Provision of horizon scanning and analysis of pathways of spread of invasive species into Scotland

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Executive summary

The number of invasive non-native species arriving in Scotland is increasing year on year.

Horizon scanning, to make predictions about the next potential invasive non-native species that could arrive, establish and impact on biodiversity and ecosystems, can inform strategy and action to reduce the threat of biological invasions.

Pathway analysis was used to rank the pathways of introduction of non-native species introduced into Scotland since 1950 and likely pathways of introduction for non-native species into Scotland in the next ten years.

Overall, 52 experts contributed to a horizon scanning study which assessed hundreds of potential species spanning freshwater, marine and terrestrial environments.

The scope of the study was to consider invasive non-native species that were currently absent in Scotland but that have the highest likelihood of arrival, establishment and the magnitude of their potential negative impact on biodiversity and ecosystems over the next 10 years. Preliminary lists, without impact scores, for invasive non-native species that could have a potential negative impact on the economy and human health were also reviewed.

Thirty invasive non-native species were agreed to have a high risk of arriving, establishing and impacting biodiversity and ecosystems in the next 10 years. From this a priority list of 10 invasive non-native species was extracted. Awareness raising was seen as critical, and likely to be effective, in preventing the arrival and spread of these top 10 invasive non-native species.

Five freshwater species were reported in the top 10 list of species: three molluscs (Asiatic clam (*Corbicula fluminea*), quagga mussel (*Dreissena rostriformis bugensis*) and zebra mussel (*Dreissena polymorpha*)) and two submerged plant species (floating pennywort (*Hydrocotyle ranunculoides*) and parrot's feather (*Myriophyllum aquaticum*)). Freshwater environments are considered to be amongst the most vulnerable habitats to biological invasions and freshwater biodiversity is culturally and economically important in Scotland. One marine mollusc *Crepidula fornicata* was also listed in the top 10 invasive non-native species.

The remaining five invasive non-native species within the top 10 comprised two terrestrial plants, highbush blueberry (*Vaccinium corymbosum* and hybrids) and pheasant's tail grass (*Anemanthele lessoniana*), two vertebrates (Reeve's muntjac (*Muntiacus reevesi*) and raccoon (*Procyon lotor*) and flatworms (four species grouped together for communication purposes (*Australoplana sanguinea*, *Caenoplana variegata*, *Kontikia andersoni* and *Obama nungara*).

The most important pathways of arrival and spread associated with the long list of 171 invasive non-native species and 1096 established non-native species in Scotland are the horticultural and ornamental pathways. The pet pathway is important for introducing species on the horizon scanning long list but was not ranked as high for established non-native species. Pathways in the contaminant category have historically been important in introducing non-native species and this is likely to continue to be the case. Furthermore, the natural dispersal of species from an existing invaded range into Scotland is considered an important pathway of arrival.

The results from this horizon scanning study coupled with the pathway analysis provide detailed information to prioritise actions to prevent the establishment of new invasive non-native species in Scotland, including action plans for priority pathways of introduction and spread.

The team

Project team

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Introduction

Invasive non-native species (INNS) are one of the major threats to biodiversity and ecosystem services (Díaz, Settele et al. 2019) and interact with other drivers of biodiversity change including notably climate change and land- or sea-use change (Bonebrake, Guo et al. 2019). The number of non-native species being introduced to new regions around the world is increasing year on year (Seebens, Blackburn et al. 2017). Preventing the arrival and spread of a subset of these non-native species that present the greatest threat, so called INNS, is seen as a priority in the Scottish Biodiversity Strategy[1] and indeed worldwide.

Here we present the outcomes of a short project comprising two main tasks:

i) horizon scanning for INNS that are likely to establish and impact on biodiversity within the next 10 years but are not yet established in Scotland; and

ii) comprehensive analysis of pathways of introduction and spread of new INNS into Scotland.

Horizon scanning, a systematic examination of potential threats and opportunities, can inform prevention strategies including development of pathway action plans, which identify measures to reduce the risk of new INNS introductions and spread, and biosecurity approaches. There are many possible ways to undertake horizon scanning (Roy, Schönrogge et al. 2014); they include consensus methods developed and implemented by the project team (Roy, Peyton et al. 2020). This involves a two-stage approach:

1. Expert groups (marine, freshwater, terrestrial invertebrates, terrestrial plants and terrestrial vertebrates) compile long lists of INNS that are likely to arrive and establish within a region and have a negative impact on native biodiversity and ecosystems within the next 10 years. The expert groups gather information and evidence, through literature and other searches to inform rapid assessment, for the agreed long list of potential INNS;

2. Expert elicitation workshops combine the outputs from the expert groups to ultimately derive a ranked list of INNS spanning all taxonomic groups.

This approach has been implemented for Great Britain (Roy, Peyton et al. 2014), Europe (Roy, Bacher et al. 2019), Ireland (Lucy, Davis et al. 2020), Cyprus (Peyton, Martinou et al. 2019, Peyton, Martinou et al. 2020) and the United Kingdom (UK) Overseas Territories[2] (Hughes, Pescott et al. 2020, Dawson, Peyton et al. 2023). Guiding principles (Roy, Peyton et al. 2020) have been published to assist the process. In these guiding principles, it is noted that is essential to include experts with a diverse range of knowledge across the various environments and taxonomic groups to ensure effective delivery of the horizon scanning.

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[1] Link to Scottish Biodiversity Strategy

[2] Horizon scanning results - GB non-native species secretariat (nonnativespecies.org)

INNS can arrive in Scotland through overseas trade and travel, which may potentially be controlled through enhanced biosecurity measures. For these species, recent horizon scanning exercises completed for Great Britain in 2019 were highly relevant. There are, however, many non-native species established in other parts of Great Britain that have yet to spread to Scotland that require specific attention while also noting that there are species that are native within the UK but non-native in Scotland. The list of Prevention Priority Species (2016) adopted by the Scottish Non-Native Species Action Group was also informative for the horizon scanning.

Scotland's context

Scotland generally has a cooler and wetter climate than the rest of Great Britain (Figure 1) with average (1971-2000) minimum temperatures in January of -0.2 °C, compared to 1.1 °C in England and maximum July temperatures of 16.9 °C compared with 20.6 °C in England[3]. Winter temperatures are warmer on the west coast of Scotland and are comparable to those recorded in western parts of England and Wales (Figure 1). Average annual rainfall levels are drier on the east coast of Scotland and are more comparable with many regions of England. Apart from the very fringes of the west coast, Scotland experiences many more ground frost days in late spring, with, on average (1971-2000), eight or more ground frost days in May. This may particularly limit the distribution of frost-sensitive INNS. Despite these generalised differences, it is also clear that southern regions of Scotland have very comparable climates to northern England and climate is only likely to broadly limit the spread of INNS within Scotland, not the establishment of species that are already present in northern England.

Scotland's geology and soils are most distinct for the Highlands and Islands region. Here they are dominated by igneous rocks and have more peaty and acidic soils than the rest of Great Britain, whereas the Central Lowlands and south of Scotland have comparable rock and soil types to those found in much of England and Wales.

The rate of arrival and establishment of INNS is influenced by socio-economic factors such as human population density, economic development, trade and transport and tourism. Scotland has a population of 5.4 million (8% of the UK total), of which 80% live in the Central Lowlands[5]. The propagule pressures from INNS are likely to be greater in the Central Lowlands, which have a human population density comparable to much of England and Wales, than in the Highlands and Islands and southern Scotland where the human population density is less than one tenth of the UK average[4].

The majority of goods entering Scotland are transported by road from or via other parts of the UK. This underlines the importance of the joint nations approach to managing pathways for introduction and spread of INNS under the GB INNS Strategy. Four major ports (Forth, Clyde, Sullom Voe and Glensanda) account for

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3 Met Office, 2021. Climate averages. Accessed on 24 November 2021 at http://www.metoffice.gov.uk/climate/uk/averages/index.html

4 ONS (2021) Mid 2020 population estimates - local authority boundaries. Office for National Statistics.

almost 90% of the international freight tonnage entering and leaving Scotland, which is mostly oil and gas and aggregates. The main sea freight partners are the EU (60%), Asia (22%,) and Africa (8%) (Transport Scotland 2019). International trade in live plants involving the large-scale movements of material for the agricultural, forestry and horticultural industries has been implicated in the unintentional introduction of many INNS globally including, as examples, oak processionary moth (*Thaumetopoea processionea*) and ramorum blight (*Phythopthora ramorum*) to the UK (Marzano, Dandy et al. 2015). The horticultural industry is estimated to support 64,000 jobs and contribute approximately £2.8bn to GDP in Scotland (Horticultural Trades Association, 2023). The Scottish Horticultural Growth Strategy highlights the importance of biosecurity to "enhance and protect Scotland's Natural Capital".

Tourism is one of seven growth industries in Scotland, contributing around £6 billion (5%) to Scottish GDP (Scottish Government, 2018). The natural environment is a key tourism asset with spending on nature-based tourism estimated to contribute nearly 40% of the total (Bryden 2010). Nature-based tourism activities are widely spread across the whole of Scotland. The risk of introduction of INNS via pathways associated with these activities is linked to the type of activity, the number of visitors, and the preventative steps taken to reduce the risk.

One distinct difference between Scotland and the rest of Great Britain is the relatively unregulated, open access allowed for recreation and tourism across much of the Scottish landscape. This includes water sports access on rivers and lochs (lakes) although noting that there are restrictions relevant to salmon fishing[5]. Social inclusion in access to the natural environment may create additional challenges for managing pathways of introduction and spread of INNS associated with recreational activities.

5 Fishing for salmon (which includes Atlantic salmon (*Salmo salar*) and sea trout (*Salmo trutta*) is a separate heritable right from land ownership and access is controlled by those who own those rights to fish. The right to fish for species other than 'salmon' (such as brown trout (*Salmo trutta*) relies on the provision of access by landowners and permission is required.

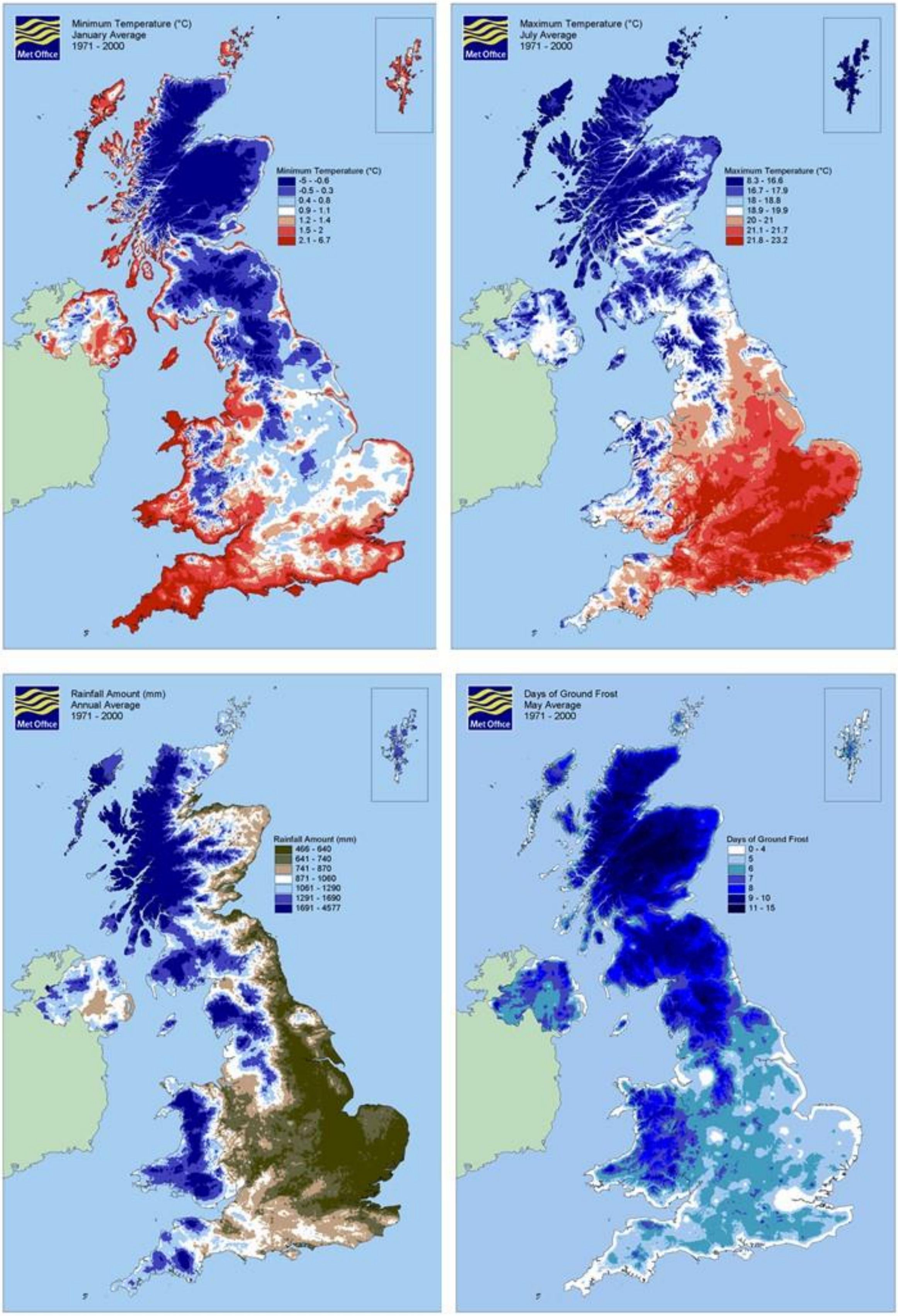

Figure 1: Maps of average climate variables for the UK (1971-2000) (Source: Met Office, 2021).

Methods

Horizon Scanning

The approach followed the process previously outlined by (Roy, Peyton et al. 2020, Dawson, Peyton et al. 2023). Five expert groups were established:

1. Marine (led by Elizabeth Cottier-Cook)
2. Freshwater (led by Laurence Carvalho and Iain Gunn)
3. Terrestrial invertebrates (led by Karsten Schönrogge)
4. Terrestrial plants (led by Wayne Dawson and Jodey Peyton)
5. Terrestrial vertebrates (led by Rich Broughton)

The expert groups developed long lists of INNS to include within the horizon scanning by reviewing the list of Prevention Priority Species[6] alongside the horizon scanning list derived for Britain in 2019[7] and additional lists, specifically INNS established in countries in close proximity to, but currently absent from, Scotland. The expert groups worked independently to agree the long lists of INNS to consider through the horizon scanning process. However, throughout there were a number of points of clarification raised particularly on the scope. The outcomes of these discussions were shared across the expert groups to ensure consistency of approach (Annex 1: Brief Summary of Horizon Scanning Approach).

The INNS included in the lists were scored for likelihoods of a) arrival, b) establishment and c) magnitude of the potential negative impact on biodiversity and ecosystem services following the methods outlined in previous studies (Dawson, Peyton et al. 2023) and provided as a briefing note to all authors (Annex 1: Brief Summary of Horizon Scanning Approach). The expert groups also assessed the potential negative economic and human health impacts of the INNS, again following the methods outlined[5]. However, more emphasis was given, and detail provided, for INNS considered likely to have impacts on biodiversity and ecosystem services because INNS likely to impact economies and human health are considered by other sectors. Therefore, given limitations in the time available, the experts did not follow a consistent scoring process for human health and economic impacts but did list INNS likely to have such impacts. Confidence levels were considered and information on likely pathways of introduction were compiled following the Convention on Biological Diversity classification of pathways (Harrower, Scalera et al. 2018). The information on the long lists for each expert group was compiled through e-mail exchange and virtual meetings. Each of the five expert groups submitted a ranked list of INNS and associated scores for inclusion in the virtual consensus workshop (Annex 2: Workshop Agenda).

The consensus workshop was held over two days with one day in between to enable the groups to refine and review the scores following the outcomes of the discussions on the first day of the workshop. During day one of the workshop the groups

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6 Link to the horizon scanning list derived for Britain in 2019

7 Horizon scanning - GB non-native species secretariat (nonnativespecies.org)

highlighted the high-scoring INNS. Discussions across the groups provided an opportunity to achieve consistency in the scoring approach and informed the discussions within each group during the breakout sessions. On day two of the workshop the participants were presented with the compiled list of all INNS from across the groups. Through further discussions and review, a top 30 list was agreed.

A small group, comprising NatureScot experts and project team members, met to review the top 30 to agree on a top 10 list of INNS. This group focussed on INNS with impacts on biodiversity and ecosystem services but noted that many of the INNS have impacts across multiple categories (human health and economies alongside impacts on biodiversity and ecosystem services), for communication and awareness raising. There was agreement that grouping the flatworms together was pragmatic for communication purposes and similarly the *Dreissena* species were grouped together. However, it is important to note that although all these species have distinct ecological traits, their pathways of arrival are likely to be similar.

Finally, a long list of 171 INNS was derived based on a review of the scores agreed by the project team and expert groups and included:

- all INNS allocated an overall score of 48 or more (arrival score x establishment score x biodiversity impact score) or;
- biodiversity impact scores of four or five if the arrival and establishment scores were three or more or;
- all species with a biodiversity score of five if the arrival was two or more and the establishment score was greater than three and;
- species allocated five for arrival and establishment for those INNS with impact scores of only two.

Comprehensive Pathways Analysis

Potential pathways of arrival were compiled for a) established non-native species in Scotland and b) the long list of INNS compiled through the horizon scanning exercise and predicted to arrive, establish and impact biodiversity and ecosystem services in the next 10 years. The analysis included all 174 INNS identified through the horizon scanning noting that subsequently three of the INNS were considered likely to be established.

The information on pathways was assessed to rank the pathways of introduction of non-native species introduced into Scotland since 1950 and likely pathways of introduction for non-native species into Scotland in the next ten years. The analysis used the Convention on Biological Diversity (CBD) classification of pathways (CBD 2014) and was based on previous analysis conducted for Great Britain (Booy 2019).

The list of non-native species established in Scotland was based on information from the GB Non-Native Species Information Portal (GBNNSIP). The GBNNSIP contains information on the status in Scotland for many species and using any species marked as either established or established indoors (typically these are household or commodities pests, such as carpet beetles or cereal/flour pests, but with a couple of greenhouse/hot house species) - hereafter both referred to as established in Scotland.

It was noted that recent information may be missing from the GBNNSIP on recently established non-native species. Therefore, occurrence of non-native species was extracted from the NBN Atlas by searching for any species listed in the GBNNSIP as established in Great Britain but not listed as established in Scotland to identify additional species that might be established in Scotland. Using NBN Atlas data from 2000 onwards, species that had more than 20 individual occurrence records, been recorded in five or more distinct 10-km squares and in five or more different years were considered to be sufficiently recorded in time and space to assume that they were likely to be established and so were added to the species list. This resulted in an additional 32 species being added to the list bringing the total to 1096 species classed as being established in Scotland in the GBNNSIP.

