and live bait, CNM: Contaminant nursery material, Con Anim: Contaminant on animals, Con Plant: Contaminant on plants, THM: Transportation of habitat material, Container: Container/bulk, Ship: Hitchhikers on ship/boat, Mach: Machinery/equipment, Lug: People and their luggage/equipment, Org: Organic packing material, Ballast: Ship/boat ballast water, Hull: Ship/boat hull fouling, Veh: Vehicles, Water: Interconnected waterways/basins/seas, Nat: Natural dispersal across borders of invasive alien species that have been introduced through pathways mentioned above. Also see Table 7.

In terms of pathways for each of the thematic groups, escape from confinement of species introduced for horticultural or ornamental purposes is the pathway most likely to introduce the highest proportion of plant species into the EU (Figure 21). Introduction either by ballast water or as hull-fouling organisms on ships and boats are the most represented pathways for marine species. After these pathways, natural spread of invasive species from areas where they are introduced was the next most likely pathway of introduction that for species in both the plant and marine thematic groups.

Escape from confinement of species introduced as aquarium pets constitute the most likely pathway of introductions for freshwater invertebrates, whereas for terrestrial invertebrates this corresponds to the unintentional introduction of species as contaminants on commercial nursery material. This pathway is followed closely by four other pathways that are likely to introduce terrestrial invertebrate species, which are the unintentional introduction as a contaminant on plants, through transportation of habitat material (e.g. soil, vegetation, etc.), as a contaminant in shipping containers, or on organic packaging material.

Lastly, for vertebrate species, the escape of pets from confinement is by far the pathway that could introduce the highest proportion of these species into the EU. The next mostly likely pathway to introduce vertebrate species is via escapes of species that are kept for public display in zoos or aquaria.

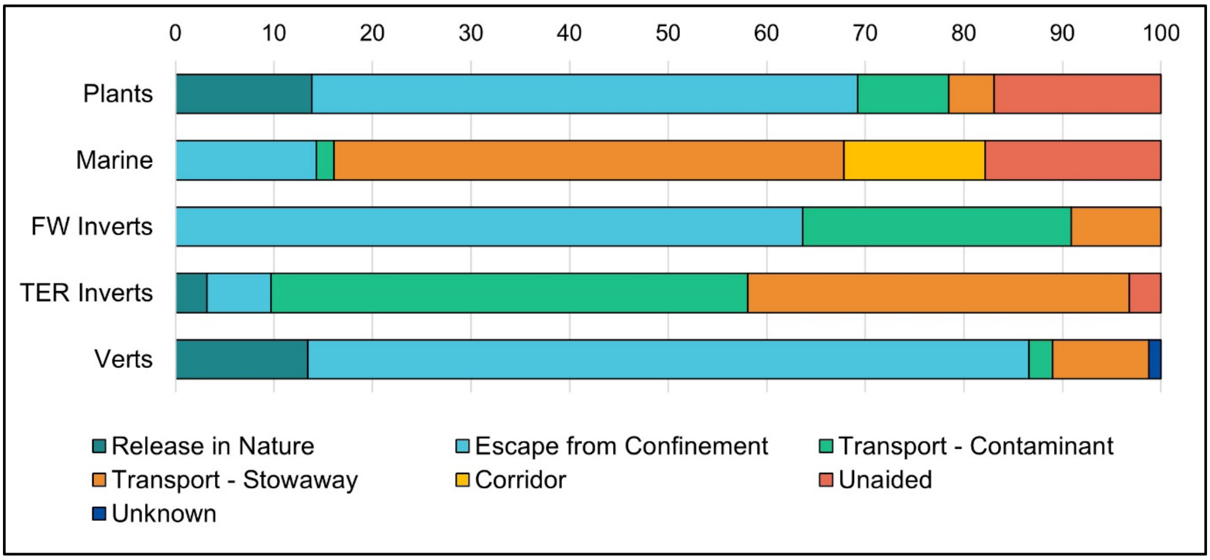

Figure 21. Proportion of current and/or potential future pathways, according to the high level CBD categories, that could introduce the risky species into the EU, per thematic group.

3.6.4. Impacts on biodiversity and ecosystem services

A total of 595 biodiversity related impacts were recorded for all the risky species. Competition with native species was by far the highest documented impact type, being recorded for 153 (out of 165) risky species, and was followed by predation and transmission of diseases (Figure 22). Interestingly, competition was also the most documented impact for each of the five thematic groups.

On average, 2.78 types of impacts on native species were recorded per risky species. Six species recorded seven types of impacts each (out of a possible ten), which was the maximum number of impacts recorded for an individual species. These corresponded to all the six *Callinectes* species present in the list of risky species.

Negative impacts on ecosystems services and on species or habitats of conservation importance were recorded for 74 and 67 risky species, respectively. Marine and vertebrate species have the most recorded impacts on ecosystem services, while plants and vertebrates seem to be most damaging to species or habitats of conservation importance (Figure 22).

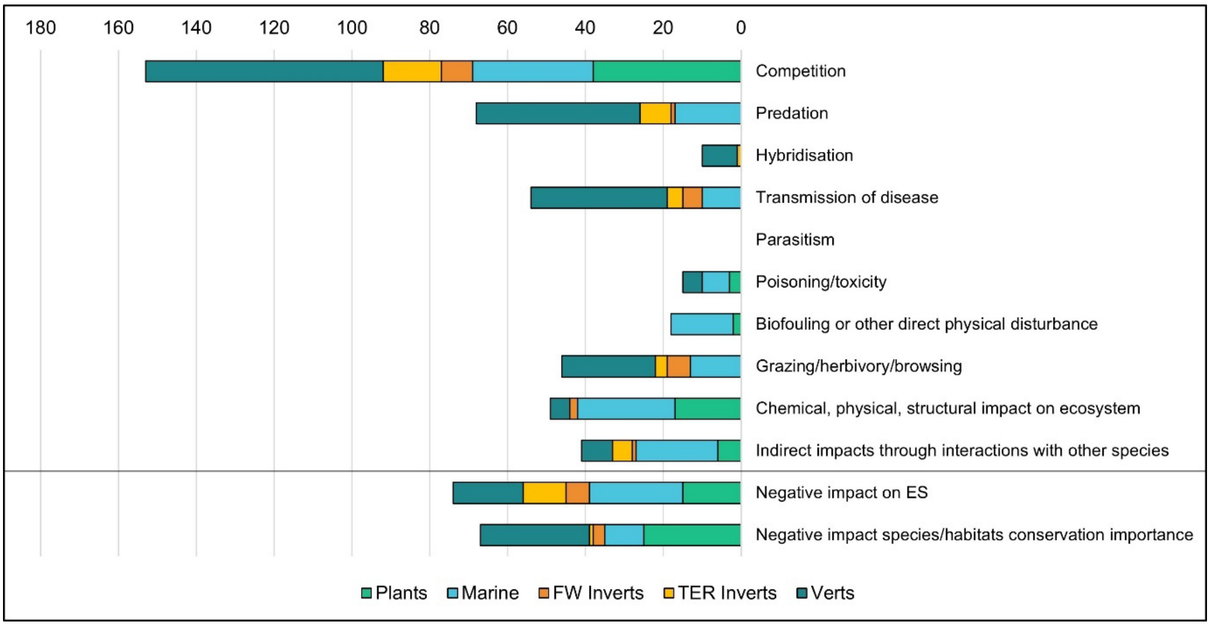

Figure 22. Number of types of biodiversity impacts of risky species per thematic group. A species can have more than one impact, thus the number of impacts exceeds the number of species (n=165). Negative impacts on ecosystem services (ES) and on species/habitats of conservation importance are also shown.

3.6.5. Presence in the EU

Almost half of the risky species are currently present in the wild in the EU, although with very limited distribution (as per the scope of this horizon scanning), with 32 of those featuring in the Top 57 (Figure 23). Of the species in the Top 57 not present in the wild, 19 species are currently present in captivity, holdings, indoors, or being cultivated in the EU. For a limited number of species, it is uncertain if they are present in the wild in the EU or not for various reasons, such as when there are unconfirmed records for presence (e.g. *Galaxaura rugosa*).

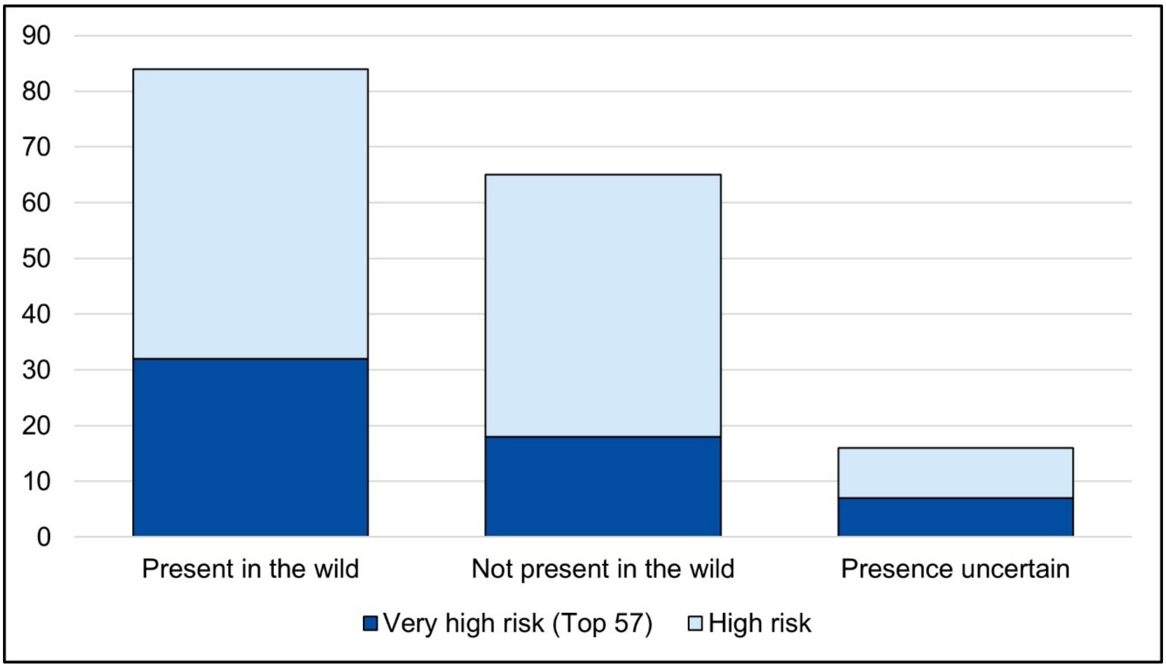

Figure 23. Number of risky species present in the wild in the EU, not including species present in captivity or cultivation.

3.6.6. Comparisons with the previous EU-level horizon scanning exercise (Roy *et al*. 2015)

The previous EU-level horizon scanning exercise prioritised 95 species to be put forward for risk assessment (Roy *et al*., 2015). This list of species is herein compared with the list of 165 risky species from this horizon scanning exercise. The proportion of species per thematic group present in the prioritised lists was largely similar between the two horizon scanning exercises for the thematic groups marine, plants and terrestrial invertebrates (Figure 24). However, this differed for the freshwater and vertebrate groups, with the current study having a higher proportion of vertebrate species and a lower proportion of freshwater species compared to the previous exercise. This is after moving the freshwater fish species of this exercise from the vertebrates to the freshwater (invertebrates) thematic group, in order to make it comparable with the previous horizon scanning exercise (where freshwater fish species were placed in an overall freshwater group).

