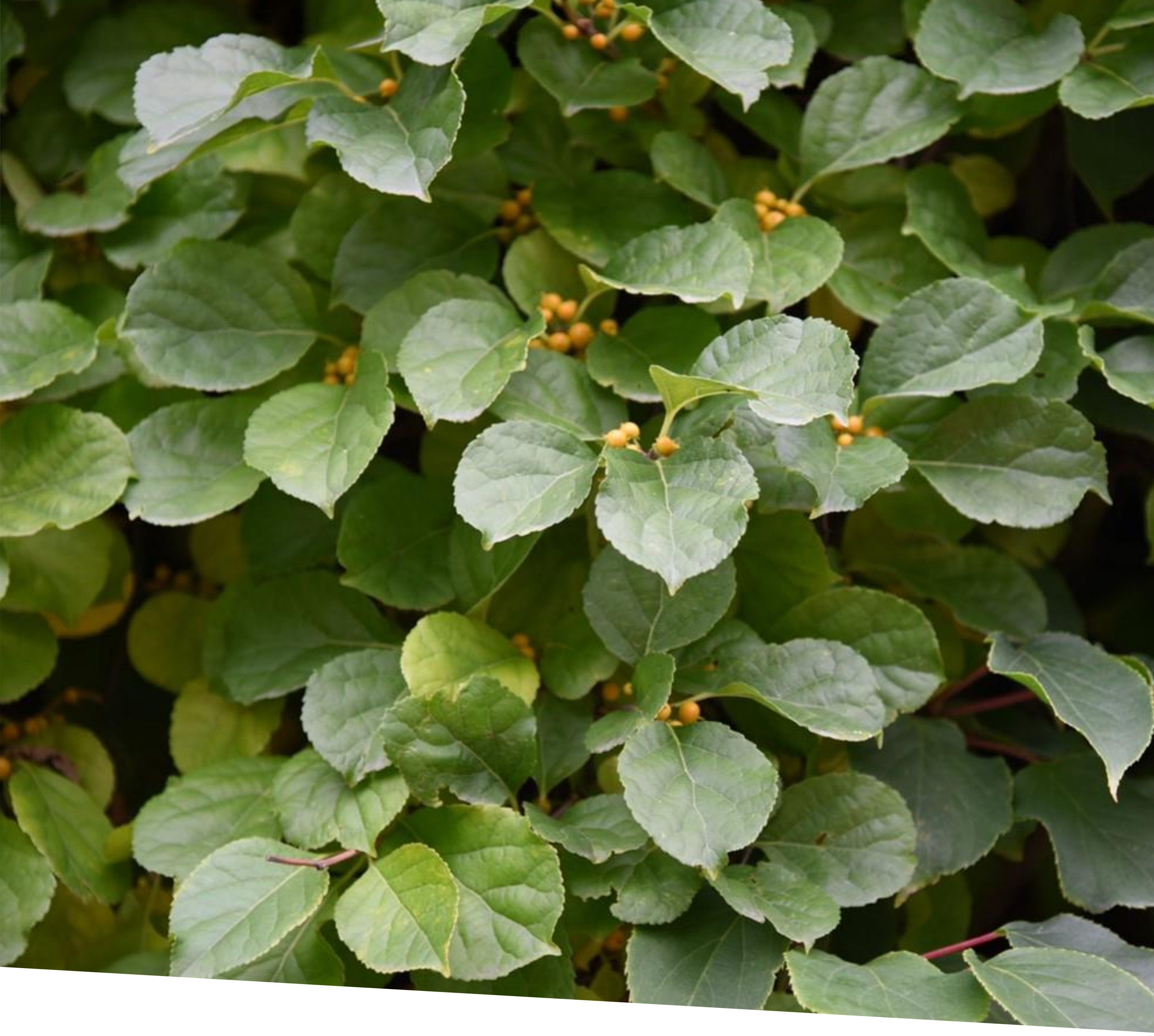

PATHWAYS OF UNINTENTIONAL INTRODUCTION AND SPREAD OF 88 INVASIVE ALIEN SPECIES OF UNION CONCERN IN BELGIUM

IDENTIFICATION AND PRIORITIZATION

National Scientific Secretariat on Invasive Alien Species

2023

Invasive Alien Species
National Scientific Secretariat

This report is an update of the 2018 and 2020 Belgian reports on identification and prioritization of introduction pathways of invasive alien species (IAS) of Union Concern, which considered respectively the 49 and 66 species that were listed at that time. This updated report includes the 22 species that were added to the list in August 2022 and thus considers a total of 88 species, representing all the species of the Union list at the time of writing (December 2023).

This report has been produced by the National Scientific Secretariat on Invasive Alien Species (main contributors: Jane Reniers and Arnaud Jacobs) and validated by the National Scientific Council on Invasive Alien Species.

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Summary

Article 13 of the Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of invasive alien species (the 'IAS Regulation') requires Member States to identify and prioritize pathways of unintentional introduction and spread of IAS of Union Concern. This report identifies priority pathways of unintentional introduction in Belgium for the 88 IAS of Union Concern listed to date (2023). Priority pathways are defined in the IAS Regulation as pathways requiring actions by priority because of the volume of the alien species using the pathway or of the potential damage these species can inflict on biodiversity.

First, pathways of introduction and spread were identified for each of the listed species by reviewing pathway information contained in the EU risk assessments using the definitions of the CBD classification framework (CBD, 2014) and the interpretation manual of Harrower *et al.* (2018). The relevance of these pathways was considered for Belgium, based on expert knowledge and review. Second, pathways were prioritised using a methodology that takes into account the species impact, establishment potential and the frequency of introduction via the different pathway.

The results of this prioritization are in line with results of the two previous prioritization analyses (NSSIAS, 2018 and 2020). The top 12 pathways are still the same, with pathways only changing a maximum of two ranks. In terms of importance, escape of animal species from the private premises of their owner and spread of plants beyond where they were planted are still the main pathways for animal and plant species. Only 3 extra pathways are added to the list of pathways through which the species of Union Concern are introduced to and spread within Belgium, but these pathways are only relevant for the four ant species and two other newly added species on the list.

Since pathway action plans were not written in a species specific manner, we see no immediate need for an update of the current National action plan on priority pathways of unintentional introduction and spread of invasive alien species of the Union list in Belgium, taking into account that the new species could be taken into account in already existing actions on awareness raising or biosecurity measures. Instead of adding extra preventative actions or tackling additional pathways, we conclude that generating more data on species and pathways would lead to better adapted plans and ameliorate prevention in the long run.

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1. Scope

The present report is the third Belgian prioritization of pathways of IAS of Union Concern in the framework of Article 13 of the European Regulation 1143/2014 on the prevention and management of the introduction and spread of invasive alien species and includes the 22 species that were added on the Union list following the entry into force 2nd of August 2022. This report is to be interpreted as a working document, which will be updated when new species are added to the list of species of Union Concern, or in the case new knowledge on species and pathways requires an update of the prioritization exercise. The current report presents the analysis and results of the prioritization exercise taking into account all invasive alien species (IAS) of Union concern that are listed to date (December 2023).

An excel spreadsheet containing all the raw data on species and their pathways used in this report is publicly available: https://doi.org/10.5281/zenodo.10363697.

2. Background

IAS are organisms that are – accidentally or deliberately – introduced by human activity outside their natural range, and whose introduction has been found to threaten or adversely impact upon biodiversity and ecosystem services (provisioning, regulating, habitat and/or cultural). They are already considered as one of the most important direct drivers of loss of ecosystem services and biodiversity (Brunel et al., 2013) and have been identified as number one driver of changes in species' traits (Jaureguiberry et al., 2022). The incidence and impact of IAS are only expected to increase in the future (*e.g.* Dudley et al., 2010).

Invasive alien species represent a threat to native plants and animals in Europe and are already causing damage worth billions of euros to the European economy every year – Estimated costs between 1960 and 2020 summed to €116.61 billion, with the majority (60%) being damage-related and impacting multiple sectors (Haubrock et al., 2021). The comprehensive IPBES Assessment Report on IAS and their control (2023) states that they cost humanity more than $400 billion a year – an amount that has quadrupled every decade since 1970. The "*Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species"* (the 'IAS Regulation') is a response at the European level to the threat posed by IAS. It entered into force on 1 January 2015 and seeks to address the problem of IAS in a comprehensive manner, preventing, minimising and mitigating the adverse effects of IAS on native biodiversity and related ecosystem services. The IAS Regulation is primarily aimed at minimizing the spread of IAS which represent a substantial threat to biodiversity and related ecosystem services in (parts of) Europe. It therefore establishes a list of species of concern to the European Union (the Union List species), for which a set of measures apply. As new IAS can be introduced continuously into the Union and alien species present are spreading and expanding their range, the list is dynamic and allows for regular updating. Species can be proposed for inclusion on the list at the initiative of Member States or the European Commission.

The IAS Regulation foresees a three-stage hierarchical approach based on 1) prevention, 2) early detection and rapid eradication, and 3) control and/or containment. This approach aims at minimising new introductions, subsequent establishment and also covers management of already established invasive species. It reflects scientific and policy consensus that prevention is generally far more cost-effective and environmentally desirable than post-introduction measures (Leung et al., 2002; Finoff et al., 2007; Kim et al., 2016; Cuthbert et al., 2022). Where prevention failed and an IAS has been introduced, early detection (backed by early warning and information exchange) and rapid eradication drastically minimise costs associated with the invasion (Ahmed, 2021). If eradication is not feasible, control and/or containment measures should be implemented in a timely matter to steeply reduce long term economic impacts (Ahmed, 2021).

Here, we address pathway analysis as a component of prevention. The importance of considering pathways is widely acknowledged as a key element of prevention (Wittenberg et al., 2005; Hulme, 2009; McGeogh et al., 2016; Matthews et al., 2017). At international and European level, several policy measures are already in place tackling pathways via which IAS are introduced, e.g. the Ballast Water Convention, (standards from) the International Plant Protection Convention, the World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures, the OiE standards (World Organization for Animal Health), the EU Aquaculture Regulation and the Wildlife Trade Regulation. In addition, introduction pathways of IAS are also addressed in the Kunming-Montreal Global Biodiversity Framework of the Convention on Biological Diversity (CBD), under Target 6: "Reduce rates of introduction and establishment of invasive alien species by 50 per cent by 2030".