The NBN Atlas was also used to provide an estimate of the year of first record for species on the established list. The year of first record was used to separate historic introductions from more recent introductions (species first recorded from 1950 onwards). The final set of non-native species added to the analyses were the 171 species on the long list from the horizon scanning part of the project.

Pathway information for all these species, the established non-native species and the 171 horizon scanning species, were collated from three main sources: the GBNNSIP, the European Alien Species Information Network (EASIN), and a dataset from a chapter on pathways within a thesis: Prioritising the Management of Invasive Non-Native Species (Booy 2019). This resulted in the compilation of comprehensive information on possible pathways for each species. Collating data from these sources required resolving nomenclature mismatches as well as pathway information which used a different pathway classification scheme, in the case of the GBNNSIP data. The pathway classification scheme used in the analysis was that proposed by the Convention on Biological Diversity (CBD) which has been relatively widely accepted and is the closest to a standardised pathway terminology in the literature (CBD 2014, Harrower, Scalera et al. 2018); see Table 1 for the categories used in the pathway analysis. Where required, pathway information was manually checked or added using online sources such as CABI's Invasive Species Compendium factsheets and the Global Invasive Species Database. In addition to this pathway information, for the 171 horizon scanning non-native species, information from the experts in the groups was also collated. The pathway information from the expert groups was more tailored to Scotland as it tended to be restricted to pathways the expert groups considered likely for arrival of species into Scotland. The other pathway information was from known introductions to other invaded regions or potential pathways including historic pathways and/or pathways for non-native species into Scotland.

For the horizon scanning species, any potentially relevant pathways noted by experts were reviewed by the project team to ensure that only pathways that the experts considered to be applicable to Scotland were included. Additionally, for the 171 horizon scanning non-native species the biodiversity impacts and overall scores from the horizon scanning were also collated for use in the analysis.

Table 1. CBD pathway categories and subcategories including codes used within figures as outlined in the suggestions of the IUCN CBD guidance document (CBD 2014).

Category	Subcategory	Code
Release	Biological control	R_BIO
Release	Stabilisation and barriers	R_STAB
Release	Fishery in the wild	R_FHRY
Release	Hunting	R_HUNT
Release	Aesthetic release	R_AES
Release	Conservation in wild	R_CON
Release	Release for use	R_USE
Release	Other release	R_OTR
Escape	Agriculture	E_AGRI
Escape	Aquaculture	E_AQC
Escape	Botanical gardens & zoos	E_BZA
Escape	Pet	E_PET
Escape	Farmed animals	E_FARM
Escape	Forestry	E_FOR
Escape	Fur farms	E_FUR
Escape	Horticulture	E_HORT
Escape	Ornamental	E_ORN
Escape	Research	E_RES
Escape	Live food & live bait	E_LFB
Escape	Other escape	E_OTR
Contaminant	Nursery material contaminant	C_NUR
Contaminant	Bait contaminant	C_BAIT
Contaminant	Food contaminant	C_FOOD
Contaminant	Contaminant of animals	C_ANI
Contaminant	Parasite of animals	C_PAR_ANI
Contaminant	Contaminant of plants	C_PLT
Contaminant	Parasite of plants	C_PAR_PLT
Contaminant	Seed contaminant	C_SEED
Contaminant	Timber trade contaminant	C_TMBR
Contaminant	Habitat material contaminant	C_HAB
Contaminant	Other contaminant	C_OTR
Stowaway	Fishing equipment	S_ANG
Stowaway	Container & bulk cargo	S_CARGO
Stowaway	Airplane	S_AIR
Stowaway	Ship excl. ballast water or hull fouling	S_SHIP
Stowaway	Machinery & equipment	S_EQUIP
Stowaway	People & luggage	S_LUGG
Stowaway	Packing material	S_PACK
Stowaway	Ballast water	S_BALL
Stowaway	Hull fouling	S_HULL
Stowaway	Land vehicles	S_LVEH
Stowaway	Other stowaway	S_OTR
Corridor	Canals and artificial waterways	L_CANAL
Corridor	Tunnels and bridges	L_TB
Unaided	Natural dispersal	U_NAT

To determine the importance of each pathway for the introduction of each non-native species to Scotland, a number of scoring metrics were calculated for each pathway. The simplest of these metrics was the total number of species associated with that pathway. For this, metric species associated with multiple pathways were counted independently for each pathway with which they are associated. This meant that while each pathway could not have a number of species higher than the number of species in the dataset, the total across all pathways was likely to be higher than and not equal to the number of species.

To correct for this, an alternative scoring approach involved scoring the values for each species by weighting the number of pathways that they are associated with, so that the value contributed by each pathway was 1/p, where p is the number of pathways. In this scoring system, a species with one pathway would still contribute a value of 1.0 to the weighted scoring to its pathway, while pathways from a species with four pathways would each contribute a score of ¼ or 0.25 to the weighted score of each pathway. Using this weighted approach, the total across all pathways was equal to the number of species that have pathway information in the dataset.

The derived horizon scanning long list of 171 INNS included additional data that offered a few alternative scoring options, specifically the biodiversity impact scores and overall horizon scanning scores for each species. Totalling the biodiversity score or overall score for species associated with each pathway, allowed the determination of pathways that were associated with the species predicted to have the largest biodiversity impacts and or with the highest overall scores for the horizon scanning.

The contributions of these pathways were compared using different subsets of the species and/or data, e.g., all established species versus only established species that have arrived since 1950, established species versus horizon scanning species to determine if the contributions of pathways had remained or were predicted to remain relatively constant. Kendall's Rank Correlation were used to test the degree of correlation in the importance of pathways between these different subsets. It is important to note that the process of attributing pathways of introduction for INNS included within the horizon scanning list is based on expert opinion. Such predictions by experts are based on the best available evidence including from other contexts in which the INNS has prior history of biological invasion or on the known introduction pathways for closely related INNS. However, there is inevitably some uncertainty in the information captured but experts were requested to document all potential pathways of introduction and so the approach is likely to be comprehensive in encompassing the breadth of likely pathways.

Results

Horizon scanning

The compiled long-lists of INNS predicted to arrive, establish and impact biodiversity and ecosystem services, human health and economies are presented in Annexes 3, 4 and 5 respectively. In total 171, 27 and 47 species were included in the long-lists of INNS predicted to have impacts on biodiversity and ecosystem services, human health and economies respectively. The top 10 list, derived through review of the long-list of INNS predicted to have impacts on biodiversity and ecosystems in consultation with NatureScot experts, included two groups of species (flatworms and

Dreissena species) alongside a further eight species spanning terrestrial, freshwater and marine environments (Table 2). Five INNS within the top 10 list were freshwater species. Only one marine species was included.

Table 2. Top 10 list of invasive non-native species predicted to arrive, establish and impact biodiversity and ecosystem services noting that the flatworms are grouped together as are the two *Dreissena* species (further information is provided in the text on the differences between these species). The Horizon Scanning (HS) Expert Group refers to the thematic group that considered the invasive non-native species. All species were attributed the maximum scores for likelihood of arrival, establishment and impact on biodiversity and ecosystems. Two further species also received these high scores, but both are considered separately within plant health (*Agrilus planipennis*, emerald ash borer) or animal health (*Gyrodactylus salaris*, salmon fluke) legislation, so not included on the list. The table is ordered alphabetically within thematic groups.

Species Name	English Name	HS Expert Group
Anemanthele lessoniana[8]	Pheasant's-tail	Terrestrial plants
Corbicula fluminea	Asian clam	Freshwater
Dreissena polymorpha	Zebra mussel	Freshwater
Dreissena rostriformis bugensis	Quagga mussel	Freshwater
Australoplana sanguinea	Australian flatworm	Terrestrial invertebrates
Caenoplana variegata (formerly known as *C. bicolor*)	Southampton flatworm	Terrestrial invertebrates
Kontikia andersoni	Brown Kontikia flatworm	Terrestrial invertebrates
Obama nungara	Obama flatworm	Terrestrial invertebrates
Hydrocotyle ranunculoides	Floating pennywort	Freshwater
Muntiacus reevesi	Reeve's muntjac	Terrestrial vertebrates
Myriophyllum aquaticum	Parrot's feather	Freshwater
Procyon lotor	Raccoon	Terrestrial vertebrates
Vaccinium corymbosum (and hybrids)	Highbush blueberry	Terrestrial plants
Crepidula fornicata	Mollusc	Marine

One-third of the INNS on the top 30 list (Table 3) were freshwater species while only three of the species were from the marine environment. There were eight terrestrial

[8] There have been four records of *Anemanthele lessoniana* which have been noted since the workshop (specifically in Glasgow, Banchory, Fochabers, Lochwinnoch)

invertebrates listed and six terrestrial plants with the remaining three species being terrestrial vertebrates. Most of the top 30 list were assigned the highest impact score of five.

Table 3. Top 30 list of invasive non-native species (INNS) predicted to arrive, establish and impact biodiversity and ecosystem services. The Horizon Scanning Expert Group refers to the thematic group that considered the INNS. Scores of 1-5 were given for likelihood of arrival, establishment and impact on biodiversity and ecosystems (noting that scores were not included for human health and economic impacts). The long list of 171 species with at least medium likelihood of arrival, establishment and impact on biodiversity and ecosystems is in Annex 3. A full spreadsheet of all species scored by the groups was also compiled for INNS with impacts on biodiversity and ecosystem services. Table ordered by overall score, expert group and then alphabetically by species name. *Kontikia andersoni* was not included in the top 30 but was with the other flatworms in the top 10 for communication campaigns.

Species name	English name	HS expert group	Arrival	Estab.	Bio. impact	Overall score
Corbicula fluminea	Asian clam	Freshwater	5	5	5	125
Dreissena polymorpha	Zebra mussel	Freshwater	5	5	5	125
Dreissena rostriformis bugensis	Quagga mussel	Freshwater	5	5	5	125
Gyrodactylus salaris	Salmon fluke	Freshwater	5	5	5	125
Hydrocotyle ranunculoides	Floating pennywort	Freshwater	5	5	5	125
Myriophyllum aquaticum	Parrot's feather	Freshwater	5	5	5	125
Crepidula fornicata	Mollusc	Marine	5	5	5	125
Agrilus planipennis	Emerald ash borer	Terrestrial invertebrates	5	5	5	125
Australoplana sanguinea	Flatworm	Terrestrial invertebrates	5	5	5	125
Caenoplana variegata (formerly known as *C. bicolor*)	Southampton flatworm	Terrestrial invertebrates	5	5	5	125
Corythucha arcuata	Oak lace bug	Terrestrial invertebrates	5	5	5	125
Obama nungara	Obama flatworm	Terrestrial invertebrates	5	5	5	125
Vespa velutina	Asian hornet	Terrestrial invertebrates	5	5	5	125
Anemanthele lessoniana	Pheasant's-tail	Terrestrial plants	5	5	5	125
Baccharis halimifolia[9]	Tree groundsel	Terrestrial plants	5	5	5	125

[9] There has been one record of *Baccharis halimifolia* which has been noted since the workshop (specifically at Machrihanish Links, Mull of Kintyre)

Species name	English name	HS expert group	Arrival	Estab.	Bio. impact	Overall score
Vaccinium corymbosum (and hybrids)	Highbush blueberry	Terrestrial plants	5	5	5	125
Muntiacus reevesi	Reeve's muntjac	Terrestrial vertebrates	5	5	5	125
Procyon lotor	Raccoon	Terrestrial vertebrates	5	5	5	125
Eriocheir sinensis	Chinese mitten crab	Freshwater	5	5	4	100
Ludwigia grandiflora	Water primrose	Freshwater	5	5	4	100
Sander lucioperca	Zander	Freshwater	4	5	5	100
Silurus glanis	Wels catfish	Freshwater	4	5	5	100
Agarophyton vermiculophyllum (previously *Gracilaria vermiculophylla*)	Alga	Marine	5	5	4	100
Homarus americanus	American lobster	Marine	5	5	4	100
Ips sexdentatus		Terrestrial invertebrates	5	5	4	100
Thaumetopoea processionea	Oak processionary	Terrestrial invertebrates	5	5	4	100
Acer negundo	Box-elder	Terrestrial plants	5	5	4	100
Ailanthus altissima	Tree of heaven	Terrestrial plants	5	4	5	100
Elaeagnus pungens	Thorny olive	Terrestrial plants	5	5	4	100
Nyctereutes procyonoides	Raccoon dog	Terrestrial vertebrates	5	5	4	100

Comprehensive Pathways Analysis

The INNS on the top 10 and top 30 lists were predicted to arrive through a range of pathways (Figure 2). Escape from confinement dominated on both lists with the ornamental and horticultural pathways being the most important pathways in relation to the number of species associated with these pathways.

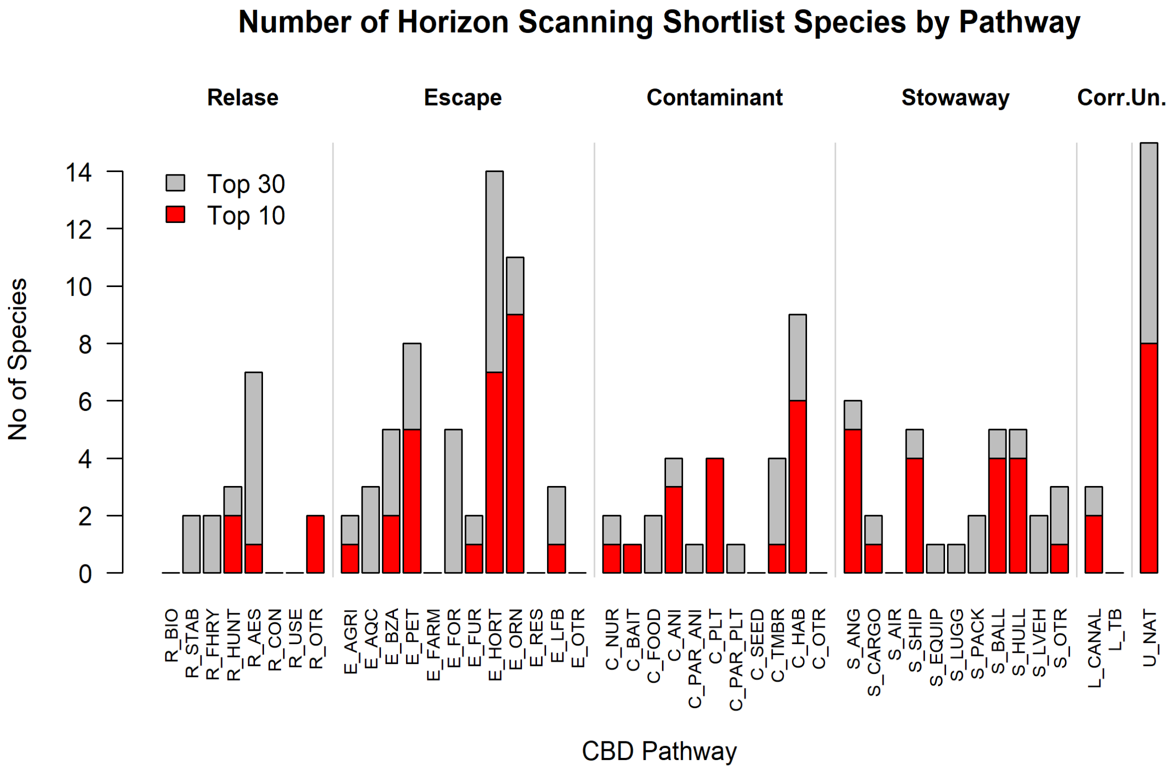


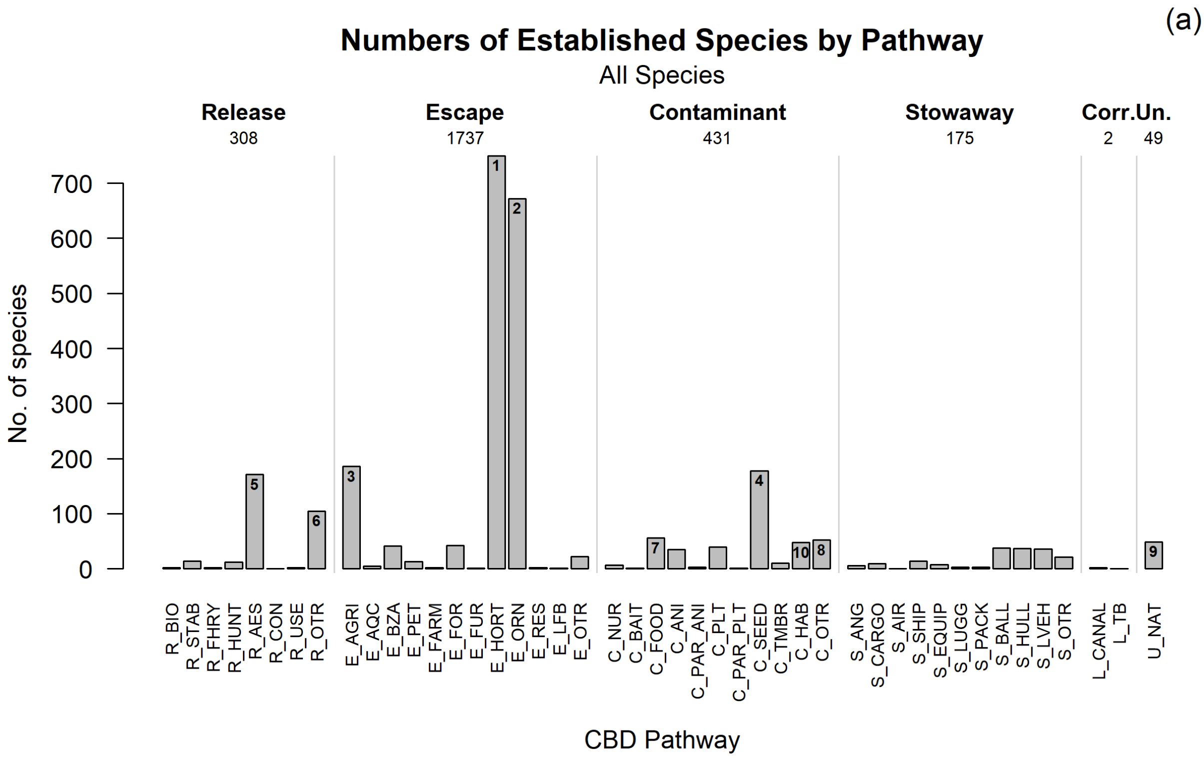
Figure 2. Total numbers of species on the top 10 and top 30 lists derived through the horizon scanning for each CBD pathway (for pathway codes see Table 1).