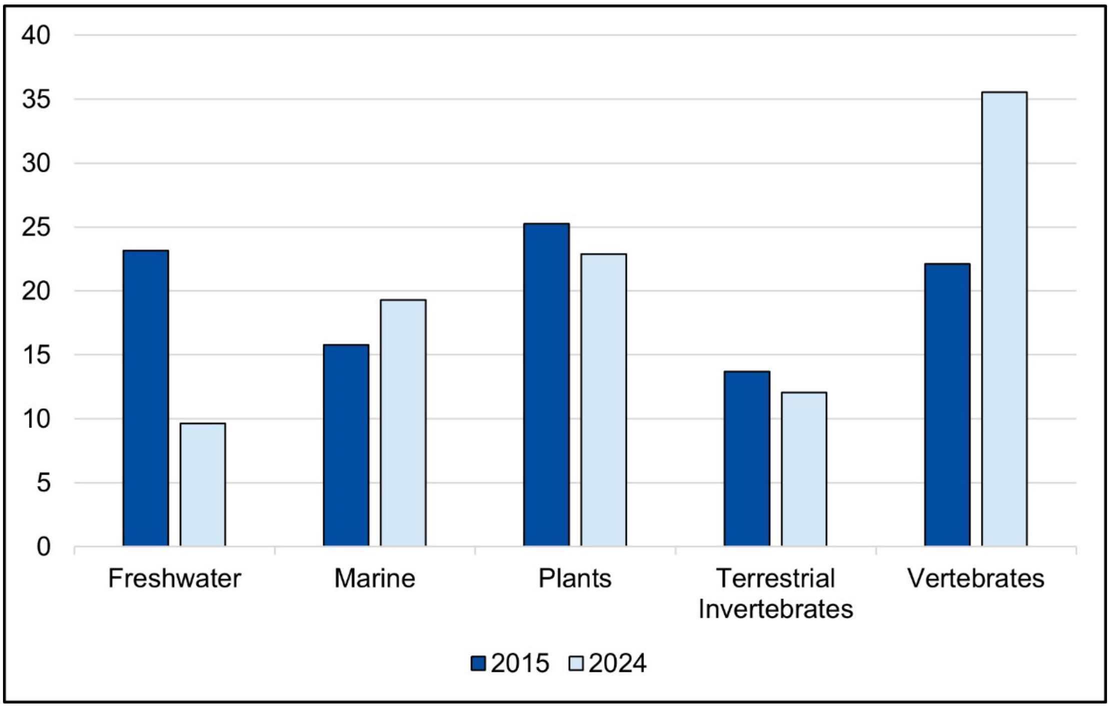

Figure 24. Proportion of species, per thematic group, on the list prioritised for risk assessment in the previous (2015) and current (2024) horizon scanning exercises. Note that the freshwater fish from this exercise were herein moved from the vertebrate to the freshwater thematic group, to allow comparison with the previous horizon scanning exercise.

Out of the 95 species prioritised by the previous horizon scanning exercise, ultimately only 56 of those were considered here, as the remaining 39 species met one (or more) of the exclusion criteria and were thus excluded (Figure 25). One of this species is *Saperda candida*, which is listed in the Annex of the Plant Health Directive. Since the previous horizon scanning exercise, a total of 43 of the 95 prioritised species have been risk assessed, and three species have a risk assessment in preparation. Of the 43 risk assessed species, 29 have been added to the Union list and six species are proposed for listing in the 2025 Union list update, and therefore have been excluded here. For the remaining eight species, although a risk assessment has been performed, they have been dismissed from being added to the Union list, therefore they were included in this horizon scanning exercise (but dismissed from the prioritised list).

Of the 56 species prioritised by Roy *et al*. (2015) considered in this horizon scanning exercise, a further 34 species were excluded for various reasons (e.g. the species has become too widespread). This resulted in 22 species being included in one of three species lists in this horizon scanning exercise: three species on the very high risk list (Top 57), eight species on the high risk list and 11 species on the remaining species list. The latter include four species that have had a risk assessment previously developed, but that have been dismissed from listing, three of which (*B. bison, M. dolomieu and P. viridis*) were deemed risky in this exercise, but moved to the ‘remaining species’ list (Figure 25).

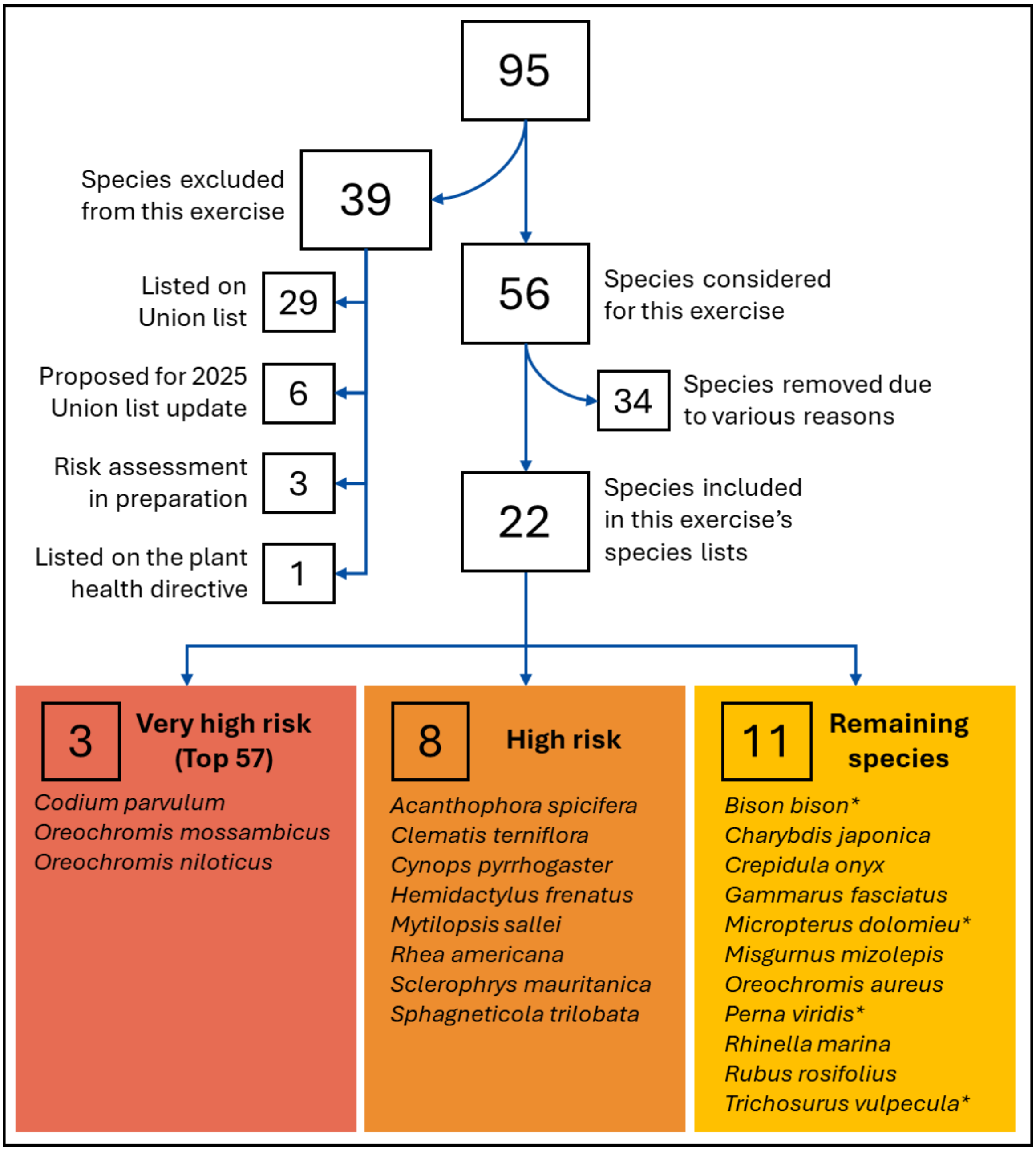

Figure 25. Breakdown of the list of 95 prioritised species from the previous EU-level horizon scanning exercise (Roy *et al*., 2015). Four species on the 'Remaining species' list (marked with *) have previously had a risk assessment developed, but were dismissed from the Union list update.

4. Task 3 – Identify possible challenges to listing

4.1. Task objective

The original aim of this task was to identify possible challenges to listing each of the species indicated as a priority under Task 2 of the project (‘*Perform a horizon scanning’*) and include these in the horizon scanning analysis. For this, criteria to identify and score challenges to listing species were to be developed.

At the project kick-off meeting that took place in January 2024, a discussion was however held on whether each species scores/ranking, or priority, should or should not be revised based on the challenges identified. It was raised that, although expert opinion could be used for flagging challenges for each species, this would be quite subjective and difficult to transpose into an adjusted species ranking. In addition, any perceived challenges do not necessarily stop species from undergoing risk assessment, so in principle the resulting priority lists should not undergo changes based on these challenges.

As such, it was agreed by the project team and the European Commission that the aim of this task would be to identify and discuss the possible challenges to species recommended for risk assessment being listed under the EU IAS Regulation. Any specific challenges linked to higher taxonomic groups are referred under Task 4 of this project.

4.2. Challenges to listing species

While the EU IAS Regulation is a critical tool for addressing the threat of IAS in the EU, its effectiveness depends on a strong list of IAS of Union concern which, in some cases, is contingent to overcoming potential scientific, management, as well as socio-economic and political challenges. These challenges to the process of listing species as IAS of Union concern under the Regulation (an overview of which process is shown in Figure 26), are largely related to:

- Species that may not clearly or robustly comply with some of the five criteria under Article 4(3) of the Regulation, all of which need to be met for an IAS to be included on the Union list (see details below);
- Species that some EU MS and stakeholders might have reservations against, and therefore be reluctant to list as an IAS of Union concern for various reasons (e.g. in line with the points mentioned under Article 4(6) of the Regulation, see details below).

Article 4 of the EU IAS Regulation

Article 4 of the EU IAS Regulation lays out specificities related to the adoption of a list of IAS of Union concern ('the Union list'), including the criteria needed for species to be part of this Union list. More specifically, Article 4(3) mentions that:

3. Invasive alien species shall only be included on the Union list if they meet all of the following criteria:

(a) they are found, based on available scientific evidence, to be alien to the territory of the Union excluding the outermost regions;

(b) they are found, based on available scientific evidence, to be capable of establishing a viable population and spreading in the environment under current conditions and in foreseeable climate change conditions in one biogeographical region shared by more than two Member States or one marine subregion excluding their outermost regions;

(c) they are, based on available scientific evidence, likely to have a significant adverse impact on biodiversity or the related ecosystem services, and may also have an adverse impact on human health or the economy;

(d) it is demonstrated by a risk assessment carried out pursuant to Article 5(1) that concerted action at Union level is required to prevent their introduction, establishment or spread;

(e) it is likely that the inclusion on the Union list will effectively prevent, minimise or mitigate their adverse impact.

In addition, Article 4(6) mentions that:

6. When adopting or updating the Union list, the Commission shall apply the criteria set out in paragraph 3 with due consideration to the implementation cost for Member States, the cost of inaction, the cost-effectiveness and the socio-economic aspects. The Union list shall include as a priority those invasive alien species that:

(a) are not yet present in the Union or are at an early stage of invasion and are most likely to have a significant adverse impact;

(b) are already established in the Union and have the most significant adverse impact.

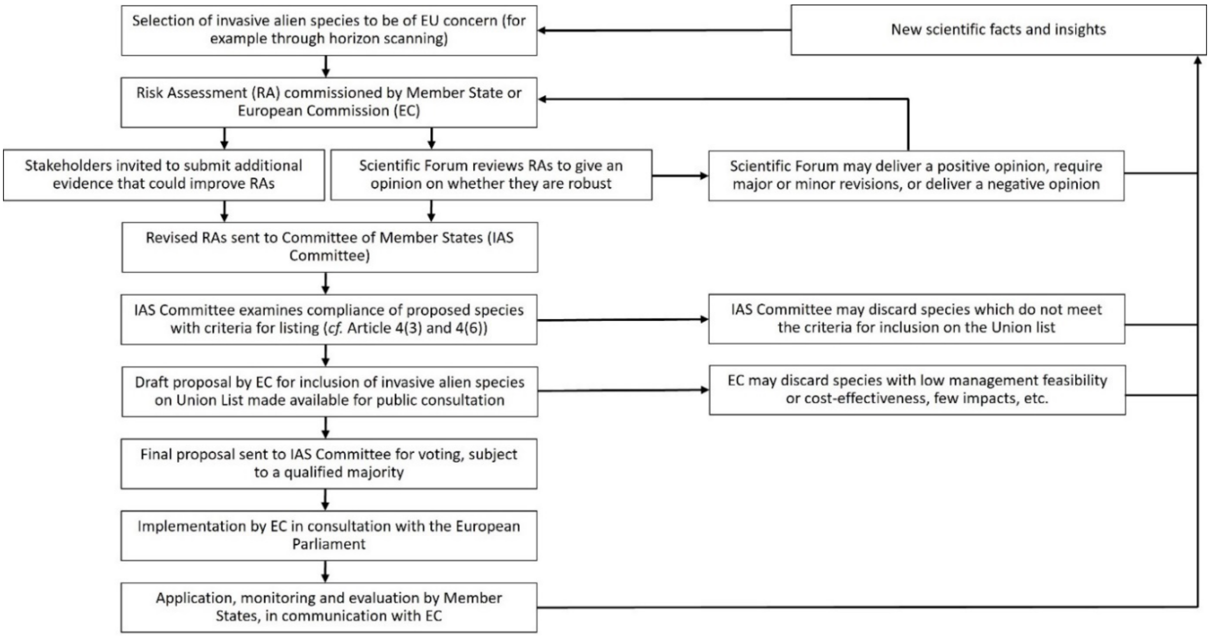

Figure 26. Overview of the process used to list IAS as of Union concern under the EU IAS Regulation. Figure adapted from de Hoop & Leuven (2017).