The IAS Regulation forbids transport, breeding, keeping, selling, exchanging and releasing listed species, thereby covering intentional pathways of introduction of IAS. However, a large proportion of IAS are also introduced unintentionally (CBD, 2014), and for some taxa intentional pathways are more prevalent than unintentional pathways (Saul et al., 2017). Unintentionally introduced species can be even more costly (Turbellin et al., 2022) and harder to manage in the new environment than intentionally introduced species (Pysec et al., 2011).

Globally, the most common invasion routes of vertebrates and plants consist of an intentional entry into captive holding with a subsequent escape or dumping into the environment. While plants usually spread beyond gardens and parks where they were originally planted via natural dispersal or dumping of green waste, animals either escape captivity or are dumped by irresponsible owners. On the contrary, most invasive invertebrates, algae, microorganisms and fungi tend to arrive as the result of contamination of a certain good or as a stowaway (Hulme, 2008; Saul et al., 2017). Invasions through transport corridors such as canals, bridges, tunnels and roadsides are also important pathways (Brisson et al., 2010; Nunes et al., 2015; Saul et al., 2017) that are often underestimated (Hulme, 2008).

Therefore, according to Article 13 of the IAS Regulation, Member States have to identify and prioritize unintentional introduction pathways for IAS for their specific countries and develop actions to prevent further introductions. More specifically, article 13 requires Member States to: "*carry out a comprehensive analysis of the pathways of unintentional introduction and spread of invasive alien species of Union concern at least in their territory, as well as in their marine waters as defined in point (1) of Article 3 of Directive 2008/56/EC, and identify the pathways which require priority action ('priority pathways') because of the volume of species or of the potential damage caused by the species entering the Union through those pathways.*"

After prioritization, each Member state has to establish and implement (a set of) action plans to address the priority pathways it has identified in their country specific analysis.

3. Methodology for identification and prioritization of introduction pathways in Belgium

The process of identification and prioritization of the pathways of introduction for Belgium involved the following steps:

1) Pathway identification: the production of a Belgian inventory of pathways of introduction and spread IAS of Union Concern.
2) Development of a prioritization method.
3) Application of developed method to introduction and spread pathways for IAS of Union Concern.

3.1. Species considered

The species covered by this pathway analysis are all 88 species of Union Concern to date (2023): (TABLE 1). These includes the species of Implementing Regulation (EU) N° 2016/1141 (37 species), Implementing Regulation (EU) N° 2017/1263 (12 species), Implementing Regulation (EU) N° 2019/1262 (17 species) and Implementing Regulation (EU) N° 2022/1203 (22 species).

Table 1. The 88 species of Union concern considered in this study. "IR" indicates whether the species was included in the Implementing regulation (EU) n° 2016/1141, in the Implementing regulation (EU) n° 2017/1263, in the Implementing regulation (EU) n° 2019/1262 or in the Implementing regulation (EU) n° 2022/1203. "": the species is unlikely to establish in Belgium under current climatical conditions (based on EU Risk assessment)*

Scientific name	Common name (Dutch)	Common name (French)	IR
Acacia saligna (Labill.) H.L.Wendl. (Acacia cyanophylla Lindl.)	Wilgacacia	Mimosa bleuâtre	2019*
Acridotheres tristis Linnaeus, 1766	Treurmaina	Martin triste	2019
Ailanthus altissima (Mill.) Swingle	Hemelboom	Ailante glanduleux	2019
Alopochen aegyptiacus Linnaeus, 1766	Nijlgans	Ouette d'Egypte	2017
Alternanthera philoxeroides (Mart.) Griseb.	Alligatorkruid	Herbe à alligator	2017*
Ameiurus melas (Rafinesque, 1820)	Zwarte dwergmeerval	Poisson-chat commun	2022
Andropogon virginicus L. (Dendy, 1894) Jones & Gerard (1999)	Amerikaans bezemgras	Barbon de virginie	2019*
Arthurdendyus triangulatus	Nieuw-Zeelandse platworm	Ver plat de Nouvelle--Zélande	2019
Asclepias syriaca L.	Zijdeplant	Asclépiade de Syrie	2017
Baccharis halimifolia L.	Struikaster	Séneçon en arbre	2016
Axis axis (Erxleben, 1777)	Axishert	Cerf axis	2022
Cabomba caroliniana Gray	Waterwaaier	Cabomba de Caroline	2016

Callosciurus erythraeus Pallas, 1779	Pallas' eekhoorn	Ecureuil de Pallas	2016
Callosciurus finlaysonii (Horsfield, 1823)	Thaise eekhoorn	Écureuil de Finlayson	2022*
Cardiospermum grandiflorum Sw.	Ballonrank	Corinde à grandes fleurs	2019*
Celastrus orbiculatus Thunb.	Aziatische boomwurger	Célastre asiatique	2027
Channa argus (Cantor, 1842)	Noordelijke slangekopvis	Poisson à tête de serpent du Nord	2022
Cortaderia jubata (Lemoine ex Carrière) Stapf	Hoog pampasgras	Herbe de la pampa pourpre	2019
Corvus splendens Viellot	Huiskraai	Corbeau familier	2016
Ehrharta calycina Sm.	Roze rimpelgras	Ehrharte calycinale	2019*
Elodea nuttallii (Planch.) St. John	Smalle waterpest	Elodée de Nuttall	2017
Eriocheir sinensis H. Milne Edwards, 1854	Chinese wolhandkrab	Crabe chinois	2016
Faxonius limosus Rafinesque, 1817	Gevlekte Amerikaanse rivierkreeft	Ecrevisse américaine	2016
Faxonius rusticus (Girard, 1852)	Roestbruine Amerikaanse rivierkreeft	Écrevisse à taches rouges	2022
Faxonius virilis Hagen, 1802	Geknobbelde Amerikaanse rivierkreeft	Ecrevisse à pinces bleues	2016
Fundulus heteroclitus (Linnaeus, 1766)	Fundulus heteroclitus	Choquemort	2024
Gambusia affinis (Baird & Girard, 1853)	Westelijk muskietenvisje	Gambusie de l'Ouest	2022
Gambusia holbrooki Girard, 1859	Oostelijk muskietenvisje	Gambusie de l'Est	2022
Gunnera tinctoria (Molina) Mirbel	Chileense reuzenrabarber	Rhubarbe géante du Chili	2017*
Gymnocoronis spilanthoides (D.Don ex Hook. & Arn.) DC.	Smalle theeplant	Faux hygrophile	2019
Hakea sericea Schrad. & J.C.Wendl.	Hakea	Hakéa soyeux	2022
Heracleum mantegazzianum Sommier & Levier	Reuzenberenklauw	Berce du Caucase	2017
Heracleum persicum Fischer	Perzische berenklauw	Berce de Perse	2016
Heracleum sosnowskyi Mandenova	Sosnowsky's berenklauw	Berce de Sosnowski	2016
Herpestes javanicus É. Geoffroy Saint-Hilaire, 1818	Indische mangoeste	Mangouste	2016*
Humulus scandens (Lour.) Merr.	Oosterse hop	Houblon du japon	2019*
Hydrocotyle ranunculoides L. f.	Grote waternavel	Hydrocotyle fausse renoncule	2016
Impatiens glandulifera Royle	Reuzenbalsemien	Balsamine de l'Himalaya	2017

*Koenigia polystachya (*Wall. ex Meisn.) T.M. Schust. & Reveal	Afghaanse duizendknoop	Renouée à nombreux épis	2022
Lagarosiphon major (Ridley) Moss	Verspreidbladige waterpest	Elodée à feuilles alternes	2016
Lampropeltis getula (Linnaeus, 1766)	Koningsslang	Serpent roi de Californie	2022*
Lepomis gibbosus Linnaeus, 1758	Zonnebaars	Perche soleil	2019
*Lespedeza cuneata (*Dum.Cours.) G.Don (Lespedeza juncea var. sericea (Thunb.) Lace & Hauech)	Chinese struikklaver	Lespedeza soyeux	2019
Limnoperna fortunei (Dunker, 1857)	Gouden mossel	Moule pygmée	2022*
Lithobates (Rana) catesbeianus Shaw, 1802	Amerikaanse stierkikker	Grenouille taureau	2016
Ludwigia grandiflora (Michx.) Greuter & Burdet	Grote waterteunisbloem	Jussie à grandes fleurs	2016
Ludwigia peploides (Kunth) P.H. Raven	Kleine waterteunisbloem	Jussie rampante	2016
Lygodium japonicum (Thunb.) Sw.	Japanse klimvaren	Fougère grimpante du japon	2019*
Lysichiton americanus Hultén and St. John	Moerasaronskelk	Faux-arum	2016
Microstegium vimineum (Trin.) A. Camus	Japans steltgras	Herbe à échasses japonaise	2017
Morone americana (Gmelin, 1789)	Amerikaanse baars	Bar blanc d'Amérique	2022
Muntiacus reevesi Ogilby, 1839	Muntjak	Muntjac de Chine	2016
Myocastor coypus Molina, 1782	Beverrat	Ragondin	2016
Myriophyllum aquaticum (Vell.) Verdc.	Parelvederkruid	Myriophylle du Brésil	2016
Myriophyllum heterophyllum Michaux	Ongelijkbladig vederkruid	Myriophylle hétérophylle	2017
Nasua nasua Linnaeus, 1766	Rode neusbeer	Coati roux	2016*
Nyctereutes procyonoides Gray, 1834	Wasbeerhond	Chien viverrin	2017
Ondatra zibethicus Linnaeus, 1766	Muskusrat	Rat musqué	2017
Oxyura jamaicensis Gmelin, 1789	Rosse stekelstaart	Erismature rousse	2016
Pacifastacus leniusculus Dana, 1852	Californische rivierkreeft	Ecrevisse signal	2016
Parthenium hysterophorus L.	Schijnambrosia	Fausse chamomille	2016*
Pennisetum setaceum (Forssk.) Chiov.	Lampenpoetsersgras	Herbe aux écouvillons pourpres	2017*
Perccottus glenii Dybowski, 1877	Amoergrondel	Goujon de l'Amour	2016
Persicaria perfoliata (L.)	Gestekelde duizendknoop	Renouée perfoliée	2016
Pistia stratiotes L.	Watersla	Laitue d'eau	2024*