The version of the horizon scanning long list used in the pathway analysis contained three plant species that were later excluded from the long list. This was due to the decision that they were probably now established based on a re-examination of records in the Botanical Society of Britain and Ireland recording database.

The breakdown of pathways associated with species that are established in Scotland, for all established species (1096 species) and also for only established species that were first recorded in Scotland since 1950 (483 species, hereafter referred to as recently established) is shown in Figure 3. The top 10 pathways for established species and their relative and cumulative contributions are shown in Table 4.

The pathways associated with the highest number of species (for both all established and recently established species) were the horticulture and ornamental pathways ranked 1st and 2nd respectively (Figure 3). These two pathways combined contributed over 50% of the total number of species (52% and 60% for all established and recently established species respectively, see Table 4).

Although notably lower than the horticulture and ornamental pathways, the agriculture, seed contaminant, aesthetic release, and other release pathways were still associated with substantial numbers of established species. These pathways were ranked 3rd, 4th, 5th and 6th for all established species and with 5th, 6th, 3rd and 4th respectively for recently established species. These top six pathways together contributed 76% of total number of species scores.



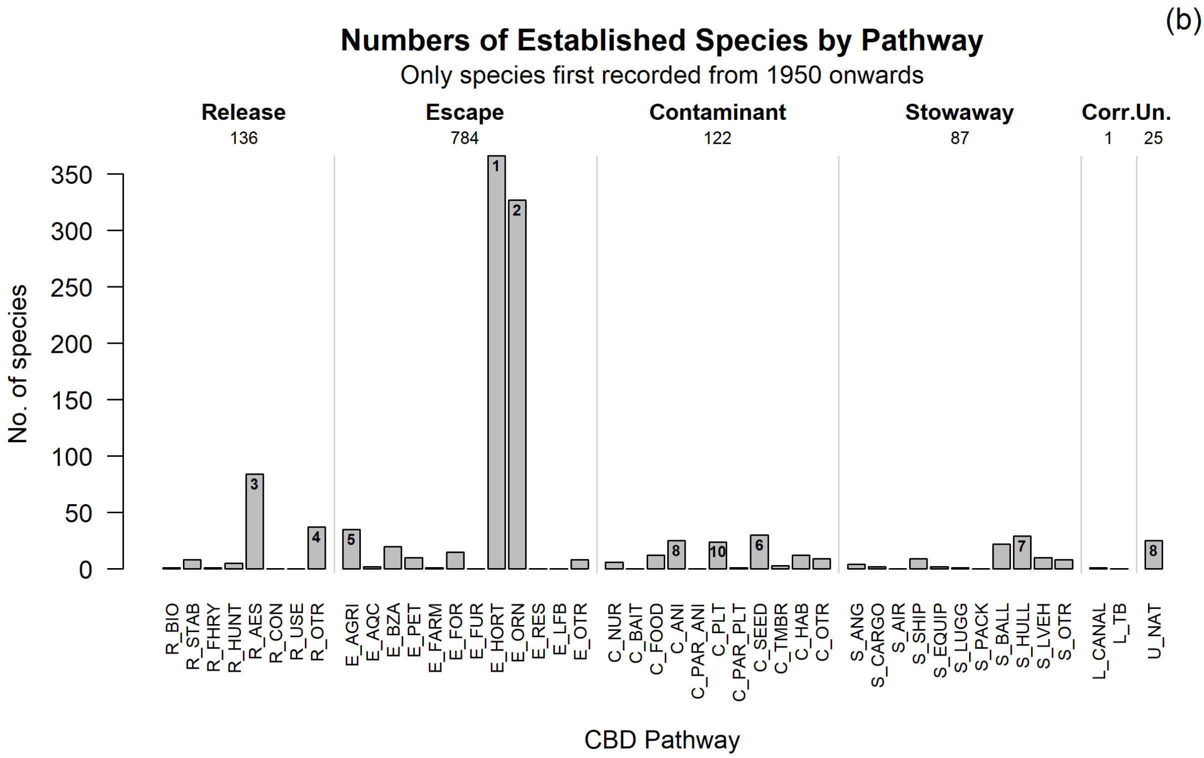


Figure 3. Total numbers of established species associated with each CBD pathway for a) all established species, b) only established species that were first recorded in Scotland since 1950. The top 10 ranked pathways are labelled with their rank in the bars.

Table 4. Top 10 ranked pathways for established species based on the number of species associated with each pathway for all established species or only established species first recorded in Scotland from 1950 onwards. For each pathway the proportion of the data associated with that pathway and the cumulative proportion (combined total of pathways ranked equal to or higher than the current pathway expressed as a proportion of the total dataset) are also shown.

	Rank	Pathway	No. Species	Proportion	Cumulative Proportion
All established species	1	Horticulture	750	0.278	0.278
	2	Ornamental	672	0.249	0.526
	3	Agriculture	186	0.069	0.595
	4	Seed contaminant	178	0.066	0.661
	5	Aesthetic release	171	0.063	0.724
	6	Other release	105	0.039	0.763
	7	Food contaminant	56	0.021	0.784
	8	Other contaminant	52	0.019	0.803
	9	Natural dispersal	49	0.018	0.821
	10	Habitat material contaminant	48	0.018	0.839
Established species first recorded since 1950	1	Horticulture	366	0.317	0.317
	2	Ornamental	327	0.283	0.600
	3	Aesthetic release	84	0.073	0.673
	4	Other release	37	0.032	0.705
	5	Agriculture	35	0.030	0.735
	6	Seed contaminant	30	0.026	0.761
	7	Hull fouling	29	0.025	0.786
	8	Contaminant of animals	25	0.022	0.808
	8	Natural dispersal	25	0.022	0.829
	10	Contaminant of plants	24	0.021	0.850

In the top 10 ranked pathways the only other pathway in common between the analyses of all established species and recently established species was the natural dispersal pathway which was ranked 9th and 8th (tied) respectively. The remaining pathways in the top 10 ranked pathways for all established species were food contaminant (7th with 56 spp.), other contaminant (8th with 52 spp.) and habitat material contaminant (10th with 48 spp.), while those for the recent established species were; hull fouling (7th with 29 spp.), contaminant of animals (tied 8th with 25 spp.) and contaminant of plants (10th with 24 spp.).

The number of species associated with each pathway for the species on the horizon scanning long list are shown in Figure 4. As with established species, the predominant pathways associated with species on the horizon scanning list were the horticulture and ornamental pathways (Figure 4). This was the case both when using all possible pathway information or only pathways the expert groups considered relevant for Scotland. The extent to which these two pathways dominated, however, was noticeably less for the horizon scanning species with only 23% percent of the total number of species being contributed by these pathways compared with more than 50% for established species (Tables 4 and 5).

After the ornamental and horticultural pathways, the most important pathways in terms of the number of species for horizon scanning species were natural dispersal and pet pathways, though the ranks differed depending on whether the analysis used all pathways or only those provided by the expert groups (ranked 3 and 4 or 4 and 3 respectively). Other pathways that were ranked in the top 10 for the horizon scanning list were, ballast water; habitat material contaminant; fishing equipment; ship excluding ballast water or hull fouling; hull fouling and contaminant of animals, though their exact ranks differed depending upon whether the analysis used all pathways or only expert contributed information on pathways.

Overall, for the 171 horizon scanning species (noting exclusion of three plant species considered established based on a re-examination of records in the Botanical Society of Britain and Ireland recording database) the contributions made by pathways other than horticulture and ornamental were notably larger and more evenly distributed amongst pathways than was the case for the established non-native species, where much of the data was dominated by relatively few pathways. As an example, the stowaway pathway appeared to be associated with a greater proportion of the species from the horizon scanning list than for species already established in Scotland. Indeed, four stowaway pathways (fishing equipment, ship excluding ballast water or hull fouling, ballast water and hull fouling) make the top 10 (Table 5). This is in contrast to the established species where only one stowaway pathway (hull fouling) made the top 10 (7^{th}) and this was only in the analysis restricted to recent established species. In addition, pathways such as pet and natural dispersal were much more important for the horizon scanning species, where they were both high in the top 10, than for the established non-native species where only natural dispersal is in the top 10.

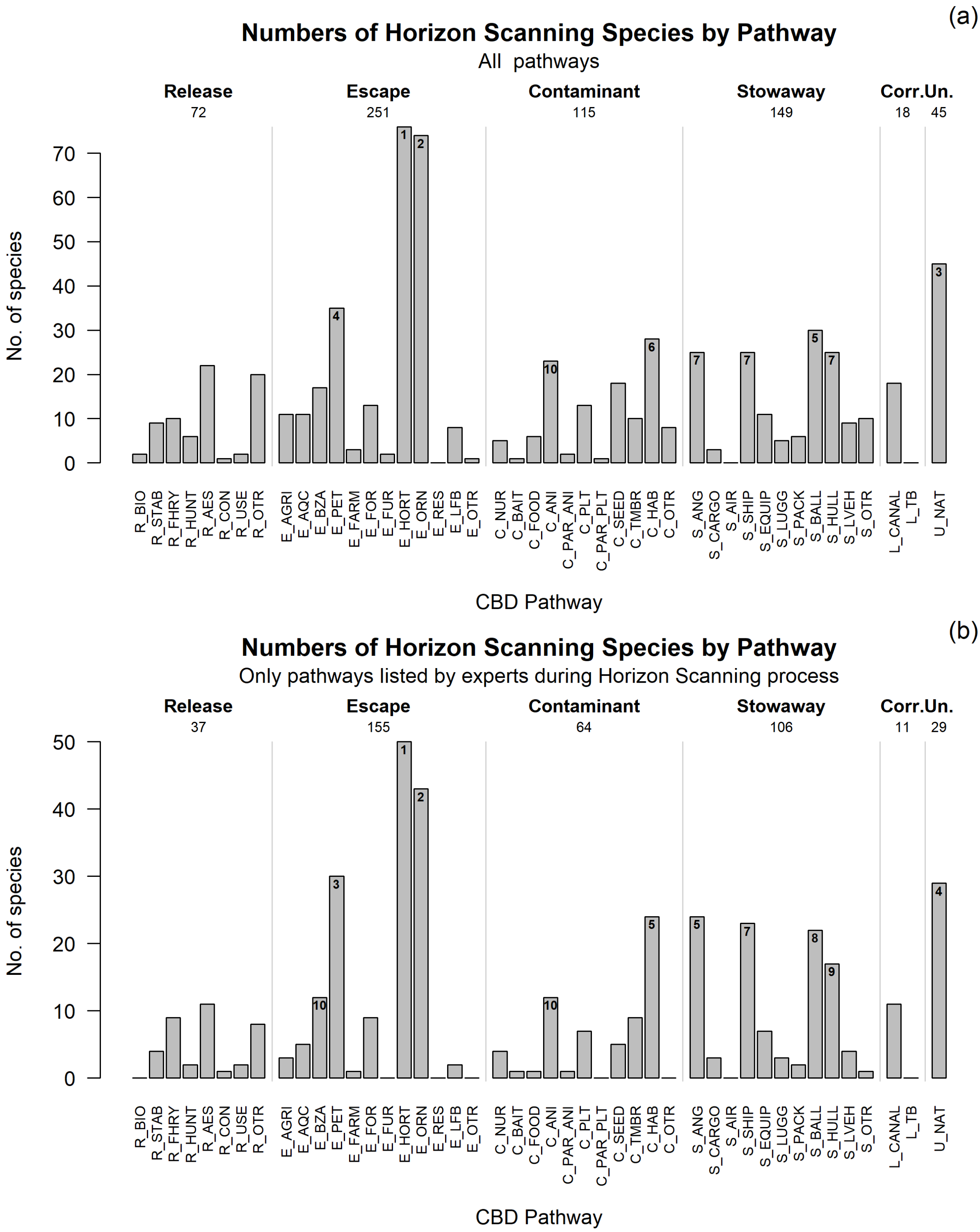


Figure 4. The total number of horizon scanning species associated with each CBD pathway using a) all pathway data, b) only pathways expert groups thought applicable to Scotland. The top 10 ranked pathways are labelled with their rank.

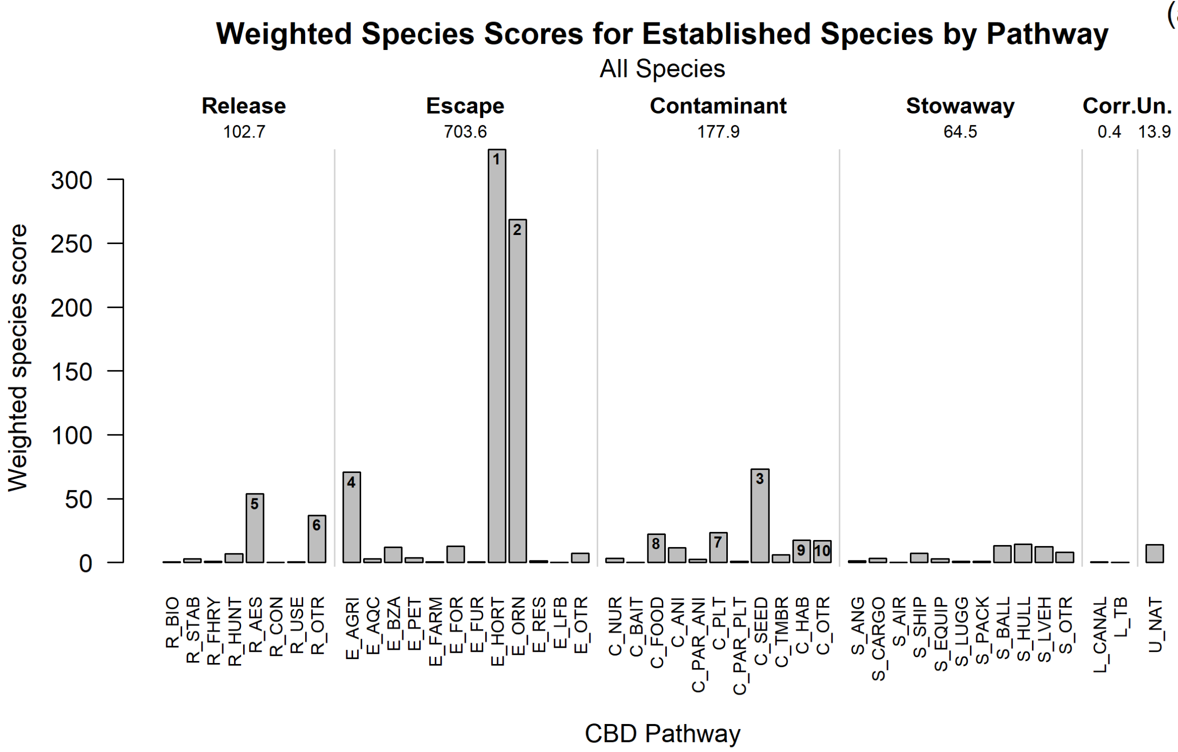
Table 5. Top 10 ranked pathways for species on the horizon scanning long list based on the number of species associated with each pathway, based on all pathway data or only pathways experts thought applicable to Scotland during the horizon scanning exercise. For each pathway the proportion of the data associated with that pathway and the cumulative proportion (combined total of pathways ranked equal to or higher than the current pathway expressed as a proportion of the total dataset) are also shown.

	Rank	Pathway	No. Species	Proportion	Cumulative Proportion
All pathways	1	Horticulture	76	0.117	0.117
	2	Ornamental	74	0.114	0.231
	3	Natural dispersal	45	0.069	0.300
	4	Pet	35	0.054	0.354
	5	Ballast water	30	0.046	0.400
	6	Habitat material contaminant	28	0.043	0.443
	7	Fishing equipment	25	0.038	0.482
	7	Ship exc. ballast water or hull fouling	25	0.038	0.520
	7	Hull fouling	25	0.038	0.558
	10	Contaminant of animals	23	0.035	0.594
Expert pathways	1	Horticulture	50	0.124	0.124
	2	Ornamental	43	0.107	0.231
	3	Pet	30	0.075	0.306
	4	Natural dispersal	29	0.072	0.378
	5	Habitat material contaminant	24	0.060	0.438
	5	Fishing equipment	24	0.060	0.498
	7	Ship excluding ballast water or hull fouling	23	0.057	0.555
	8	Ballast water	22	0.055	0.609
	9	Hull fouling	17	0.042	0.652
	10	Botanical gardens & Zoos	12	0.030	0.682
	10	Contaminant of animals	12	0.030	0.711

Analysis using weighted number of species

The relative importance of pathways using the weighted species score was similar to that using the unmodified number of species scoring, though rankings of some pathways changed slightly (Figure 5). This appears to be the case when considering all established species or only established species that were first recorded after 1950.

(a)



(b)

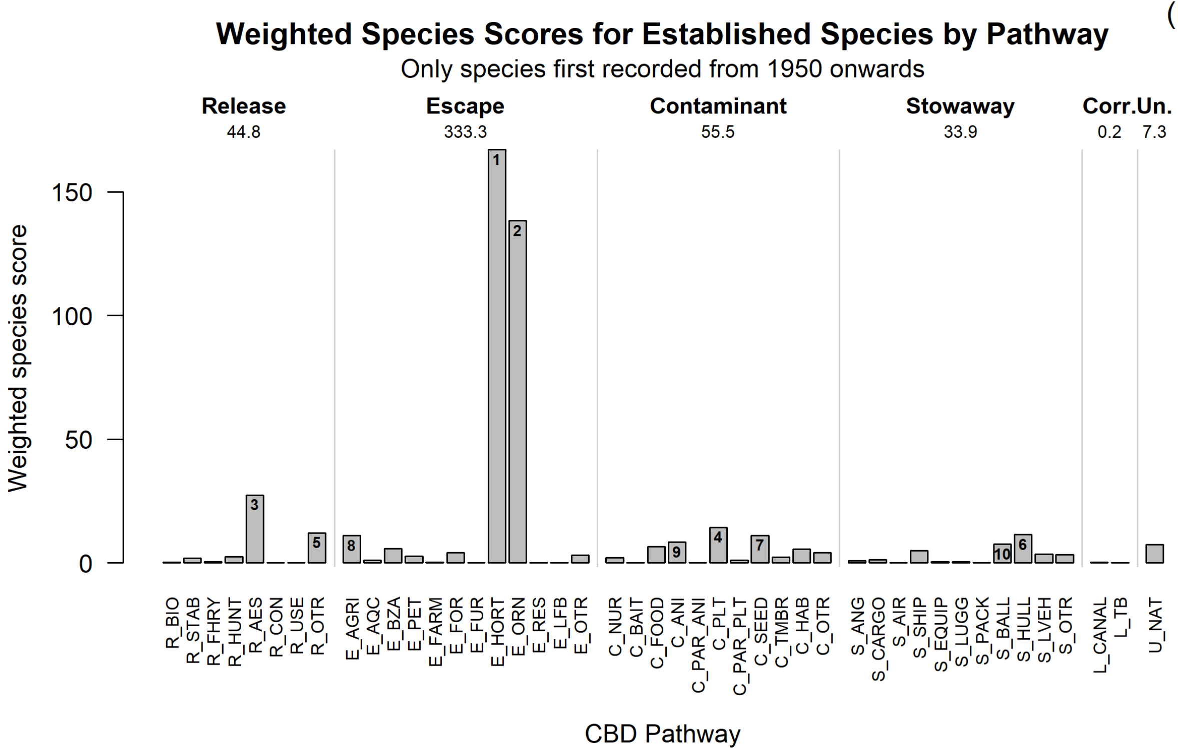


Figure 5. The weighted numbers of established species associated with each CBD pathway for a) all established species, b) only established species that were first recorded in Scotland since 1950. The top 10 ranked pathways are labelled with their rank.