4.2.1. Scientific challenges

The scientific challenges related to listing species as of Union concern under the EU IAS Regulation are related to various scientific complexities associated with each species. These will inevitably come to light when preparing the risk assessment for a species and can make the reviewing process by the Scientific Forum (and by the IAS Committee) challenging. For a species to be included in the Union list, the Regulation requires evidence to demonstrate that a species is capable of establishing viable populations in the environment, has significant adverse impacts on biodiversity or the related ecosystem services, and can and should be effectively managed at the EU level. However, collecting and validating such information for some IAS can be challenging due to potential uncertainties and gaps, such as those described below.

Lack of robust scientific evidence for impact

This refers to the potential lack of robust scientific evidence on species' impacts on biodiversity and/or ecosystem services, or difficulty in understanding how environmental impacts of a certain species may be realised across different regions. The latter is especially relevant given that many of the species proposed for listing are not yet present in the EU, so impacts on biodiversity and/or ecosystem services will only have been recorded from non-EU countries and their ecosystems. One example refers to IAS impacts on native biodiversity in islands. These are often documented outside the EU and are significant if impacting island ecosystems (e.g.

endemic species, vulnerable ecosystems). However, extrapolating such impacts to islands in the EU is not straightforward, even if these are of relevance for achieving Target 12 of the EU Biodiversity Strategy for 2030. Related to this, the scale of the impact of a species is also of relevance, as for example reported impacts might be significant in only one biogeographic region, or a specific type of habitat, making it hard to establish if these will be of regional/national significance.

In addition, even though Article 4(3)(c) of the Regulation mentions that IAS suggested for listing need only to *likely* have a significant adverse impact on biodiversity and/or the related ecosystem services, this is to be based on scientific evidence, which is not always straightforward to gather or justify, especially for species that might have mostly potential (unverified) impacts (e.g. if a species from the same genus is known to have major impacts somewhere, but impacts for the species in focus are still unreported). In addition, even if some evidence is available of potential impacts of an alien species (for example by extrapolating data from dietary habits in its native range) and/or can be inferred from alien populations occurring in other regions, or from other species with a similar ecology (e.g. especially in the case of species in the same genus), often the magnitude of that impact has not been quantified, being hard to estimate. In this context, it becomes challenging to establish in which situations the precautionary principle should be applied.

Gaps in ecological and biological knowledge

Potential gaps in knowledge of the species ecology and biology, including information on species life history, especially related with its invasiveness (and the invasibility of native communities), can make it difficult to understand and assess the likelihood of a species establishing a viable population and spreading in the environment under current and foreseeable climate change conditions. Moreover, the inherent variability (context dependency) associated with the invasiveness of species depending on local environmental conditions, adds further complexity to the evaluation of IAS establishment and spread likelihood. In general, although species distribution models do provide informative and transparently derived hypotheses of current and possible future occurrences, and partly incorporate some of the unknowns in the model, there are inherent uncertainties surrounding this approach relating to the assumptions of niche equilibrium and transferability of realised niches to other areas outside the native range. Most models do not account for biotic interactions, which may be decisive on how successful a new invasion will be. Further, most models do not take into account dispersal capacities of the species and require a minimum amount of information, i.e. the smaller the information on occurrences in the native and alien range are, the more the uncertainty increases.

Uncertainty on pathways of introduction and spread

Often there is uncertainty linked to the pathways and vectors through which certain species might be introduced into, or spread, within the EU. In some cases, species pathways are identified only retrospectively, largely through expert knowledge, and this may entail some level of speculation. Besides, it is often not entirely clear which of the various potential pathways of introduction and spread are currently active for a certain species or could become active in the near future. Furthermore, the propagule pressure associated with each of those pathways is even harder to predict and gauge, adding further difficulties to the assessment of species likelihood of introduction, establishment and spread. This represents an area where horizon scanning procedures can be much improved, for instance by including data that represent proxies for propagule pressure/introduction effort (e.g. interception data, trade volumes, commonness in trade, popularity of pets, number of captive populations).

Biosystematics and taxonomic uncertainty

Complexities and ambiguities related to the classification, identification and scientific naming of species can lead to complications associated with the listing process. This is the case when it is unclear if the potential environmental impacts are imposed by a certain named species or a different one due to, for example, known species identification difficulties. Other examples arise in cases when a certain species has recently undergone nomenclatural reclassification (or is undergoing it while it is being proposed for listing); for example, a species may be suggested to be moved to a different genus, appears to be a hybrid, is lumped with other species into a new species (complex), or is split into multiple species. This may affect the correct identification of a well-defined target entity, making the collection and analysis of data to inform the risk assessment process difficult, and may also entail difficulties related to potential name changes during the legal listing process. In fact, in some cases, taxonomic complexity might raise issues relating to the validity of the risk assessment for the taxon at hand described therein. In this sense, cryptic species are of special concern, or species that without being cryptic are morphologically very similar to native ones, leading to misidentification in the early stages of introduction.

A linked complexity refers to the market demands for new ornamental plants that increase annually, forcing scientists and breeders to create new cultivars with novel appearances and improved techniques for stress tolerance and quality attributes. Consequently, the breeding origin of many (new) ornamentals may be obscure, including the correct identification of the parental lines, hindering risk assessment.

4.2.2. Management challenges

There are various challenges associated with management of IAS, some of those related to the feasibility of implementing appropriate actions and others related to a potential mismatch in management objectives across national boundaries. Given that part of the listing process entails the preparation of risk management notes for each species, it is likely that these challenges are already highlighted at that stage.

Management Feasibility

For species proposed to be listed as of Union concern, management measures to effectively prevent, minimise or mitigate their adverse impact will need to be put in place. However, for some species, or certain taxonomic groups, it is possible that appropriate and effective management measures may currently not be available, may be technically difficult to put in place, or may not be cost-effective. This can be particularly relevant, for example, with species inhabiting marine environments (especially concerning their eradication), making the listing of these species sometimes challenging. This can be further complicated by countries with no coastline being reluctant to accept, or understand, the listing of these species, or at least not supporting it. On the other hand, the inherent challenges of managing marine species are often used as an excuse to exclude them from being listed as of Union concern, despite the availability of effective management measures that have been successfully implemented worldwide (e.g., in the case of the lionfish), and the fact that effective measures for the prevention of introductions and spread can also be put in place. Another example refers to species that are introduced and/or spread as contaminants, and those that spread naturally very quickly (rapidly becoming widespread), the management of which can pose serious challenges across all environments, with their listing therefore potentially being discouraged.

Transboundary Management

The management of IAS of Union concern often requires a coordinated approach among MS and a shared understanding of their risks. However, differences in national policies, resources, and expertise, as well as potential conflicting views on the ecological and economic impacts posed by a species, might bring about challenges to the listing of species. For example, species deemed highly problematic in one country may be economically important in another. In other cases, the resources available to manage a species might be very disparate between neighbouring countries, or the priorities on which species to manage might differ, therefore generating disagreements and conflicts on how a certain species should be managed. This potential lack of agreement between MS could hinder collaboration and make listing of the species difficult to agree on. Furthermore, there can be additional challenges when countries outside the EU, or even Europe, share areas invaded by certain IAS (e.g. MS and non-European countries sharing invaded areas for Mediterranean marine species).

4.2.3. Socio-economic and political challenges

There are various socio-economic and political challenges associated with proposing new species to be listed as IAS of Union concern. Independently of the scientific robustness of the risk assessment produced for each proposed species, the compliance of the proposed species with the criteria for listing (cf. Art 4(3) and 4(6) of the Regulation), which is examined by the IAS Committee, can be subject to various complexities. These are divided into different categories and discussed in more detail below.

Resource and Capacity Constraints

As mentioned in Article 4(6), when proposing species for the Union list, the Commission needs to consider, among other factors, the implementation cost for MS and cost-effectiveness aspects. These aspects can pose quite a significant challenge to listing species, given that an effective implementation of the Regulation will require resources to prevent, detect, monitor spread and manage the species that are listed. Many EU countries may face limitations in funding and institutional capacity, which can be a deterrent to particularly listing widespread (or simply more) species as IAS of Union concern. In particular, it is likely that some MS would be resistant to the inclusion of species that are likely to impose disproportionate costs or resource burdens. This is especially the case for MS with fewer resources, which may struggle to meet these obligations, reducing the willingness of listing certain species due to the perceived infeasibility of undertaking the necessary actions.

Economic Interests by Stakeholders

Although Article 4(6) mentions that, when proposing species for the Union list, the Commission needs to consider, among other factors, socio-economic aspects related to that species, economic interests of some stakeholders can seriously hinder and shape the listing of IAS under the Regulation. This is because, due to the restrictions in trade and sales imposed on IAS of Union concern, the listing of species might have significant economic implications for sectors dealing with them, such as agriculture, aquaculture, forestry, horticulture and ornamental/pet trade. As such, stakeholders in these sectors often lobby against the inclusion of the species they utilise, creating a conflict between ecological priorities and economic interests. This is particularly true for species that support jobs or livelihoods, to which MS will most likely oppose their listing, even if their ecological impacts are significant and well documented.

Public Resistance

Similarly to the above, the listing of species that are charismatic, or that have a cultural interest to the public, or other stakeholders, will also very likely be challenging. Public resistance mainly arises when species have a significant cultural or aesthetic value, which is often the case for ornamental plants or popular pet species. Furthermore, the public may not perceive these species as harmful, as often they lack understanding of the ecological and economic consequences caused by IAS. This knowledge gap can reduce support for listing species, particularly when the risks or impacts are not immediately visible, occur over long periods and/or occur outside urban areas. In addition, public opposition linked to ethical concerns, usually related to management measures perceived as cruel, can further complicate the listing of certain species. As policymakers are often sensitive to public opinion, strong public opposition will most likely affect the willingness of governments to list those species.

5. Task 4 – Identify taxonomic groups that could be invasive, but where the great number of species that are candidate for listing would call for additional measures

5.1. Task objective

The main aim of this task was to identify at least seven groups at genus or family level that contain a large number of potentially invasive species that could be candidates for listing under the EU IAS Regulation and propose supporting policy measures to address the capacity limitations of the listing process.

For this, thematic leads and their additional experts were asked to, while compiling information on each species for the scoring exercise, take note of genera or families with four or more species that could potentially align with the requirements of the Regulation and be considered for listing. Although the EU IAS Regulation does not currently allow listing a whole genus or family as IAS of Union concern (but only single species), these groups could still undergo a genus- or family-level risk assessment. Furthermore, different policy measures to prevent the negative impacts potentially caused by these large groups on European biodiversity could be undertaken, as is suggested below. The large groups and corresponding policy measures have been explored separately for each of the five thematic groups, and therefore are quite varied.

5.2. Large groups of species and policy measures

The subsections below highlight a variable number of genera or families that incorporate a large number of IAS that could potentially be candidates for listing, for each of the five thematic groups under consideration in this horizon scanning. For each of these genera/families, the reason for their inclusion is shown, as well as some attributes of those groups, which is followed by the policy measures suggested to address them.

5.2.1. Plants

For plant species, a total of 12 genera have been suggested as incorporating a large number of species that could potentially be candidates for listing under the EU IAS Regulation (Table 19).

Table 19. Genera of plants with a large number of IAS that could be listed and the number of species in each of those taxa, shown in alphabetical order. Indication of how many species in each of those taxa are naturalised outside their native range, how many are in the very high risk (Top 57) or high risk (score ≥192) list of this horizon scanning, as well as how many are in the Union list, or are native to the EU territory is included.