Plotosus lineatus (Thunberg, 1787)	Gestreepte koraalmeerval	Poisson-chat rayé	2019*
Pontederia crassipes (Mart.)	Waterhyacint	Jacinthe d'eau	2016*
Procambarus clarkii Girard, 1852	Rode Amerikaanse rivierkreeft	Ecrevisse de Louisiane	2016
Procambarus virginalis Lyko, 2017	Marmerkreeft	Ecrevisse marbrée	2016
Procyon lotor Linnaeus, 1758	Wasbeer	Raton laveur	2016
Prosopis juliflora (Sw.) DC	Mesquite	bayahonde	2019*
Pseudorasbora parva Temminck & Schlegel, 1846	Blauwbandgrondel	Goujon de Chine	2016
Pueraria montana (Lour.) Merr. var. lobata (Willd.)	Kudzu	Kudzu	2016*
Pycnonotus cafer (Linnaeus, 1766)	Roodbuikbuulbuul	Bulbul à ventre rouge	2022*
Rugulopterix okamurae (E.Y.Dawson) I.K. Hwang, W.J.Lee & H.S.Kim, 2009	Stomp gaffelwier	Algue brune du Japon	2022*
Salvinia molesta D.S. Mitch. (Salvinia adnata Desv.)	Grote vlotvaren	Salvinie géante	2019*
Sciurus carolinensis Gmelin, 1788	Grijze eekhoorn	Ecureuil gris	2016
Sciurus niger Linnaeus, 1758	Amerikaanse voseekhoorn	Ecureuil fauve	2016
Solenopsis geminata (Fabricius, 1804)	Tropische vuurmier	Fourmi de feu tropicale	2022*
Solenopsis invicta Buren, 1972	Rode vuurmier	Grande fourmi de feu	2022*
Solenopsis richteri Forel, 1909	Zwarte vuurmier	Fourmi de feu noire	2022*
Tamias sibiricus Laxmann, 1769	Siberische grondeekhoorn	Tamia de Sibérie	2016
Threskiornis aethiopicus Latham, 1790	Heilige ibis	Ibis sacré	2016
Trachemys scripta Schoepff	Lettersierschildpad	Tortue de Floride	2016
Triadica sebifera (L.) Small (Sapium sebiferum (L.) Roxb.)	Talgboom	Arbre a suif	2019*
Vespa velutina nigrithorax de Buysson, 1905	Aziatische hoornaar	Frelon asiatique	2016
Wasmannia auropunctata (Roger, 1863)	Dwergvuurmier	Petite fourmi de feu	2022*
Xenopus laevis (Daudin, 1802)	Afrikaanse klauwkikker	Xénope lisse	2024

3.2. Pathway identification

3.2.1. Pathway categorization

In order to classify pathways, the definitions of the CBD classification, Harrower et al. (2018) were used, supplemented with extra information received from the European Commission on the distinction between intentional and unintentional introductions.

In general, there are six principal pathways for IAS (Hulme et al., 2008; CBD 2014; Harrower et al. 2018): 1) release in nature, 2) escape from confinement, 3) transport-contaminant, 4) transport-stowaway, 5) corridor and 6) unaided. For these main pathways, different subcategories are identified (CBD, 2014; FIG 1).

As the regulation demands prioritization of pathways of unintentional introduction and spread, the principal pathway “release in nature”, was not retained for analysis since it is an intentional pathway. Release of animals by irresponsible owners or release of plants by inadequate disposal of garden material, was placed under the pathway “escape” after clarification by the European Commission and was retained for analysis.

1) **Release in nature** refers to the intentional introduction of live alien organisms for the purpose of human use in the natural environment. Examples include release in nature of organisms for biological control, erosion control (and dune stabilization), for fishing or hunting in the wild; landscape “improvement” and introduction of threatened organisms for conservation purposes.

2) **Escape** refers to the movement of (potentially) invasive alien species from confinement (e.g. in zoos, aquaria, botanic gardens, agriculture, horticulture, aquaculture and mariculture facilities; scientific research or breeding programs) into the natural environment. In this pathway, the organisms were initially purposefully imported or transported to be held in a “captive setting”, and then escaped (*e.g.* escape of live bait from a fishing line). Their presence in the environment is therefore considered accidental. Following clarification by the European Commission (pers. com), this pathway also includes the release of pets or the disposal of plants into the environment.

3) **Contaminant** refers to the unintentional movement of live organisms as contaminants of a commodity that is intentionally transferred through international trade, development assistance, or emergency relief. This includes pests and diseases of food, seeds, timber and other products of agriculture, forestry, and fisheries as well as contaminants of other products.

4) **Stowaway** refers to the moving of live organisms attached to transporting vessels and associated equipment and media. The physical means of transport-stowaway include various conveyances, ballast water and sediments, biofouling of ships, boats, offshore oil and gas platforms and other water vessels, dredging, angling or fishing equipment, civil aviation, sea and air containers.

5) **Corridor** refers to movement of alien organisms into a new region following the construction of transport infrastructures in whose absence spread would not have been possible. Such trans-biogeographical corridors include international canals (connecting river catchments and seas) and transboundary tunnels linking mountain valleys or oceanic islands.

6) **Unaided** refers to the secondary natural dispersal of IAS that have been introduced by means of any of the foregoing pathways. Secondary natural dispersal (unaided) takes place after introduction via other pathways through human intervention. Information on the mechanisms of secondary spread of IAS, after their introduction, are relevant to define the best response measures.

Figure 1. CBD pathway categories and subcategories, adapted from Harrower et al., 2018. "Release in nature" was considered intentional and not retained in the current pathway analysis, whereas the other listed categories and subcategories were considered. Release of pets or inadequate disposal of plants by irresponsible owners was considered under the "escape from confinement pathway".

3.2.2. Inventory of species' specific pathways

In this study, pathways of introduction of Union List species were retrieved from published sources which are mainly based on available pathway information in the European risk assessments, supplemented with information from the DAISIE and GRISS database (Saul et al., 2017), the CABI Invasive Species Compendium, pathway information in the European risk assessments, and available pathway analysis performed in other Member States (CLM, 2010; Madsen et al., 2014; Ministère du Développement durable et des Infrastructures, Luxemburg, 2016; Rabitsch et al., 2018).

This information was reviewed to assess the relevance of the pathways for the Belgian territory by expert review. For plants, popularity in the ornamental sector was also verified with stakeholders and via the website *plantago.nl*. For animals, information on permits for research, the presence in zoo collections and popularity of the species as pets was acquired from the regional animal welfare departments. Additionally, the information on the pathways (Brunel, 2009; Roy et al., 2013; Gallardo et al., 2016; Adriaens, 2016; Nunes et al., 2015; Carboneras et al., 2017; Saul et al., 2017) was also taken into account.

Pathways of spread of Union List IAS were equally considered and were analyzed together with the pathways of introduction.

3.3. Pathway prioritization

3.3.1. Identification of species' impacts

Article 13 requires Member States to: "…identify the pathways which require priority action because of the volume of species or of the potential damage caused by the species entering the Union through those pathways." To assess the magnitude of impact (damage) of an invasive alien species, we allocated a "risk-score" (from 1-12) to every species as a proxy for species impact. The calculation of these scores was based on the environmental impact protocol "ISEIA" (Invasive Species Environmental Impact Assessment; Branquart et al, 2009; Vanderhoeven et al., 2015). This protocol was developed to classify alien species according to their level of impact in Belgium and allocate alien species to the different hazard categories of the Harmonia information system[1] in an attempt to minimize the use of subjective opinions and to warrant the transparency and repeatability of the assessment process (Daehler et al., 2004, Vanderhoeven et al., 2017).

The allocation of scores to individual species is based on semi-quantitative scores for four different elements of impact. It takes into account four criteria, matching the last steps of the invasion process: (i) dispersal potential, (ii) colonization of natural habitats, (iii) adverse ecological impacts on native species, (iv) alteration of ecosystem functions. A score for the four different variables (i-iv) was attributed based on species information in literature and databases.

The ISEIA protocol was designed to assess species able to establish and adapt to the current climatic conditions in Belgium. Since not all species have the same establishment potential in

[1] http://ias.biodiversity.be

Belgium, we also included an assessment of the “establishment potential”, and used it to weigh variable “dispersal potential” in the formula to calculate an ISEIA score that can be used for species that are not (fully) able to establish under current climatic conditions and that is fully compatible with ISEIA scores of species established in Belgium in the framework of other assessments in the past and the future. To this end, we used a scale from 1 (the species cannot establish in Belgium under current nor future climatic conditions) to 5 (the species is able to establish under current climatic conditions). This ISEIA score that considers establishment potential in Belgium, will be referred to as “Belgian ISEIA score” for the remainder of the assessment.

$$\begin{aligned}\boldsymbol{BE\ ISEIA} = \boldsymbol{Colonisation\ of\ high\ value\ area} + \boldsymbol{Impact} \\ + \boldsymbol{Alteration\ of\ ecosystem\ functions} + (\boldsymbol{Dispersal\ potential} \\ * \boldsymbol{Establishment\ potential})/\mathbf{5}\end{aligned}$$

For the species under consideration, the ability of species to adapt to the current climatic conditions in Belgium and to establish in Belgium ranges from 1 (*e.g. Prosopis juliflora*, a (sub)tropical species) to 5 (e.g. *Eriocheir sinensis,* already established over 100 years) (TABLE 2). The ecological impact assessment score and the score for establishment potential are both integrated in the pathway prioritization formula. Hence, pathways of introduction and spread for species unable to establish in Belgium are downgraded in the prioritization. The assigned value for the species is based upon expert consultation and literature. Though such “Belgian ISEIA scores” were already available for 48 of the 88 species of the Union List species (*ias.biodiversity.be* ; prioritization report 1), these scores were validated and adapted where necessary in the light of newly available species information.

