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Integrating expert knowledge at regional and national scales improves impact assessments of non-native species

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Abstract

Knowledge of the impacts of invasive species is important for their management, prioritisation of control efforts and policy decisions. We investigated how British and Irish botanical experts assessed impacts at smaller scales in areas where they were familiar with the flora. Experts were asked to select the 10 plants that they considered were having the largest impacts in their areas. They also scored the local impacts of 10 plant species that had been previously scored to have the highest impacts at the scale of Great Britain. Impacts were scored using the modified classification scheme of the EICAT framework (Environmental Impact Classification for Alien Taxa). A total of 782 species/score combinations were received, of which 123 were non-native plants in 86 recording areas. *Impatiens glandulifera*, *Reynoutria japonica* and *Rhododendron ponticum* were the three species considered to have the highest impacts across all regions. Four of the species included in the list of the 10 highest impact species in Great Britain were also in the top 10 of species reported in our study. Species in the higher impact categories had, on average, a wider distribution than species with impacts categorised at lower levels. The main habitat types affected were woodlands, followed by linear/boundary features and freshwater habitats. Thirty-nine native plant species were reported to be negatively affected. In comparison to the overall non-native flora of Britain and Ireland, the lifeform spectrum of the species reported was significantly different, with higher percentages of aquatic plants and trees, but a lower proportion of annuals. The study demonstrates the value of local knowledge and expertise in identifying invasive species with negative impacts on the environment. Local knowledge is useful to both confirm national assessments and to identify species and impacts on native species and habitats that may not have gained national attention.

Keywords
Alien plants, biological recording, Europe, habitat impacts, impact, local knowledge, scoring

Introduction

Invasive non-native species continue to be introduced, spread and cause environmental and socio-economic impacts globally (Diagne et al. 2021; Seebens et al. 2021). They are one of the main drivers of global biodiversity decline (IPBES 2019; Dueñas et al. 2021) and species extinctions (Bellard et al. 2016). There is, therefore, a need for consistent appraisals of impacts to support risk assessments, decisions on invasive species management, prioritisation of control efforts and policy-making. Impact assessments of invasive species play an important part in risk assessments and support policy decisions based on them (Leung et al. 2012). For example, one key measure of the EU Regulation (No 1143/2014) on invasive species is the listing of species of Union concern, which are species that '*based on available scientific evidence, are likely to have a significant adverse impact on biodiversity or the related ecosystem services and may also have an adverse impact on human health or the economy*' (§4c, EU 2014).

To support these policy and management decisions and to advance the understanding of how invasive species' impacts are assessed across taxa and regions, frameworks and methodologies for delivering this evidence in a consistent and comparable way have been developed (Bartz and Kowarik 2019; González-Moreno et al. 2019; Vilà et al. 2019). In 2020, the IUCN adopted the EICAT framework (Environmental Impact Classification of Alien Taxa) developed by Hawkins et al. (2015) as its global standard for impact assessments (IUCN 2020; Volery et al. 2020). The EICAT methodology has been applied at the global level for the assessment of introduced birds (Evans et al. 2016), bamboos (Canavan et al. 2019), reptiles and amphibians (Kraus 2015) and ungulates (Volery et al. 2021), amongst others. At regional levels, it has been used for non-native mammals in Cuba (Borroto-Páez and Mancina 2017) and invasive grasses in South Africa (Visser et al. 2017).

A modified version of the EICAT framework was first applied in 2016 for a national impact assessment applied across taxon groups (Booy 2019). Specifically, it was used to assess a selection of 238 non-native species in Great Britain (GB), which had been identified from a longer list of 1,954 established non-natives and considered to have more than minimal impacts, based on information in the GB Non-Native Species Information Portal database (Booy 2019). The modified EICAT scoring was carried out by experts using published evidence, anecdotal knowledge and their own field experience, followed by a consensus workshop (Booy 2019). For non-native plants, a group of seven experts (including authors KDS and KJW) assessed 122 species that were identified in the pre-screening process. All plants were assigned an impact rating, 10 of which were rated in the top two EICAT impact levels (major and massive). This GB impact assessment process illustrates how impact assessments rely on evidence mostly generated in field or experimental studies at local levels (Vilà et al. 2019), before being evaluated and extrapolated in expert assessments to national levels. However, as impacts are context-dependent (Bartz and Kowarik 2019), this approach may overestimate impacts at larger scales. It could also result in species with major and/or emerging local impacts not being considered as important species at larger scales. Consequently, species with more local impacts could be missed from policy frameworks and their management may not be supported sufficiently. Similarly, experts involved in scoring at the national scale could over- or underestimate the impacts of species. For example, where available evidence is only locally available, anecdotal or from other territories or in the absence of impact data, they may rely solely on distribution data which may not always relate to important local-scale impacts (Pearman and Walker 2009). The 2016 GB scoring, therefore, offered an opportunity to test the results of the national assessment with a group of local experts, i.e. regional volunteer expert botanical recorders of the Botanical Society of Britain and Ireland (BSBI). In contrast to experts evaluating published evidence and data, these botanical recorders are more likely to base their impact judgements on their field experience of the region in which they work, their knowledge of local occurrences of native and non-native plants from recording activities (Pescott et al. 2015) and often, their experience of change in species distributions from their long-term involvement in these local activities (Preston 2003; Walker 2003). These local botanical experts are, therefore, also uniquely placed to observe habitats and native species affected by non-native species invasions.