The horticulture and ornamental pathways were the most important pathways, ranked 1st and 2nd respectively. Together these pathways contributed a notable proportion of the total weighted species scores. The contribution of these pathways appeared to be slightly greater when using the weighted species score, with them explaining 56% (all established) and 64% (recently established) of the total weighted scores compared with 53% and 60% for the unmodified number of species scores (Tables 4 and 6).

For all established species the pathways in the top 10 using the weighted scores were almost the same as when using the unmodified total number of species, though the ranks changed slightly, and the natural dispersal category was lost while the contaminant of plants was gained. The agriculture and seed contaminant pathways switched ranks (ranked 4th and 3rd respectively), while the food contaminant and other contaminant pathways were ranked lower (now 8th and 10th) and habitat material contaminant increased to 9th position.

The natural dispersal category was also lost from the top 10 for the recently established species, though in this case the new pathway in the top 10 was the ballast water pathway which appeared at 10th place. For recently established species the other changes in the top 10 using weighted species score instead of the raw total number of species is the reduction in ranks of the other release (4th to 5th), agriculture (5th to 8th) and the contaminant of animals pathways (8th to 9th) along with the increase in ranks of the contaminant of plants (10th to 4th) and hull fouling pathway (7th to 6th).

The proportion of data cumulatively explained by pathways in the top 10 was relatively independent of whether the rankings used the raw number of species or weighted species scores, with the values now being 85% and 86% for all established species and recent established species respectively (Table 6).

Table 6. Top 10 ranked pathways for established non-native species based on the total weighted number of species score associated with each pathway for all established non-native species or only established species first recorded in Scotland from 1950 onwards. For each pathway the proportion of the data associated with that pathway and the cumulative proportion (combined total of pathways ranked equal to or higher than the current pathway expressed as a proportion of the total dataset) are also shown.

	Rank	Pathway	Weighted No. Species Score	Proportion	Cumulative Proportion
All established species	1	Horticulture	323.6	0.304	0.304
	2	Ornamental	268.4	0.253	0.557
	3	Seed contaminant	73.3	0.069	0.626
	4	Agriculture	70.8	0.067	0.693
	5	Aesthetic release	53.8	0.051	0.743
	6	Other release	37.0	0.035	0.778
	7	Contaminant of plants	23.6	0.022	0.800
	8	Food contaminant	22.3	0.021	0.821
	9	Habitat material contaminant	17.5	0.016	0.838
	10	Other contaminant	17.1	0.016	0.854
Established species first recorded since 1950	1	Horticulture	166.9	0.351	0.351
	2	Ornamental	138.3	0.291	0.642
	3	Aesthetic release	27.4	0.058	0.700
	4	Contaminant of plants	14.4	0.030	0.730
	5	Other release	12.2	0.026	0.756
	6	Hull fouling	11.4	0.024	0.780
	7	Seed contaminant	11.2	0.023	0.803
	8	Agriculture	11.1	0.023	0.827
	9	Contaminant of animals	8.4	0.018	0.845
	10	Ballast water	7.6	0.016	0.860

Although the general patterns in the relative contributions of the pathways were similar between the two scoring metrics (raw number of species and weighted species score) for the data for horizon scanning species, the exact rankings for pathways did vary more (Figure 6). The horticulture and ornamental pathways were still the top 2 pathways ranked 1st and 2nd respectively. Together, these pathways explained a notable proportion of the total weighted score (28% and 26%) for all pathways and only expert supplied pathways, respectively (Table 7). These values were similar to those obtained using the raw number of species to rank pathways which was 23% for both. The other pathways, and their relative ranks, within the top 10 were less consistent.

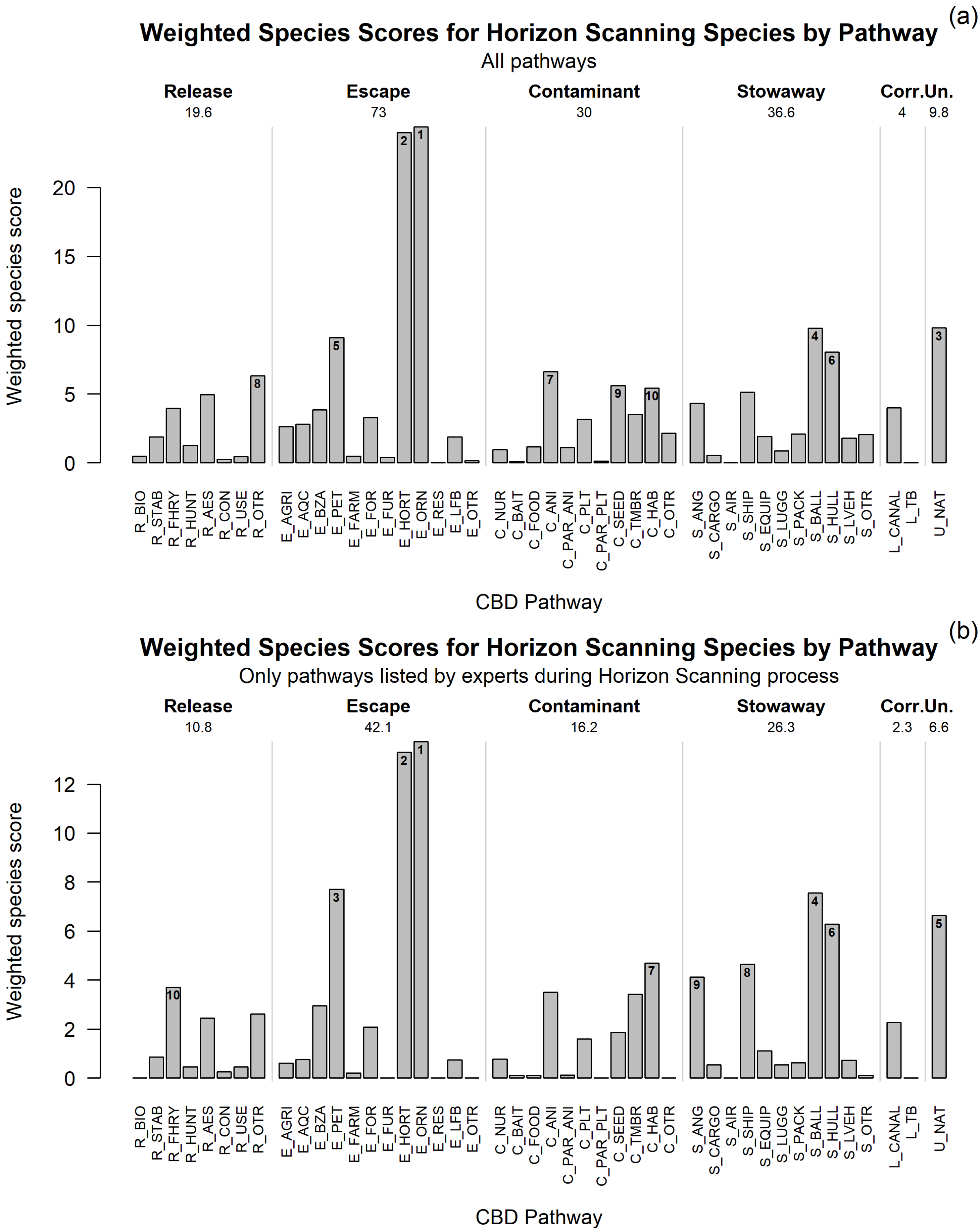


Figure 6. The weighted numbers of horizon scanning species associated with each CBD pathway using a) all pathway data, b) only pathways expert groups thought applicable to Scotland. The top 10 ranked pathways are labelled with their rank. For full pathway names see Table 1.

Based on all pathways data for the horizon scanning species three pathways, seed contaminant, angling and ship excluding ballast water or hull fouling, were lost from the top 10 and two gained, other release (8th) and seed contaminant (9th), when changing the scoring metric from the raw number of species to the weighted species scores. A similar situation was found for the rankings using only the expert supplied pathways where two pathways dropped out of the top 10, botanical gardens & zoos and contaminant of animals, and one, fishery in the wild (10th), gained.

Table 7. Top 10 ranked pathways for species on the horizon scanning long list based on the total weighted species score for each pathway, based on all pathway data or only pathways experts thought applicable to Scotland during the horizon scanning exercise. For each pathway the proportion of the data associated with that pathway and the cumulative proportion are also shown.

	Rank	Pathway	Weighted No. Species Score	Proportion	Cumulative Proportion
All pathways	1	Ornamental	24.4	0.141	0.141
	2	Horticulture	24.0	0.139	0.280
	3	Natural dispersal	9.8	0.057	0.336
	4	Ballast water	9.8	0.057	0.393
	5	Pet	9.1	0.053	0.446
	6	Hull fouling	8.0	0.047	0.492
	7	Contaminant of animals	6.6	0.038	0.530
	8	Other release	6.3	0.037	0.567
	9	Seed contaminant	5.6	0.032	0.599
	10	Habitat material contaminant	5.4	0.031	0.631
Expert pathways	1	Ornamental	13.7	0.132	0.132
	2	Horticulture	13.3	0.128	0.259
	3	Pet	7.7	0.074	0.333
	4	Ballast water	7.6	0.073	0.406
	5	Natural dispersal	6.6	0.064	0.469
	6	Hull fouling	6.3	0.060	0.530
	7	Habitat material contaminant	4.7	0.045	0.575
	8	Ship excluding ballast water or hull fouling	4.6	0.045	0.619
	9	Fishing equipment	4.1	0.040	0.659
	10	Fishery in the wild	3.7	0.036	0.694

Biodiversity impact and overall horizon scanning score

The breakdown of pathways based upon total biodiversity impact scores (Figure 7) and the overall horizon scanning scores (Figure 8) were very similar to those obtained based on the uncorrected number of species with generally the same pathways being shown as most important (Tables 8-9).

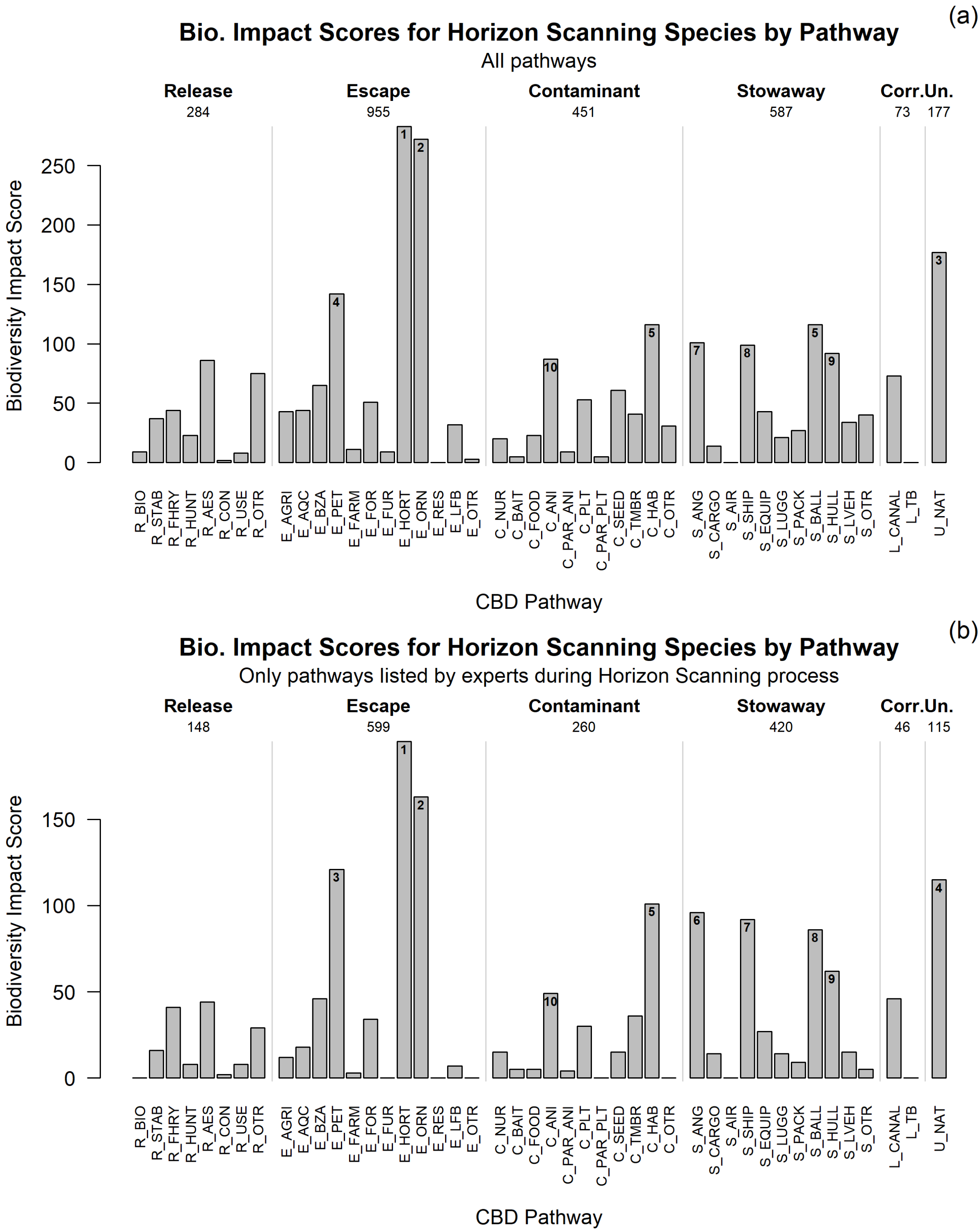
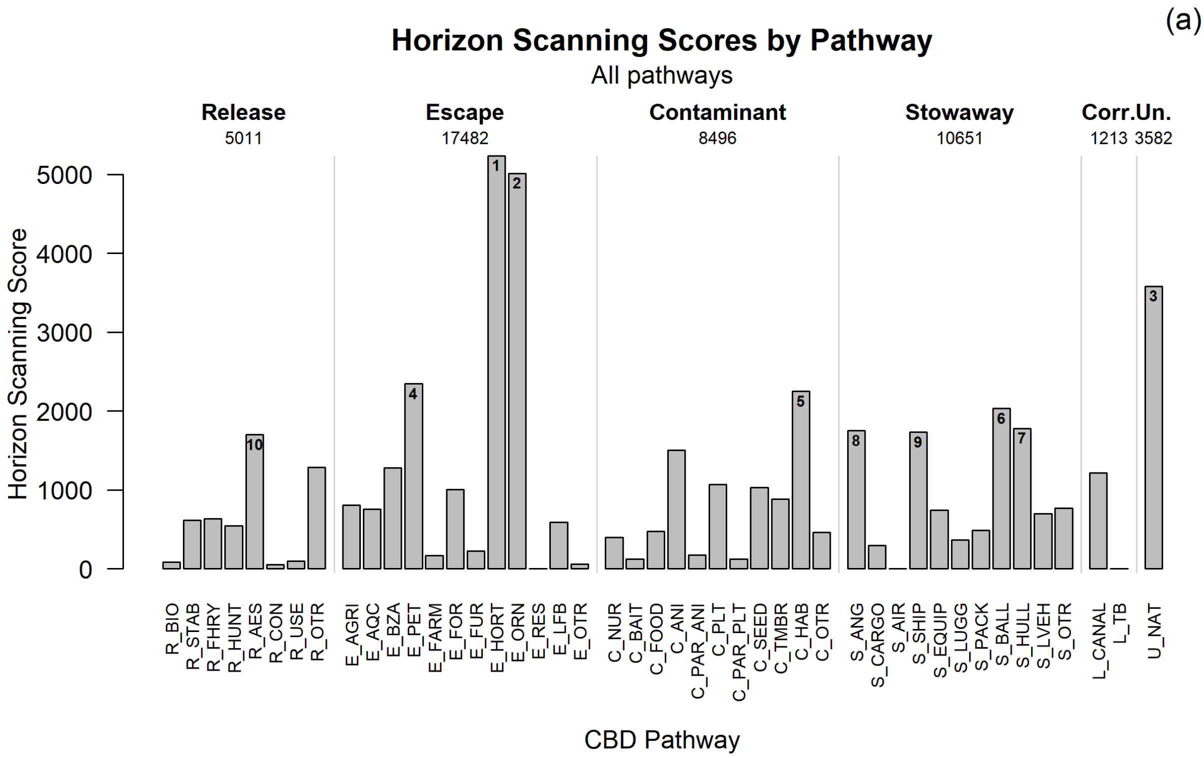


Figure 7. The total biodiversity impact associated with each CBD pathway for horizon scanning species using a) all pathway data, b) only pathways expert groups

thought applicable to Scotland. The top 10 ranked pathways are labelled with their rank. For full pathway names see Table 1.

Table 8. Top 10 ranked pathways for species on the horizon scanning long list based on the total biodiversity impact score for each species associated with that pathway, using either all pathway data or only pathways experts thought applicable to Scotland during the horizon scanning exercise. For each pathway the proportion of the data associated with that pathway and the cumulative proportion are also shown.