3.3.2. Assessment of the frequency of introduction pathways

Article 13 requires Member States to: “…identify the pathways which require priority action because of the volume of species or of the potential damage caused by the species entering the Union through those pathways.” The “volume” as set out in the EU IAS Regulation was found to be difficult to assess, as information is scant (see also Adriaens, 2016 and Pergl et al., 2020) and interception data and quantitative data on pathways is generally lacking. Hence, we used a crude assessment of the frequency of introduction of the species via a given pathway as a proxy for volume. To this end, we performed an assessment of the frequency of introduction of the species for each introduction pathway identified and allocated them in three categories**,** following a precautionary approach (TABLE 3). When the pathway was mentioned in international literature, but its relevance could not be corroborated for Belgium, a score (0.33) was allocated instead of a zero. This way all potential pathways were considered in the analysis. All scores for each species frequency of use in each pathway are available in Annex 1 of the report. For the pathway “escape”, we considered the historical popularity of the species in the domestic Belgian trade when allocating a score.

Table 2. Assessment of establishment potential (ESTAB; 1: unlikely to establish in Belgium under CC and FC; 2: marginally able to establish under FC; 3: able to establish under FC; 4: Marginally able to establish under CC; 5 able to establish under CC) and resulting Belgian ISEIA score for the species considered.

Species	ESTAB.	BE ISEIA	Species	ESTAB.	BE ISEIA
Acacia saligna	3	11	*Lithobates catesbeianus*	5	12
Acridotheres tristis	4	7	*Ludwigia grandiflora*	5	12
Ailanthus altissima	5	12	*Ludwigia peploides*	5	12
Alopochen aegyptiacus	5	12	*Lygodium japonicum*	2	9
Alternanthera philoxeroides	3	11	*Lysichiton americanus*	5	10
Ameiurus melas	5	8	*Microstegium vimineum*	5	12
Andropogon virginicus	2	9	*Morone americana*	5	8
Arthurdendyus triangulatus	5	10	*Muntiacus reevesi*	5	12
Asclepias syriaca	5	12	*Myocastor coypus*	5	12
Axis axis	5	10	*Myriophyllum aquaticum*	5	12
Baccharis halimifolia	5	12	*Myriophyllum heterophyllum*	5	12
Cabomba caroliniana	5	10	*Nasua nasua*	3	9
Callosciurus erythraeus	5	11	*Nyctereutes procyonoides*	5	9
Callosciurus finlaysonii	2	8	*Ondatra zibethicus*	5	12
Cardiospermum grandiflorum	3	11	*Oxyura jamaicensis*	5	10
Celastrus orbiculatus	5	11	*Pacifastacus leniusculus*	5	12
Channa argus	5	12	*Parthenium hysterophorus*	2	5
Cortaderia jubata	5	12	*Pennisetum setaceum*	2	9
Corvus splendens	5	7	*Perccottus glenii*	5	11
Ehrharta cacycina	2	10	*Persicaria perfoliata*	5	11
Elodea nuttallii	5	12	*Pistia stratiotes*	2	10
Eriocheir sinensis	5	12	*Plotosus lineatus*	1	7
Faxonius limosus	5	12	*Pontederia crassipes*	1	8
Faxonius rusticus	5	12	*Procambarus clarkii*	5	12
Faxonius virilis	5	12	*Procambarus virginalis*	5	12
Fundulus heteroclitus	5	10	*Procyon lotor*	5	11
Gambusia affinis	5	11	*Prosopis juliflora*	1	9
Gambusia holbrooki	5	11	*Pseudorasbora parva*	5	11
Gunnera tinctoria	3	10	*Pueraria lobata*	3	10
Gymnocoronis spilanthoides	4	11	*Pycnonotus cafer*	1	6
Hakea sericea	4	11	*Rugulopterix okamurae*	2	10
Heracleum mantegazzianum	5	10	*Salvinia molesta*	3	11
Heracleum persicum	5	11	*Sciurus carolinensis*	5	11
Heracleum sosnowskyi	4	10	*Sciurus niger*	5	9
Herpestes javanicus	3	8	*Solenopsis geminata*	1	5
Humulus scandens	3	10	*Solenopsis invicta*	1	7
Hydrocotyle ranunculoides	5	12	*Solenopsis richteri*	1	6
Impatiens glandulifera	5	12	*Tamias sibiricus*	5	9
Koenigia polystachya	5	10	*Threskiornis aethiopicus*	5	11
Lagarosiphon major	5	12	*Trachemys scripta*	2	7
Lampropeltis getula	1	6	*Triadica sebifera*	3	11
Lepomis gibbosus	5	9	*Vespa velutina nigrithorax*	5	12
Lespedeza cuneata	5	11	*Wasmannia auropunctata*	1	7
Limnoperna fortunei	3	11	*Xenopus laevis*	5	10

Table 3. Three frequency-categories are distinguished for scoring species within pathways for their frequencies of introduction for Belgium.

Frequency	Category description	Score
Absent to low (1)	The pathway is infrequently used by the species or even not at all, it is unlikely (but possible) that the pathway is relevant for the species. Very few cases are described in literature. Very few observations are being made of this species in the pathway.	0,33
Medium (2)	The pathway is regularly being used by the species. Several cases are described in literature. Observations of the species in the pathway are regular but not common.	0,66
High (3)	The pathway is commonly used by the species and represents the main pathway of entry. Most cases in literature are observed in this pathway. Observations of this species in the pathway are common. *e.g. Ambrosia artemisiifolia* is a common seed contaminant in bird food. *e.g.* Several references in literature describe the high dispersal ability of Asian Hornet, *Vespa velutina*. The pathway “Natural dispersal” will score 1 for this species.	1,00

The pathway frequency category that was allocated to a certain species for a specific pathway, was further complemented with a confidence level (high, medium, low):

- **High confidence**: evidence of frequency is available.
- **Medium confidence**: there is limited evidence on frequency available from published information or observations, and the assessment is mainly based on expert judgment.
- **Low confidence**: there is no direct evidence on frequency available, and the assessment is fully based upon expert judgment.

In case the level of confidence was low, and no decision could be made with regard to the allocation of a species to one of the three categories, allocation is made to the category low. In case some information was available but there was still some doubt remaining on whether a species should be for example in category low or medium, then it was allocated to the category medium.

3.3.3. Pathway prioritization

Priority pathways are defined by the European IAS regulation (art 13) as “pathways requiring actions by priority because of the volume of the alien species using it or of the potential damage of these species”.

Prioritization involves 1) the ranking of pathways with the purpose of determining their relative environmental impact (and sometimes socio-economic impact; sensu Blackburn et al., 2014), and as such, deciding which pathways pose the biggest threat, and 2) and assess which pathways that are manageable and offer a good chance of preventing such threats and decide on the relative priority of actions to mitigate impact of IAS. The current report looks at the first step of prioritization: the prioritization of pathways according to their impact.

To prioritize pathways, we followed an approach based on the impact of species and the frequency of introduction per pathway, in line with the EU IAS Regulation’s requirements. Pathways are ranked based on a formula that takes into account the number of species in the pathway, the relative ecological impact score of these species (BE-ISEAI score/average BE-ISEIA score) and the frequency score (as a proxy for volume – see 5.3.2). This formula is defined as follows:

$$\boldsymbol{Pathway\ priority\ score} = \sum \boldsymbol{Species}\left(\left[\frac{\boldsymbol{BE\ ISEIA\ score}}{\mathbf{10}}\right] * [\boldsymbol{Pathway\ frequency}]\right)$$

By definition, the ISEIA scores for ecological impact of Union List species are rather high – though in our dataset they are weighed by establishment potential which can decrease the scores substantially. While scores can range from 4 to 12, in this dataset, scores range between 4,5 and 12 with a median of 11 and a mean value of 10. Scores were normalized in line with the scoring range for frequency. The confidence level on the frequency score (high – medium – low) was not taken into account in this exercise but can be used as an additional consideration in the decision-making process on which priority pathways to tackle.

We illustrate the application of the formula with the example below (TABLE 4):

- The simple summation of the number of species using the hypothetical pathway would result in a pathway score of 12.
- When only considering the species impact (I), the hypothetical pathway receives a score of 13. This is higher than when solely considering species number, because some species have a high impact (>1).
- When jointly considering species impact and species frequency, the score declines due to the relatively high proportion of species that only have low to medium scores for pathway frequency (<1).

Table 4. Example to illustrate the calculation of the priority score of a hypothetical pathway. Species impact (BE ISEIA/average BE ISEIA) ; Frequency: a proxy for the volume of the species on the pathway: low (0,33), medium (0,66) high (1).

	Impact (I)	Frequency (V)	I × V
Species 1	0,9	0,33	0,297
Species 2	1,0	0,66	0,660
Species 3	1,1	1,00	1,100
Species 4	1,2	1,00	1,200
Species 5	0,9	0,33	0,297
Species 6	1,0	0,66	0,660
Species 7	1,2	0,33	0,396
Species 8	1,2	0,33	0,396
Species 9	1,2	0,33	0,396
Species 10	1,0	0,66	0,660
Species 11	1,1	0,33	0,363
Species 12	1,2	0,33	0,396
∑(spp.) = 12	∑(I) = 13		∑(I×V) = 6,821

4. Results

4.1. Pathway identification

General description

A total of 27 out of 33 potential pathways of introduction and spread were identified for the 88 listed species of Union concern, representing 4 out of 5 main unintentional pathway categories: unaided, escape from confinement, transport stowaway and transport contaminant (TABLE 5; FIG 2).

Some pathways were relevant for a large number of species in the dataset, whereas others were relevant for only a handful of species. For example, natural dispersal and escape of pet/aquarium/terrarium species were identified as a pathway of introduction or spread for more than half of the species. The pathways escape of animal species from zoos, escape of plant species in other use than horticulture, and contaminant of transport of habitat material were relevant for one third of the species in the dataset. On the other hand, escape from confinement in research and forestry, and transport stowaway on the hull were relevant for only one or two species. It should be noted that the low importance or even total absence of some pathways in our dataset is not because these pathways are not important in a Belgian context, but rather reflects the bias caused by the limited number of species on the Union list. For example, while marine pathways are important pathways of unintentional introduction around the world, hull fouling and ballast water do not appear in top positions in our ranking because of the limited representation of marine species on the Union list.