Different species traits may explain the success of species at different stages of the invasion process and this has been investigated for different stages of the plant invasion process (Dehnen-Schmutz et al. 2007; Pyšek and Richardson 2007). Few studies have investigated how species traits influence invasive species' impacts; however, amongst investigated traits, lifeform has already been shown to be important (Pyšek et al. 2012; Ni et al. 2021). The aim of our study was, therefore, to investigate which non-native plants are currently perceived to have the highest impacts at regional scales, as well as across Britain and Ireland, based on the knowledge of local experts. We then use these data to analyse if there are differences in these perceptions between regions and how the impacts of the 10 non-native plant species that were previously assessed to have the highest impacts in the 2016 GB assessment (Booy 2019) were assessed at regional levels by these local experts. Furthermore, we used species distribution data and plant lifeform characteristics to investigate the relationships between local impact assessment scores and range size and between assessment score and lifeform. Finally, we explore which broad habitats and native species were most affected by the invasive non-native species identified by local experts.

Methods

Study area and participants

The study was conducted at the regional scale in 152 recording units, known as 'Watsonian vice-counties', across the whole of Britain and Ireland (Fig. 1). These vice-counties (VC) were devised in 1852 with the aim of creating a series of stable geographical

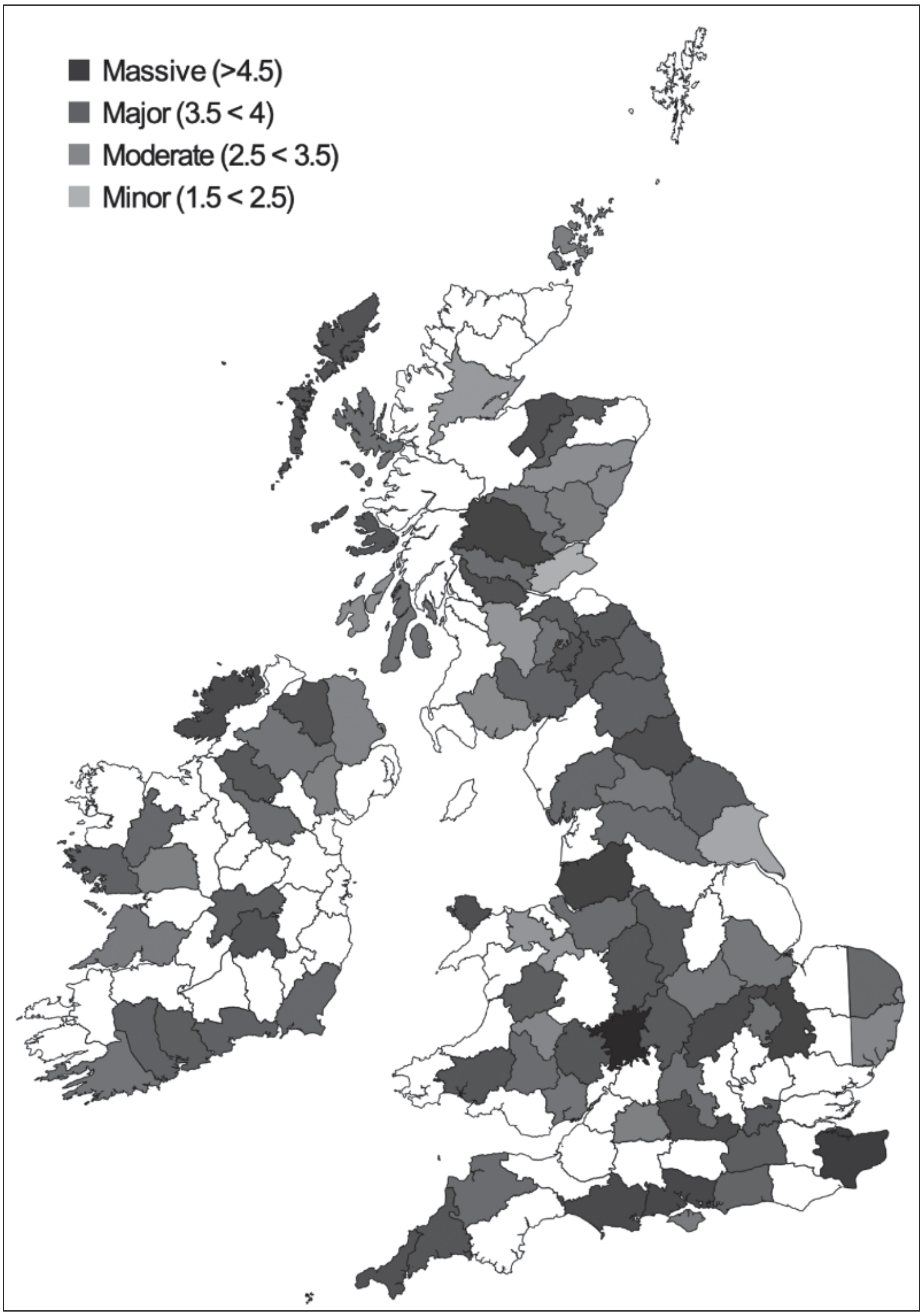

Figure 1. Map showing vice-county boundaries in Britain and Ireland. Vice-counties participating in the study are coloured in a grey-scale representing the average impact score of the species reported.

units for recording natural history observations and continue to be used to this day by the Botanical Society of Britain and Ireland (BSBI) and other societies (Preston et al. 2002). These vice-counties have an average size of about 2000 km^2, with a range of 207 to 4857 km^2 (Fig. 1).

The BSBI is the backbone of botanical recording in Britain and Ireland (Pescott et al. 2015) and appoints volunteer vice-county recorders to both collect and collate botanical records for their areas and to submit them to the BSBI centrally (https://database.bsbi.org/maps/). Vice-county recorders, therefore, have an unrivalled knowledge of the plant species, both native and non-native, that occur at a local level, including their distribution, abundance, habitats and regeneration, while also being aware of impacts on other plant species and