	Rank	Pathway	Biodiversity Impact Score	Proportion	Cumulative Proportion
All pathways	1	Horticulture	283	0.112	0.112
	2	Ornamental	272	0.108	0.220
	3	Natural dispersal	177	0.070	0.290
	4	Pet	142	0.056	0.346
	5	Habitat material contaminant	116	0.046	0.392
	5	Ballast water	116	0.046	0.438
	7	Fishing equipment	101	0.040	0.478
	8	Ship excluding ballast water or hull fouling	99	0.039	0.517
	9	Hull fouling	92	0.036	0.553
	10	Contaminant of animals	87	0.034	0.588
Expert pathways	1	Horticulture	195	0.123	0.123
	2	Ornamental	163	0.103	0.225
	3	Pet	121	0.076	0.302
	4	Natural dispersal	115	0.072	0.374
	5	Habitat material contaminant	101	0.064	0.438
	6	Fishing equipment	96	0.060	0.498
	7	Ship excluding ballast water or hull fouling	92	0.058	0.556
	8	Ballast water	86	0.054	0.610
	9	Hull fouling	62	0.039	0.649
	10	Contaminant of animals	49	0.031	0.680



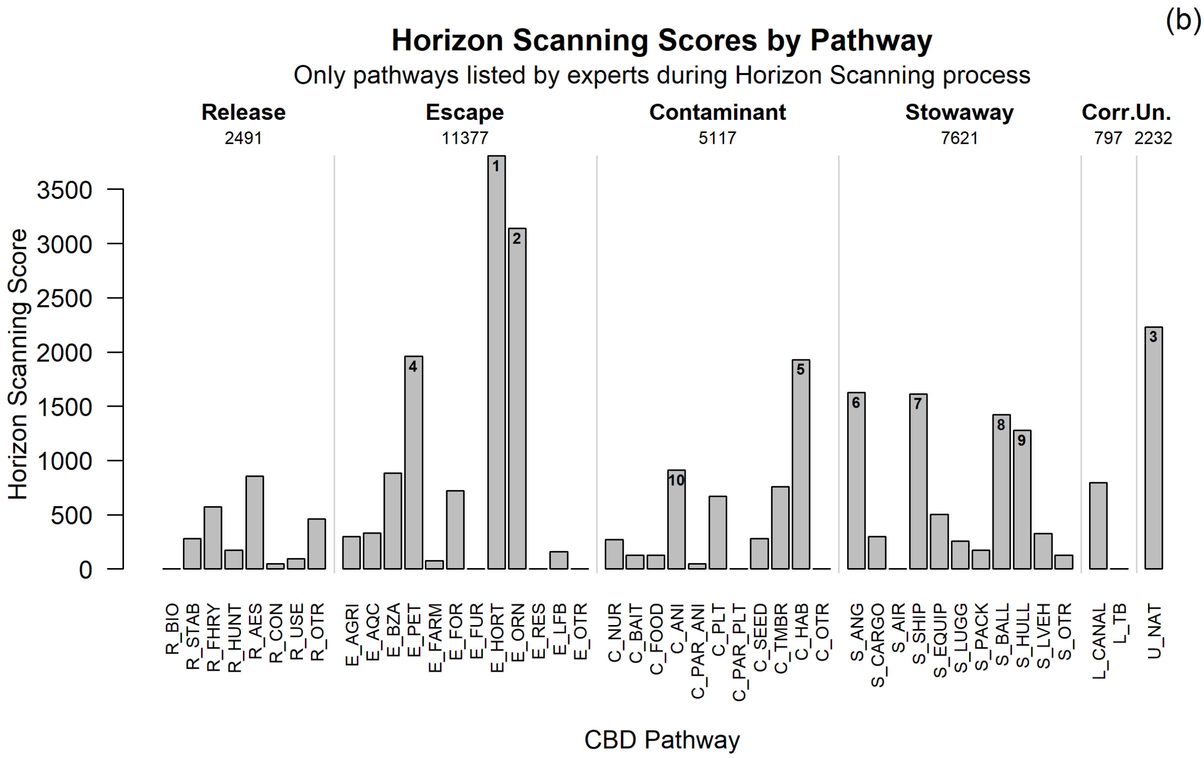


Figure 8. The total biodiversity impact associated with each CBD pathway for horizon scanning species using a) all pathway data, b) only pathways expert groups thought applicable to Scotland. The top 10 ranked pathways are labelled with their rank. For full pathway names see Table 1.

Table 9. Top 10 ranked pathways for species on the horizon scanning long list based on the total overall horizon scanning score for each species associated with that pathway, using either all pathway data or only pathways experts thought applicable to Scotland during the horizon scanning exercise. For each pathway the proportion of the data associated with that pathway and the cumulative proportion are also shown.

	Rank	Pathway	Horizon Scanning Score	Proportion	Cumulative Proportion
All pathways	1	Horticulture	5237	0.113	0.113
	2	Ornamental	5012	0.108	0.221
	3	Natural dispersal	3582	0.077	0.298
	4	Pet	2345	0.051	0.348
	5	Habitat material contaminant	2250	0.048	0.397
	6	Ballast water	2033	0.044	0.441
	7	Hull fouling	1780	0.038	0.479
	8	Fishing equipment	1751	0.038	0.517
	9	Ship excluding ballast water or hull fouling	1734	0.037	0.554
	10	Aesthetic release	1698	0.037	0.591
Expert pathways	1	Horticulture	3806	0.128	0.128
	2	Ornamental	3138	0.106	0.234
	3	Natural dispersal	2232	0.075	0.310
	4	Pet	1960	0.066	0.376
	5	Habitat material contaminant	1930	0.065	0.441
	6	Fishing equipment	1626	0.055	0.496
	7	Ship excluding ballast water or hull fouling	1614	0.054	0.550
	8	Ballast water	1421	0.048	0.598
	9	Hull fouling	1277	0.043	0.641
	10	Contaminant of animals	911	0.031	0.672

Correlations between rankings

The relative importance of the pathways, particularly for the higher ranking pathways was similar between all and recently established species (Figure 9a), with a reasonably high correlation coefficient (τ = 0.821). This suggests that the rankings of the pathways associated with the recently established species are similar to those associated with all of the established species, although there are differences as represented by the points lying further away from the dotted 1:1 line (Figure 9a). The rankings obtained using weighted scores were also found to be highly correlated (τ = 0.869) with rankings using the raw number of species (Figure 9b). Similarly, for horizon scanning species the rankings were highly correlated (τ = 0.819) when comparing rankings using all pathway data against that using only expert supplied pathways (Figure 9c), though there was more divergence from the 1:1 for the pathways near the bottom of the rankings (i.e., least important).

Correlation between pathway rankings

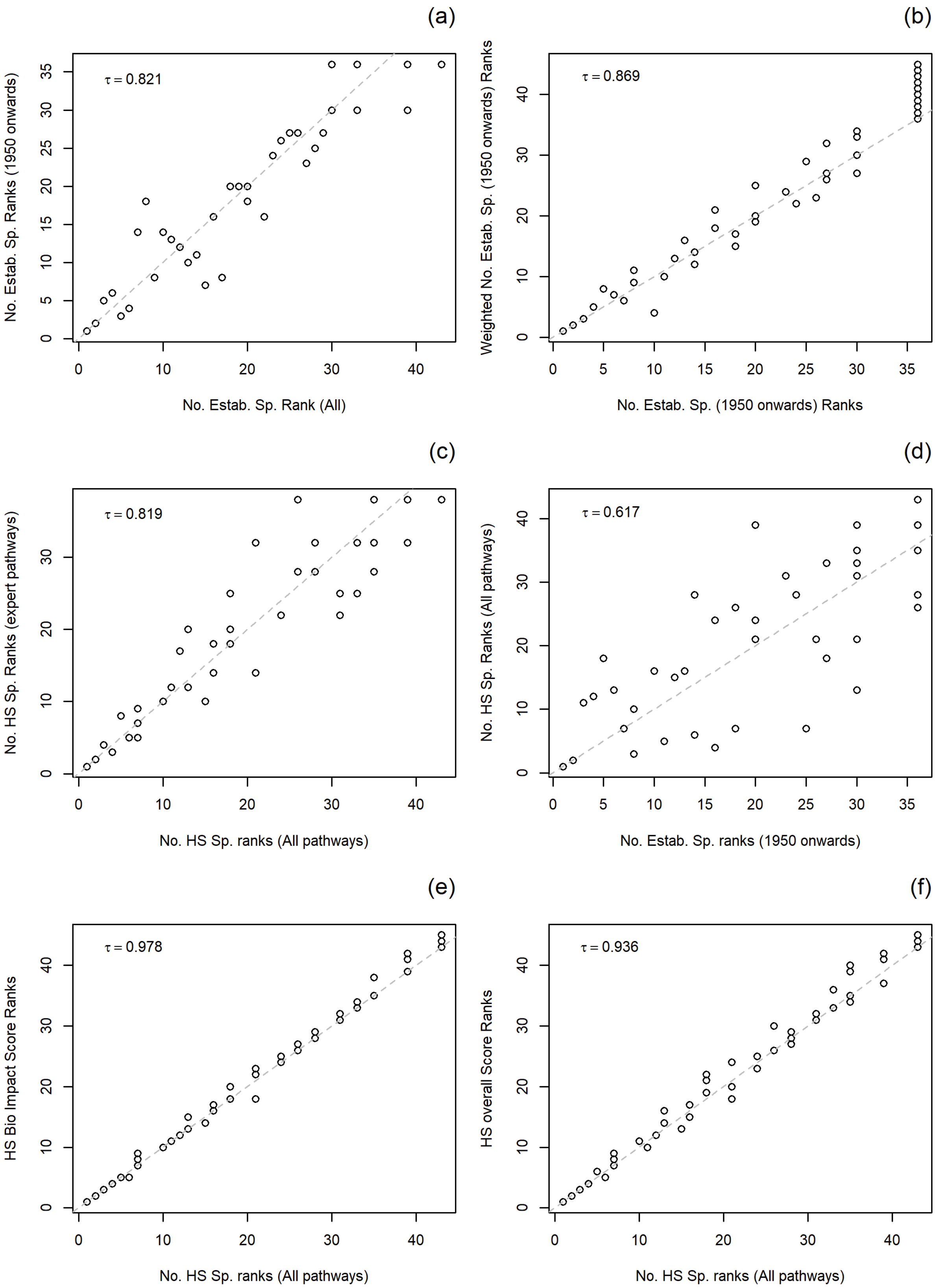


Figure 9. Correlations between pathway rankings for the different importance scoring methods and or subsets of data, specifically; a) all established species and species

established since 1950, b) total number of species and weighted number of species, c) all pathways and only pathways suggested by expert groups as likely for Scotland, d) established species and horizon scanning species, e) number of species and total biological impact for horizon scanning species, and f) number of species and overall total horizon scanning score for horizon scanning species. Each plot also shows the Kendall's correlation coefficient between the pairs of ranks (a value of $\tau = 1$ indicates a perfect match, $\tau = -1$ a perfect inverse match and $\tau = 0$ no relationship, i.e., random).

Although there was a correlation ($\tau = 0.617$) between the pathway ranks for recently established species and the horizon scanning species, it was much lower than that for the other pairing and the plot for this pair showed much scatter around the 1:1 line (Figure 9d). The rankings obtained using the biodiversity score and overall horizon score were very highly correlated ($\tau = 0.978$ and 0.936, respectively) with the ranks that used the raw number of species (Figures 9e and 9f).

Discussion

Much of Scotland is relatively distinct from the rest of Great Britain in terms of climate, with colder winter temperature minima and many fewer frost-free days in winter and spring. This limits the establishment of cold-sensitive invasive non-native species (INNS) from tropical, sub-tropical and Mediterranean regions, some of which have been able to establish in southern England. This limiting effect is likely to be greatest for terrestrial plants and animals, with freshwater INNS, such as submerged plants, fish and terrapins, more buffered against extreme cold air temperatures. North-south gradients in average monthly surface water temperatures are less extreme, and lag behind those in air temperature by several weeks because water heats up and cools down more slowly than land. The natural nutrient status and pH values of freshwaters within Scotland mirror those of the rocks and soils in the catchments. Scotland's freshwater environment shares greater similarity with that of Wales compared with that of England (Abell, Thieme et al. 2008). Open access legislation, especially to boating and watersports, does however, potentially increase the spread of INNS that are generally introduced through recreational pathways. This may be a particular threat to the arrival of freshwater INNS in Scotland (Chapman et al., 2020). Recent tourism developments in Scotland, such as the promotion and development of the North Coast 500, have led to exceptional increases in the number of visitors to this region of northern Scotland, which could intensify pathways for INNS transported through vehicles, boats, equipment and clothing.

The top 10 and top 30 lists include a diverse range of INNS spanning all environments. Five freshwater species are present in the top 10: three molluscs and two submerged plant species. Freshwaters are considered to be one of the most vulnerable habitats, affected greatly by multiple pressures, such as climate change, overexploitation, sewage, nutrient pollution and recreation which can act synergistically with pressures from INNS (Birk, Chapman et al. 2020). Indeed, there is increasing attention on the interactions amongst drivers of biodiversity change including climate change and biological invasions. Some of the UK's rarest fish, such as the cold-water loving species, the Arctic charr (*Salvelinus alpinus*) and powan (*Coregonus lavaretus*), are found in Scottish lochs. These species are vulnerable to the effects of climate change, which may, in turn, facilitate the expansion of INNS that could outcompete them for resources. A good example of where this has already occurred is in Loch Lomond, with the introduction of the non-native perch-like fish, the ruffe *(Gymnocephalus cernuus),* in the early 1980s as live bait by anglers. Subsequently, the ruffe population expanded and was implicated in the decline of the native powan in one of its only two natural sites in Scotland (Winfield, Fletcher et al. 2011).

Freshwater biodiversity is also culturally and economically important in Scotland, with salmon and trout angling in particular contributing significantly to some rural Scottish economies (Marine Scotland 2017). The two freshwater invasive non-native plant species (floating pennywort, *Hydrocotyle ranunculoides*, and parrot's feather, *Myriophyllum aquaticum*) are widely distributed in England and Wales but have only been recorded (and removed) from one site each in northern Scotland. They can colonise vegetatively through the introduction of stem fragments and are very competitive, forming dense emergent stands that can outcompete native flora, impact water quality and alter natural flow regimes. The latter impact can lead to social and economic impacts through exacerbating flood risk.

Of the three invasive non-native mollusc species, only one, zebra mussel (*Dreissena polymorpha*), has been recorded in Scotland previously, where it was present in the Forth & Clyde Canal and Union Canal and in Perth Docks (a brackish habitat). It is thought to have been lost from these sites in the 1970s, due to a severe deterioration in water quality. There have only been three records of zebra mussel (*D. polymorpha*) in Scotland in recent decades, relating to interceptions of overland transport of canal boats, and these did not establish. Quagga mussel (*D. bugensis*) has also been intercepted in Scotland before it was able to enter the canal network. Given this evidence, and the fact that it is locally distributed in many English rivers and canals, *D. polymorpha* is considered to be a priority species because of its imminent potential for arrival, and clear introduction pathway through boat traffic in the canal network. The other two mussel species are considered to be high priority because they are spreading quickly in England. *D. bugensis* has also been intercepted in Scotland before it was able to enter the canal network and both *Dreissena* species have been intercepted simultaneously. All three species have also established in Ireland in recent decades, illustrating their ongoing range expansion. In terms of biodiversity impact, all three mussels have the capacity to outcompete native molluscs and alter freshwater benthic habitats (Sousa, Novais et al. 2014, Modesto, Dias et al. 2021), facilitating establishment of other INNS (Gallardo and Aldridge 2015).

There is evidence from long-term lake data that indicates that *Dreissena* invasion in lakes can lead to greater dominance by harmful algal blooms of cyanobacteria, due to selective feeding. This can have consequent impacts on biodiversity, economic interests and health. The *Dreissena* species are grouped together in the top 10 list for communication purposes, in part because they have previously demonstrated a shared introduction pathway and because for recording purposes the public are asked to look out for stripey mussels. The targeting of control actions may vary for the two species due to their respective habitat requirements/impacts, particularly when it comes to engaging with knowledgeable audiences. The invasion capacity of *Corbicula fluminea* appears to be particularly high due to its life strategy traits (rapid growth, early sexual maturity, short life span, high fecundity, extensive dispersal capacities). For these reasons, its rapid spread in England, and its possible role in the apparent loss of a critically endangered mussel species (*Sphaerium solidum*) from the UK fauna, it has been the focus for a rapid risk assessment by the GB Non-native Species Secretariat[10].

Crepidula fornicata, commonly known as the American slipper limpet was the only marine species included in the top 10 priority list. This mollusc arrived on the south coast of the UK between 1887 and 1890, with American oysters imported from North America (Bohn, Richardson et al. 2012). It has since spread throughout the north-east Atlantic and is now established as far north as Belfast Lough in the UK. This species attaches to other slipper limpets and can form long chains of up to 12 individuals. It also readily attaches to commercially important bivalve species, such as oysters, mussels and scallops. The intentional movement of these commercial species for stocking purposes has been identified as the primary pathway for the spread of *C. fornicata* throughout Europe. The slipper limpet has no species-specific predators, it is long-lived and has high reproductive viability and fecundity. It can occupy a wide range of habitats, including harbours, marinas, inlets, bays, estuaries and open coast, settling on substrates ranging from rocks and stones to artificial surfaces. This species can form dense populations (up to 10,000 individuals m^{-2}), to the extent that in certain regions, commercial oyster grounds require regular clearing before new seed is sown. It can also readily alter the nature of the sediment substrata and smother areas previously dominated by native bivalves. A number of records exist for *C. fornicata* in Scotland, but to date none of these have been verified. With the possible spread through fishing and culture practices and/ or through natural dispersal of the pelagic planktonic larval stage, it is highly likely, therefore, that this species will become established in Scottish waters within the next 10 years.

Alongside the two aquatic plant species (floating pennywort, *Hydrocotyle ranunculoides*, and parrot's feather, *Myriophyllum aquaticum*) one terrestrial plant species was also included in the top 10 INNS, the northern highbush blueberry (hereafter blueberry), *Vaccinium corymbosum*, and its hybrids (*Vaccinium corymbosum* x *angustifolium*). It is a deciduous shrub reaching a height of 1.8–3.7 m and can form dense thickets through vegetative growth (suckering). The species is a member of the Ericaceae (heather) family and is found in open and wooded areas mostly on acidic soils in its native range of eastern North America (from Florida in the south to Ontario and Nova Scotia in the north). This species and its hybrids are already established elsewhere in Europe. For example, in northern Germany, plants have spread from hybrid commercial crop plantations to peat bog and planted Scots pine (*Pinus sylvestris*) habitats (located within 3 km of plantations). The fruits, each fruit containing multiple seeds, are likely to be bird-dispersed. This means that spread potential within landscapes with open commercial plantations is likely to be high. Blueberry is not able to self-pollinate, which may serve to limit its reproduction and establishment when populations are small. However, the ability to spread to and form thickets in important habitats that occur within Scotland means that the potential for biodiversity and ecosystem impacts is high, through outcompeting lower-growing plant species, and possibly through altering water content of bog soils due to increased rates of evapotranspiration.