By species groups

When looking at species groups (aquatic animals, aquatic plants, terrestrial plants, birds, mammals, reptiles and amphibians and terrestrial invertebrates) (FIG 3A and B), only one pathway – unaided – was relevant for all groups. Additionally, escape from private premises (pet/aquarium/terrarium; escape ornamental other than horticulture, escape from zoo/aquaria/botanical garden) was identified as relevant in all species groups except the terrestrial invertebrates.

Apart from the escape pathways, terrestrial plants are also implicated in all categories of contaminant pathways identified for Belgium (except contaminated bait), as well as the stowaway pathways “vehicles”, “machinery”, “luggage” and “angling and fishing equipment” – probably mainly through contamination by seeds or vegetative fragments. The aquatic plants share a lot of the pathways of introduction and spread with their terrestrial counterparts, though they are excluded from transport or contaminant pathways linked more to terrestrial activities such as “stowaway on luggage and vehicles” and included in more aquatic transport and contaminant pathways such as “hitchhiker on boats”, “hull” and “ballast water”.

Generally, the animal groups are implied in less introduction pathways than the plant groups, but this can also be an artifact of the level of splitting of the groups – indeed, overall, the animals feature in 21 out of 33 pathways and the plants in 20 out of 33. Apart from the escape pathways – some of which unique to the mammals (e.g. fur farms, farmed animals) – mammals are only implicated in the stowaway pathway "container” and “ship/boat". Birds are implicated in even less pathways – only escapes from zoos or as pets and stowaway on boats. Reptiles and amphibians are also only implicated in few pathways apart from the escape from zoo or as pets. The amphibians are implicated in escape from research and the tadpoles can occur as a contaminant of aquatic animals. Reptiles could be implicated as a contaminant of plants or as a stowaway on a ship/boat.

Aquatic animals are a relatively diverse group (vertebrates and invertebrates) and are uniquely implied in a few escape pathways such as “aquaculture”, “live food and bait” next to escape from zoos and aquaria. For the rest they are implied in 2 contaminant pathways (on animals and on plants) and three stowaway pathways (angling/fishing equipment, ballast, hull).

We identified a total of 8 pathways for the terrestrial invertebrates 4 transport contaminant (food, nursery and habitat material, and timber) and 4 transport stowaway pathways (container, airplane, machinery, vehicles).

4.2. Pathway prioritization

Natural dispersal ranks number 1 in the pathway prioritisation (TABLE 5), with a relatively large drop in the cumulative impact of the species along this pathway for the second ranked pathway “escape from confinement”. This is not surprising since we not only assessed pathways of introduction but also considered pathways of spread in parallel. In contrast to other pathways, “natural dispersal” is therefore scored for many species under consideration, increasing its importance in the ranking exercise.

Escape or disposal of pets, garden plants and zoo species ranked at number 2, 3 and 4. This indicates that escape pathways are very important in the introduction and spread of IAS, though escape from zoos shows only half of the cumulative impact of species as compared to escape of pets from private owners and 2/3rd of that from escape from plants from gardens or public greenery. The pathway **stowaway on angling/fishing material** is ranked at 5th place and even though it is implicated in less species than escape from zoos, the impact is nearly identical. The pathway **transport of habitat material** was ranked at the 6th place. From ranks 7 to 10, cumulative impacts of species along those pathways are almost identical and amount to one third of the impact from the second ranked pathway escape of pet/aquarium/terrarium species. Concerned pathways are **transport contaminant of nursery material**, **hitchhikers on ships/boats**, **contaminant on animals** and lastly **contaminant of machinery** as number 10. From the pathway **contaminant on plants** onwards, which is ranked on the 11th place with a cumulative impact of 6,9, there is a gentle decline in cumulative impacts for the next 16 pathways to eventually reach 0,3.

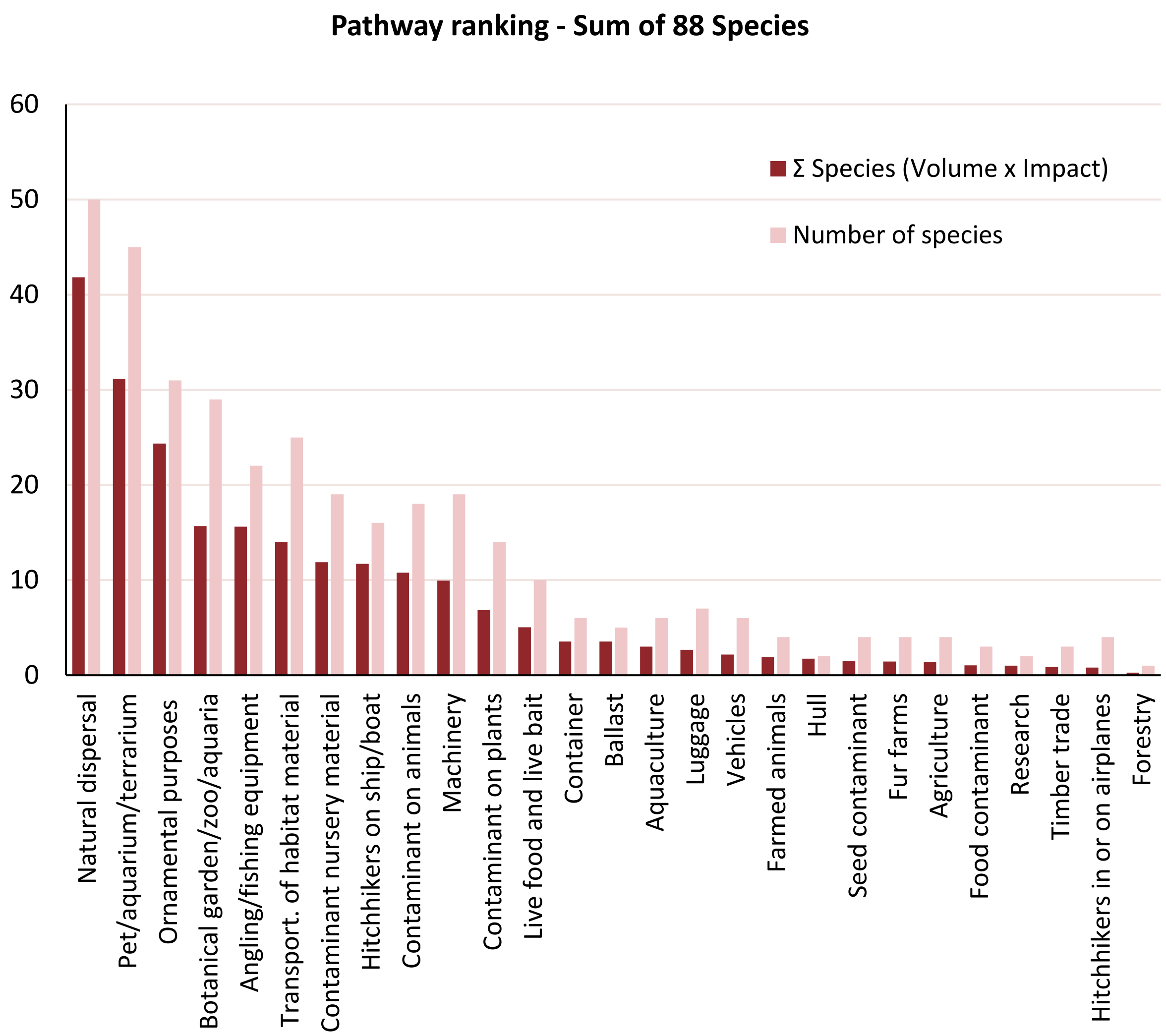
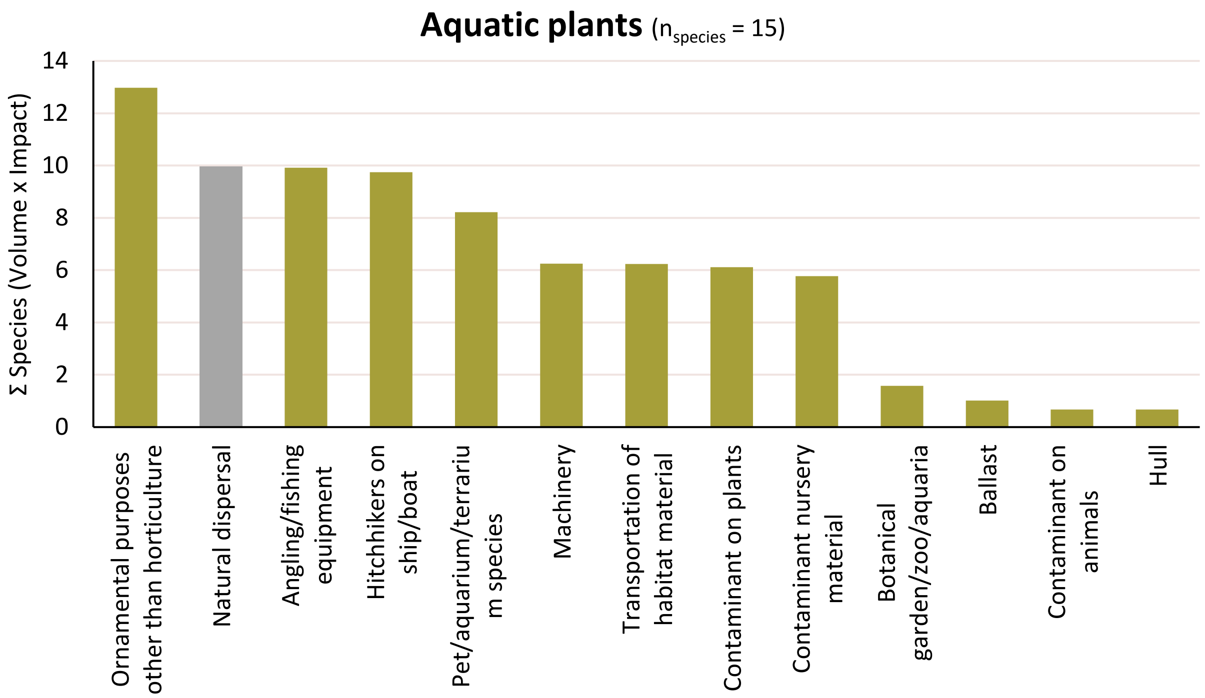


Figure 2. Pathway ranking for the 88 species of Union concern according to the cumulative factor on impact and volume (frequency of introduction for the species in a pathway) and showing the number of species in a pathway.