ecosystem processes. Vice-county recorders existed long before the term 'citizen science' was used in Britain; however, because of their voluntary role, they would now also be considered citizen scientists (Pescott et al. 2015). Considering their expertise and their focused recording efforts (systematic recording of all plant species in contrast to unstructured or opportunistic recording) and following the classification of citizen scientists suggested by Pocock et al. (2015), these vice-county recorders would be classified as volunteer regional experts.

Survey design

An online questionnaire was designed using the 'Online surveys' platform (www.onlinesurveys.ac.uk). The survey link was distributed to all BSBI vice-county recorders in March 2019 and the survey was closed at the end of May 2019. The questionnaire (see Suppl. material 1, Part 1) consisted of a short introduction, followed by an explanation of the criteria for scoring species' impacts and the respondents' confidence (Table 1). Participants were asked to name the 10 plant species that they considered were having the highest environmental impacts in their vice-counties, based on the modified EICAT scoring criteria (Table 1). Respondents were also asked to name the species with the highest impacts first, thus creating a list ranked by their perception of local impact. Each species' impact score was assigned to a broad habitat type from a list provided, corresponding to the UK Biodiversity Action Plan habitat descriptions (http://jncc.defra.gov.uk/page-5706). In the second part of the survey, participants based in Great Britain were presented with the list of the top 10 highest ranked plant species from the 2016 GB national-level impact workshop (Booy 2019) and asked to score the impacts of these species in their vice-county using the same criteria, but only if they had not already included them in their top 10 scoring list in the previous section of the survey. Vice-county recorders from Ireland did not participate in this part of the survey, because the 2016 impact scoring was conducted for Great Britain only. In both sections, respondents could leave comments for individual species and were asked to do so, in particular, if they were aware of impacts in habitats considered as priority in the UK Biodiversity Action Plan or invasives that were known to have caused the local extinction of any native species. The questionnaire was approved through Coventry University's ethical approval procedure (Ethic no: P87103).

Table 1. Definition of impact categories and confidence scores as presented to the participants in the survey in Great Britain and Ireland. Modified from the EICAT framework (Hawkins et al. 2015).