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Approx. N species naturalised outside native range	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
Genus *Acacia* s.l.	All species have traits that make them potential invaders. In fact, these species have been identified as being part of the invasion syndrome WATTLES (Woody Australian Trees that Transform landscapes: Leguminous, Enemy-free, with persistent Seed banks).	Approximately 1084	69	*Acacia decurrens*	No	*Acacia saligna*	No
Genus *Azolla*	All species have traits that make them potential invaders. They propagate vegetatively, rapidly increasing their population size.	7	5	No	No	No	No
Genus *Cenchrus/ Pennisetum*	All species within the genus *Cenchrus* could be potentially invasive in Europe due to their adaptability to disturbed habitats, tolerance to drought and fires, efficient dispersal via spiny burs, and competitive traits, such as	Approximately 107	34	No	No	*Pennisetum setaceum /Cenchrus setaceus*	No

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Approx. N species naturalised outside native range	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
	allelopathy and resource efficiency.						
Genus *Cotoneaster*	All species present vigorous growth, giving them the capacity to occupy open spaces rapidly.	70 – 300	76	*Cotoneaster glaucophyllus*	No	No	At least one (*Cotoneaster integerrimus*), potentially more.
Genus *Cylindropuntia*	All cactus species that can reproduce by clonal fragmentation and have spines are potential invaders in arid areas. Moreover, *Cylindropuntia* species can hybridise with related taxa, causing taxonomic issues.	Approximately 50	8	No	No	No	No
Genus *Harrisia*	All cactus species that can reproduce by clonal fragmentation and have spines are potential invaders in arid areas.	Approximately 40	4	*Harrisia martinii*	No	No	No
Genus *Ipomoea*	All species present rapid growth, are climbers, produce abundant seeds that are easily dispersed, and tolerate a wide range of environmental conditions, including disturbed and degraded habitats.	644	63	No	No	No	No?

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Approx. N species naturalised outside native range	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
Genus *Kalanchoe*	All species have traits that make them potential invaders, and they hybridise, causing taxonomic issues. Hybrids have been seen to be highly invasive.	Approximately 150	23	No	No	No	No
Genus *Ludwigia*	All species have traits that make them potential invaders, such as rapid growth, prolific reproduction, ability to thrive in aquatic and semi-aquatic environments, and ability to rapidly form dense mats.	Approximately 82	25	No	*Ludwigia peruviana*	*Ludwigia grandiflora, Ludwigia peploides*	At least one (*Ludwigia palustris),* potentially more.
Genus *Opuntia*	All cactus species that can reproduce by clonal fragmentation and have spines are potential invaders in arid areas. Moreover, *Opuntia* species can hybridise, causing taxonomic issues.	Approximately 200	36	No	No	No	No
Genus *Rubus*	All species have traits that make them potential invaders, such as rapid growth, vigorous vegetative reproduction, ability to form dense thickets, capacity to thrive in a wide range of habitats, including disturbed	1475 species and 64 hybrids	100	No	*Rubus cuneifolius,* *Rubus ellipticus*	No	Many (200 – 300) native species, taxonomically challenging with many microspecies formed

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Approx. N species naturalised outside native range	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
	areas, and the palatability of their fruits, which allow them to be dispersed widely by animals.						through apomixis.
Genus *Solanum*	All species have traits that make them potential invaders, such as adaptability to diverse habitats, rapid growth, and efficient seed production and dispersal of berries by animals.	Approximately 1500 – 2000	120	*Solanum seaforthianum*	*Solanum marginatum*	No	At least three (*Solanum dulcamara, Solanum nigrum, Solanum villosum*), probably more

5.2.1.1. Suggested policy measures

As indicated in the table, all species within the listed genera exhibit traits that suggest they are potentially invasive. Many of these species are already recorded as naturalised in various regions worldwide. Although Australian *Acacias* could be introduced for agroforestry, and species within the genera *Rubus* and *Harrisia* could be introduced for agriculture, the primary pathway for the introduction of the species within the genera listed above is the ornamental trade. Furthermore, when one species from these genera is regulated under national or EU legislation, another species from the same genus often begins to be traded as a substitute. Thus, regulating the use of these genera (instead of single species) in the ornamental trade would be crucial to preventing further invasions. One option to reduce introductions of these risky species through the ornamental trade would be through voluntary codes of conduct, identifying native species that could be alternatives to the risky alien species or creating a European quality label for plant nurseries that can identify them as nurseries that follow such codes of conduct.

5.2.2. Marine

Among species that inhabit the marine environment, a total of 13 genera (with two important families highlighted) are suggested as containing a large number of species that could potentially be candidates for listing under the EU IAS Regulation (Table 20).

5.2.2.1. Suggested policy measures

Prior to considering supporting policy measures for marine invasive alien species, it must be noted that the representation of marine species currently on the list of Union concern is limited, with just *Rugulopteryx okamurae* and *Plotosus lineatus* present as the two fully marine species, and *Eriocheir sinensis* present as a catadromous species. Accordingly, a significant step towards dealing with marine IAS in EU waters would be to see more marine species pass through the legislative process, from risk assessment through to proposal, and then to Member State acceptance onto the Union list.

When considering supporting policy measures for marine IAS, it is important to remember that the pathways of introduction and spread which are consistently identified include ballast water, hull fouling and aquaculture/mariculture (including contaminants on gear, shellfish consignments, etc.), in addition to natural dispersal. Addressing these pathways is fundamental to preventing the movement of marine IAS.

Table 20. Genera (and families) of marine species with a large number of IAS that could be listed and the number of species in each of those taxa, shown in alphabetical order (except algal groups, which are combined at the end). Indication of how many species in each of those taxa are in the very high risk (Top 57) or high risk species list of this horizon scanning, as well as how many are in the Union list, or are native to the EU territory is included.

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
Genus *Callinectes*	Considering the impacts of *Callinectes sapidus* (predation, competition, bioturbation etc.) this genus of crabs should be considered as a whole. Multiple species have the potential to arrive and it should also be noted that *C. sapidus* was first observed in the Mediterranean Sea in 1949, so there can be a significant lag between introduction and extreme population expansion.	Currently 15 accepted in WoRMS	*Callinectes bocourti, Callinectes marginatus, Callinectes exasperatus*	*Callinectes amnicola*, *Callinectes pallidus, Callinectes danae*	No, but *Callinectes sapidus* is proposed for listing in the 2025 update	No
Genus *Caulerpa*	The genus comprises a group of green algae which can display highly invasive behaviour, therefore posing a threat to marine ecosystems. There is previous evidence to support this, specifically the severe impacts caused by *Caulerpa taxifolia* and *C. cylindracea* in the Mediterranean Sea. In addition to the major pathways of ballast water and hull fouling, they may be present in the saltwater aquarium trade.	Currently 108 accepted in WoRMS	*Caulerpa chemnitzia*	*Caulerpa serrulata*	No	*Caulerpa prolifera*
Genus *Didemnum* (Family Didemnidae)	The didemnids are high-impact invasive alien species. They are colonial tunicates which can foul natural and artificial structures (e.g. often found in association with aquaculture activities). They are capable of rapid growth and overgrowing various substrates, and are also important filter feeders, which has a	Currently 248 accepted in WoRMS	No	*Didemnum perlucidum, Didemnum candidum*	No	Yes, but given the species-richness of the genus (plus revisions to taxonomy) further research required to identify the

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
	detrimental effect on other sessile organisms, including aquaculture objects.					(partly) native species.
Genus *Eriocheir*	One species within this genus is already present on the Union list (competition, herbivory, bioturbation etc.) with two further species considered in the Top 57. The impacts of this genus are comparable between species and their likelihood of arrival and establishment is high.	Currently 4 accepted in WoRMS	*Eriocheir hepuensis*, *Eriocheir japonica*	No	*Eriocheir sinensis*	No
Genus *Hemigrapsus*	This genus of crabs contains multiple species known for their invasive behaviour, for example *H. sanguineus* and *H. takanoi*. These species can have major ecological impacts on intertidal communities due to predation and competition.	Currently 13 accepted in WoRMS	*Hemigrapsus pencillatus*	No	No, but *Hemigrapsus sanguineus* was previously dismissed from the Risk Assessment process	No
Genus *Hydroides*	Species within this genus of tubeworms can be abundant fouling organisms, secreting calcareous tubes on hard surfaces (natural and artificial) such as bivalve shells, marina structures, ship hulls etc. High densities can also impede oyster settlement and cause spat mortality (see e.g. Alvarez-Aguilar *et al.* (2022) for a review of alien polychaete species).	Currently 104 accepted in WoRMS (and see recently published 2023 CSIRO book)	No, but see Tsiamis *et al.* (2019), as a number of high impact species were identified there, so best to consider the set of (invasive) alien *Hydroides* as a whole.	No, but see Tsiamis *et al.* (2019) as a number of high impact species were identified there, so best to consider the set of (invasive) alien *Hydroides* as a whole.	No	Yes, see Sun *et al.* (2018)
Genus *Polydora*	These spionid polychaetes burrow into mud/sediment and bore holes into rocks and mollusc shells (thereby proving detrimental to aquaculture). They are significant biofoulers,	Currently 64 accepted in WoRMS (as	No	No	No	Yes, but given the species-richness of the genus further research is

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
	and a number of species are also seen as indicative of pollution (see e.g. Alvarez-Aguilar *et al*. (2022) for a review of alien polychaete species).	*Polydora* Bosc, 1802)				required to identify the (partly) native species.
Genus *Trididemnum* (Family Didemnidae)	The didemnids are high-impact invasive alien species. They are colonial tunicates which can foul natural and artificial structures (e.g. often found in association with aquaculture activities). They are capable of rapid growth and they are significant filter feeders, leading to deleterious impacts on the surrounding ecosystems.	Currently 75 accepted species in WoRMS	No	Yes, *Tridemnum savignii*	No	Yes, but given the species-richness of the genus (plus revisions to taxonomy) further research required to identify the (partly) native species.
Genus *Dictyota* (Family Dictyotaceae)	Life history performance of species of several genera within this family allows them to produce rapidly new clonal individuals, severely competing with the native community.	Currently 93 in AlgaeBase (plus varieties). Currently 100 accepted in WoRMS. '222 different species documented in AlgaeBase of which 98 have been accepted taxonomically' (Rushdi *et al*., 2022)	No	No	No	Yes, see Tronholm (2010)
Genus *Padina* (Family Dictyotaceae)	Information on invasive behaviour is limited, but the genus can be found attached to hard structures and growing as epiphytes to larger	Currently 54 accepted in WoRMS, Ni-Ni-	No	No	No	Yes, see Ni-Ni-Win *et al*. (2021)

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
	seaweeds (*Padina* are distinguishable by their characteristic 'peacock tail' structure). Conditions in the Risk Assessment area (e.g. Mediterranean) are suitable for establishment and introductions to the eastern Mediterranean have been recorded.	Win *et al*. (2021) added four to bring to 58				
Genus *Rugulopteryx* (Family Dictyotaceae)	Species within this genus are capable of rapid growth and spread. Taking *Rugulopteryx okamurae* as an example, this species can reach 100 % coverage and cause drastic ecosystem shifts which can include near-eradication of native benthic species (Borriglione *et al*., 2024; Díaz-Tapia *et al*., 2025)	Currently 4 (WoRMS and AlgaeBase)	No	No	*Rugulopteryx okamurae*	No
Genus *Stypopodium* (Family Dictyotaceae)	Species within this genus have the potential to outcompete native species – they may also be cast ashore in large quantities which impacts the recreational value of the affected area.	Currently 17 in AlgaeBase (plus varieties)	No	No	No	No, but species can be native to outermost regions e.g. *S. zonale* in the Canary Islands and Madeira
Genus *Taonia* (Family Dictyotaceae)	Information on invasive behaviour is limited, but conditions in the Risk Assessment area are suitable for establishment. Potential impacts could be the same as *R. okamurae*.	Currently 6 accepted in AlgaeBase, with one extra (7 in total) currently accepted in WoRMS	No	No	No	Yes, *T. atomaria, T. lacheana*

In terms of **ballast water management**, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (the Ballast Water Management/BWM Convention) is the primary mechanism of dealing with this pathway and is already in existence. Under the terms of the BWM Convention, all ships must meet the D-2 standard (in effect as of 8th September 2024), with this standard specifying the maximum number of viable organisms allowed to be discharged – usually necessitating the installation of a ballast water management system. Arising from this, all ships registered under contracting Parties must have a ballast water management plan, a ballast water record book and an International Ballast Water Management Certificate. Ships registered under a flag which has not ratified the BWM Convention may not be issued with the relevant certificates, however port States which are Parties will expect the ships to comply with the requirements of the Convention.