*Table 5. Pathway ranking for the 88 species of Union concern according to the cumulative number of species using the pathway, and the cumulate impacts * volume (frequency of introduction for the species in a pathway) of the species using the pathway.*

Pathway category	Pathway	∑ Impact x volume	Nb of species
Unaided	Natural dispersal	41,8	50
Escape from confinement	Pet/aquarium/terrarium species	31,1	45
Escape from confinement	Ornamental purposes other than horticulture	24,4	31
Escape from confinement	Botanical garden/zoo/aquaria	15,7	29
Transport stowaway	Angling/fishing equipment	15,6	22
Transport contaminant	Transportation of habitat material	14,0	25
Transport contaminant	Contaminant nursery material	11,9	19
Transport stowaway	Hitchhikers on ship/boat	11,7	16
Transport contaminant	Contaminant on animals	10,8	18
Transport stowaway	Machinery	9,9	19
Transport contaminant	Contaminant on plants	6,9	14
Escape from confinement	Live food and live bait	5,0	10
Transport stowaway	Container	3,5	6
Transport stowaway	Ballast	3,5	5
Escape from confinement	Aquaculture	3,0	6
Transport stowaway	Luggage	2,7	7
Transport stowaway	Vehicles	2,2	6
Escape from confinement	Farmed animals	1,9	4
Transport stowaway	Hull	1,8	2
Transport contaminant	Seed contaminant	1,5	4
Escape from confinement	Fur farms	1,5	4
Escape from confinement	Agriculture	1,4	4
Transport contaminant	Food contaminant	1,1	3
Escape from confinement	Research	1,0	2
Transport contaminant	Timber trade	0,9	3
Transport stowaway	Hitchhikers in or on airplanes	0,8	4
Escape from confinement	Forestry	0,3	1



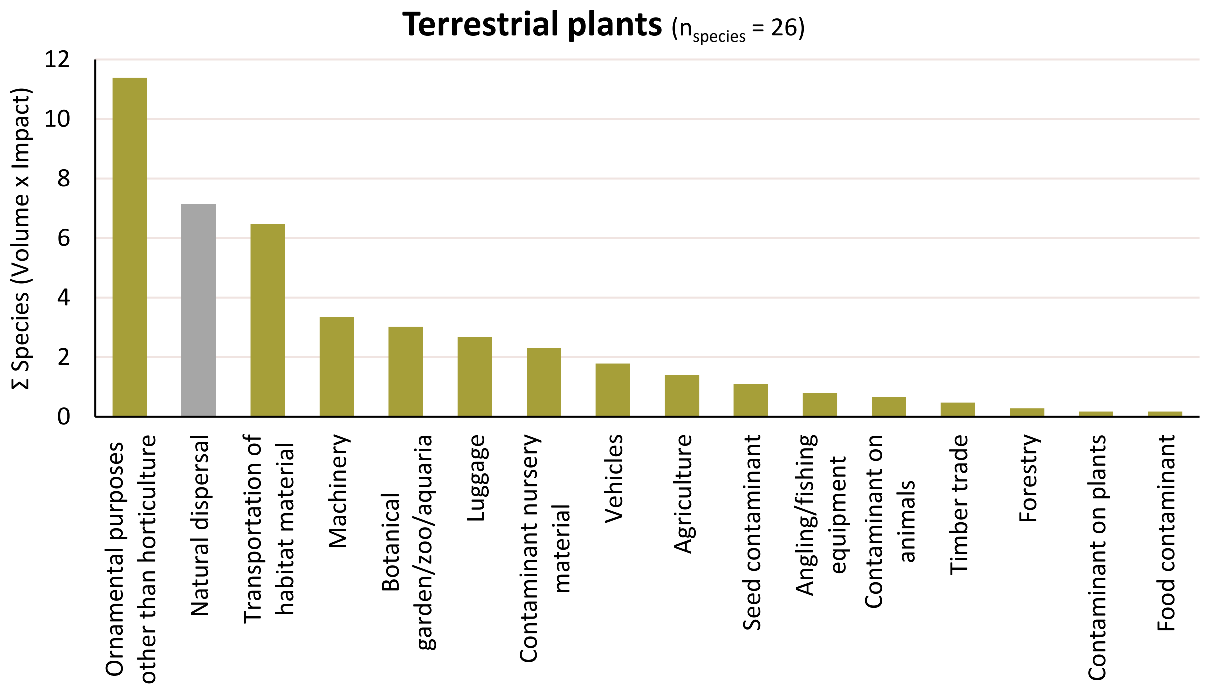


Figure 3A. Pathways ranking for the 88 species of Union concern according to species groups: Part 1 - "Aquatic plants" and "terrestrial plants"

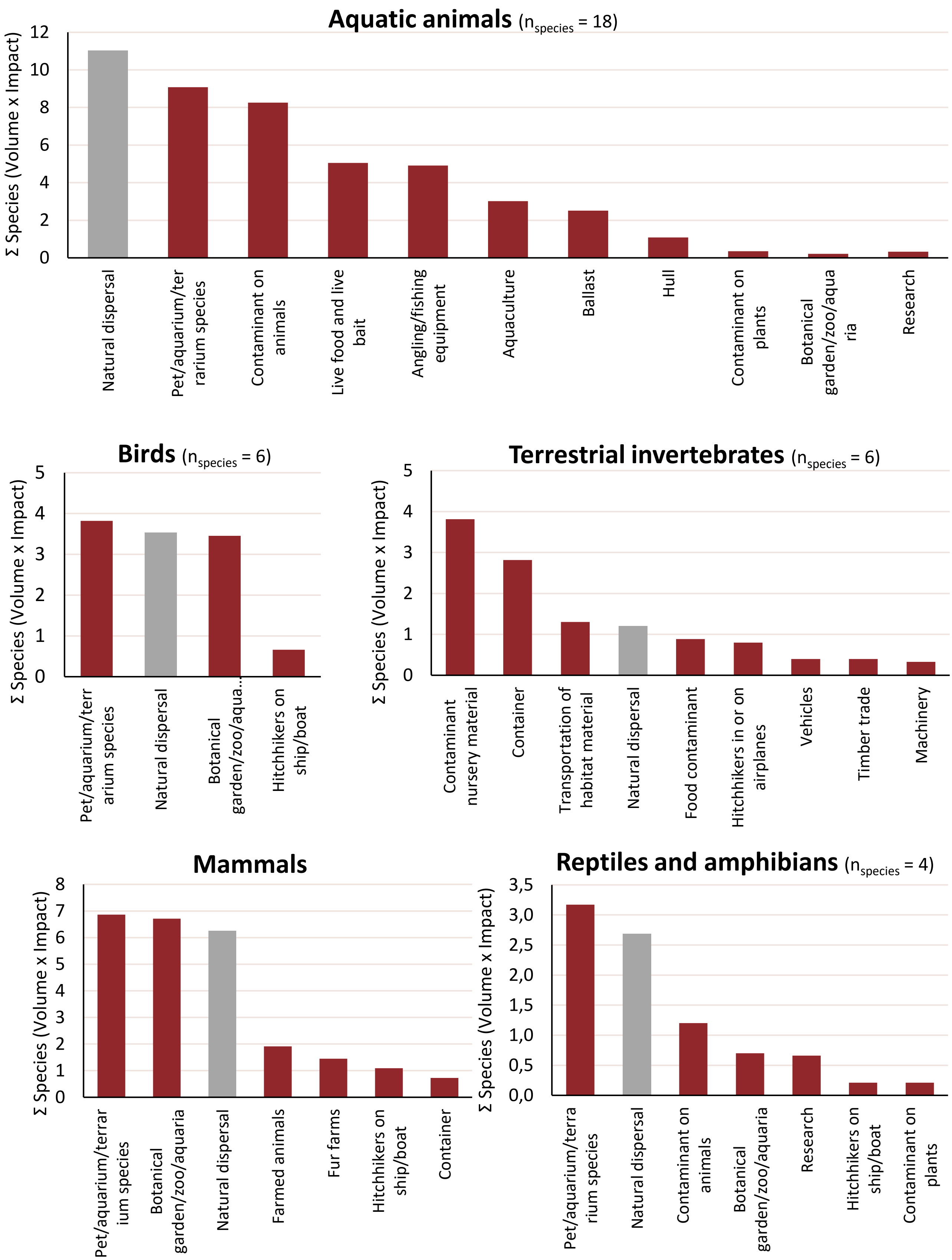


Figure 3B. Pathways ranking for the 88 species of Union concern according to species groups: Part 2 - "aquatic animals", "birds", "terrestrial invertebrates", "mammals" and "reptiles and amphibians"

Comparison with Prioritization of 66 species

The **top 12 pathways for the 88 species are identical as the previous prioritization with 66 species** (Table 6). While the ranking of the top 3 remained exactly the same, there were a few changes of ranks for other pathways. Botanical gardens increased one rank to the detriment of angling and fishing equipment. The main progressions are for contaminants of nursery material and animals, both going up of two ranks.

With the addition of the 22 new species, **a few pathways outside of this top 12 gained in importance for Belgium. Transport stowaways of containers and ballasts** are now 13th and 14th in the ranking, with 4 new species being considered for these two pathways (Table 5). Three other pathways (**Hull fouling, Research and Hitchhikers in or on airplanes**), not featured in the previous analysis, are now identified – though with a low impact and a maximum of four species involved.

Table 6. Comparison between pathway ranks after prioritization on impact for the dataset of 66 species and the dataset of 88 species.

