PATHWAYS OF UNINTENTIONAL INTRODUCTION AND SPREAD OF IAS OF UNION CONCERN IN BELGIUM

REPORT 1. IDENTIFICATION AND PRIORITIZATION

2018

Invasive Alien Species
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This report is based on a preliminary report on the identification and prioritization of introduction pathways of invasive alien species (IAS) of Union Concern by Arcadis Belgium nv/sa (Van Gossum, 2017).

This report has been produced by the National Scientific Secretariat on Invasive Alien Species and validated by the National Scientific Council on Invasive Alien Species.

The main contributors are Dido Gosse and Jane Reniers (National Scientific Secretariat on Invasive Alien Species), Tim Adriaens (Research Institute for Nature and Forest), Sonia Vanderhoeven (Belgian Biodiversity Platform), Bram D'hondt (Agency for Nature and Forest) and Etienne Branquart (Service Public de Wallonie - Département de l'Etude du Milieu Naturel et Agricole).

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2 EXECUTIVE 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 (Report 1) identifies priority pathways of unintentional introduction in Belgium for 49 IAS of Union Concern listed to date (2018). Priority pathways are defined in the IAS Regulation as pathways requiring actions by priority because of the volume of the alien species using it or of the potential damage of these species 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, a prioritization methodology was developed which took into account the species impact and the frequency of introduction via the pathway. Based on the results of the prioritization, a policy decision was made in 2018 to proceed with developing the following action plans:
1) action plan on introductions of pets, garden and pond plants, aquarium plants and animals, and terrarium plants and animals from private ownership, 2) action plan on introductions through recreational use of freshwater, and 3) action plan for contamination of sediment transports. In further step, the development of these action plans will be further described (Report 2).

Box 1: Terminology according to the Regulation No 1143/2014

Alien species: any live specimen of a species, subspecies or lower taxon of animals, plants, fungi or microorganisms introduced outside its natural range; it includes any part, gametes, seeds, eggs or propagules of such species, as well as any hybrids, varieties or breeds that might survive and subsequently reproduce.
Invasive alien species (IAS): an alien species whose introduction or spread has been found to threaten or adversely impact upon biodiversity and related ecosystem services.
Pathways: the routes and mechanisms of the introduction and spread of IAS.
Vector: refers in the context of the IAS Regulation to a vehicle or medium that carries a species from one location to another.

3 SCOPE

The present report is the first of two reports that deal with pathways of unintentional introduction and spread of invasive alien species (IAS). The first one deals with the identification and prioritization of IAS pathways at the Belgian scale, whereas the second presents the development of action plans for addressing the introduction and spread of IAS through the identified priority pathways. Both reports have to be interpreted as working documents, 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. The current report presents the analysis and results of the prioritization exercise and further discusses the next steps to be taken as well as some points of consideration.

An excel spreadsheet containing all the raw data on species and their pathways, including the scores of the pathway prioritization, that has been used for this report, can be acquired from the National Scientific Secretariat on Invasive Alien Species on request.

4 BACKGROUND

IAS are organisms that are introduced accidentally or deliberately 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 one of the most important direct drivers of loss of ecosystem service change and biodiversity loss (Brunel et al., 2013) And 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. 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 that 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 suit 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 covers minimising new introductions and establishment as well as and 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). Where an IAS has been introduced, early detection and rapid eradication are the most cost-effective ways to prevent establishment and further spread, backed by early warning and information exchange. If eradication is not feasible, control and/or containment measures should be implemented. 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). 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 OiE standards (World Organization for Animal Health) and the EU Aquaculture Regulation, Wildlife Trade Regulation. In addition, introduction pathways of IAS are also addressed in the Aichi biodiversity targets of the Convention on Biological Diversity (CBD), under Target 9: "*By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment*". Thus, three actions with regard to pathways are highlighted under Target 9: to identify pathways, to prioritize pathways and to manage pathways. The IAS Regulation reiterates the commitment of the European Union to meet the CBD targets.

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 can be even harder to manage in the new environment than intentionally introduced species (Pysec et al., 2011). Indeed, globally, the most common routes of invasion by vertebrates is escape from containment or deliberate release by irresponsible owners, while most invasive invertebrates arrive as the result of contamination (Hulme, 2008). Plants are most likely to spread due to escape from gardens and parks. Microorganisms, diseases and fungi tend to arrive as contaminants of their hosts. Invasions through transport corridors such as canals, bridges, tunnels and roadsides are 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.

5 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: Production of a Belgian inventory of introduction pathways of 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.

5.1 SPECIES CONSIDERED

The species covered by this pathway analysis are all 49 species of Union Concern to date (2018): (TABLE 1). These includes the species of Implementing Regulation (EU) No 2016/1141 (37 species) and Implementing Regulation (EU) No 2017/1263 (12 species). To downgrade the importance of pathways for the listed species that are unlikely to establish a viable population on the Belgian territory, we included establishment potential in the prioritization formula. Establishment potential was considered particularly low for *Eichhornia crassipes*, *Parthenium hysterophorus*, *Pueraria montana*, *Gunnera tinctoria*, *Pennisetum setaceum*, *Alternanthera philoxeroides, Herpestes javanicus, Nasua nasua.*

TABLE 1: LIST OF 49 SPECIES OF CONCERN IN THIS STUDY. IT IS INDICATED WHETHER THE SPECIES IS INCLUDED IN THE IMPLEMENTING REGULATION (EU) NO 2016/1141) OR IN THE 'IMPLEMENTING REGULATION (EU) NO 2017/1263). "*": THE SPECIES CANNOT ESTABLISH IN BELGIUM.