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10 Risk assessment - GB non-native species secretariat (nonnativespecies.org)

Another notable invasive non-native plant species included within the top 30 is *Anemanthele lessoniana* (synonym: *Stipa arundinacea*) or pheasant's tail (or sometimes called New Zealand wind grass). Pheasant's tail is a fast-growing perennial, clump-forming grass with short rhizomes, introduced and widely planted as an ornamental in gardens within Britain, including Scotland. Pheasant's tail is easy to grow and has received the Royal Horticultural Society (RHS) award of garden merit; according to the RHS, it has a hardiness level of H4, which means the species is hardy throughout most of Britain (withstanding minimum temperatures of -10 to -5° C). This grass produces large numbers of seeds which germinate easily and has already been recorded as established in England and Wales. The species may already be on the verge of escaping plantings and establishing in Scotland. While the species is known to be introduced to Britain, there is little information available on its introduction and invasion history elsewhere. However, this grass tends to produce a large amount of thatch, representing a potential fire risk in fire-prone habitats. Production of thatch could also alter litter inputs into soils and prevent germination of seeds of other species, though concrete evidence of impacts is lacking. The prolific production of small seeds that could be wind-dispersed means that spread potential from plantings to semi-natural and natural habitats is likely to be high.

The top 10 list included two vertebrates: Reeve's muntjac (*Muntiacus reevesi*) and raccoon (*Procyon lotor*) although there was considerable discussion around the other non-native vertebrates included within the top 30. The Reeve's muntjac is a small deer that can have a big impact. Introduced from Asia, muntjacs have been very successful in colonising much of England and parts of Wales, thriving in woodland, farmland and even suburban and garden habitats. They are able to breed throughout the year and reach densities of over 100 animals per square kilometre; where muntjacs become abundant they can have a serious impact on native vegetation through browsing pressure. Woodland herbs, understorey shrubs and tree regeneration can be seriously damaged, changing the habitat structure and vegetation composition to the detriment of native flora and fauna. Muntjacs would be a significant threat to Scotland's existing woodlands and goals for woodland expansion. Raccoons are highly adaptable omnivores that originate from North America but have established large populations in Germany (estimated at 200 000–400 000 individuals) and smaller populations in France, Belarus and Azerbaijan (Roy, Peyton et al. 2014). Raccoons pose a threat to biodiversity through predation and disease transmission (Roy, Tricarico et al. 2022).

Four species of geoplanid flatworms, *Australoplana sanguinea*, *Caenoplana bicolor*, *Kontikia andersoni* and *Obama nungara*, are listed among the top 10 on the basis of impact studies in other parts of their range or the equivalence in the biology to other well-studied species (Boag & Yeates 2001). Flatworms are voracious top-level predators in soil communities. With the exception of *C. bicolor*, the other three species are known to predate, among other groups, on lumbricid earthworms that are widely recognised as key ecosystem engineers. Thus, the main impact of the flatworms is likely to be indirect, but would affect soil structure, nutrient cycling and ultimately plant communities, while also having a direct predatory impact on native soil invertebrates such as gastropods (Keith et al. 2018). The flatworms listed here are known from invaded ranges south of Scotland in the UK, but also from the European continent (e.g., France, Germany, Italy) and elsewhere in the world. Once established there is currently no known method of removal or control (Justine et al. 2020, Mori et al. 2021). These invasive non-native flatworm species are thought to be moved with horticultural materials and ornamental plants, as most records are from urban environments, such as gardens and parks. However, the native and other invaded ranges of these flatworms suggest that there is the potential that they could move into non-urban environments.

The impact of beetles, similarly to that of the flatworms, is mostly indirect, damaging and removing trees, which are foundation species, with often well-defined communities associated with them. A notable potential invader is *Agrilus planipennis*, the emerald ash borer. Known to cause significant damage to its hosts, *Fraxinus* spp., in other parts of its invaded range, such as North America, the trees in Europe are already highly impacted by ash dieback, *Hymenoscyphus fraxineus*, a non-native fungal disease. While a small proportion, estimated to be 1–3% of the ash trees in the UK, show signs of disease tolerance, a dual challenge by pest and disease would make any management harder (Broome et al. 2019).

It is important to mention two species not included in the Top Ten priority list, despite their predicted high biodiversity and economic impact. Both are not yet recorded from Great Britain or Ireland, but are already recognised in plant and animal health legislation in Scotland because of their potential for severe economic impact. They are, therefore, already a focus of legislation to prevent their establishment and spread. *Agrilus planipennis*, the emerald ash borer, is a beetle that can cause extensive mortality of ash trees in regions where it has been introduced, including eastern North America, the European part of Russia, and more recently eastern Ukraine. *A. planipennis* is listed as a priority quarantine pest in Schedule 1 of The Plant Health (Amendment etc.) (EU Exit) Regulations 2020/1482 and as such its introduction into and movement within Great Britain is banned with a detailed Plant Health Response Plan in place to prevent its establishment and spread. *Gyrodactylus salaris* (salmon fluke) is a small parasitic flatworm. In Norway, catastrophic losses of Atlantic salmon (*Salmo salar*) occurred following the introduction of *G. salaris* to the country in the 1970s on imported live fish. Many Norwegian rivers were infected, and their salmon populations decimated (Marine Scotland, 2019). Although the most severely affected species is Atlantic salmon, *G. salaris* has been reported on other native fish species, such as Arctic char (*Salvelinus alpinus*), grayling (*Thymallus thymallus*) and brown trout (*Salmo trutta*). Because of the severe economic and biodiversity impacts this species poses, the Scottish Government has introduced strict provisions under the Aquatic Animal Health (Scotland) Regulations 2009 to eradicate, prevent or limit the spread of *G. salaris* in Scotland.

From the pathway analysis, horticultural and ornamental pathways emerged as the most important potential ways of introduction of INNS. This result is due to the high number of plants within all the lists assessed. Additionally, as these two pathways can be difficult to separate for many species, this could have compounded the high representation of these pathways. The pet pathway is considered important for introducing species on the horizon scanning long list but was not ranked as high for already established non-native species. Pathways in the contaminant category have historically been important in introducing non-native species. It is likely that this will continue to be the case as is evident from the analysis of the pathways considered relevant to the horizon scanning long list derived in this study. Contaminant of animals, seed contaminant and contaminant of habitat material are associated with a number of the non-native species listed. Furthermore, the natural dispersal of species from an existing invaded range into Scotland is considered an important pathway of arrival of INNS.

The results from the horizon scanning study coupled with the pathway analysis provide detailed information to prioritise actions to prevent the establishment of new INNS in Scotland, including action plans for priority pathways of introduction and spread. Noting the importance of pathways such as the ornamental and horticultural pathways, there are opportunities to further promote biosecurity campaigns such as Be Plant Wise. However, the pathway analysis also highlights a diverse range of pathways including the importance of contaminant pathways.

Key conclusions

There are many INNS spanning a range of species groups and environments that have the potential to arrive, establish and impact biodiversity and ecosystem services, human health and economies in Scotland.

A high proportion of the INNS (species groups including plants, animals and microorganisms) are predicted to arrive through the movement of plants through horticultural trade routes including within soil. There are opportunities to address unintentional introductions through the horticultural trade through biosecurity approaches.

In some cases, it may be appropriate to aggregate taxonomically similar INNS for the purposes of planning management actions or communication campaigns, for example flatworms.

Horizon scanning can underpin prioritisation of actions to prevent the arrival and establishment of INNS in Scotland. It is important to regularly review horizon scanning lists and repeat the approach every five years which is considered to be the approximate lag in flow of information across all non-native species.

Raising awareness and communication are important in preventing the introduction and spread of INNS. The Top 10 list agreed in consultation with NatureScot experts could be used within resources for diverse stakeholder groups spanning sectors.

Baseline information is critical to inform horizon scanning and databases on non-native species underpin such approaches. It is important to ensure rapid flow of information on non-native species to open access databases. There can be delays in detecting and reporting non-native species and additionally establishment status can be difficult to attribute for some non-native species. Adopting standard approaches and harmonising terminology, for example with respect to establishment status, should be prioritised and particularly noting the relevance to the Kunming-Montreal Global Biodiversity Framework Target 6 to "reduce rates of introduction and establishment of invasive alien species by 50 per cent".

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We are extremely appreciative of the extensive and inspiring contributions from all the people involved within the expert groups providing time and expertise as volunteers. Thank you to the Scottish Government for the opportunity to undertake this study and to all the experts from NatureScot and associated organisations for their excellent contributions. The study aligned with work from the Defra-funded GB Non-Native Species Information Portal which is partly supported through Natural Environment Research Council award number NE/R016429/1 as part of the UK-SCAPE programme delivering National Capability. The National Biodiversity Atlas was used to assess the distribution of a number of the INNS considered through this study.

Annex 1: Brief Summary of Horizon Scanning Approach

Briefing note circulated to all experts in advance of the horizon scanning

Prioritising Invasive Non-Native Species through Horizon Scanning for Scotland

UK Centre for Ecology & Hydrology, Crowmarsh Gifford, Oxfordshire, OX10 8BB, UK

It is useful to note that this is the first step in prioritising INNS for action. Consequently, the assessment process, while based on specific criteria, employed is by necessity crude and used for the purposes of ranking.

Consensus approach to horizon scanning
We will use an adapted version of the consensus method (Sutherland, Fleishman et al. 2011) for a horizon scanning approach previously used to derive a ranked list of potential INNS with high impact on biodiversity and ecosystems in Great Britain (Roy, Peyton et al. 2014) and Europe (Roy, Bacher et al. 2019) (Figure 1). We have extended the approach to consider human health and economic impacts.

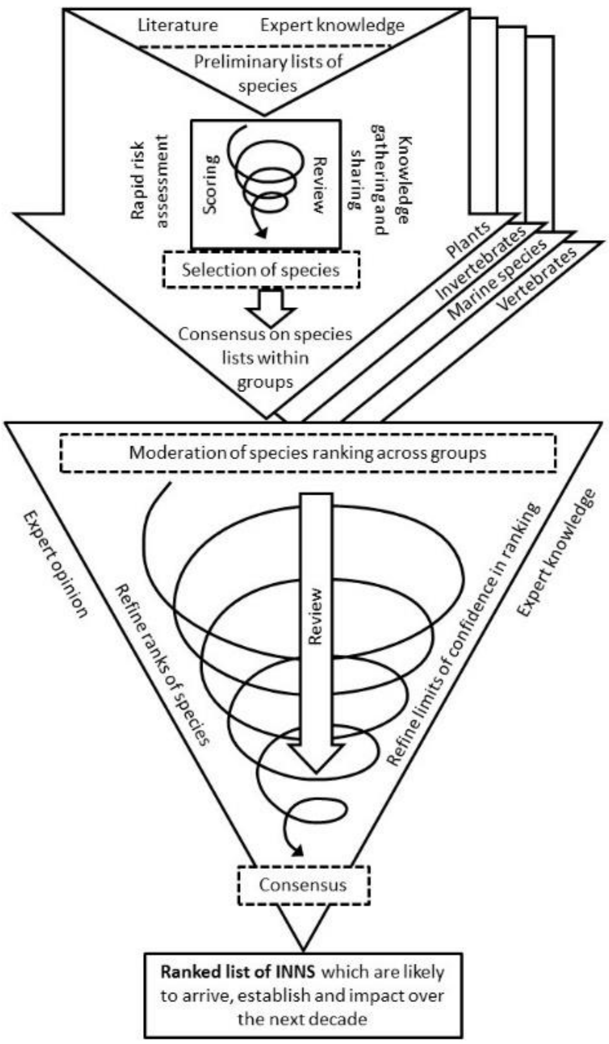

Figure 1. Horizon scanning process, based on consensus method, to derive a ranked list of INNS which are likely to arrive, establish and have an impact over the next decade.

Step 1. Establishment of thematic groups

Species will be considered within five broad thematic groups:

- Plants
- Terrestrial invertebrates
- Freshwater invertebrates
- Vertebrates
- Marine species

Step 2. Compilation of preliminary lists of potential INNS

Each thematic group will assemble preliminary lists of potential INNS that they considered to constitute the highest risk with respect to the likelihood of arrival, establishment and the magnitude of their potential negative impact on biodiversity and ecosystems or human health or economies over the next ten years.

Each thematic group will derive these lists from a combination of systematic literature searches (including academic journals, risk assessments, reports, authoritative websites and other 'grey' literature), checklists, floras, querying of INNS databases and their own expert knowledge. The approaches adopted by each thematic group will differ slightly with respect to methods followed to derive the preliminary lists because of the diverse nature of the taxonomic groups and variation in the sources of information available (Table 1). The leaders will coordinate activities and discussion between group members throughout the process. The consultation between experts will be completed both through e-mail discussions in advance of the workshops and through the workshop breakout groups.

We will provide lists of INNS from previous exercises (Great Britain, Europe and the UK Overseas Territories). We will also provide a spreadsheet template for gathering data.

The geographic scope of the search for potential INNS will be global but with the following restrictions:

(i) Are absent in Scotland
(ii) Have documented histories of invasion and causing undesirable impacts in other regions worldwide with similar climatic conditions.
(iii) Traded within Scotland or are present in areas that have strong trade or travel connections with Scotland and where there is a recognised potential pathway for arrival.
(iv) Are present in captivity including gardens, zoological parks, aquaculture facilities and glasshouses.

For this horizon scanning exercise, we will focus on species that have not yet become established in Scotland in the wild, that is have not yet formed self-sustaining populations (Blackburn, Pysek et al. 2011). However, a few species will be included, which have formed transient local populations that have been detected and either failed to persist or been deliberately removed. In accordance with definitions outlined by the CBD[11], we will categorize species as non-native, if their arrival was likely to be mediated by human activities.

Table 1. Major data sources, in addition to literature from web-based searches and expert knowledge, used previously within horizon scanning approaches by each thematic group (a. Plants; b. Invertebrates; c. Vertebrates; d. Marine species) to compile preliminary lists of potential INNS with high impact on biodiversity and ecosystems, human health or economies.

	Data sources
Plants	GBIF Database; Caribbean Invasive Alien Species Network database (CIASNET); Weber (2003) Invasive Plant Species of the World; Randall (2002) A Global Compendium of Weeds; BSBI Distribution Database; CABI Horizon Scanning Database;
Invertebrates	CABI Horizon Scanning Tool; CABI Invasive Species Compendium; EPPO Database; Global Register of Introduced and Invasive Species
Vertebrates	Caribbean Invasive Alien Species Network database (CIASNET); CABI Horizon Scanning Tool; Global Register of Introduced and Invasive Species (GRIIS); GBIF Database; Global Avian Introduction database (GAVIA); CABI Invasive Species Compendium; Wikipedia List of invasive species in Florida; JNCC Database of non-native species occurring in UK Overseas Territories; CABI horizon scanning tool; Sistema Nacional de Información sobre Especies Exóticas Invasoras (Argentinian IAS database); Avibase - Bird Checklists of the World
Marine	CABI Horizon Scanning Tool; GBIF Database; WORMS Database, AlgaeBase.org; CABI Invasive Species Compendium; NEMESIS (US Based database)

We will consider species on the GB INNS species lists present in England and Wales, but not yet present in Scotland, whereas species that are deemed likely to arrive by natural dispersal from their native range in GB will be excluded from consideration.

We will also exclude from this exercise potential invasions of microbial pathogens, bacterial, fungal, oomycetes or otherwise. While clearly of potential importance, a recent review identified significant knowledge gaps and identified 10 key areas for research (Roy, Hesketh et al. 2016). However, we do consider potential macroscopic INNS which are known vectors of disease for impact assessments.

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11 Link to CBD definitions of non-native species

Where invertebrates that occupy terrestrial and freshwater habitats at different stages of their life cycle have egg and larval stages bound to freshwater habitats, e.g. most mosquitoes and midges, they will be reviewed by the freshwater group. Establishment as a crucial phase in becoming invasive is likely to be determined by adaptation to the abiotic environment at the immature stages.

Species associated with brackish water habitats will be considered explicitly by the Freshwater team but will be reviewed by the Marine Team for any gaps.

The temporal scope of the horizon scanning exercise will be only species likely to arrive in the next 10 years within GB. This temporal limit informs the relevance of, for instance, long-term climate change projections.

Step 3: Scoring of species

Experts were advised that the scoring approach was not absolute but to provide an initial ranking of all potential INNS. This context was important to ensure that experts were empowered to use expert judgement alongside available evidence sources. Experts were asked to score each species within their thematic group for their separate likelihoods of: i) arrival, ii) establishment, iii) magnitude of the potential negative impact on biodiversity or ecosystems, human health or economies. A 5-point scale from 1=very low to 5=very high (Blackburn, Essl et al. 2014) was adopted. The scores from each expert within each thematic group were then compiled and discussions within the thematic groups (at the workshop) led to an overall agreed impact and confidence score for each species.

Scoring arrival
Scores for the likelihood of arrival should be based on a consideration of several relevant factors, including: previous history of invasion by the species in other regions; the existence of a plausible introduction pathway; qualitative consideration of volume and frequency of trade and travel between the existing range of the species. A score of 1 denotes that the species is considered unlikely to arrive within the chosen timeframe. A score of 5 is used to denote near-certain arrival; for example if there was a previously documented inception of the species. In the case of species already in GB (such as those held commonly in captivity or planted in gardens), the likelihood of arrival was agreed to be given a score of 5.

Scoring establishment
Having arrived, the probability of a species establishing a self-sustaining population in the wild depends on the ecological properties of both the species and the community that it is invading (Leung, Roura-Pascual et al. 2012). Scores should reflect life-history characteristics including reproductive rate and ecological features such as tolerance of a broad range of environmental conditions or availability of food supply in the introduced range.

Scoring impacts
Scores are required for each of the three impact categories (biodiversity and ecosystems (e.g. species, habitats, ecosystems and ecosystem functioning), human health or economies (Table 2). The impact scoring system has been modified from the Invasive Species Environmental Impact Assessment protocol (Branquart 2009), the GB Non-Native Risk Assessment scheme (Booy, White et al. 2006) and the

proposed unified framework for environmental impacts - Environmental Impact Classification of Alien Taxa EICAT (Volery, Bacher et al. 2020) and Socio-Economic Impact Classification of Alien Taxa SEICAT (Bacher, Blackburn et al. 2017).

Confidence levels

Confidence levels (high, medium or low confidence) should be attributed to each score to help focus discussions and refine the list of species and in guiding discussion within some thematic groups (Table 3).

While acknowledging that the scores are only for guidance on ranking and not to be used as absolute, an overall risk score for each species will be calculated as the product of the individual scores for arrival, establishment and impact on biodiversity. With a 3-criterion, 5-point scoring system, this produces a maximum score of 125.