Ranking	Prioritization 66 species	∑IxV	Prioritization 88 species	∑IxV	
1	Natural dispersal	37,5	Natural dispersal	41,8	
2	Pet/aquarium/terrarium species	26,2	Pet/aquarium/terrarium species	31,1	
3	Ornamental purposes other than horticulture	21,6	Ornamental purposes other than horticulture	24,4	
4	Angling/fishing equipment	13,5	**Botanical garden/zoo/aquaria**	15,7	↑
5	Botanical garden/zoo/aquaria	13,3	Angling/fishing equipment	15,6	↓
6	Transportation of habitat material	12,8	Transportation of habitat material	14,0	
7	Hitchhikers on ship/boat	11	**Contaminant nursery material**	11,9	↑
8	Machinery	9,9	Hitchhikers on ship/boat	11,3	↓
9	Contaminant nursery material	9,5	**Contaminant on animals**	10,8	↑
10	Contaminant on animals	7,4	Machinery	9,9	↓
11	Contaminant on plants	6,0	Contaminant on plants	6,9	
12	Live food and live bait	4,3	Live food and live bait	5,0	

5. Discussion

5.1. Update of the national action plan?

A. **The current national action plan on pathways of introduction and spread is still relevant as it already covers the priority pathways identified in this analysis.** Therefore, we do not consider it necessary to include additional pathways into the separate thematic chapters. However, since natural dispersal was identified as the top pathway of introduction and spread in this dataset, we argue that seeking more cooperation with neighbouring countries in terms of management should be considered, as well as implementing coordination of management between the Belgian regions.

Firstly, the current National action plan on priority pathways of unintentional introduction and spread of invasive alien species of the Union list in Belgium (further mentioned as National action plan), which is divided into three thematic chapters, included actions on 10 of the first 12 pathways (excluding natural dispersal and escape from botanical garden, zoo, aquaria, as decided by a policy decision). **The top 12 pathways with the most cumulative impact of species along the pathway has not changed** compared to the previous analysis on which the development of the national action plan on IAS was based.

Secondly, **only three new pathways were scored as relevant for Belgium** in this updated dataset (escape from research, hull fouling, hitchhikers on ships/boats). These 3 pathways are relevant for a total of 8 species: 4 ants, 1 amphibian, 1 fish, 1 aquatic invertebrate and 1 marine algae. Of these 8 species, only the fish (*F. heteroclitus*) and the amphibian (*X. laevis*) are able to establish under current climatic conditions and they are both in the pathway "escape from confinement – research". At this moment in time, only *Xenopus* is used in research in Belgian research institutes. Since a derogation has to be requested at the competent authority, we estimate that the competent authority itself could impose stringent measures of the use of this animal or decide to forego such requests. However, this is at the hands of the authority itself and reaches beyond the scope of the national action plan. The pathway "hull fouling" is nevertheless already considered in the actions of increased biosecurity for freshwater users (*ACTION 3 of Freshwater Action Plan*) – although not formally mentioned.

Thirdly, while **the pathway "escape from botanical garden, zoo, aquaria"** now appears in the top 4 we argue it **should not be included in the pathway action plans following the same argumentation why it was excluded previously**: escapes are mainly of historical importance, facilities in Belgium are held to a good standard (*e.g.* contingency planning in case of escape), enclosures are already obliged to be escape proof and they are a valuable ally in awareness raising for the public.

Lastly, the **action plan already covers the top-ranking pathway for all species groups under consideration** (mammals, birds, amphibians and reptiles, fish, aquatic animals, terrestrial invertebrates, aquatic plants, terrestrial plants). Nevertheless, **it should be noted that the pathways "container" is not covered by the current action plan** even though it is an important pathway (frequency scored as 1) for the four ants. These four species could most likely only establish indoors in Belgium and thus cannot impact biodiversity in Belgium, nor is Belgium at a risk of spreading these species to other member states. Nevertheless, we advise to exert caution with regards to the "container" pathway. Additionally, since the current flow of pathway prioritization and 'intervention' through action plans is notoriously slow, we advise to consider the potential need of a rapid response approach for this pathway.

B. Since the actions in the current national action plan are already sufficient to address the pathways, we do not consider adding extra actions is relevant for the moment. The new Union list species should be included in the existing actions.

In general, the national action plan was not designed with a focus on species but rather with a focus on the processes. As such, the current actions are already broad and cover the risk of introduction and spread of multiple organisms along these pathways – including newly added species (*e.g.* through increased biosecurity, awareness raising, increased capacity for dumped pets).
Nevertheless, we assessed if extra actions should be envisioned for the three pathways that increased in importance compared to the previous analysis. Of these three pathways, **"contaminant on animals" and "contaminant of nursery material"** increased most in relative importance. The "contaminant on animals" pathway is relevant for a total of **7 newly listed aquatic species**, and mainly concerns the **contamination of fish or mollusc imports and/or transports**. Therefore, results of the baseline analysis on importation of aquatic animals (*ACTION 1 of Freshwater Action Plan*) should be reevaluated in the light of the newly added species. For the "contaminant of nursery material, we also recommend to reevaluate the analysis of imports of habitat material in the light of the four newly listed ant species. However, since information on actual interceptions and detection methods is absent and since the four species in these pathways are not likely to be able to establish in Belgium, we do not consider it opportune to already incorporate new actions for these pathways.

C. It could be considered to include a new thematic chapter on research and data generation.

Real data on frequency and volume of species along certain unintentional pathways of introduction is scarce. This is already evident in the **lack of interception data from trade**, either because current systems are insufficient in recording the necessary detail (*e.g.* GN codes, TRACES data and veterinary documents) – especially on the long term – or because they are simply inexistent (*e.g.* intra EU-trade of ornamental plants and thus assessment of contaminants of plants). In order to properly assess the risk of mislabelling or contamination of shipments, it would be a mandatory prerequisite to know what is entering Belgium.

Additionally, **data on risks of introduction and spread of contaminants and hitchhikers is often also lacking** (*e.g.* data on the fouling of ropes of freshwater ships, on propagules transported by fishing rods or waders, on contamination of containers). Such quantitative data is rightfully requested by stakeholders before they invest time and money in preventative action. The generation of such data is thus paramount to decrease unintentional introduction and spread of IAS. However, this problem is exacerbated by the lack of detection protocols focusing on individual species, rendering it almost impossible to generate such data.

There is clearly still a long way to go, and the lack of trade data and information on the propagule load on certain pathways is an important barrier for creating more effective public policy.

5.2. Addressing knowledge gaps on introduction pathways

During the process of prioritization of pathways of introduction and spread of IAS of Union concern for Belgium, we identified a few knowledge gaps relating to pathway information and species. Describing and addressing these gaps will aid follow-up work through research, improvement of inspection and data collection methodology in Belgium, and may lead to identify necessary changes to European policy for obtaining such information. Some considerations and limitations of the current analysis are considered below.

The current analysis is **not a full pathway analysis of all IAS relevant for Belgium**, **but only considers the list of species of Union Concern**. Although including species that are not of Union concern in the pathway prioritization is not obliged by the EU Regulation on IAS, it can be of added value. For example, the **absence of a strategy for preventing marine invasions is** not because it is not an important pathway, but rather **an artefact of having only two fully marine organisms on the list**. Focusing a prioritization on a larger set of species considering the entirety of aliens entering the Belgian territory (*e.g.* Verleye et al., 2020; GRIIS checklist, Desmet at al., 2019) would better prevent future invasions and also render the action plans more fit for purpose and more robust against future list updates. However, which species should be included in such a robust assessment should be carefully considered. For example, using the list of exotics species present in Belgium (Desmet et al., 2019) would exclude species that are not yet established in Belgium. Additionally, such an analysis is very time consuming and not as targeted on the individual species on the list of Union concern, a list that has been compiled through a robust process of scientific assessment and taking into account policy concerns.

There still is **uncertainty about the role of certain pathways of introduction and spread**. In the case where no pathway information was available in literature or documents, expert opinion was used to assess pathway relevance in the current analysis. Some considerations can help reducing the need of expert opinion:

- **Knowledge on the role of pathways for all species is lacking.** Data on frequency, number and identity of propagules that are imported, transported or spread through certain pathways are simply not available for Belgium and can be hard to attain – *e.g.* data on marine pathways. An example for introduction and spread data is given below:
    - Introduction: interception data on goods from third countries are currently not fit for purpose. Some numbers on the frequency of certain commodities and goods are available, but more detailed knowledge on the importance of certain routes is needed. Furthermore, there is a lack or even complete absence of data on transport between member states (*e.g.* Montagnani et al., 2022).
    - Spread: information on the differences in propensity of certain propagules to be spread via a certain pathway is lacking. For example, research on the capacity of propagules of plant species to adhere to machinery is scant at best. Therefore, such differences cannot be taken into account and we end up having to use raw estimations for appointing species involvement in pathways.
- **Improving and expanding registration and storage of data on inspections and interception** of exotic species is needed for an improved analysis of pathways of

spread and introduction and the development of policy tools relating to introduction and management of IAS.

For some species, detailed information on the establishment potential under current and future climate is not available. For example, for many listed species (*e.g. Cortaderia jubata*) quantification of seed set and germination and thus spread capability is inexistent for the local climate. Additionally, it is difficult to assess the potential impact on ecosystems in Belgium for species that are not established in Europe or in a similar climate. Therefore, revisiting the scores given during previous prioritization analysis when new information is available may change pathway ranking.

Finally, if knowledge gaps were addressed the pathway analysis could be refined. **Historic and current proxies for quantifying introduction effort and spatiotemporal changes in pathway analyses should be incorporated in the analysis**, though that is very difficult when even contemporary data is lacking. **Separating pathways of introduction into Belgium or Europe and spread within Belgium or Europe** (primary and secondary pathways see Pergl et al., 2020) would also lead to more targeted action plans and better prevention of new introductions or spread within Belgium. One could for example attribute more weight to introduction pathways of species not yet established in Belgium or make more precise distinctions within specific pathways (*e.g.* introduction via hull fouling is more likely for short boat travels within Europe near the coast than for transatlantic travels where the monetary implications of having a non-streamlined hull are much larger). However, such considerations are nearly impossible to incorporate before the analysis given the lack of data on certain pathways and would increase uncertainty.