Scientific name	Common name (Dutch)	Common name (French)	Entry into force
Baccharis halimifolia L	Struikaster	Séneçon en arbre	2016
Cabomba caroliniana Gray	Waterwaaier	Cabomba de Caroline	2016
Eichhornia crassipes (Martius) Solms	Waterhyacint	Jacinthe d'eau	2016*
Hydrocotyle ranunculoides L. f.	Grote waternavel	Hydrocotyle fausse renoncule	2016
Heracleum persicum Fischer	Perzische berenklauw	Berce de Perse	2016
Heracleum sosnowskyi Mandenova	Sosnowsky's berenklauw	Berce de Sosnowski	2016
Lagarosiphon major (Ridley) Moss	Verspreidbladige waterpest	Elodée à feuilles alternes	2016
Myriophyllum heterophyllum Michaux	Ongelijkbladig vederkruid	Myriophylle hétérophylle	2017
Myriophyllum aquaticum (Vell.) Verdc.	Parelvederkruid	Myriophylle du Brésil	2016
Ludwigia grandiflora (Michx.) Greuter & Burdet	Grote waterteunisbloem	Jussie à grandes fleurs	2016
Ludwigia peploides (Kunth) P.H. Raven	Kleine waterteunisbloem	Jussie rampante	2016
Lysichiton americanus Hultén and St. John	Moerasaronskelk	Faux-arum	2016
Parthenium hysterophorus L.	Schijnambrosia	Fausse chamomille	2016*

Pueraria montana (Lour.) Merr. *var. lobata* (Willd.)	Kudzu	Kudzu	2016*
Heracleum mantegazzianum Sommier & Levier	Reuzenberenklauw	Berce du Caucase	2017
Impatiens glandulifera Royle	Reuzenbalsemien	Balsamine de l'Himalaya	2017
Persicaria perfoliata (L.) H. Gross	Gestekelde duizendknoop	Renouée perfoliée	2016
Elodea nuttallii (Planch.) St. John	Smalle waterpest	Elodée de Nuttall	2017
Gunnera tinctoria (Molina) Mirbel	Chileense reuzenrabarber	Rhubarbe géante du Chili	2017*
Pennisetum setaceum (Forssk.) Chiov.	Lampenpoetsersgras	Herbe aux écouvillons pourpres	2017*
Asclepias syriaca L.	Zijdeplant	Asclépiade de Syrie	2017
Alternanthera philoxeroides (Mart.) Griseb.	Alligatorkruid	Herbe à alligator	2017*
Microstegium vimineum (Trin.) A. Camus	Japans steltgras	Herbe à échasses japonaise	2017
Alopochen aegyptiacus Linnaeus	Nijlgans	Ouette d'Egypte	2017
Oxyura jamaicensis Gmelin	Rosse stekelstaart	Erismature rousse	2016
Corvus splendens Viellot	Huiskraai	Corbeau familier	2016
Threskiornis aethiopicus Latham	Heilige ibis	Ibis sacré	2016
Sciurus carolinensis Gmelin	Grijze eekhoorn	Ecureuil gris	2016
Tamias sibiricus Laxmann	Siberische grondeekhoorn	Tamia de Sibérie	2016
Callosciurus erythraeus Pallas	Pallas' eekhoorn	Ecureuil de Pallas	2016
Sciurus niger Linnaeus	Amerikaanse voseekhoorn	Ecureuil fauve	2016
Muntiacus reevesi Ogilby	Muntjak	Muntjac de Chine	2016
Procyon lotor Linnaeus	Wasbeer	Raton laveur	2016
Nyctereutes procyonoides Gray	Wasbeerhond	Chien viverrin	2017
Herpestes javanicus É. Geoffroy Saint-Hilaire	Indische mangoeste	Mangouste	2016*
Nasua nasua Linnaeus	Rode neusbeer	Coati roux	2016*
Myocastor coypus Molina	Beverrat	Ragondin	2016
Ondatra zibethicus Linnaeus	Muskusrat	Rat musqué	2017
Lithobates (Rana) catesbeianus Shaw	Amerikaanse stierkikker	Grenouille taureau	2016
Eriocheir sinensis H. Milne Edwards	Chinese wolhandkrab	Crabe chinois	2016
Perccottus glenii Dybowski	Amoergrondel	Goujon de l'Amour	2016
Pseudorasbora parva Temminck & Schlegel	Blauwbandgrondel	Goujon de Chine	2016
Trachemys scripta Schoepff (incl. subspecies)	Lettersierschildpad	Tortue de Floride	2016
Vespa velutina nigrithorax de Buysson	Aziatische hoornaar	Frelon asiatique	2016
Procambarus clarkii Girard	Rode Amerikaanse rivierkreeft	Ecrevisse de Louisiane	2016
Procambarus fallax (Hagen, 1870) f. virginalis	Marmerkreeft	Ecrevisse marbrée	2016
Pacifastacus leniusculus Dana	Californische rivierkreeft	Ecrevisse signal	2016

Orconectes virilis Hagen	Geknobbelde Amerikaanse rivierkreeft	Ecrevisse à pinces bleues	2016
Orconectes limosus Rafinesque	Gevlekte Amerikaanse rivierkreeft	Ecrevisse américaine	2016

5.2 PATHWAY IDENTIFICATION

5.2.1 PATHWAY CATEGORIZATION

To classify pathways, the definitions the CBD classification, Harrower et al. (2018) were used, as well as input from the European Commission:
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).

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".

5.2.2 *INVENTORY OF SPECIES SPECIFIC PATHWAYS*

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.

In this study, pathways of introduction of Union List species were retrieved from published sources which are mainly based on available pathway information in 1) the DAISIE and GRISS database (Saul et al., 2017), 2) the CABI compendium (e-ref1), 3) pathway information in the European risk assessments (e-ref2), 4) pathway assessments at larger geographical scales (NOBANIS, 2015) and 5) 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 supplemented, adapted and reviewed to assess the relevance of the pathways for the Belgian territory using 1) published 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), 2) online databases and 3) expert review.
Pathways of spread of Union List IAS were equally considered and were analyzed together with the pathways of introduction.