To ensure effective implementation of the BWM Convention at EU level, it could be beneficial to liaise with the port authorities in coastal MS to determine what is happening in real terms, as compliance with the BWM Convention means that 'Ships may be subject to port State control in any port or offshore terminal of a Party to the BWM Convention. This inspection may include verifying that there is onboard a valid Certificate and an approved ballast water management plan; inspection of the ballast water record book; and/or sampling of the ship's ballast water, carried out in accordance with the 'Guidelines for ballast water sampling'[20]. It could also be beneficial to learn from existing HELCOM/OSPAR guidance on ballast water, which includes detailed information on port surveys, and guidelines on granting exemptions under the BWM Convention.

It should equally be recognised that there are numerous existing policy instruments which can act in synergy with the IAS Regulation. This means that, rather than suggesting all new policy measures, there are situations where it would be more beneficial to ensure existing policies are implemented and enforced and to ensure full coordination between frameworks. Fundamentally, this includes the Marine Strategy Framework Directive (MSFD), as this legislation contains the Descriptor (D2) 'Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems'. While it seems probable that information from the MSFD is feeding into IAS policy to some extent, for example when MS enter the IAS Regulation reporting period, it is possible that more could be done. To quote a few examples under the scope of the MSFD:

> 'The marine environment is a precious heritage that must be protected, preserved and, where practicable, restored with the ultimate aim of maintaining biodiversity and providing diverse and dynamic oceans and seas which are clean, healthy and productive…' (3)
>
> 'The establishment of marine protected areas ... [*reference to Habitats Directive, Birds Directive, other international/regional agreements*] is an

[20] https://www.imo.org/en/MediaCentre/HotTopics/Pages/Implementing-the-BWM-Convention.aspx

important contribution to the achievement of good environmental status under this Directive' (6)

'By reason of the transboundary nature of the marine environment, Member States should cooperate to ensure the coordinated development of marine strategies for each marine region or subregion. Since marine regions or subregions are shared both with other Member States and with third countries, Member States should make every effort to ensure close coordination with all Member States and third countries concerned …' (13)

When considering the above information in the context of IAS, the themes are all interoperable. Increasing resilience and restoration of marine ecosystems may help form a natural barrier to the impacts of IAS, particularly considering the challenges to management in marine ecosystems, and perhaps restrict the extent to which potential IAS can exploit any available niche. Identifying and establishing marine protected areas (MPAs) will highlight areas of high importance, for example to focus biosecurity efforts and stakeholder engagement. Lastly, building in transboundary cooperation can help facilitate species alerts/early warning systems, identify pathways and document species spread/distribution. Furthermore, promoting the involvement of the fisheries sector, especially in preventative actions, would provide mutual benefits.

In terms of **hull fouling**, the measures in place to address this pathway are currently insufficient at an EU (and global) level, and warrant further attention. At present, there is no globally enforced hull fouling policy that could be considered comparable to the BWM Convention. This means that measures to address hull fouling are essentially voluntary, leaving this pathway open to marine IAS. However, it should be noted here that the International Maritime Organization has produced clear guidance in the form of 'Guidelines for the control and management of ships' biofouling to minimise the transfer of invasive aquatic species (Biofouling Guidelines)' (IMO 2023, *superseding 2011 guidance*). This means that relevant information is readily available, and should be proactively disseminated to EU MS with instructions to pass it beyond the competent authorities to all stakeholders working in the sector.

Following from this, it should also be noted that biofouling is a problem not solely linked to cargo shipping/larger vessels – the role played by recreational vessels should not be underestimated. This is particularly important when considering that recreational vessels will often travel between multiple marinas, harbours, MPAs, etc., and as a vector they are frequently implicated in the movement of IAS. To counter this, routine monitoring needs to be established for both vessels and marinas, along with frequent, biosecure pontoon cleaning. Additionally, policy could require preliminary screenings for incoming vessels from new regions, particularly those emanating from high-risk marinas (Ulman *et al*., 2019). When protecting sensitive sites, lessons can be learned from other countries. For example, the governmental Parks Canada Agency mandates Aquatic Invasive Species Prevention Permits[21]

[21] https://parks.canada.ca/pn-np/mtn/eaux-waters

when accessing freshwater bodies in national parks with any type of watercraft, gear or angling equipment. The type of permit is dependent on the park, craft and/or gear.

When considering **aquaculture**, the risk of species introduction arises both from the introduction of the target cultured species and from the (potential) contaminant species carried by consignments/gear. At the EU level, Regulation (EC) No 708/2007 – Use of Alien and Locally Absent Species in Aquaculture is designed to ensure adequate protections in the aquatic environment from the risks associated with the use of non-native and locally absent species in aquaculture. While this provides the framework for dealing with cultured species, it must still be recognised that deliberate species introductions could still occur (potentially on a more ad-hoc basis by individuals, not necessarily by licenced aquaculture facilities). Additionally, it is still the case that despite current aquaculture regulation and biosecurity practices, species introductions do occur. Taking the algal genera listed above as examples, these species belong to the same family as *R. okamurae*, first observed in the Thau lagoon, France in 2002 and possibly introduced through oyster aquaculture (Terradas-Fernández *et al*., 2023). Thus, if species do become introduced, efforts to minimise assisted spread could include strengthening the conditions for authorised aquaculture movements from the invaded zones/regions.

It is also worth acknowledging the growing discussion on the use of harvest incentives as management techniques for widespread, well-established IAS populations. For species with a commercial fishery or other use available (e.g. various crabs, fishes, select algal species, etc.), targeted fishing/harvest may limit further population expansion or control their populations at low level, mitigating their impacts (Kleitou *et al*. 2021). It is essential, however, that any use involves careful review, planning, implementation and monitoring. It is also important to ensure incentive mechanisms do not unintentionally lead to further spread of IAS, waste resources and/or cause harm to native species (see e.g. Wiltshire *et al*., 2014; de Carvalho-Souza *et al*., 2024).

5.2.3. Freshwater invertebrates

For freshwater invertebrate species, a total of seven genera are suggested as incorporating a large number of species that could potentially be candidates for listing under the EU IAS Regulation (Table 21).

Table 21. Genera of freshwater invertebrates with a large number of IAS that could be listed and the number of species in each of those taxa, shown in alphabetical order. Indication of how many species in each of those taxa are in the very high risk (Top 57) or high risk species list of this horizon scanning, as well as how many are in the Union list, or are native to the EU territory is included.

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
Genus *Cambarus*	It contains some potentially invasive species.	Around 100	No	No	No	No
Genus *Corbicula*	It contains some invasive species.	Exact number still unclear (at least 72)	*Corbicula largillierti*	No	No	No
Genus *Daphnia*	It contains some invasive species.	More than 200	No	*Daphnia lumholtzi*	No	At least eight species.
Genus *Faxonius*	It contains some invasive species.	More than 90	No	No	*Faxonius limosus*, *Faxonius rusticus*, *Faxonius virilis*	No
Genus *Macrobrachium*	It contains some invasive species.	265	*Macrobrachium nipponense*	No	No	No
Genus *Neocaridina*	It contains some invasive species.	26	No	*Neocaridina davidi*, *Neocaridina denticulata*	No	No
Genus *Procambarus*	It contains some invasive species.	Around 161	*Procambarus alleni*	No	*Procambarus clarkii*, *Procambarus virginalis*	No

5.2.3.1. Suggested policy measures

The listed genera contain some already known or potentially invasive alien species, but not all species of the genera are invasive. Indeed, for some genera, such as *Procambarus* and *Faxonius*, the species are quite diverse, and not all have the traits to become invasive. Overall, it is more important to address the most common pathway of these listed genera, i.e., the ornamental trade, as the species can be introduced voluntary or accidentally as contaminants of other ornamental plants and animals (e.g. *Daphnia*). Another important pathway to be considered is aquaculture (for *Corbicula* and *Macrobrachium*), considering both the target and non-target species. Please note that the genus *Corbicula* includes some species whose status is not taxonomically solved.

5.2.4. Terrestrial invertebrates

For terrestrial invertebrate species, a total of six genera and one family are suggested as incorporating a large number of species that could potentially be candidates for listing under the EU IAS Regulation (Table 22).

Table 22. Genera and families of terrestrial invertebrates with a large number of IAS that could be listed and the number of species in each of those taxa, shown in alphabetical order, firstly by genera and then family level. Indication of how many species in each of those taxa are in the very high risk (Top 57) or high risk species list of this horizon scanning, as well as how many are in the Union list, or are native to the EU territory is included.

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
Genera *Achatina, Archachatina, Limicolaria, Lissachatina*	See section below	*Achatina* (39), *Archachatina* (13), *Limicolaria* (21), *Lissachatina* (15)	*Limicolaria aurora* (J.C. Jay, 1839)	No	No	No
Genus *Apis*	See section below	9 – 12 (depending on author)	*Apis florea*	No	No	*Apis mellifera* (including up to – depending on the author – 25 geographically separated subspecies), some of which native to the EU, some not.
Genus *Nylanderia*	See section below	More than 120, of which ca. 20 are considered invasive	*Nylanderia fulva*	*Nylanderia flavipes*	No	No
Family Geoplanidae	See section below	More than 800	*Australoplana sanguinea*	*Dolichoplana striata*	*Arthurdendyus triangulatus* (and *Bipalium kewense,*	Several species in the subfamilies Microplaninae and Rhynchodeminae, but

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
					Obama nungara and *Platydemus manokwari* are proposed for listing in the 2025 update).	the majority of species are (sub)tropical.

5.2.4.1. Suggested policy measures

Genera *Achatina, Archachatina, Limicolaria, Lissachatina*. Several species from different genera within the mollusc family Achatinidae are regularly kept as pets and can breed prolifically in captivity. Escapes and releases from confinements occur regularly, although often are not well documented and remain anecdotal. Some of these species are well documented invaders in other regions and capable of establishing in parts of the EU, as long as habitat and climate are not restricting their survival and reproduction. It seems unlikely, however, to justify a general ban on pet snails for such a diverse group of species. Instead, it is suggested to have a closer look into selected species and their invasion history, and produce single species-based Risk Assessments, as it is currently done for e.g. *Lissachatina fulica*.

Genus *Apis*. With the recent introduction of *A. florea* to the EU (Uzunov *et al.*, 2024), it is reasonable to raise concerns of potential negative impacts of other Asian *Apis* species, particularly the Eastern honeybee *Apis cerana* and the Giant honeybee *Apis dorsata*. Impacts might include competition with the native *A. mellifera*, the transmission of parasites and pathogens, hybridisation, and effects on pollination and on honey production. *Apis mellifera* has been intentionally moved for breeding purposes for a very long time to increase their productivity. Since these movements inadvertently also translocated parasites and pathogens, e.g. the Varroa mite *Varroa destructor*, the small beehive beetle *Aethina tumida* and several viruses, restrictions and regulations have been put in place to minimise such introductions. Specific animal health requirements are needed to import honeybees into the EU from specified third countries, e.g. in Delegated Regulation (EU) 2020/692 and in Implementing Regulation (EU) 2021/404. While there are no imports of honeybees from Asian countries legally possible, the legislation only applies to *Apis mellifera*, and not to other *Apis* species, which are considered of little interest for apiculture. It is more likely that Asian *Apis* species will be introduced unintentionally as stowaways, as it happened for *Apis florea*. Therefore, it is recommended to cover potentially invasive non-native *Apis* species under the remit of the EU IAS Regulation. On a side note, it should be noted that while abovementioned Regulations do explicitly refer to *A. mellifera* (and not *Apis* spp.), they do refer to *Bombus* spp. as bumblebees, thus including all of the approximately 250 bumblebee species.