As a concluding remark, it can be highlighted that, in addition to the above limitations, the current flow of pathway prioritization and intervention through action plans is notoriously slow. It therefore needs to be complemented with a rapid response approach supported by contingency plans, similar to post-border introductions.

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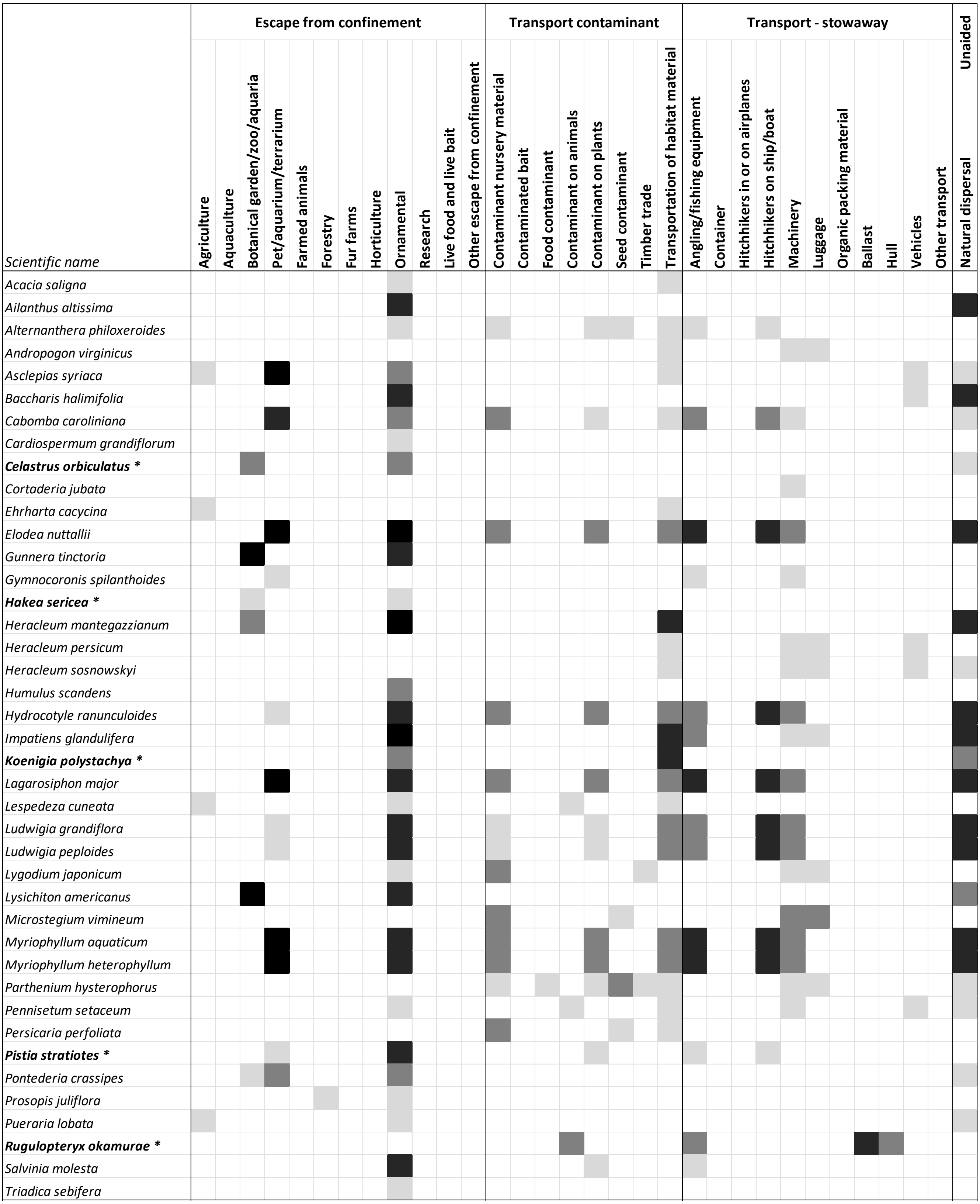
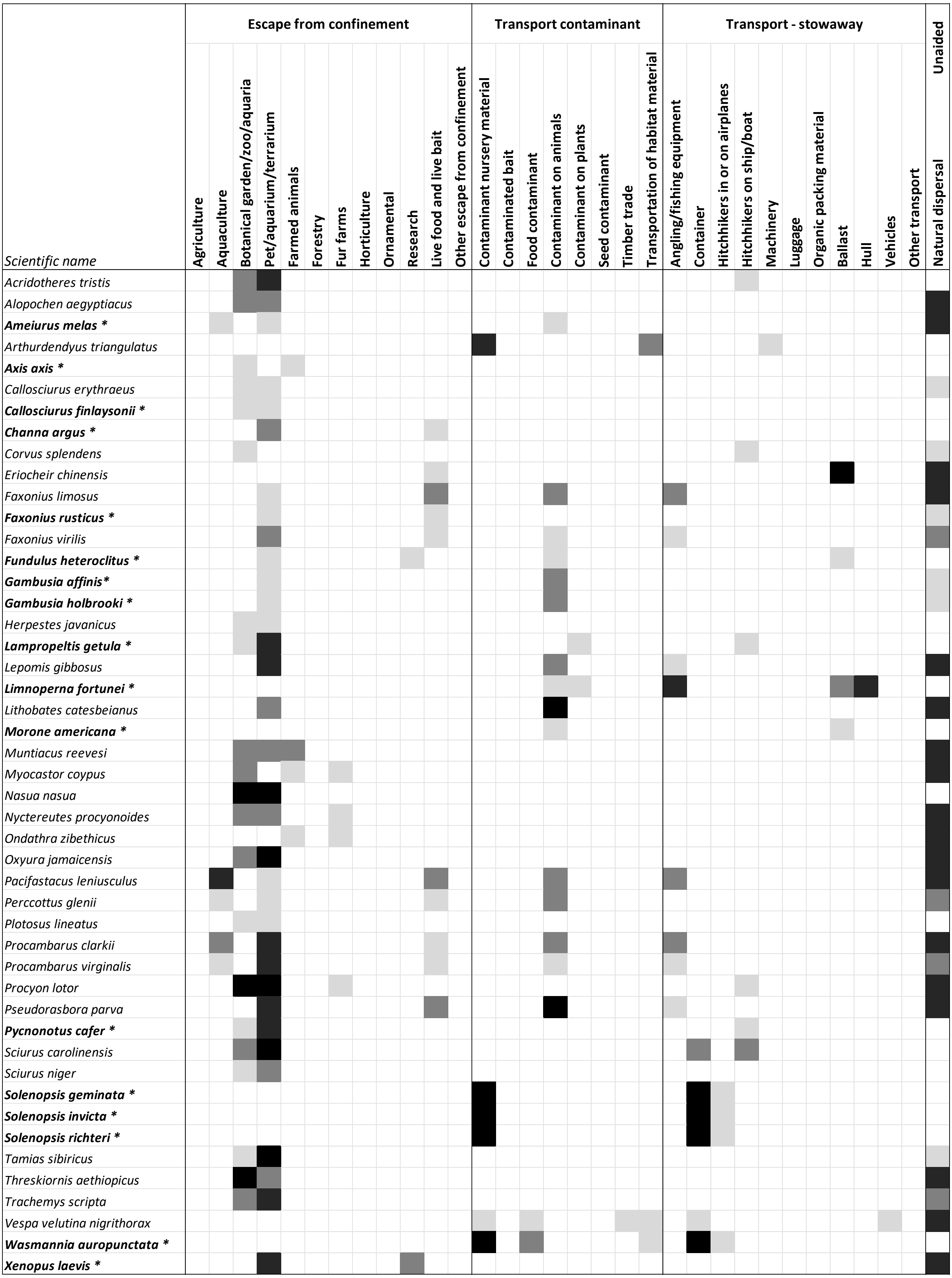
7. Annex

Table presenting frequency-categories (as a proxy for volume) of use of all species in each pathway (light grey: 0,33 / grey: 0,66 / black: 1 / white: 0) – more information on the scores is available in Table 3.




Escape from confinement
Transport contaminant
Transport - stowaway
Unaided
Scientific name
Agriculture
Aquaculture
Botanical garden/zoo/aquaria
Pet/aquarium/terrarium
Farmed animals
Forestry
Fur farms
Horticulture
Ornamental
Research
Live food and live bait
Other escape from confinement
Contaminant nursery material
Contaminated bait
Food contaminant
Contaminant on animals
Contaminant on plants
Seed contaminant
Timber trade
Transportation of habitat material
Angling/fishing equipment
Container
Hitchhikers in or on airplanes
Hitchhikers on ship/boat
Machinery
Luggage
Organic packing material
Ballast
Hull
Vehicles
Other transport
Natural dispersal
Acridotheres tristis
Alopochen aegyptiacus
Ameiurus melas *
Arthurdendyus triangulatus
Axis axis *
Callosciurus erythraeus
Callosciurus finlaysonii *
Channa argus *
Corvus splendens
Eriocheir chinensis
Faxonius limosus
Faxonius rusticus *
Faxonius virilis
Fundulus heteroclitus *
Gambusia affinis*
Gambusia holbrooki *
Herpestes javanicus
Lampropeltis getula *
Lepomis gibbosus
Limnoperna fortunei *
Lithobates catesbeianus
Morone americana *
Muntiacus reevesi
Myocastor coypus
Nasua nasua
Nyctereutes procyonoides
Ondathra zibethicus
Oxyura jamaicensis
Pacifastacus leniusculus
Perccottus glenii
Plotosus lineatus
Procambarus clarkii
Procambarus virginalis
Procyon lotor
Pseudorasbora parva
Pycnonotus cafer *
Sciurus carolinensis
Sciurus niger
Solenopsis geminata *
Solenopsis invicta *
Solenopsis richteri *
Tamias sibiricus
Threskiornis aethiopicus
Trachemys scripta
Vespa velutina nigrithorax
Wasmannia auropunctata *
Xenopus laevis *