5.3 PATHWAY PRIORITIZATION

5.3.1 *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) per 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-quantitive 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. ISEIA scores were already available for 28 of the 49 species of the Union List species (ias.biodiversity.be), based on systematic assessment by

[1] http://ias.biodiversity.be (accessed 16/08/2017).

expert panels through the Harmonia information system. The remaining 21 species for which no ISEIA impact score was available for Belgium (TABLE 2), a score for the four different variables (i-iv) was attributed by experts for each species, 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 Belgium, we also included an assessment of the "establishment potential" for the current dataset, and used it to weigh variable "dispersal potential" in the formula. To this end, we used a scale from 1 (very low likelihood of establishment in Belgium) to 5 (very high likelihood of establishment in Belgium). Already established species in Belgium received the maximum score (5). The ability of species to adapt to the current climatic conditions in Belgium and to establish in Belgium ranges from low (e.g. *Eichhornia crassipes*, a (sub)tropical species) to high (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 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.

TABLE 2: ASSESSMENT OF ESTABLISHMENT POTENTIAL AND RESULTING ISEIA SCORE IN BELGIUM FOR THE SPECIES CONSIDERED. *: ADDED FOR THE 21 SPECIES FOR WHICH NO IMPACT SCORES WERE ALREADY AVAILABLE FOR BELGIUM.

Species	Establishment	ISEIA score
Alopochen aegyptiacus	5	12
*Alternanthera philoxeroides**	2	10
*Asclepias syriaca**	4	11
Baccharis halimifolia	5	12
Cabomba caroliniana	5	10
Callosciurus erythraeus	5	11
*Corvus splendens**	5	7
*Eichhornia crassipes**	1	8
Elodea nuttallii	5	12
*Eriocheir sinensis**	5	12
*Gunnera tinctorial**	3	10
Heracleum mantegazzianum	5	10
*Heracleum persicum**	4	10
*Heracleum sosnowskyi**	4	10
*Herpestes javanicus**	4	9
Hydrocotyle ranunculoides	5	12
Impatiens glandulifera	5	12
Lagarosiphon major	5	12
Lithobates catesbeianus	5	12
Ludwigia grandiflora	5	12
Ludwigia peploides	5	12
Lysichiton americanus	5	10
*Microstegium vimineum**	3	11
Muntiacus reevesi	5	12

Myocastor coypus	5	12
Myriophyllum aquaticum	5	12
Myriophyllum heterophyllum	5	12
*Nasua nasua**	4	9
Nyctereutes procyonoides	5	9
Ondatra zibethicus	5	12
*Orconectes limosus**	5	12
*Orconectes virilis**	5	12
Oxyura jamaicensis	5	10
*Pacifastacus leniusculus**	5	12
*Parthenium hysterophorus**	3	6
*Pennisetum setaceum**	2	9
Perccottus glenii	5	11
*Persicaria perfoliata**	4	10
Procambarus clarkii	5	12
*Procambarus fallax forma virginalis **	5	12
Procyon lotor	5	11
Pseudorasbora parva	5	11
*Pueraria lobate**	3	10
Sciurus carolinensis	5	11
Sciurus niger	5	9
Tamias sibiricus	5	9
Threskiornis aethiopicus	5	11
*Trachemys scripta(incl. subspecies)**	1	7
*Vespa velutina nigrithorax**	5	12

5.3.2 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). Hence, we used a crude assessment of the frequency of introduction of the species with a given pathway as a proxy for volume in the absence of interception data. 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 (TABLE 3). The scores were reviewed by experts. Bearing in mind the absence of quantitative data on pathways in Belgium and the limited information available (e.g. due to a lack of interception data), the assessment of frequency followed a precautionary approach. 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.

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. E.g. *Cabomba caroliniana* is known to be spread by boating. The few locations in Belgium where the species occurs are isolated ponds without boating activity.	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 being 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 on 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.

5.3.3 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 two approaches in line with the EU IAS Regulation's requirements:

1) Prioritization based on the number of species: pathways are ranked based on the number of species from the list of 49 species that are introduced through that pathway.

2) Prioritization based on the impact of a species and the frequency of introduction per pathway: pathways are ranked based on a formula that takes into account the number of species in the pathway, the relative ecological impact score (corrected with establishment potential) and the frequency score (as a proxy for volume – see 5.3.2). This formula is defined as follows:

[Pathway priority score] = ([establishment potential] * [ISEIA score/10] * [pathway frequency])

By definition, the ISEIA scores for ecological impact of Union List species should be (and are) rather high. ISEIA scores range between 4 and 12 and were standardized 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 (ISEIA/10) ; 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	
			∑(I×V)	=
∑(spp.) = 12	∑(I) = 13		6,821	

6 RESULTS

6.1 PATHWAY IDENTIFICATION

A total of 23 (potential) pathways of introduction and spread were identified for the 49 listed species of Union concern, representing 4 main pathway categories: natural dispersal, escape from confinement, transport stowaway, transport contaminant (TABLE 5; FIG 2).

Some pathways were relevant for more than 1/3th of the species in the dataset (escape of pet/aquarium/terrarium species, escape of species from zoos, escape of plant species in other use than horticulture, contaminant of transport of habitat material), whereas others were only relevant for two or even a single species (contaminant of food and timber, transport stowaways in ballast water or containers and escape from confinement in agriculture and (fur)farms).

When looking at species groups (aquatic animals, aquatic plants, terrestrial plants; birds and mammals (FIG 3), some pathways are relevant across groups. For example, natural dispersal and the escape from containment pathway, were represented in all groups. More specifically, the represented "escape from confinement" subcategories indicate that release/disposal by private owners plays a role for all groups, as well as (historical) escape from zoos or botanical gardens. Whereas other pathways are only relevant for a particular group (e.g. escape as live bait is only mentioned for aquatic animals).

For the identified "contaminant of transported goods" pathways, the group of the terrestrial plants was always concerned, as they can easily contaminate batches through their seeds (e.g. contaminant of timber, food, seeds, animals, plants, habitat and nursery material). The aquatic plants are mainly introduced when contaminated goods were sourced from the water (contaminant of habitat and nursery material, plants, seeds), and aquatic animals were only implicated as contaminants of batches of fish.