Table 2. Guidance notes for scoring impacts on biodiversity and ecosystems (e.g. impacts on species, habitats, ecosystems and ecosystem functioning), human health or economies.

Score	Impact on biodiversity and ecosystems	Impact on human health	Impact on economies
1	No deleterious impacts or local, short-term impact on few species or ecosystems, reversible	No deleterious impacts or local, short-term reversible effects to few individuals	No deleterious impacts reported
2	Local, short-term impact on communities or several ecosystems, reversible	Local, short-term reversible effects to larger groups of people	Negative effect on crops or livestock local, short-term and reversible; loss of revenue minor
3	Long-term impact, but little spread, no extinction	Local, but irreversible effects on small groups of people or reversible effects on larger groups of people	Negative effect on crops or livestock local, but irreversible
4	Long-term irreversible impact, spreading beyond the local area	Local, significant irreversible effects at the regional scale or reversible effects over large areas	Negative effect on crops and livestock irreversible at the regional scale (i.e. beyond local areas), or reversible over larger areas
5	Widespread, severe, long-term impact, including extinction	Widespread, severe, long-term, irreversible health effects over large areas	Negative effect on crops and livestock severe, irreversible over large areas

Table 3. Examples of information relevant for justification of a specific confidence scores (high, medium, low). Modified from (Hawkins, Bacher et al. 2015).

Confidence Score	Examples
High	There is direct relevant evidence to support the assessment. The situation can easily be predicted. There are reliable/good quality data sources on impacts of the species. The interpretation of data/information is straightforward. Data/information are not controversial, contradictory.
Medium	There is some evidence to support the assessment. Some information is indirect, e.g. data from phylogenetically or functionally similar species have been used as supporting evidence. The interpretation of the data is to some extent ambiguous or contradictory.
Low	There is no direct evidence to support the assessment, e.g. only data from other species have been used as supporting evidence. Evidence is poor and difficult to interpret, e.g. because it is strongly ambiguous.

Information on pathways
Information should be gathered throughout the workshop by the experts within the thematic groups on the likely pathways of arrival, using published classifications (Harrower, Scalera et al. 2018) (Table 2).

Step 4: Expert (consensus) workshop

Each thematic group will present an overview of the INNS to inform the other participants of the range of species and their life-histories within each group, enabling subsequent review and moderation of the scores within the breakout sessions for each thematic group. During the breakout session, participants can add or remove species, justify and moderate scores and consider levels of confidence attached to scores. All the species lists from across the thematic groups will be collated into single lists for each of the impact categories (biodiversity and ecosystems, human health or economic). Experts will be invited to justify their scores in comparison to those of other groups.

All participants will then be invited to review, consider and refine the rankings of all species through plenary discussion. Again scores will be adjusted accordingly. The end result will be an agreed ranked lists of INNS with the potential to arrive, establish and pose a threat through biodiversity and ecosystem, human health or economic impacts.

Step 5: Post workshop compilation of information on species

Following the workshop all participants will be invited to review the pathway information for the INNS identified as priorities. Additional taxonomic information and other details for the INNS will also be reviewed.

Table 2. Pathway classification

	Category	Subcategory
Movement of Commodity	Release in Nature	Biological control
		Erosion control/ dune stabilization (windbreaks, hedges, …)
		Fishery in the wild (including game fishing)
		Hunting
		Landscape/flora/fauna “improvement” in the wild
		Introduction for conservation purposes or wildlife management
		Release in nature for use (other than above, e.g., fur, transport, medical use)
		Other intentional release
	Escape from Confinement	Agriculture (including Biofuel feedstocks)
		Aquaculture / mariculture
		Botanical garden/zoo/aquaria (excluding domestic aquaria)
		Pet/aquarium/terrarium species (including live food for such species)
		Farmed animals (including animals left under limited control)
		Forestry (including afforestation or reforestation)
		Fur farms
		Horticulture
		Ornamental purpose other than horticulture
		Research and ex-situ breeding (in facilities)
		Live food and live bait
		Other escape from confinement
	Transport - Contaminant	Contaminant nursery material
		Contaminated bait
		Food contaminant (including of live food)
		Contaminant on animals (except parasites, species transported by host/vector)
		Parasites on animals (including species transported by host and vector)
		Contaminant on plants (except parasites, species transported by host/vector)
		Parasites on plants (including species transported by host and vector)
		Seed contaminant
		Timber trade
		Transportation of habitat material (soil, vegetation,…)

Questions and Answers received through the preliminary consultation:

1. For the column "Already present in EU?" – should this be **EU or Europe** including GB or not?

Europe-wide but exclude GB.

2. Should the **arrival** score be for GB or specifically Scotland?

The arrival score should be for Scotland specifically – as an example a species in captivity in a zoo in the south of England may not score 5 for arrival in Scotland.

Likelihood of arrival may differ between Scotland and GB for some pathways, e.g. travel from the Continent for angling and boating.

Remember: the **scoring is purposefully crude** to allow initial ranking of the species so experts should not be overly concerned – that said of course it is helpful to ensure the criteria are applied as consistently as possible across groups so when the lists from all groups are merged they look sensible! The first workshop will help though in providing an opportunity for moderation of scores by comparing species across groups.

1. How is **establishment** defined?

Self-sustaining populations of alien species are considered established. However, this can be difficult to determine definitely so we have discussed how to deal with species that do breed in Scotland but don't have clear evidence of a self-sustaining population yet (e.g. ring-necked parakeet). There are also examples of long-lived species that cannot breed but have sustained populations because of their longevity. We agreed to include these species on the long initial list but move them onto a separate list of species that don't fully meet the horizon scanning criteria but we have some concerns about. Examples include *Onchorhynchus gorbuscha* and *Trachemys scripta*.

In summary it is useful to capture the species that are potentially at early establishment phase within a separate table noting that the scope of the horizon scanning includes species that are currently absent from "the wild". However, where people have a sufficient level of uncertainty about the establishment status then I suggest taking a precautionary approach and including them for now.

Likelihood of establishment may differ also, based on climate matching and other environmental factors.

For species that are currently climatically limited it is worth thinking about the next 10 years and whether the climate might become favourable in that time-frame.

With the aphids where we're getting alate dispersal flights in more than one year, and often at more than one site, we can say that there's an established population *somewhere* in Scotland, even if it's not been identified on the ground. But if all the known host plants are horticultural (and it is therefore confined to gardens, and cannot escape to the wider environment) does that still count as established?

It is fascinating to consider Fiona's example of a species that could only establish in gardens because that is where the host plant occurs. These species could of course have a potentially high economic impact and so I would include them in the "main" HS list if doubtful about current establishment or in a table of other species of interest (i.e. evidence of early establishment) with just a short comment on why they are not in the "main" HS list.

The Notes on Impact on the scoring sheet seem to limit economic impacts to those on crops and livestock, i.e. agricultural settings – should this be extended?

Yes - be quite broad here – we should extend the economic impact to other trade such as nursery trade – indeed any economic impact – perhaps people could then note the specific sector in the comments.

Annex 2: Workshop Agenda

Day 1

Aim: Overview from each thematic group to enable review and moderation of the species lists within each thematic group

0930 – 0945 Arrival and introductions

0945 – 1000 Overview of the project – Helen Roy and Laurence Carvalho

1000 – 1100 Overview of lists from each thematic group (~10 minutes per group)

1100 – 1115 Break

1115 – 1200 Breakout groups for each thematic group to reflect on process and any clarifications

1200 – 1230 Plenary discussion

Session between Day 1 and 2 (each group has a different time): Review and moderate scores and ranks within expert groups

Day 2

Aim: Share information on high ranking species from each thematic group to enable experts to collaboratively agree on a priority list spanning all taxa and environments

0930 – 0945 Arrival

0945 – 1030 Presentations summarising group progress (each of the thematic group leaders)

Overview of high ranking species – terrestrial invertebrates: Karsten

Overview of high ranking species – plants: Wayne and Jodey

Overview of high ranking species – freshwater species: Laurence

Overview of high ranking species – marine species: Liz

Overview of high ranking species – vertebrates: Rich

Discussion in plenary of commonalities across groups.

1030 – 1045 Final review and moderate scores and ranks within expert groups

1045 – 1100 Coffee break (Revisions compiled into master spreadsheet)

1100 – 1230 Plenary – consensus for horizon scanning and discussion of project outputs (including peer-reviewed paper(s)

1230 close

Annex 3: Compiled long list of INNS: Biodiversity and Ecosystem Impacts

Species name	English name	HS expert group	Arrival	Estab.	Bio. impact	Overall score[12]
Anemanthele lessoniana	Pheasant's-tail	Terrestrial plants	5	5	5	125
Crepidula fornicata	Mollusc	Marine	5	5	5	125
Dreissena polymorpha	Zebra mussel	Freshwater	5	5	5	125
Vespa velutina	Asian hornet	Terrestrial invertebrates	5	5	5	125
Dreissena rostriformis bugensis	Quagga mussel	Freshwater	5	5	5	125
Corythucha arcuata	Oak lace bug	Terrestrial invertebrates	5	5	5	125
Baccharis halimifolia	Tree groundsel	Terrestrial plants	5	5	5	125
Gyrodactylus salaris	Salmon fluke	Freshwater	5	5	5	125
Agrilus planipennis	Emerald ash borer	Terrestrial invertebrates	5	5	5	125
Vaccinium corymbosum (and hybrids)	Highbush blueberry	Terrestrial plants	5	5	5	125
Procyon lotor	Raccoon	Terrestrial vertebrates	5	5	5	125
Myriophyllum aquaticum	Parrot's feather	Freshwater	5	5	5	125
Muntiacus reevesi	Reeve's muntjac	Terrestrial vertebrates	5	5	5	125
Hydrocotyle ranunculoides	Floating pennywort	Freshwater	5	5	5	125
Corbicula fluminea	Asian clam	Freshwater	5	5	5	125
Australoplana sanguinea	Flatworm	Terrestrial invertebrates	5	5	5	125
Caenoplana variegata (formerly known as *C. bicolor*)	Southampton flatworm	Terrestrial invertebrates	5	5	5	125
Kontikia andersoni	Flatworm	Terrestrial invertebrates	5	5	5	125
Obama nungara	Obama flatworm	Terrestrial invertebrates	5	5	5	125
Ailanthus altissima	Tree of heaven	Terrestrial plants	5	4	5	100
Sander lucioperca	Zander	Freshwater	4	5	5	100
Silurus glanis	Wels catfish	Freshwater	4	5	5	100
Eriocheir sinensis	Chinese mitten crab	Freshwater	5	5	4	100
Elaeagnus pungens	Thorny olive	Terrestrial plants	5	5	4	100

[12] Product of Arrival, Establishment and Biodiversity Impact

Species name	English name	HS expert group	Arrival	Estab.	Bio. impact	Overall score[12]
Agarophyton vermiculophyllum (previously *Gracilaria vermiculophylla*)	Alga	Marine	5	5	4	100
Persicaria nepalensis	Nepal persicaria	Terrestrial plants	5	5	4	100
Sarracenia purpurea	Purple pitcher plant	Terrestrial plants	5	5	4	100
Nyctereutes procyonoides	Raccoon dog	Terrestrial vertebrates	5	5	4	100
Thaumetopoea processionea	Oak processionary	Terrestrial invertebrates	5	5	4	100
Homarus americanus	American lobster	Marine	5	5	4	100
Ips sexdentatus		Terrestrial invertebrates	5	5	4	100
Ludwigia grandiflora	Water primrose	Freshwater	5	5	4	100
Acer negundo	Box-elder	Terrestrial plants	5	5	4	100
Anoplophora glabripennis	Asian longhorn beetle	Terrestrial invertebrates	4	4	5	80
Grateloupia turuturu	Alga	Marine	5	4	4	80
Amelanchier spicata	Low juneberry	Terrestrial plants	4	5	4	80
Cotoneaster ellipticus	Lindley's cotoneaster	Terrestrial plants	5	4	4	80
Cyperus eragrostis	Pale galingale	Terrestrial plants	5	4	4	80
Dikerogammerus villosus	Killer shrimp	Freshwater	4	5	4	80
Ips typographus	Eight-toothed spruce bark beetle	Terrestrial invertebrates	4	5	4	80
Heracleum persicum	Persian hogweed	Terrestrial plants	4	5	4	80
Heracleum sosnowskyi	Sosnowskyi's hogweed	Terrestrial plants	4	5	4	80
Houttuynia cordata	Fish-plant	Terrestrial plants	5	4	4	80
Lactuca tatarica	Blue lettuce	Terrestrial plants	4	5	4	80
Myriophyllum heterophyllum	Two leaf Watermilfoil/Broadleaf watermilfoil	Freshwater	4	5	4	80
Robinia pseudoacacia	Black locust	Terrestrial plants	5	3	5	75
Watersipora arcuata	Bryozoan	Marine	5	5	3	75
Cotoneaster moupinensis	Moupin cotoneaster	Terrestrial plants	5	5	3	75
Selenochlamys ysbryda	Ghost slug	Terrestrial invertebrates	5	5	3	75

Species name	English name	HS expert group	Arrival	Estab.	Bio. impact	Overall score[12]
Scolytus laevis		Terrestrial invertebrates	5	5	3	75
Rangifer tarandus	Reindeer	Terrestrial vertebrates	5	5	3	75
Psittacula krameri	Ring-necked parakeet	Terrestrial vertebrates	5	5	3	75
Mnemiopsis leidyi	Cnidaria: Comb jelly	Marine	5	5	3	75
Egeria densa	Large-flowered waterweed	Freshwater	5	5	3	75
Crangonyx floridanus	Florida Crangonyx	Freshwater	5	5	3	75
Bubo bubo	Eurasian eagle owl	Terrestrial vertebrates	5	5	3	75
Arcuatula senhousia	Mollusc: Asian date mussel	Marine	5	5	3	75
Alopochen aegyptiacus	Egyptian goose	Terrestrial vertebrates	5	5	3	75
Lupinus perennis	Wild lupin	Terrestrial plants	4	4	4	64
Cotoneaster vilmorinianus	Vimorin's cotoneaster	Terrestrial plants	4	4	4	64
Anoplophora chinensis	Citrus longhorn beetle	Terrestrial invertebrates	4	4	4	64
Ameiurus melas	Black bullhead	Freshwater	4	4	4	64
Ludwigia peploides	Floating primrose willow	Freshwater	4	4	4	64
Glyceria striata	Fowl manna grass	Terrestrial plants	4	4	4	64
Pimephales promelas	Fathead minnow	Freshwater	4	4	4	64
Micropterus salmoides	Largemouth bass	Freshwater	4	4	4	64
Pseudorasbora parva	Topmouth gudgeon	Freshwater	4	3	5	60
Triturus carnifex	Italian crested newt	Terrestrial vertebrates	3	4	5	60
Neogobius gymnotrachelus	Racer goby	Freshwater	3	5	4	60
Neogobius fluviatilis	Monkey goby	Freshwater	3	5	4	60
Elaeagnus angustifolia	Oleaster	Terrestrial plants	5	3	4	60
Drosanthemum floribundum	Pale dewplant	Terrestrial plants	5	3	4	60
Neogobius melanostomus	Round goby	Freshwater	3	5	4	60
Pontogammarus robustoides		Freshwater	3	5	4	60
Proterorhinus marmoratus	Tubenose goby	Freshwater	3	5	4	60
Proterorhinus semilunaris	Western goby	Freshwater	3	5	4	60
Rangia cuneata	Gulf wedge clam	Freshwater	3	5	4	60
Spartina pectinata	Prairie cord-grass	Terrestrial plants	5	3	4	60

Species name	English name	HS expert group	Arrival	Estab.	Bio. impact	Overall score[12]
Xanthium spinosum	Bathurst burr	Terrestrial plants	5	3	4	60
Disphyma crassifolium	Purple dewplant	Terrestrial plants	5	3	4	60
Chelicorophium curvispinum	Amphipod	Freshwater	3	5	4	60
Akebia quinata	Five-leaf akebia	Terrestrial plants	5	3	4	60
Dittrichia graveolens	Stinkwort	Terrestrial plants	5	3	4	60
Scolytus pygmaeus	Pygmy elm bark beetle	Terrestrial invertebrates	4	5	3	60
Pinus pinaster	Maritime pine	Terrestrial plants	5	4	3	60
Prunus virginiana	Bitter-berry	Terrestrial plants	5	4	3	60
Ruditapes philippinarum	Mollusc	Marine	5	4	3	60
Smittoidea prolifica	Bryozoan	Marine	4	5	3	60
Solidago graminifolia	Grass-leaved goldenrod	Terrestrial plants	5	4	3	60
Symphoricarpos albus var. laevigatus		Terrestrial plants	5	4	3	60
Watersipora subatra	Bryozoan	Marine	5	4	3	60
Hemigrapsus sanguineus	Arthropoda: Decapod crab	Marine	4	5	3	60
Hemigrapsus takanoi	Arthropoda: Decapod crab	Marine	4	5	3	60
Acacia melanoxylon	Australian blackwood	Terrestrial plants	4	5	3	60
Amaranthus palmeri	Dioecious amaranth	Terrestrial plants	5	4	3	60
Ambrosia trifida	Giant ragweed	Terrestrial plants	5	4	3	60
Amelanchier laevis	Juneberry	Terrestrial plants	4	5	3	60
Asarum europaeum	Foalfoot	Terrestrial plants	5	4	3	60
Cabomba caroliniana	Carolina water-shield	Freshwater	5	4	3	60
Cotoneaster lucidus	Shiny cotoneaster	Terrestrial plants	5	4	3	60
Dikerogammarus haemobaphes	Demon shrimp	Freshwater	4	5	3	60
Geranium sibiricum		Terrestrial plants	4	5	3	60
Lysimachia terrestris	Lake loostrife	Terrestrial plants	4	5	3	60
Phalaris paradoxa	Awned canary-grass	Terrestrial plants	4	5	3	60
Vincetoxicum rossicum	Dog strangling vine	Terrestrial plants	2	5	5	50