Genus *Nylanderia*. Some ant genera are extremely species rich, e.g. *Camponotus* and *Pheidole* (>1000 species each), *Strumigenys* (>800 species), *Monomorium* (>300 species). Even if only a small percentage of species within such genera are invasive, it seems impractical to provide full risk assessments for each species. There might be exceptions, if the invasive species within a genus are relatively well identified, as for example demonstrated by Williams and Lucky (2020), who concluded that "only" 20 of more than 120 species within the genus *Nylanderia* have an invasion history. Because the species do show some differences in biology, ecology and consequently impact, however, it probably still would be challenging to deal with these species in just one risk assessment. Although the three fire ant taxa *Solenopsis geminata*, *Solenopsis invicta*, and *Solenopsis richteri* share many commonalities, three separate Risk Assessments were produced to take rather minor differences into account. The same approach was taken for several closely related and similar fish species (e.g. *Ameirus melas* and *Ameirus nebulosus*; *G. affinis* and *G. holbrooki*; *M. anguillicaudatus* and *M. bipartitus*), while in other cases very similar species have been assessed within one Risk Assessment (e.g. *Amynthas agrestis*, *Amynthas tokioensis* and *Metaphire hilgendorfi*; *Reynoutria japonica*, *Reynoutria* x *bohemica* and *Reynoutria sachalinensis*).

The main pathways of introduction of ants are relatively well known: as contaminants with the trade of live plants and as stowaways with containers. It was suggested by Blight & Rabitsch (2024) that a two-pronged approach might be useful for dealing with invasive ants. On the one hand, a blacklist of selected invasive ant species for which restrictions according to the EU IAS Regulation apply, including ban from trade (some ants are kept as pets), surveillance, and early warning and rapid response. This Regulation also requires action to be taken at the pathways of introduction and spread; however, the biosecurity inspections of live plants, containers and other shipments lies within the remit (and legislation) of European Plant Health Authorities. Given that ants are not considered as "harmful organisms", actions are rarely taken, even if ants are intercepted. There is an obvious need for cooperation and coordination between authorities to avoid not only duplications, but also loopholes. Similar arguments apply to terrestrial flatworms (Geoplanidae) (see below).

Family Geoplanidae. Similar arguments as for ants apply to terrestrial flatworms (Geoplanidae), including their pathways of introduction, with unintentional imports as contaminants with the trade of live plants being the most relevant. There are more than 800 described species, with a significant amount of yet undescribed species, mostly occurring in tropical and subtropical regions. They all are predators of other animals with potentially irreversible impacts on the "keystone" functional group of decomposers in soil ecosystems, specifically earthworms. As with ants, a two-pronged approach also appears reasonable here: provide dedicated Risk Assessments for specific species with documented invasion histories and/or assumed high negative impacts and initiate discussions with Plant Health Authorities to combine forces and strengthen biosecurity capacities in relation to the import of live plants into the EU.

5.2.5. Vertebrates

For the vertebrates' thematic group, a total of 11 genera and five families have been suggested as containing a large number of species that could potentially be candidates for listing under the EU IAS Regulation (Table 23).

Mammals

Callosciurus. Escape from confinement is the primary pathway for the introduction of *Callosciurus* species. Two species from this genus are already listed on the Union list, and one additional species features on the Top 57 list. Because *Callosciurus* species are popular in the pet trade, zoos, and wildlife parks, there is a significant risk of new introductions. If more *Callosciurus* species are added to the Union list, it is plausible that other species from this genus will be imported as alternatives in the pet trade. To mitigate this risk, a precautionary measure would be to prohibit the importation of the entire *Callosciurus* genus.

Sciurus. Escape from confinement is the primary pathway for the introduction of *Sciurus* species. Two species from this genus are already listed on the Union list, and one additional species features on the Top 57 list. Because *Sciurus* species are popular in the pet trade, zoos, and wildlife parks, there is a significant risk of new introductions. If more *Sciurus* species are added to the Union list, it is plausible that other species from this genus will be imported as alternatives in the pet trade. To mitigate this risk, a precautionary measure would be to prohibit the importation of the *Sciurus* species not native to Europe.

Table 23. Genera and families of vertebrates with a large number of IAS that could be listed and the number of species in each of those taxa, shown in alphabetical order, firstly by genera and then family level. Indication of how many species in each of those taxa are in the very high risk (Top 57) or high risk species list of this horizon scanning, as well as how many are in the Union list, or are native to the EU territory is included.

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
Genus *Acridotheres*	Well-documented invasive potential of several members of this genus. Species like the common myna (*Acridotheres tristis*) and the crested myna (*Acridotheres cristatellus*) have established invasive populations worldwide, often causing significant ecological and economic impacts, including competition with native birds, predation on smaller species, and damage to crops. The shared behavioural and ecological traits across the genus, such as high adaptability, opportunistic feeding, and association with human-altered landscapes, suggest that other species within *Acridotheres* may also pose similar risks.	11 (GBIF)	*Acridotheres fuscus*	No	*Acridotheres tristis*	No
Genus *Amazona*	Strong candidate due to the increasing number of species establishing populations outside their native ranges. These parrots are popular in the pet trade, which facilitates introductions, and their ecological versatility enables them to thrive in urban and semi-natural environments. This horizon scanning includes all *Amazona* species that were	36 (GBIF)	No	*Amazona farinosa, Amazona autumnalis, Amazona oratrix, Amazona*	No	No

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
	present in the long list, but it should be noted that *Amazona ventralis, Amazona ochrocephala, Amazona albifrons* and *Amazona aestiva* are also present in the bird trade and as invasive species (Mori *et al.*, 2017, *A. aestiva* may already be established in Italy and *Amazona oratrix* has established in Germany).			*viridigenalis, Amazona finschi*		
Genus *Callosciurus*	*Callosciurus* species impact native squirrels through competition, and forestry through bark stripping. Escape from confinement is the primary pathway for the introduction. Two species from this genus are already listed on the Union list, and two additional species feature on the high risk list. Because *Callosciurus* species are popular in the pet trade, zoos, and wildlife parks, there is a significant risk of new introductions. If more *Callosciurus* species are added to the Union list, it is plausible that other species from this genus will be imported as alternatives in the pet trade. To mitigate this risk, a precautionary measure would be to prohibit the importation of the entire genus.	17 (IUCN Red List)	*Callosciurus prevostii*	*Callosciurus inornatus*	*Callosciurus erythraeus, Callosciurus finlaysonii*	No
Genus *Lampropeltis*	Several species are morphologically similar, of unresolved taxonomy, and popular in the pet trade.	26 (several morphologically distinct subspecies)	No	No	*Lampropeltis getula sensu latu*	No

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
Genus *Misgurnus*	Many species are in aquarium trade and aquaculture, with some already invasive in the EU. One problem besides competition is hybridisation with native species.	10	No	No	No, but *Misgurnus anguillicaudatus* and *Misgurnus bipartitus* (established in the EU) proposed for the 2025 update	*Misgurnus fossilis* is native and considered endangered. It is also protected under the Habitats Directive.
Genus *Oreochromis*	Tropical species, but some (mostly *Oreochromis mossambicus* and *Oreochromis niloticus*) widely used in aquaculture and established in Morocco, the Canary Islands, thermal waters of Italy and very invasive in tropical countries.	32	*Oreochromis mossambicus*, *Oreochromis niloticus*	No	No	No
Genus *Oxyura*	Replacement in trade due to bans imposed on *Oxyura jamaicensis*. The risk of hybridisation with white-headed duck is potentially the same as the risk posed by *O. jamaicensis*.	9 (GBIF)	No	*Oxyura maccoa*, *Oxyura vittata*	*Oxyura jamaicensis*	No
Genus *Pantherophis*	Several species are morphologically similar, of unresolved taxonomy, and popular in the pet trade	10 (several varieties, some entirely domestic)	*Pantherophis guttatus*	No	No	No
Genus *Pelophylax*	Many species of the genus *Pelophylax* can be identified with certainty only through genetic analysis, and some have already	13 (several still unresolved)	*Pelophylax shqipericus*	*Pelophylax porosus*	No	Several, at least eight

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
	been translocated within the EU or have been introduced in the EU through different pathways. This can lead to the collapse of native frog populations, particularly by disrupting the equilibrium in the peculiar hybridogenetic systems of the genus *Pelophylax*, as they may induce genetic pollution (through introgressive hybridisation) or cause the elimination of parental germlines (through hybridogenesis).					
Genus *Pycnonotus*	Demonstrated propensity of several species within this genus to be introduced, establish and spread in non-native regions. Members of *Pycnonotus* (commonly known as bulbuls) are highly adaptable, often thrive in disturbed habitats, and have generalist diets, traits commonly associated with invasive success.	50 (GBIF), 31 (Winkler *et al.* 2020)	*Pycnonotus aurigaster*	*Pycnonotus sinensis, Pycnonotus goiavier*	*Pycnonotus cafer. P. jocosus* is proposed for the 2025 update.	No
Genus *Sciurus*	*Sciurus* species impact native squirrels though competition and pathogen transmission, and forestry through bark stripping. Two species from this genus are already listed on the Union list, and one additional species features on the Top 57 list. Because *Sciurus* species are popular in the pet trade, zoos, and wildlife parks, there is a significant risk of new introductions. If more *Sciurus* species are added to the Union list, it is plausible that other species	33 (IUCN Red List)	*Sciurus lis*	No	*Sciurus carolinensis,Sciurus niger*	*Sciurus vulgaris, Sciurus meridionalis*

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
	from this genus will be imported as alternatives in the pet trade. To mitigate this risk, a precautionary measure would be to prohibit the importation of the *Sciurus* species not native to Europe.					
Family Centrarchidae	The whole family is not native to the EU (native to North America). *Lepomis gibbosus* is invasive and included in the list of EU concern. *Micropterus salmoides* is also very invasive in part of the EU. *Micropterus dolomieui* was identified as "high risk" in the present exercise. Various *Lepomis* species are invasive elsewhere and were analysed in the present exercise.	34	No	*Micropterus dolomieu*	*Lepomis gibbosus*	No
Family Emydidae	One of its subfamilies (Deirochelynae) contains five genera that are heavily traded, all of them sources of invasives and with frequent taxonomic rearrangements. The genus *Trachemys* (15 species) in particular has a number of species that are potentially invasive, but there are known invasives in other genera too (*Chrysemys*, *Pseudemys*).	50	*Graptemys geographica*	*Trachemys ornata*	*Trachemys scripta*	*Emys orbicularis* is native and protected under the Habitats Directive.
Family Gobiidae	Many species are very invasive in the EU.	100s	*Tridentiger bifasciatus*	No	No	Several Ponto-Caspian gobies native to Romania and Bulgaria (round, tubenose,

Name of taxon	Reason to include taxon	Approximate number of species in taxon	Any species in very high risk list (Top 57)	Any species in high risk list	Any species in Union list	Any species native to EU
						bighead, monkey, racer), which have become invasive in other parts of the EU
Family Poeciliidae	Many species are popular in the aquarium trade. The whole family is not native to the EU (native to the Americas). *Gambusia holbrooki* is invasive and included in the list of EU concern. *Gambusia affinis* and *Poecilia reticulata* (guppy) are very invasive worldwide. The guppy is a tropical species, but established in the Canary islands and sometimes in thermal waters in the EU.	274	*Xiphophorus hellerii*	*Poecilia latipinna*	*Gambusia holbrooki, Gambusia affinis*	No
Family Trionychidae	Several species in this softshell turtle family are morphologically similar and several have proven invasive. For example, *Pelodiscus sinensis* and *Pelomedusa subrufa* (with other freshwater turtles in the family Kinosternidae such as *Kinosternon baurii* and *Sternotherus odoratus*) have been identified as high risk species for Europe (Masin *et al.*, 2014).	32	No	*Apalone ferox, Apalone spinifera*	No	No

Birds

Amazona**.** The genus *Amazona* is a strong candidate for genus-level invasive alien species risk assessments due to the global establishment of several species outside their native ranges, facilitated largely by the pet trade. At least nine species have been documented breeding or establishing populations across various regions worldwide, including in Europe, South Africa, and the Americas. In Europe, *A. aestiva* has established breeding populations in Genoa and Milan, Italy, as well as Tenerife, Spain. *Amazona oratrix* has an expanding population in Stuttgart, Germany. These populations are small but show a slow and steady increase. In Tenerife, there is evidence of a hybrid population between *Amazona ochrocephala* and *A. amazonica*. In the Americas, *A. aestiva* has been recorded in Florida, California, and Argentina, with breeding populations in Miami and Buenos Aires. Similarly, *A. viridigenalis* has established large populations in Texas and California. Other species, such as *A. finschi, A. autumnalis*, and *A. albifrons*, have also established populations, particularly in southern Florida and the Caribbean islands. These species share traits like high adaptability, long lifespans, and versatile diets, making them effective colonisers. Southern Europe's climate matches their native ranges, further increasing the risk of establishment and spread. Breeding populations in regions with favourable climates underline the urgency for early risk assessments and management interventions.