The aquatic plants were represented in all the identified transport stowaway categories (hitchhikers on ships and boats, machinery and angling equipment), although these subcategories were not exclusive for aquatic plants: angling and fishing equipment for example also aids in the introduction and spread of terrestrial shore plants such as *Impatiens glandulifera*; machinery also transports several terrestrial plants and two animals *Corvus splendens* and *Scurius carolinensis* hitchhike on ships/boats.

Vespa velutina was not included in one of the species group since it is the only terrestrial invertebrate and has his own specific dispersal pattern that does not relate with other species.

6.2 PATHWAY PRIORITIZATION

Pathway prioritization based on 1) numbers of species using the pathway or based on 2) the impact of the species using the pathway were relatively similar (TABLE 5). Only 5 of the 23 identified pathways that were relevant for Belgium changed rank when we compared the two prioritization methods. The changes were minimal since the pathways were downgraded only one or two ranks in the ranking method based on species' impact. Those five main pathways are: transport stowaway on angling/fishing equipment, hitchhikers on ships and boats, transport contaminant on

animals, escape from aquaculture and escape of farmed animals. Because both ranking methods produced such similar results, we will only discuss here the prioritization results based on species impact. Moreover, during the selection of the pathways to be addressed in action plans, the total number of species covered will be specifically considered.

"Natural dispersal" ranks number 1 in the pathway ranking (according to species impact), with a relatively large drop in importance for the subsequent pathways such as 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 plant and zoo species ranked at number 2, 3 and 5. Stowaways on angling and fishing equipment was ranked 4th. The pathway contaminant of habitat material is ranked at 6th place, having roughly half of the impact/importance as escape of pet/aquarium and terrarium species. Stowaways on shops and machinery are ranked 7th and 8th respectively. Transport contaminant of nursery material, animals and plants are ranked 9, 10th and 11th respectively. The pathway showing the lowest priority is "food contaminant", yet still relevant for *Parthenium hysterophorus* and *Vespa velutina*.

TABLE 5: PATHWAYS RANKED 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	No of species	∑Impact x volume
Unaided	Natural dispersal	40	35,44
Escape from confinement	Pet/aquarium/terrarium species	31	23,97
Escape from confinement	Ornamental purposes other than horticulture	18	16,62
Transport stowaway	Angling/fishing equipment	16	12,50
Escape from confinement	Botanical garden/zoo/aquaria	19	12,31
Transport contaminant	Transportation of habitat material	18	10,69
Transport stowaway	Hitchhikers on ship/boat	11	10,35
Transport stowaway	Machinery	14	8,15
Transport contaminant	Contaminant nursery material	13	7,7352
Transport contaminant	Contaminant on animals	9	6,48
Transport contaminant	Contaminant on plants	10	5,61
Escape from confinement	Live food and live bait	8	4,26
Escape from confinement	Aquaculture	5	2,75
Transport stowaway	Vehicles	6	2,15
Transport stowaway	Luggage	5	1,99
Escape from confinement	Farmed animals	3	1,58
Escape from confinement	Fur farms	4	1,45
Transport contaminant	Seed contaminant	4	1,42
Transport stowaway	Ballast	1	1,20
Transport stowaway	Container	2	1,12
Escape from confinement	Agriculture	2	0,69

Transport contaminant	Timber trade	2	0,59
Transport contaminant	Food contaminant	2	0,59
Corridor	Interconnected waterways	0	0,00
Escape from confinement	Horticulture	0	0,00
Escape from confinement	Research	0	0,00
Transport stowaway	Other transport	0	0,00
Transport stowaway	Organic packing material	0	0,00
Escape from confinement	Forestry	0	0,00
Transport stowaway	Hull	0	0,00
Transport contaminant	Contaminated bait	0	0,00
Escape from confinement	Other escape from confinement	0	0,00
Transport stowaway	Hitchhikers in or on airplanes	0	0,00