Species name	English name	HS expert group	Arrival	Estab.	Bio. impact	Overall score[12]
Vincetoxicum nigrum	Black swallow-wort	Terrestrial plants	2	5	5	50
Salvelinus malma	Dolly Varden trout	Freshwater	2	5	5	50
Setaria faberi	Giant foxtail	Terrestrial plants	5	5	2	50
Sorbaria sorbifolia	False spirea	Terrestrial plants	5	5	2	50
Sorbus mougeotii		Terrestrial plants	5	5	2	50
Caulacanthus okamurae	Alga	Marine	5	5	2	50
Salvia sclarea	Clary sage	Terrestrial plants	5	5	2	50
Cyclamen coum	Eastern sowbread	Terrestrial plants	5	5	2	50
Onobrychis viciifolia	Sanfoin	Terrestrial plants	5	5	2	50
Muscari botryoides	Grape hyacinth	Terrestrial plants	5	5	2	50
Cotula dioica	Buttonweed	Terrestrial plants	5	5	2	50
Anisantha madritensis	Compact brome	Terrestrial plants	3	4	4	48
Erigeron annuus subsp. septentrionalis		Terrestrial plants	4	3	4	48
Trapa natans	Water chestnut	Freshwater	4	3	4	48
Threskiornis aethiopicus	African sacred ibis	Terrestrial vertebrates	4	3	4	48
Symphyotrichum parviflorum		Terrestrial plants	4	3	4	48
Spartina patens	Saltmeadow cordgrass	Terrestrial plants	4	3	4	48
Sinanodonta woodiana (Anodonta woodiana)	Chinese giant mussel	Freshwater	3	4	4	48
Sarracenia flava	Yellow pitcher plant	Terrestrial plants	4	3	4	48
Pinus radiata	Monterey pine	Terrestrial plants	4	3	4	48
Pelophylax ridibundus	Marsh frog	Terrestrial vertebrates	3	4	4	48
Orconectes virilis	Virile crayfish	Freshwater	3	4	4	48
Orconectes limosus	Spiny-cheek crayfish	Freshwater	3	4	4	48
Mulinia lateralis	Mollusc: Dwarf surf clam	Marine	4	3	4	48
Muehlenbeckia complexa	Wireplant	Terrestrial plants	4	3	4	48
Lithobates catesbeianus	American bullfrog	Terrestrial vertebrates	3	4	4	48
Bufotes viridis	European green toad	Terrestrial vertebrates	3	4	4	48
Carassius gibelio		Freshwater	3	4	4	48

Species name	English name	HS expert group	Arrival	Estab.	Bio. impact	Overall score[12]
Allium neapolitanum	Neapolitan garlic	Terrestrial plants	3	4	4	48
Artemisia austriaca		Terrestrial plants	4	3	4	48
Bidens frondosa	Beggarticks	Terrestrial plants	4	3	4	48
Celastrus orbiculatus	Staff-vine	Terrestrial plants	4	3	4	48
Cyperus rotundus	Purple nutsedge	Terrestrial plants	3	4	4	48
Dendrolimus sibiricus		Terrestrial invertebrates	3	4	4	48
Erodium manescavi	Garden stork's-bill	Terrestrial plants	4	3	4	48
Galium spurium	False cleavers	Terrestrial plants	4	3	4	48
Hemimysis anomala	Bloody-red/carrion shrimp	Freshwater	4	3	4	48
Humulus scandens	Japanese hop	Terrestrial plants	4	3	4	48
Impatiens capensis	Orange balsam	Terrestrial plants	4	3	4	48
Limonium hyblaeum	Sicilian sea lavender	Terrestrial plants	4	3	4	48
Perophora japonica	Ascidian	Marine	4	4	3	48
Leptospermum scoparium	Broom tea-tree	Terrestrial plants	4	4	3	48
Hydropotes inermis	Chinese water deer	Terrestrial vertebrates	4	4	3	48
Genista monspessulana	Montpellier broom	Terrestrial plants	4	4	3	48
Elodea callitrichoides	South American waterweed	Freshwater	4	4	3	48
Dyspanopeus sayi	Arthropoda: decapod say mud	Marine	4	4	3	48
Zanardinia typus	Alga - penny weed	Marine	4	4	3	48
Celtodoryx ciocalyptoides	Porifera: sponge	Marine	4	4	3	48
Acroptilon repens	Russian knapweed	Terrestrial plants	4	4	3	48
Theora lubrica	Mollusc	Marine	4	4	3	48
Tulipa saxatilis	Lilac wonder	Terrestrial plants	4	4	3	48
Pulmonaria mollis		Terrestrial plants	4	4	3	48
Polydrusus impar		Terrestrial invertebrates	4	4	3	48
Centaurea diffusa	Small-flowered star-thistle	Terrestrial plants	4	4	3	48

Species name	English name	HS expert group	Arrival	Estab.	Bio. impact	Overall score[12]
Potamocorbula amurensis	Mollusc	Marine	3	3	5	45
Corbicula fluminalis	Asian clam	Freshwater	2	4	5	40
Gambusia holbrooki	Eastern mosquitofish	Freshwater	2	4	5	40
Tamarix ramosissima	Saltceder	Terrestrial plants	3	3	4	36
Calystegia sepium subsp. spectabilis		Terrestrial plants	3	3	4	36
Lindernia dubia	False pimpernel	Terrestrial plants	3	3	4	36
Mephitis mephitis	Striped skunk	Terrestrial vertebrates	3	3	4	36
Procambarus fallax	Deceitful crayfish	Freshwater	3	3	4	36
Myriophyllum pinnatum		Freshwater	3	3	4	36
Myriophyllum propinquum		Freshwater	3	3	4	36
Procambarus clarkii	Red swamp crayfish	Freshwater	3	3	4	36
Myriophyllum hippuroides		Freshwater	3	3	4	36

Annex 4: Compiled long list of INNS: Human Health Impacts

Aedes japonicus
Aedes koreicus
Aedes vexens
Ambrosia artemisiifolia
Ambrosia trifida
Anthrenocerus australis
Anthrenus (Anthrenops) coloratus
Anthrenus (Anthrenus) flavipes
Anthrenus (Anthrenus) scrophulariae
Anthrenus (Florilinus) olgae
Anthrenus flavidus
Anthrenus oceanicus
Argemone mexicana
Blatta orientalis
Culex modestus
Dittrichia graveolens
Humulus scandens
Reesa vespulae
Rhipicephalus sanguineus
Steatoda grossa
Steatoda nobilis
Thaumetopoea processionea
Trogoderma glabrum
Trogoderma granarium
Trogoderma inclusum
Vespa velutina
Xanthium strumarium

Annex 5: Compiled long list of INNS: Economic Impacts

Acroptilon repens
Agrilus planipennis
Ailanthus altissima
Amaranthus retroflexus
Anoplophora chinensis
Anoplophora glabripennis
Anthonomus (Furcipus) rectirostris
Avena sterilis
Bactericera cockerelli
Blatta orientalis
Cecidophyopsus grossulariae
Cecidophyopsus ribis
Cenchrus longispinus
Centaurea diffusa
Contarinia pyrivora
Corbicula fluminea
Cyperus rotundus
Dasineura pyri
Dittrichia graveolens
Dreissena polymorpha
Dreissena rostriformis bugensis
Enigmadiplosis agapanthi
Epitrix papa
Eriocheir sinensis
Eupteryx decemnotata
Galleria mellonella
Gyrodactylus salaris
Halyomorpha halys
Hydrocotyle ranunculoides
Ips typographus
Leptinotarsa decemlineata
Ludwigia grandiflora
Ludwigia peploides
Nassella trichotoma
Nezara viridula
Oncorhynchus gorbuscha
Persicaria nepalensis
Phalaris paradoxa
Pimephales promelas
Sander lucioperca
Silurus glanis
Solanum carolinense

Solanum vernei
Sorghum halepense
Symphoricarpos albus var. laevigatus
Vespa velutina
Xanthium strumarium

References:

Abell, R., M. L. Thieme, C. Revenga, M. Bryer, M. Kottelat, N. Bogutskaya, B. Coad, N. Mandrak, S. C. Balderas and W. Bussing (2008). "Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation." BioScience **58**(5): 403-414.

Bacher, S., T. M. Blackburn, F. Essl, P. Genovesi, J. Heikkilä, J. M. Jeschke, G. Jones, R. Keller, M. Kenis, C. Kueffer, A. F. Martinou, W. Nentwig, J. Pergl, P. Pyšek, W. Rabitsch, D. M. Richardson, H. E. Roy, W.-C. Saul, R. Scalera, M. Vilà, J. R. U. Wilson and S. Kumschick (2017). "Socio-economic impact classification of alien taxa (SEICAT)." Methods in Ecology and Evolution.

Birk, S., D. Chapman, L. Carvalho, B. M. Spears, H. E. Andersen, C. Argillier, S. Auer, A. Baattrup-Pedersen, L. Banin and M. Beklioğlu (2020). "Impacts of multiple stressors on freshwater biota across spatial scales and ecosystems." Nature Ecology & Evolution **4**(8): 1060-1068.

Blackburn, T. M., F. Essl, T. Evans, P. E. Hulme, J. M. Jeschke, I. Kühn, S. Kumschick, Z. Marková, A. Mrugała, W. Nentwig, J. Pergl, P. Pyšek, W. Rabitsch, A. Ricciardi, D. M. Richardson, A. Sendek, M. Vilà, J. R. U. Wilson, M. Winter, P. Genovesi and S. Bacher (2014). "A Unified Classification of Alien Species Based on the Magnitude of their Environmental Impacts." PLoS Biol 12(5): e1001850. doi:10.1371/ journal.pbio.1001850.

Blackburn, T. M., P. Pysek, S. Bacher, J. T. Carlton, R. P. Duncan, V. Jarosik, J. R. U. Wilson and D. M. Richardson (2011). "A proposed unified framework for biological invasions." Trends in Ecology & Evolution **26**(7): 333-339.

Bohn, K., C. Richardson and S. Jenkins (2012). "The invasive gastropod Crepidula fornicata: reproduction and recruitment in the intertidal at its northernmost range in Wales, UK, and implications for its secondary spread." Marine Biology **159**(9): 2091-2103.

Bonebrake, T. C., F. Guo, C. Dingle, D. M. Baker, R. L. Kitching and L. A. Ashton (2019). "Integrating proximal and horizon threats to biodiversity for conservation." Trends in Ecology & Evolution **34**(9): 781-788.

Booy, O. (2019). Prioritising the management of invasive non-native species, University of Newcastle.

Booy, O. (2019). Priotising the management of invasive non-native species. PhD, University of Newcastle.

Booy, O., V. White and M. Wade (2006). Non-Native Organism Risk Assessment Scheme: Trialling and Peer Review (Scottish Executive reference: FF/05/22). Cambridgeshire, RPS Ecology.

Branquart, E. (2009). Guidelines for environmental impact assessment and list classification of non-native organisms in Belgium: version 2.6. Bruxelles, Belgian Forum on Invasive Species.

Bryden, D. (2010). Assessing the economic impacts of nature based tourism in Scotland, Scottish Natural Heritage.

CBD (2014). Pathways of introduction of invasive species, their prioritization and management, Secretariat of the Convention on Biological Diversity Montréal.

Dawson, W., J. M. Peyton, O. L. Pescott, T. Adriaens, E. J. Cottier-Cook, D. S. Frohlich, G. Key, C. Malumphy, A. F. Martinou and D. Minchin (2023). "Horizon scanning for potential invasive non-native species across the United Kingdom Overseas Territories." Conservation Letters **16**(1): e12928.

Díaz, S., J. Settele, E. Brondízio, H. Ngo, M. Guèze, J. Agard and C. Zayas (2019). "IPBES global assessment summary for policymakers." Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Accessed **28**.
Gallardo, B. and D. C. Aldridge (2015). "Is Great Britain heading for a Ponto–Caspian invasional meltdown?" Journal of applied Ecology **52**(1): 41-49.
Harrower, C., R. Scalera, S. Pagad, K. Schonrogge and H. Roy (2018). "Guidance for interpretation of CBD categories on introduction pathways."
Hawkins, C. L., S. Bacher, F. Essl, P. E. Hulme, J. M. Jeschke, I. Kühn, S. Kumschick, W. Nentwig, J. Pergl and P. Pyšek (2015). "Framework and guidelines for implementing the proposed IUCN Environmental Impact Classification for Alien Taxa (EICAT)." Diversity and Distributions **21**(11): 1360-1363.
Hughes, K. A., O. L. Pescott, J. Peyton, T. Adriaens, E. J. Cottier-Cook, G. Key, W. Rabitsch, E. Tricarico, D. K. Barnes and N. Baxter (2020). "Invasive non-native species likely to threaten biodiversity and ecosystems in the Antarctic Peninsula region." Global Change Biology.
Leung, B., N. Roura-Pascual, S. Bacher, J. Heikkilä, L. Brotons, M. A. Burgman, K. Dehnen-Schmutz, F. Essl, P. E. Hulme, D. M. Richardson, D. Sol and M. Vilà (2012). "TEASIng apart alien species risk assessments: a framework for best practices." Ecology Letters **15**: 1475-1493.
Lucy, F. E., E. Davis, R. Anderson, O. Booy, K. Bradley, J. R. Britton, C. Byrne, J. M. Caffrey, N. E. Coughlan and K. Crane (2020). "Horizon scan of invasive alien species for the island of Ireland." Management of Biological Invasions **11**(2): 155-177.
Marine Scotland (2017). An Analysis of the Value of Wild Fisheries in Scotland, Edinburgh, UK: Marine Scotland.
Marzano, M., N. Dandy, H. R. Bayliss, E. Porth and C. Potter (2015). "Part of the solution? Stakeholder awareness, information and engagement in tree health issues." Biological Invasions **17**: 1961-1977.
Modesto, V., E. Dias, M. Ilarri, M. Lopes-Lima, A. Teixeira, S. Varandas, P. Castro, C. Antunes and R. Sousa (2021). "Trophic niche overlap between native freshwater mussels (Order: Unionida) and the invasive Corbicula fluminea." Aquatic Conservation: Marine and Freshwater Ecosystems.
Peyton, J., A. F. Martinou, O. L. Pescott, M. Demetriou, T. Adriaens, M. Arianoutsou, I. Bazos, C. W. Bean, O. Booy and M. Botham (2019). "Horizon scanning for invasive alien species with the potential to threaten biodiversity and human health on a Mediterranean island." Biological Invasions **21**(6): 2107-2125.
Peyton, J. M., A. F. Martinou, T. Adriaens, N. Chartosia, P. K. Karachle, W. Rabitsch, E. Tricarico, M. Arianoutsou, S. Bacher and I. Bazos (2020). "Horizon scanning to predict and prioritize invasive alien species with the potential to threaten human health and economies on Cyprus." Frontiers in Ecology and Evolution **8**: 284.
Roy, H. E., S. Bacher, F. Essl, T. Adriaens, D. C. Aldridge, J. D. Bishop, T. M. Blackburn, E. Branquart, J. Brodie and C. Carboneras (2019). "Developing a list of invasive alien species likely to threaten biodiversity and ecosystems in the European Union." Global change biology **25**(3): 1032-1048.
Roy, H. E., H. Hesketh, B. V. Purse, J. Eilenberg, A. Santini, R. Scalera, G. D. Stentiford, T. Adriaens, K. Bacela-Spychalska and D. Bass (2016). "Alien pathogens on the Horizon: opportunities for predicting their threat to wildlife." Conservation Letters.
Roy, H. E., J. Peyton, D. C. Aldridge, T. Bantock, T. M. Blackburn, R. Britton, P. Clark, E. Cook, K. Dehnen-Schmutz, T. Dines, M. Dobson, F. Edwards, C. Harrower, M. C. Harvey, D. Minchin, D. G. Noble, D. Parrott, M. J. O. Pocock, C. D. Preston, S. Roy, A. Salisbury, K. Schönrogge, J. Sewell, R. H. Shaw, P. Stebbing, A. J. A.

Stewart and K. J. Walker (2014). "Horizon scanning for invasive alien species with the potential to threaten biodiversity in Great Britain." Global Change Biology **20**: 3859-3871.
Roy, H. E., J. Peyton, D. C. Aldridge, T. Bantock, T. M. Blackburn, R. Britton, P. Clark, E. Cook, K. Dehnen-Schmutz and T. Dines (2014). "Horizon scanning for invasive alien species with the potential to threaten biodiversity in Great Britain." Global change biology **20**(12): 3859-3871.
Roy, H. E., J. M. Peyton and O. Booy (2020). "Guiding principles for utilizing social influence within expert-elicitation to inform conservation decision-making." Global change biology **26**(6): 3181-3184.
Roy, H. E., K. Schonrogge, H. Dean, J. Peyton, E. Branquart, S. Vanderhoeven, G. Copp, P. Stebbing, M. Kenis, W. Rabitsch, F. Essl, S. Schindler, S. Brunel, M. Kettunen, L. Mazza, A. Nieto, J. Kemp, P. Genovesi, R. Scalera and A. Stewart (2014). Invasive alien species – framework for the identification of invasive alien species of EU concern (ENV.B.2/ETU/2013/0026). European Commission, Brussels.
Roy, H. E., E. Tricarico, R. Hassall, C. A. Johns, K. A. Roy, R. Scalera, K. G. Smith and B. V. Purse (2022). "The role of invasive alien species in the emergence and spread of zoonoses." Biological Invasions: 1-16.
Seebens, H., T. M. Blackburn, E. E. Dyer, P. Genovesi, P. E. Hulme, J. M. Jeschke, S. Pagad, P. Pyšek, M. Winter, M. Arianoutsou, S. Bacher, B. Blasius, G. Brundu, C. Capinha, L. Celesti-Grapow, W. Dawson, S. Dullinger, N. Fuentes, H. Jäger, J. Kartesz, M. Kenis, H. Kreft, I. Kühn, B. Lenzner, A. Liebhold, A. Mosena, D. Moser, M. Nishino, D. Pearman, J. Pergl, W. Rabitsch, J. Rojas-Sandoval, A. Roques, S. Rorke, S. Rossinelli, H. E. Roy, R. Scalera, S. Schindler, K. Štajerová, B. Tokarska-Guzik, M. van Kleunen, K. Walker, P. Weigelt, T. Yamanaka and F. Essl (2017). "No saturation in the accumulation of alien species worldwide." Nature Communications **8**: 14435.
Sousa, R., A. Novais, R. Costa and D. L. Strayer (2014). "Invasive bivalves in fresh waters: impacts from individuals to ecosystems and possible control strategies." Hydrobiologia **735**(1): 233-251.
Sutherland, W. J., E. Fleishman, M. B. Mascia, J. Pretty and M. A. Rudd (2011). "Methods for collaboratively identifying research priorities and emerging issues in science and policy." Methods in Ecology and Evolution **2**(3): 238-247.
Transport Scotland (2019). Transporting Scotland's Trade 2019. Edition. Scottish Government
Volery, L., S. Bacher, T. Blackburn, S. Bertolino, T. Evans, P. Genovesi, S. Kumschick, H. Roy and K. Smith (2020). "Improving the Environmental Impact Classification for Alien Taxa (EICAT): a summary of revisions to the framework and guidelines."
Winfield, I., J. Fletcher and J. James (2011). "Invasive fish species in the largest lakes of Scotland, Northern Ireland, Wales and England: the collective UK experience." Hydrobiologia **660**(1): 93-103.

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