Acridotheres. The genus *Acridotheres* includes several species that have successfully established invasive populations worldwide, often with significant ecological and economic consequences. In addition to the well-documented invasive impacts of *A. tristis* and other myna species, such as *A. cristatellus*, *Acridotheres cinereus*), and *A. fuscus*, demonstrate a strong capacity for establishment and spread across diverse regions. From the GAVIA database on established invasive alien bird species, *A. cristatellus* is established in multiple locations, including Luzon and Negros Oriental in the Philippines, Honshu in Japan, and Buenos Aires in Argentina. *Acridotheres cinereus* has established populations in regions like Nusa Tenggara Timur, Flores, Sumatra, and Sarawak, highlighting its ability to thrive in both island and continental habitats. *Acridotheres fuscus* has successfully invaded islands such as Viti Levu and Nukulau in Fiji, Upolu in Samoa, and parts of the Andaman and Nicobar Islands. These records underscore the genus' adaptability to a wide range of environmental conditions and their association with anthropogenic landscapes. Their impacts include competition with native species for resources, damage to agricultural crops, and potential disease transmission.

Amphibians and reptiles

All the suggested groups of amphibians and reptiles include a relatively large number of morphologically similar species, and some with unresolved taxonomy. They are mostly traded as pets, with the exception of frogs, which are also introduced for human consumption. There are examples of successful introduction in Europe for some representatives of all suggested taxa, and sightings of isolated individuals are also frequent. For example, many species of the genus *Pelophylax* are present in

Europe in different MS and beyond. Usually, all such species can be identified with certainty only through genetic analysis and some have already been translocated within the EU or introduced in the EU through different pathways. In the case of the *Pelophylax* frogs, this can lead to the collapse of native frog populations, particularly by disrupting the equilibrium in the peculiar hybridogenetic systems of this genus, as they may induce genetic pollution (through introgressive hybridisation) or cause the elimination of parental germlines (through hybridogenesis). Under a warming climate, it is probable that *Pelophylax* frogs may expand into the high latitudes and altitudes where cold conditions currently hamper their establishment. This can also happen with the alien species of the genus. In these cases, in addition to impacts due to predation and/or competition with other native amphibians, there is also the risk of spreading deleterious pathogens, like the chytrid fungus, to which many species of the *Pelophylax* genus are partly resistant.

Trachemys scripta is part of the Union list and considered a risk to the EU. In the current horizon scanning, a new *Trachemys* species emerged (*T. ornata*), and there are many more *Trachemys* species that can pose a threat to the EU in the near future. There are also a number of softshell turtles in other families that have been identified as posing a high risk of establishing in Europe due to high climate matching, coexistence with humans, high fecundity and human tolerance (Masin *et al.*, 2014).

Fish

Misgurnus. Three risk assessments have already been prepared for different *Misgurnus* species which have a similar habitat, life history and probably impact. On top of that, they look very similar and are sometimes difficult to distinguish from each other. The native *M. fossilis* is, however, easy to distinguish from the oriental ones. As such, a single risk assessment for the genus *Misgurnus* would streamline the process.

5.2.5.1. Suggested policy measures

To reduce the risk of alien vertebrate species escaping and becoming invasive, policy measures should focus on enhancing the management of captive populations and regulating trade (particularly the pet and aquarium trade sectors, but not exclusively). The adoption and enforcement of appropriate legislation and codes of best practice to control or limit the intentional movement of the species through these pathways should reduce the probability of further introductions. The design and implementation of appropriate surveillance measures, coupled with detailed inspections at entry points would also prevent introductions. Stricter licensing requirements for breeders and sellers, along with mandatory implementation of biosecurity protocols at breeding facilities, can significantly lower the risk of escapes. Zoos and private collections, which often maintain exotic vertebrate species, should also be held to rigorous standards to ensure containment. Enhanced reporting and monitoring systems for these institutions can help track escapes of animals. For species with a known invasive potential, restrictions or outright bans on breeding and sale could be considered to mitigate risks. Given the likelihood of illegal trade, increased enforcement efforts are essential. This could include strengthening border controls, enhancing penalties for trafficking, and improving traceability through systems such as mandatory microchipping or genetic registration.

For birds, although the import of wild-caught animals into the EU has been prohibited since 2005, breeding and sales through specialised breeders, pet shops, and online platforms continue to represent pathways of introductions. Concerning amphibians and reptiles, the main problem for most taxa is the difficulty in correctly identifying the species, especially when animals are found at arrival "hubs" by official entities. This could be solved by increasing awareness and knowledge among staff, for example through the production of detailed identification guides, a network of experts available for purposes of species identification, as well as by increasing the availability of tools and infrastructures (e.g. state laboratories) for quick "genetic identification" through barcoding. Some freshwater fish, e.g. centrarchids or *Oreochromis*, might eventually be intentionally introduced for angling or accidentally as contaminants in the aquarium trade. This problem can be addressed by increasing biosecurity measures in the sector. Moreover, it is important to consider that for the gobies, inland ballast water exchange is the main pathway, while aquarium trade is a main pathway for *Misgurnus*, *Oreochromis* and *Gambusia* (whose trade should therefore be prohibited).

5.3. Overview of all groups

Considering the five thematic groups together, considering both genus and family levels combined, the vertebrates' group was the one suggesting the highest number of groups containing a large number of potentially invasive species that could be candidates for listing under the EU IAS Regulation (16 groups). This was followed by the marine group, which suggested 13 genera, and the plants group, which suggested 12 genera. Both the freshwater and terrestrial invertebrates suggested seven different groups containing a large number of species candidates for listing. Overall, a total of 49 different genera and six families were suggested as groups having a large number of species that could be candidates for listing (Table 24).

Table 24. Overview of number of genera and families highlighted by each of the five different thematic groups as containing a large number of species that could be suggested for listing under the EU IAS Regulation.

Taxa	Marine	Vertebrates	Terrestrial invertebrates	Freshwater invertebrates	Plants	Total
Genera	13	11	6	7	12	49
Families	0	5	1	0	0	6

6. Discussion

The current horizon scanning resulted in a list of 165 alien species considered to be the most risky to EU environments in the next ten years, in what concerns their likelihood of introduction, establishment, spread and impact on biodiversity and ecosystem services. These species are recommended for prioritisation for risk assessment due to the threats they pose, in order to be considered for listing under the EU IAS Regulation. The list is composed of a relatively balanced variety of species from five different thematic groups, and native ranges spanning around the world (although largely from the Americas and Asia). These species can arrive and spread in the EU through a multitude of pathways – however, escapes from confinement, especially of species kept as pets (or in aquarium/terrarium), seems to be the pathway of most significance. It is possible that this is partly related to the relatively high number of vertebrate species present in the list.

Rather surprisingly, a large number of the risky species are already present in the EU, although in limited areas, in line with the scope of this horizon scanning exercise. This reinforces the immediate need to take action on these problematic species with a limited distribution, before they become widespread and undoubtedly more costly and challenging to control. In addition, some other species, although not present in the wild, can be found in the EU in contained holdings, which reiterates the importance of effective biosecurity protocols in these settings.

Even though the recommendation is for risk assessments to be developed for all the risky species identified as very high or high priority for the EU, the alien species present in the 'remaining' list (of lower priority) should also be reviewed with attention. This is because, for various reasons, some of these species, such as the Manchurian wild rice *Zizania latifolia*, the scarlet sage *Salvia coccinea*, the eastern subterranean termite *Reticultermes flavipes*, or the eastern cottontail *Sylvilagus floridanus*, can also be of considerable risk and potentially cause problems in the future. Furthermore, there are additional species that featured in the initial long lists of species that were not taken forward for scoring, or for the workshop, that are of note and should be looked into at regular intervals. This is, for example, the case for a freshwater invertebrate species with high impacts, which was excluded from this exercise due to the pathway of introduction being currently closed (*Faxonius juvenilis*). Other examples are the spotted lanternfly *Lycorma delicatula* and some Hymenoptera, which were not prioritised due to being mostly plant pests. Similarly, the land snail *Limicolaria aurora* was also not taken forward, as the experts did not feel there was enough evidence for its establishment and spread, although the species would certainly have a high impact on biodiversity, if introduced.

Regarding the methodology developed for the current horizon scanning exercise, this was somewhat different to other horizon scans undertaken for IAS. Instead of producing a list of candidate species from scratch, the approach here relied on combining lists of species produced by all previous IAS horizon scans and some additional species lists deemed of relevance. This had the disadvantage of generating a very long list of thousands of species that was very difficult to refine and address, especially given the limited time and resources available. As such, it is difficult to gauge if using this approach was more or less advantageous but, considering the large scale at which the horizon scanning had to be developed (27 EU MS), this certainly helped ensure the comprehensiveness of the species scanned.

Although at the beginning of the horizon scanning the project team intended to separate more of the thematic groups per habitat (e.g. freshwater and terrestrial vertebrates, freshwater and terrestrial plants), it became clear that combining these groups independently of habitat was more suitable for developing this horizon scanning exercise. The only group that clearly needs to be separated by habitat is the invertebrates, due to the major differences between the species from freshwater and terrestrial environments. At the same time, it is possible that some of the thematic groups were perhaps too taxonomically diverse and, for this reason, the vertebrates group subdivided into freshwater fish, amphibians and reptiles, birds, and mammals.

Regarding some of the difficulties encountered by experts while developing this horizon scanning exercise, it was concluded that, although GBIF data was incredibly useful to retrieve species distribution data used both for establishing thresholds for species considered ‘widely spread’ and for developing species climate matching under current and future conditions, these data and procedures had some caveats. Firstly, it is commonly recognised that GBIF data is relatively incomplete for specific groups, such as terrestrial invertebrates and marine species. In addition, climate matching cannot be reliably used for aquatic species, which created quite serious limitations for those groups and/or species, especially the marine group. Additionally, at the workshop, although several experts acknowledged that having the overview of openly available data on distribution of the species was useful, they also indicated the results of the climate matching were very crude and to be interpreted with caution. Future exercises could make use of more sophisticated techniques, such as repeatable workflows for making species distribution models (e.g. Davis *et al*. 2024).

Related to this, establishing which species could be considered as ‘widely spread’ in the EU (or not) proved particularly challenging, as there is no standard and accepted definition for this. Even using a somehow quantitative approach to establish a potential threshold was not straightforward and came with additional issues related to the reliance on GBIF data which, as mentioned above, is at times incorrect or incomplete. This was raised as one of the concerns of the vertebrates group given that, for example, many bird species popular in captivity frequently escape, leading to inflated GBIF occurrence records. These records could misrepresent the species as widespread, despite the absence of self-sustaining populations or their presence in very early establishment stages. Consequently, this resulted in some species being inadvertently excluded from the list, raising the need for careful interpretation of such data. In any case, for this horizon scanning, the procedure of dealing with widely spread species was always well documented, with full lists made available to experts at all times and the possibility to sense-check and recuperate or add species.

The extent and quality of available information on the ecology and other characteristics of the IAS assessed for this exercise was found to be very variable, and often still lacking. This substantially adds to the difficulty of scoring species in these cases, which was the case for species from various thematic groups. Even if EASIN and other tools, such as CABI HST, certainly have a very important role to play in gathering information on species relevant to lists for horizon scanning exercises, both these and other tools are limited in scope and do not contain much of the detailed information needed to score each individual species.

Another difficulty linked to scoring species relates to the geographical scale at which the likelihood of impacts is assessed. For example, the impact of IAS on island ecosystems, which needs to be taken into account, is usually deemed very high, particularly for vertebrate predators. This can have serious repercussions on the scores given to the likelihood of species impacts and, in this exercise, might have inflated these (and the overall) scores for some of the vertebrate species. However, it is also important to note that there is often much more information available for vertebrate species than for species of other groups, potentially also contributing to higher likelihood scores.