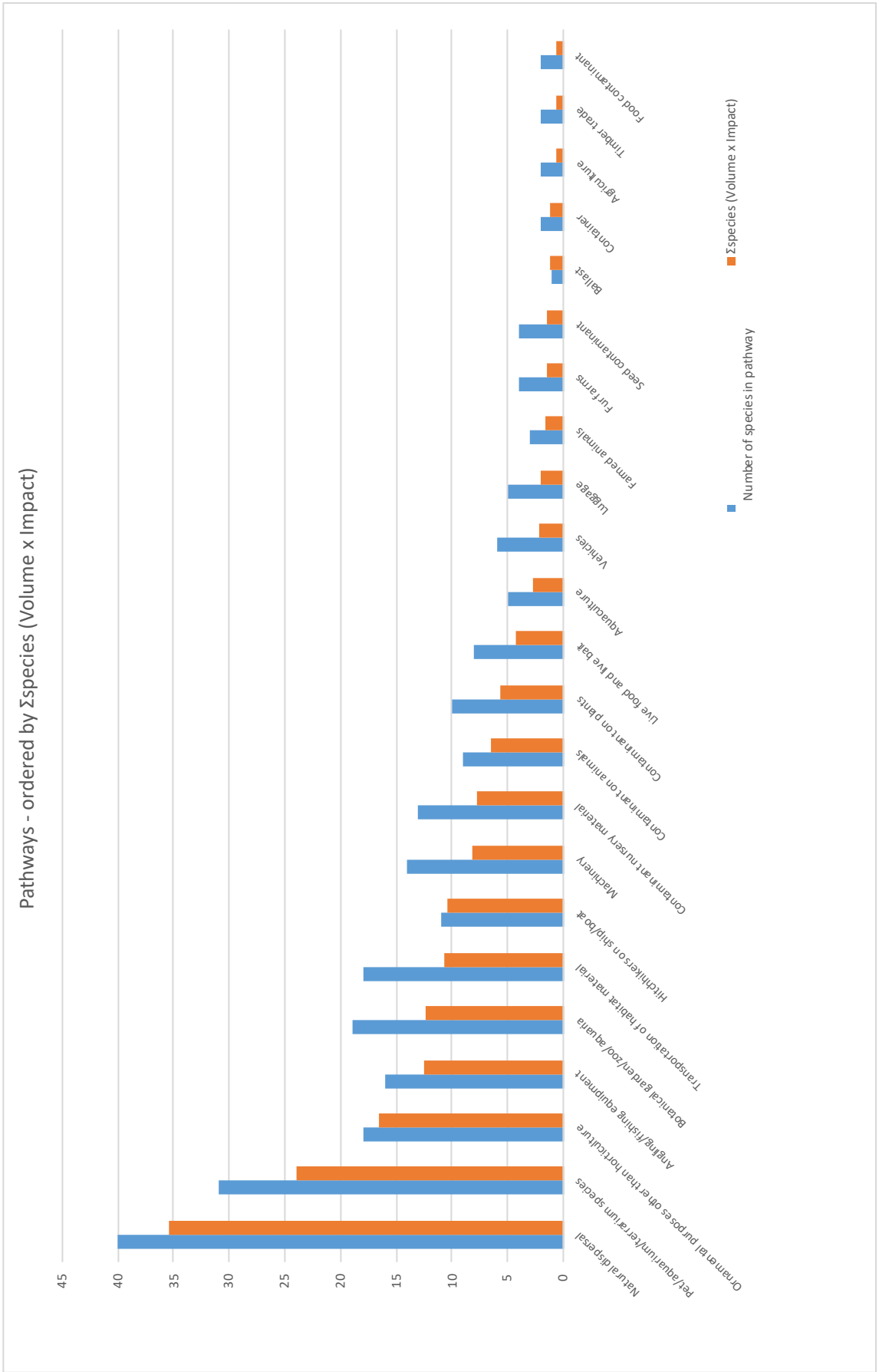
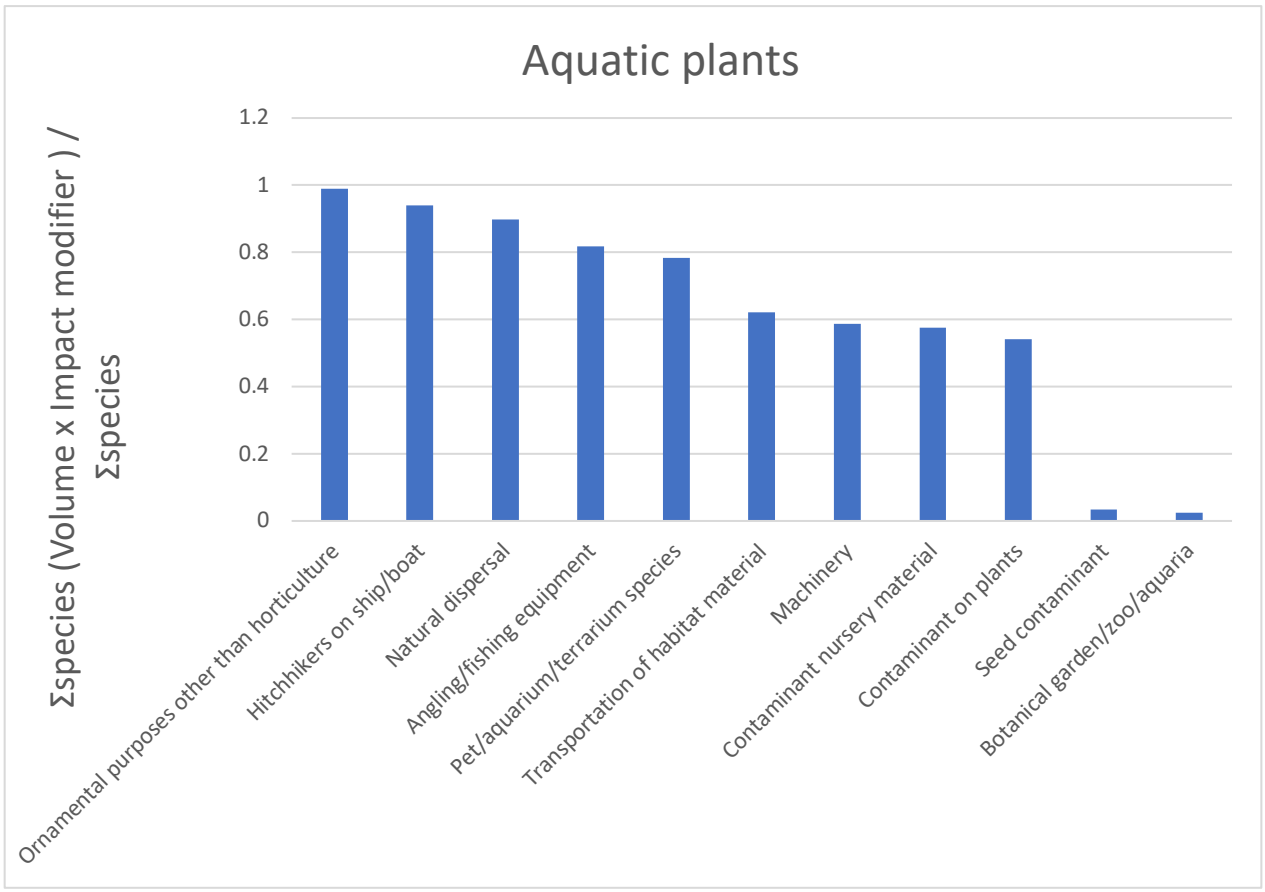
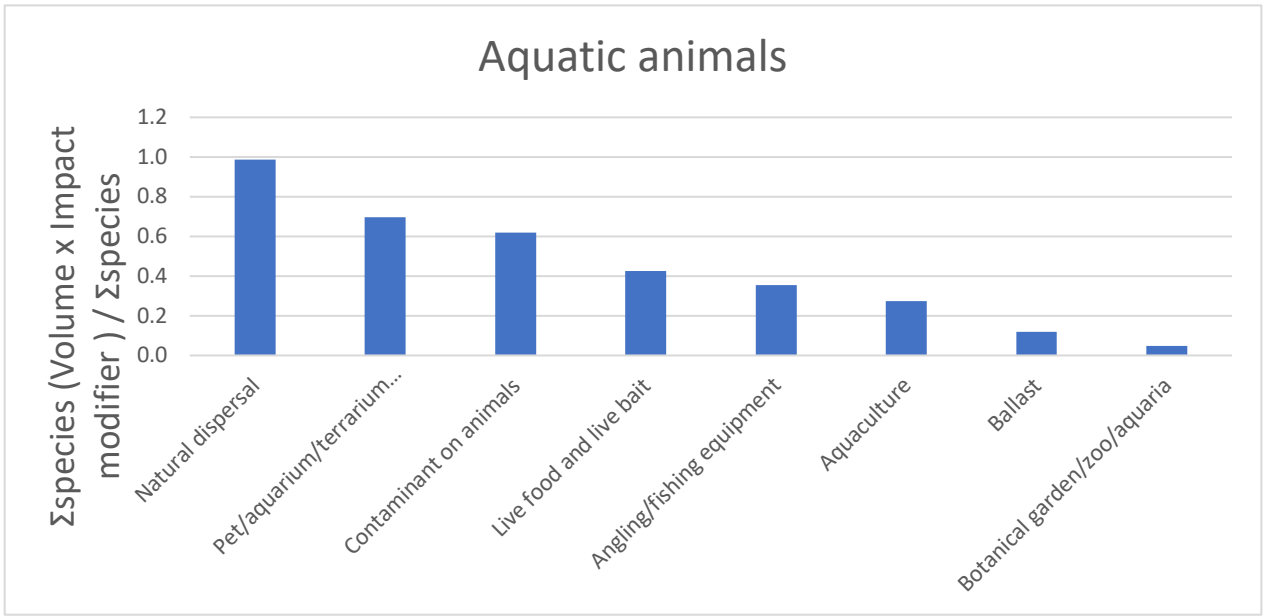
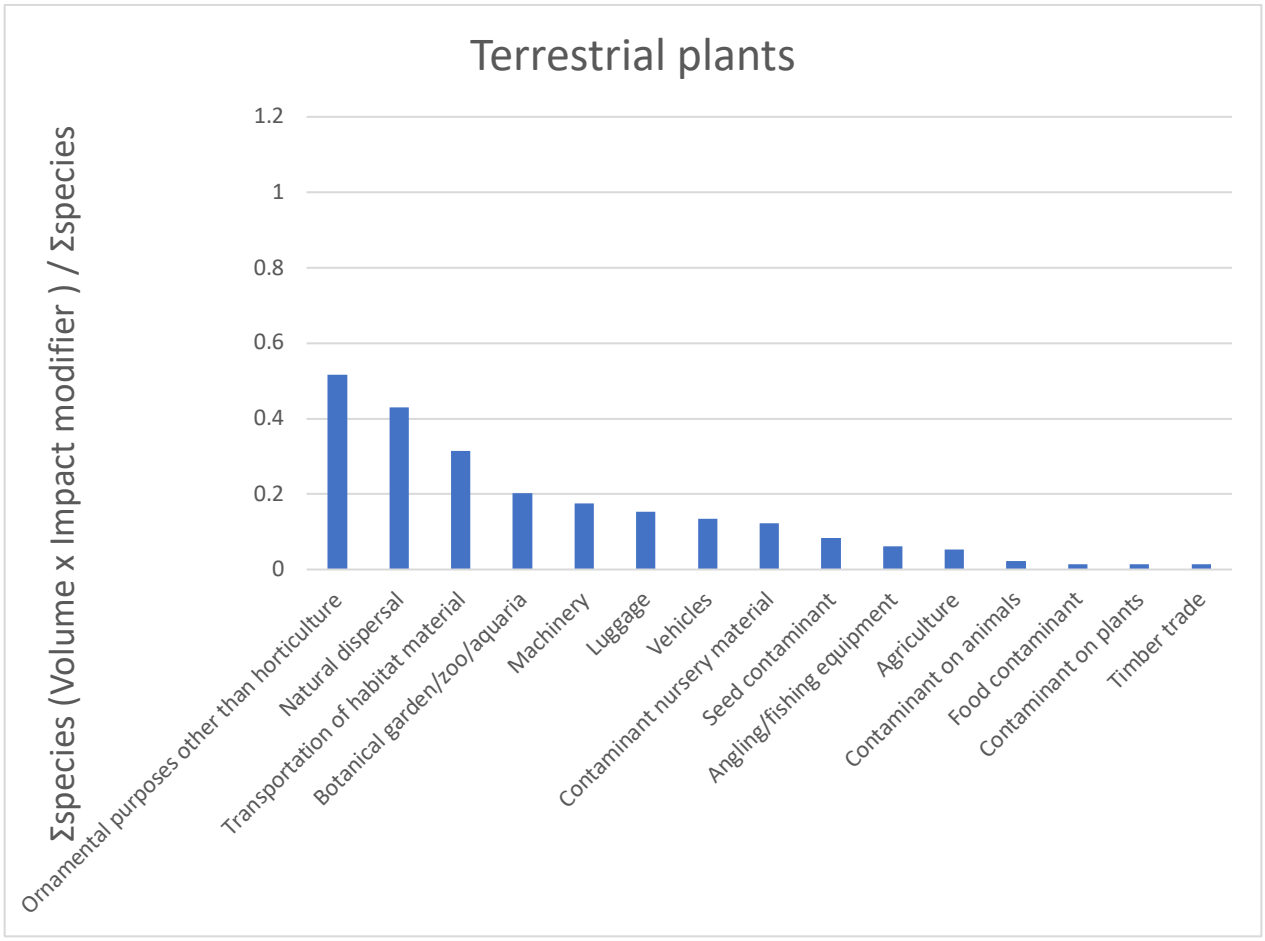