It is important to note that, although many of the risky species (especially the Top 57) have an overall ‘High’ confidence level (see Supplementary Material 2; Nunes *et al.*, 2025), a large proportion of those also had a ‘Medium’ or ‘Low’ confidence level. This is also true for the confidence levels of the scores of each individual category (likelihood of introduction, establishment, spread and impact). This not only highlights the potential difficulty of attributing these scores, but also the lack of detailed data for some species, as mentioned above. The latter, in turn, emphasises the strong and different research needs for some of these species.

As mentioned by various authors (e.g. Roy *et al.*, 2015; Hulme, 2025), it is important to recognise that horizon scanning lists are of an imperfect nature and, by relying on pre-existing knowledge or information about species, occasionally fail to address the unpredictable nature of IAS introductions. As such, it is very likely that there are some species that have not been considered through this horizon scanning exercise that could be introduced into the EU in the future and be problematic. Indeed, shortly after the workshop, the terrestrial invertebrates thematic group became aware of a new publication on the Southern giant hornet *Vespa soror* du Buysson, 1905, reporting its first detection in Spain. Sánchez *et al.* (2024) report findings of four workers in a trap designed for *Vespa velutina* in El Campo in the north of Spain (Asturias). *Vespa soror* is native to parts of Tropical Asia, occurring from India, through Thailand, Myanmar, Laos, Vietnam to southern China. It is a very large hornet species, which nests are built in the ground. It is a predator, feeding on insects of any size and even small geckos, and might attack honeybee colonies in coordinated groups. The latter is similar to the Asian giant hornet *Vespa mandarinia* (i.e. completely destroying bee colonies), for which a Risk Assessment is available, resulting in a "high risk with medium confidence" score (Kenis, 2020). Sánchez *et al.* (2024) suggest that arrival happened unintentionally during hibernation as a stowaway with imported goods from Asia. The potential impact of this predatory species on other insects, ecosystem dynamics and human health are concerning and, although the species was not scored during this horizon scanning exercise, it probably would score high, and it should be considered a high priority candidate for a detailed risk assessment in the near future.

It is interesting to realise that ten years after the first EU-level horizon scanning was undertaken (Roy *et al.*, 2015), almost a quarter of the species prioritised back then are again showcased in this current horizon scanning, with half of those featuring in the risky species list. This means that these latter species have not undergone the risk assessment process, and it would be worth to investigate why this is the case, given that action should certainly be prioritised to address the risk caused by these IAS. Furthermore, the divergence in number of species considered in the high risk category for the freshwater and vertebrates group between the current and the previous horizon scan might simply reflect the fact that different experts were involved in the two exercises (or any other methodological difference), but would also be worth to further explore.

Additionally, many of the issues raised by Roy *et al.* (2015) are still applicable, some of the most significant ones being the pervasive lack of information on some species impacts (as detailed above) and the difficulty in streamlining methodological approaches across different thematic groups. Although here particular attention was given to the latter, it is clear that it was not feasible to completely standardise the approaches undertaken by the different groups. In line with this, and perhaps due to the intrinsic characteristics of this environment, the marine group feels particularly removed from the others, also due to the lack of robust data available on species distributions on GBIF and the impossibility of easily developing climate matching for these species.

If we are to try genuinely standardise the methodological approaches used by the various thematic groups, and even across different horizon scans, there is the utmost need to develop a comprehensive and standardised workflow for gathering both lists and information of species (see suggestions below) and, more importantly, for defining in detail how to score likelihood of introduction, establishment, spread and impact of IAS. This could only be achieved through a separate project entirely dedicated to this, which would certainly require appropriate resources and time, and would need consultation with a multitude of experts and stakeholders. Likewise, evaluating the success of horizon scanning approaches in terms of how well they actually forecasted biological invasions is necessary to better identify shortcomings.

A further recommendation linked to the expert-based consensus building part of the exercise, would be to start by holding a one-day within-group workshop for each of the thematic groups to score their species and ideally reach consensus. This should then be followed by a three-day between-group workshop, where groups would discuss and refine their scores based on the combined lists from all thematic groups. It is particularly important to ensure that enough time is allocated for between group discussions, as often large discrepancies between groups occur, so that groups often have to reconvene and re-score some of their species again. The interactive format of a workshop also offers the opportunity to bring together a wider community of practitioners and researchers to review and get consensus on possible risks, especially if aspects of risk management were to be included in the exercise.

Recently Hulme (2025) has suggested the frequent misapplication of the term ‘horizon scanning’ in biological invasions, coining the term ‘environmental scanning’ to refer to the process of surveying existing data sources and using expert-based consensus to gather information to anticipate specific alien species that might pose future risks. The author emphasises some of the limitations inherent to this process and recommends potential improvements, such as establishing standards for the process of scoring and prioritising species (which has already been recommended above and attempted in most previous exercises) and using data trends from border controls and interception databases to inform future forecasts of risk (which are, however, currently unavailable in most European countries). The author further mentions the use of social media to crowd knowledge on emerging species, as well as the different and more automated approaches used to scan potential threats in the plant, animal and human health fields. Currently, work on more data driven horizon scans, also using online data in different ways (namely through iEcology/culturomics) is ongoing in the framework of the Horizon Europe project ‘OneBiosecurity Systems and Technology for People, Places and Pathways (OneSTOP).

A significant advance could consist of establishing completely or partially automated searches using web scraping tools to continuously scan for species of relevance in (1) a multitude of databases and publications; (2) social media; (3) data resulting from official controls at borders; and (4) online trading platforms, among other sources. This would still need to be followed by a manual analysis and prioritisation process developed by experts, which could either be undertaken at regular intervals (similar to what is done by EFSA[22]), or on a rolling basis as significant numbers of potential new species are identified. Finally, if or when rethinking and potentially redefining the development of future horizon scanning processes at the EU level, it would be of utmost importance to ensure engagement with relevant stakeholders, as this would undoubtedly make the process of scanning for future possible threats much more robust.

[22] https://www.efsa.europa.eu/en/topics/horizon-scanning-plant-pests

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Annex I. Simplified ecosystem services classification according to CICES V5.1

Table. Ecosystem services classification according to CICES V5.1 (and simplified) and examples, as used in the production of EU Risk Assessments under the framework of Regulation 1143/2014.

Section	Division	Group	Examples (i.e. relevant CICES "classes")
Provisioning	**Biomass**	**Cultivated *terrestrial* plants**	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes; Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials); Cultivated plants (including fungi, algae) grown as a source of energy. *Example: negative impacts of non-native organisms to crops, orchards, timber etc.*
		Cultivated *aquatic* plants	Plants cultivated by in- situ aquaculture grown for nutritional purposes; Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials); Plants cultivated by in- situ aquaculture grown as an energy source. *Example: negative impacts of non-native organisms to aquatic plants cultivated for nutrition, gardening etc. purposes.*
		Reared animals	Animals reared for nutritional purposes; Fibres and other materials from reared animals for direct use or processing (excluding genetic materials); Animals reared to provide energy (including mechanical). *Example: negative impacts of non-native organisms to livestock*

Section	**Division**	**Group**	**Examples (i.e. relevant CICES "classes")**
		Reared *aquatic* animals	Animals reared by in-situ aquaculture for nutritional purposes; Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials); Animals reared by in-situ aquaculture as an energy source. *Example: negative impacts of non-native organisms to fish farming.*
		Wild plants (terrestrial and aquatic)	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition; Fibres and other materials from wild plants for direct use or processing (excluding genetic materials); Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy. *Example: reduction in the availability of wild plants (e.g. wild berries, ornamentals) due to non-native organisms (competition, spread of disease etc.).*
		Wild animals (terrestrial and aquatic)	Wild animals (terrestrial and aquatic) used for nutritional purposes; Fibres and other materials from wild animals for direct use or processing (excluding genetic materials); Wild animals (terrestrial and aquatic) used as a source of energy. *Example: reduction in the availability of wild animals (e.g. fish stocks, game) due to non-native organisms (competition, predations, spread of disease etc.).*
	Genetic material from all biota	**Genetic material** from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population; Higher and lower plants (whole organisms) used to breed new strains or varieties; Individual genes extracted from higher and lower plants for the design and construction of new biological entities.

Section	Division	Group	Examples (i.e. relevant CICES "classes")
			Example: negative impacts of non-native organisms due to interbreeding.
		Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population; Wild animals (whole organisms) used to breed new strains or varieties; Individual genes extracted from organisms for the design and construction of new biological entities. *Example: negative impacts of non-native organisms due to interbreeding.*
	Water[23]	**Surface water** used for nutrition, materials or energy	Surface water for drinking; Surface water used as a material (non-drinking purposes); Freshwater surface water, coastal and marine water used as an energy source. *Example: loss of access to surface water due to spread of non-native organisms.*
		Ground water for used for nutrition, materials or energy	Ground (and subsurface) water for drinking; Ground water (and subsurface) used as a material (non-drinking purposes); Ground water (and subsurface) used as an energy source. *Example: reduced availability of ground water due to spread of non-native organisms and associated increase of ground water consumption by vegetation.*
Regulation and Maintenance	**Transformation** of biochemical	**Mediation of wastes or toxic substances** of	Bio-remediation by micro-organisms, algae, plants, and animals; Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals

[23] Note: in the CICES classification, provisioning of water is considered as an abiotic service, whereas the rest of ecosystem services listed here are considered biotic.

Section	Division	Group	Examples (i.e. relevant CICES "classes")
	or physical inputs to ecosystems	anthropogenic origin by living processes	*Example: changes caused by non-native organisms to ecosystem functioning and ability to filtrate etc. waste or toxics.*
		Mediation of nuisances of anthropogenic origin	Smell reduction; noise attenuation; visual screening (e.g. by means of green infrastructure). *Example: changes caused by non-native organisms to ecosystem structure, leading to reduced ability to mediate nuisances.*
	Regulation of physical, chemical, biological conditions	**Baseline flows and extreme event** regulation	Control of erosion rates; Buffering and attenuation of mass movement; Hydrological cycle and water flow regulation (Including flood control, and coastal protection); Wind protection; Fire protection. *Example: changes caused by non-native organisms to ecosystem functioning or structure leading to, for example, destabilisation of soil, increased risk or intensity of wild fires etc.*
		Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context); Seed dispersal; Maintaining nursery populations and habitats (Including gene pool protection). *Example: changes caused by non-native organisms to the abundance and/or distribution of wild pollinators; changes to the availability /quality of nursery habitats for fisheries.*
		Pest and disease control	Pest control; Disease control. *Example: changes caused by non-native organisms to the abundance and/or distribution of pests.*

Section	Division	Group	Examples (i.e. relevant CICES "classes")
		Soil quality regulation	Weathering processes and their effect on soil quality; Decomposition and fixing processes and their effect on soil quality. *Example: changes caused by non-native organisms to vegetation structure and/or soil fauna leading to reduced soil quality.*
		Water conditions	Regulation of the chemical condition of freshwaters by living processes; Regulation of the chemical condition of salt waters by living processes. *Example: changes caused by non-native organisms to buffer strips along water courses that remove nutrients in runoff and/or fish communities that regulate the resilience and resistance of water bodies to eutrophication.*
		Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans; Regulation of temperature and humidity, including ventilation and transpiration. *Example: changes caused by non-native organisms to ecosystems' ability to sequester carbon and/or evaporative cooling (e.g. by urban trees).*
Cultural	**Direct, in-situ and outdoor interactions** with living systems that depend on presence in the environmental setting	**Physical and experiential** interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions; Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions. *Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that make it attractive for recreation, wildlife watching etc.*

Section	Division	Group	Examples (i.e. relevant CICES “classes”)
		Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge; Characteristics of living systems that enable education and training; Characteristics of living systems that are resonant in terms of culture or heritage; Characteristics of living systems that enable aesthetic experiences. *Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that have cultural importance.*
	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	**Spiritual, symbolic** and other interactions with natural environment	Elements of living systems that have symbolic meaning; Elements of living systems that have sacred or religious meaning; Elements of living systems used for entertainment or representation. *Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that have sacred or religious meaning.*
		Other biotic characteristics that have a **non-use value**	Characteristics or features of living systems that have an existence value; Characteristics or features of living systems that have an option or bequest value. *Example: changes caused by non-native organisms to ecosystems designated as wilderness areas, habitats of endangered species etc.*

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Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

EU open data

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

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