FIGURE 2: PATHWAYS RANKED ACCORDING TO THE CUMULATIVE FACTOR ON IMPACTS AND VOLUME (FREQUENCY OF INTRODUCTION FOR THE SPECIES IN A PATHWAY) AND SHOWING THE NUMBER OF SPECIES IN A PATHWAY.


Aquatic plants
Σspecies (Volume x Impact modifier) / Σspecies
1.2
1
0.8
0.6
0.4
0.2
0
Ornamental purposes other than horticulture
Hitchhikers on ship/boat
Natural dispersal
Angling/fishing equipment
Pet/aquarium/terrarium species
Transportation of habitat material
Machinery
Contaminant nursery material
Contaminant on plants
Seed contaminant
Botanical garden/zoo/aquaria


Aquatic animals
Σspecies (Volume x Impact modifier) / Σspecies
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Natural dispersal
Pet/aquarium/terrarium...
Contaminant on animals
Live food and live bait
Angling/fishing equipment
Aquaculture
Ballast
Botanical garden/zoo/aquaria



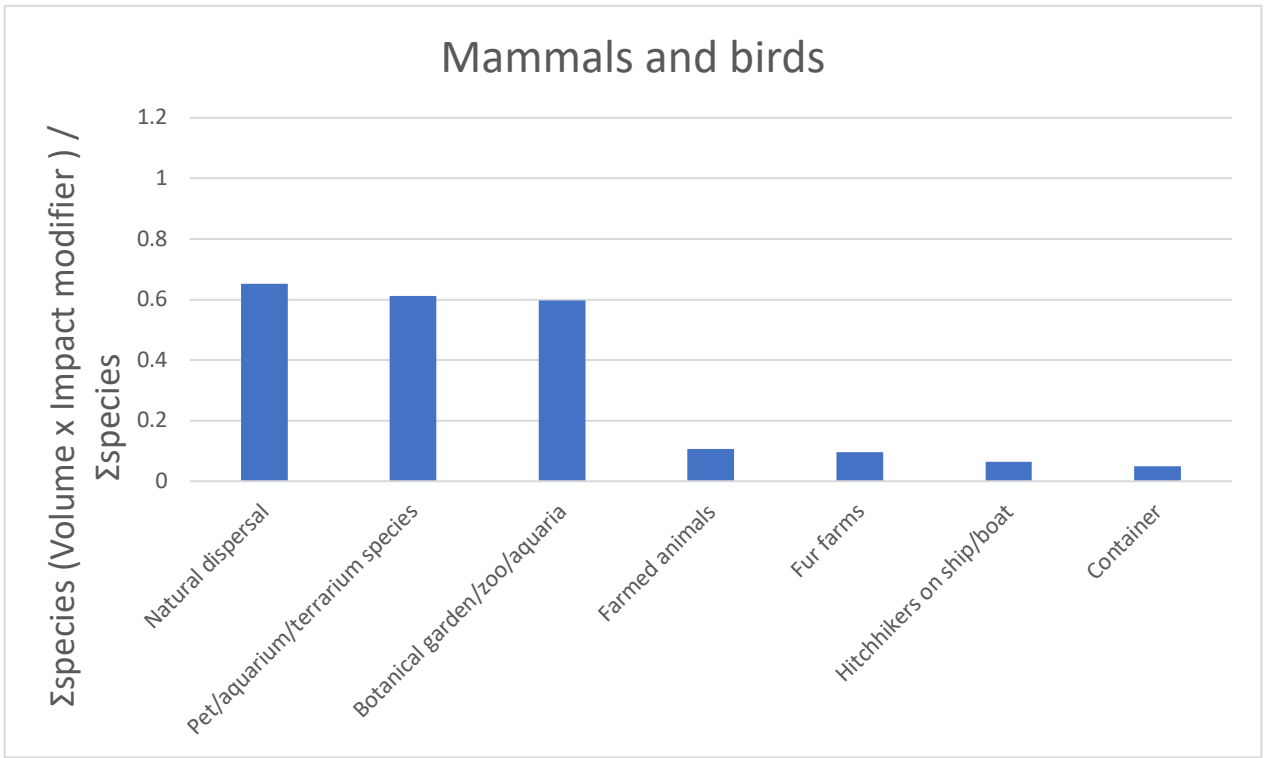


FIGURE 3: PATHWAY RANKING ACCORDING TO SPECIES GROUPS: "AQUATIC PLANTS", "AQUATIC ANIMALS", "TERRESTRIAL PLANTS" AND "MAMMALS AND BIRDS"

7 TOWARDS ACTION PLANS ON PRIORITY PATHWAYS FOR IAS IN BELGIUM

7.1 DEVELOPING ACTION PLANS FOR PRIORITY PATHWAYS

The identification and prioritization of pathways, as presented in this report, is a first step in the development of preventive strategies towards introduction pathways through action plans. In the development of these action plans, other factors than the cumulative impact of the species being transported along the pathway come into play. Decision making on pathways action plans is not only based on the scientific ranking but also considers socio-economic factors. In Belgium, measures to be taken under a pathway action plan fall under different federal and regional competent authorities. The federal authority in Belgium is competent for import, export and transit, customs as well as the marine environment. The regions (Flanders, Wallonia and Brussels-Capital region) are competent for internal trade, possession, inspection, monitoring and management of IAS. Therefore, when considering suitable actions to be taken to prevent further introductions of IAS, the different legislative and policy frameworks need to be addressed and potential differences in pathway relevance for each of the regions may be reflected.

Based on the results described here above, there has been a policy decision in 2018 to proceed with developing the following action plans:

1. Action plan on introductions of pets, garden and pond plants, aquarium plants and animals and terrarium plants and animals from private ownership. This action plan pertains to escape of species of Union Concern that are kept in private possession. Under escape, both dumping and escape is included.
2. Action plan on introductions through recreational use of freshwater. This action plan pertains to introductions of plants and animals through recreational angling, fish breeding and freshwater boating.
3. Action plan for contamination of sediment transports. This action plan pertains to transportation and propagules of plants and animals with sediment and machinery used. Since the Union list does not contain marine species, marine sediment transportation is not covered by this action plan.

These three action plans cover 9 pathways out of the first 12 from the prioritization ranking and are relevant for 46 out of 49 listed species (TABLE 6).

As described in the EU regulation, action plans can entail a diverse set of measures: "(…) *voluntary actions and codes of good practice, (…) measures (…) to raise awareness; minimize contamination of goods, commodities, vehicles and equipment by specimens of invasive alien species, including*

measures to tackle transportation of invasive alien species from third countries; ensure appropriate checks at the Union borders, other than the official controls pursuant to Article 15."

TABLE 6: SPECIES' USE OF THE PATHWAYS OF INTRODUCTION AND SPREAD SELECTED TO BE ADDRESSED THROUGH ACTION PLANS. ACTIONS PLANS: - 1: ACTION PLAN ON INTRODUCTIONS OF PETS, GARDEN AND POND PLANTS, AQUARIUM PLANTS AND ANIMALS AND TERRARIUM PLANTS AND ANIMALS FROM PRIVATE OWNERSHIP - 2: ACTION PLAN ON INTRODUCTIONS THROUGH RECREATIONAL USE OF FRESHWATER - 3: ACTION PLAN FOR CONTAMINATION OF SEDIMENT TRANSPORTS.

	1			2				3	
→ Pathways ↓ Species	Pet / Aquarium / Terrarium	Ornamental purposes other than horticulture	Contaminant on plants	Angling and fishing	live food and live bait	hitchikers on ship/boats	contaminant on animals	Transportation of habitat material	Machinery
Alopochen aegyptiacus	v								
Callosciurus erythraeus	(v)								
Corvus splendens									
Eriocheir sinensis					(v)				
Herpestes javanicus	(v)								
Lithobates (Rana) catesbeianus	v						v		
Muntiacus reevesii	v								
Myocastor coypus									
Nasua nasua	v								
Nyctereutes procyonoides	v								
Ondatra zibethicus									
Orconectes limosus	(v)			v	v		v		
Orconectes virilis	v			(v)	(v)		(v)		
Oxyura jamaicensis	v								
Pacifastacus leniusculus	(v)			v	v		v		
Perccottus glenii	(v)				(v)		v		
Procambarus cf fallax	v			(v)	(v)		(v)		
Procambarus clarkii	v			v	(v)		v		
Procyon lotor	v								
Pseudorasbora parva	v			(v)	v		v		
Sciurus carolinensis	v								
Sciurus niger	v								
Tamias sibiricus	v								
Threskiornis aethiopicus	v								
Trachemys scripta	v								
Vespa velutina nigrithorax								(v)	
Alternanthera philoxeroides	(v)	(v)	(v)	(v)		(v)		(v)	
Asclepias syriaca		v						(v)	
Baccharis halimifolia		v							
Cabomba caroliniana	v	v	(v)	v		v		(v)	(v)
Eichhornia crassipes	v	v							
Elodea nuttallii	v	v	v	v		v		v	v
Gunnera tinctoria		v							
Heracleum mantegazzianum		v						v	
Heracleum persicum								(v)	(v)
Heracleum sosnowskyi								(v)	(v)
Hydrocotyle ranunculoides	(v)	v	v	v		v		(v)	v
Impatiens glandulifera		v		v				v	(v)
Lagarosiphon major	v	v	v	v		v		v	v
Ludwigia grandiflora	(v)	v	(v)	v		v		v	v
Ludwigia peploides	(v)	v	(v)	v		v		v	v
Lysichiton americanus		v							
Microstegium vimineum									v
Myriophyllum aquaticum	v	v	v	v		v		v	v
Myriophyllum heterophyllum	v	v	v	v		v		v	v
Parthenium hysterophorus			(v)					(v)	(v)
Pennisetum setaceum		(v)					(v)	(v)	(v)
Persicaria perfoliata								(v)	
Pueraria montana var. *lobata*		(v)							

v = Union list species actively using the pathway (BE). (v) = Union list species potentionally using the pathway (BE).

7.2 ADDRESSING KNOWLEDGE GAPS ON INTRODUCTION PATHWAYS

Current prioritization of pathways of introduction and spread of IAS of union concern lead to the identification of important pathways of introduction and spread of IAS, relevant for Belgium. During the process, some knowledge gaps were identified. Describing and where possible addressing these gaps will aid in a required follow-up work such as future prioritization upon future update of the list of species of EU concern. Some limitations of current analysis are considered below:

- The current analysis is not a full pathway analysis on IAS relevant for Belgium. By definition, the list of species of EU Concern only considers a subset of high impact species. Although including species that are not of Union concern in the pathway prioritization is not an obligation for the EU legislation, it can be of added value. 1) 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 the current absence of marine species on the list. Focusing a prioritization on a larger set of species (e.g. all alien species) would better prevent future invasions and also render the action plans more fit for future list update. A documented register of al exotic species in Belgium is currently being developed by TrIAS project (Desmet P. et al, 2019).
- There still is uncertainty about the role of certain pathways of introduction. In the case where no pathway information was available in literature or documents, expert opinion was used to asses pathway relevance in the current analysis. Some considerations can help reducing the need of expert opinion:
    - Data on frequency, number and identity of propagules that are imported, transported or spread through introduction routes are not available for Belgium. For example interception data 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.
    - Improving and expanding registration and storage of data on inspections and interception on exotic species (to other goods), 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.

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Annex 1

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.