Impact categories	Confidence Score
1. Minimal Concern … unlikely to have caused deleterious impacts on the native biota or abiotic environment.	**High** … approx. 90% chance of assessment being correct, i.e. direct observational evidence by the assessor or there are reliable/good quality data sources on impacts of the taxa in the VC.
2. Minor … causes reductions in the fitness of individuals in the native biota, but no declines in native population sizes and has no impacts that would cause it to be classified in a higher impact category.	**Medium** … defined as 65–75% chance of the assessor score being correct, i.e. there is some direct observational evidence to support the assessment, but some information is inferred.
3. Moderate … causes declines in the population size of native species, but no changes to the structure of communities or to the abiotic or biotic composition of ecosystems and has no impacts that would cause it to be classified in a higher impact category.	**Low**…only about 35% chance of being correct, i.e. no direct observational evidence or reliable data sources to support the assessment, for example, only inferred data have been used as supporting evidence.
4. Major … causes the local or population extinction of at least one native species and/or leads to substantial, but reversible changes in the structure of communities and the abiotic or biotic composition of ecosystems and has no impacts that cause it to be classified in the MV impact category.	
5. Massive … leads to the replacement and local extinction of native species and produces irreversible changes in the structure of communities and the abiotic or biotic composition of ecosystems.	

Impact scoring framework

We used the modified scoring categories that were applied in the 2016 national GB assessment (Booy 2019), based on the EICAT methodology (Hawkins et al. 2015). Impacts were scored, based on the five categories namely 'massive',' major', 'moderate', 'minor' and 'minimal' concern (Table 1). The modification of the EICAT categories in the GB assessment involved a change in the definition of the 'major' category, which was changed to specify that a species extinction (national or local) or a substantial, but reversible change in affected ecosystems needs to be observed, in contrast to the EICAT scheme, where both conditions need to be fulfilled (extinction and reversible change). For each species' score, respondents were also asked to score their confidence following the definitions given in the survey (Table 1) and based on the GB assessment's definition. In contrast to the EICAT framework and the GB assessment, which distinguished current and maximum impacts that could be reached if a species would occupy all suitable habitats, respondents in our survey were only asked to score the current impacts.

Data analysis

To identify the highest scoring species and to compare impact scores between species and vice-county recorders, we assigned each impact category an integer value, ranging from 1 for the 'minimal' category to 5 for the 'massive' category. We also compared the rank order in which respondents had reported the 10 species for their vice-county as they were asked to report species in the order of perceived impact magnitude from highest to lowest.

We derived the list of highest scoring species for the whole region using three complementary approaches. First, we ranked species by the number of respondents who had included them in their list of 10. Second, we calculated an average impact score for each species, both for the whole sample (with an impact score of zero for vice-counties in which the species was not included in the top 10), as well as the average for only those vice-counties that included the species in their top list. Third, we added the rank scores for each species (where listed by a respondent) and ranked the overall species list by these sums. To analyse the consistency in the scoring, we followed the methodology used by Gonzáles-Moreno et al. (2019) and calculated a coefficient of variation (CV) for all species that had received at least four scores. We also used the CV to compare the variation in scoring between respondents (i.e. how they used the scale of impact categories across the 10 species).

Species' current distribution data were extracted from the BSBI's Distribution Database (https://database.bsbi.org/) at a 2 × 2 km gridded resolution in March 2022. As the size of the vice-counties varies, we used the percentage of total 2 × 2 km grid cells occupied per vice-county. For nine reports of species with no records in particular counties, we used an arbitrary value of one grid cell. Nomenclature and common names for vascular plants followed Stace (2019), while species' native or non-native status was based on Preston et al. (2002). In cases where species that are native in some parts of Britain or Ireland were reported, we confirmed the status in the vice-county from where it was reported as non-native. Data on the Raunkiaer lifeform of the reported species was derived from ALIENATT, an unpublished BSBI compilation which is also the basis for this information in Henniges et al. (2022). A list of the 1,690 non-native plants confirmed in Britain and Ireland was extracted from Henniges et al. (2022). This list was used to compare the lifeform of plants (chamaephyte, geophyte, hemcryptophyte, helophyte, hydrophyte, phanerophyte, therophyte) reported in the survey using a two-sample z-test of proportions and *post hoc* row-wise Fisher tests with *p*-values adjusted for pairwise comparisons between proportions of single categories. Species reported in the survey that are native in parts of Britain and Ireland and non-native in others were excluded from this comparison (i.e. *Clematis vitalba*, *Fagus sylvatica*, *Nymphoides peltata*, *Papaver cambricum*, *Pinus sylvestris*, *Ranunculus* subgenus *Batrachium*, *Stratiotes aloides*, *Symphytum tuberosum* and *Typha latifolia*).

Where respondents had not assigned a main broad habitat type, we used the comments provided by them to assign a main habitat. Out of 75 species (9.6% of all species reported) with no habitat assignment, we allocated 61 species to habitats including the two additional habitat categories 'urban' and 'brownfield', that were not included as an option in the survey design. The remaining 14 species which could not be allocated or where the respondent indicated the species could not be assigned to a main habitat type, were categorised as 'other'. The International Union for the Conservation of Nature's (IUCN) Red List status of species reported to be threatened by invasive plants was checked for records in GB and Ireland separately in the respective lists as compiled in Wyse Jackson et al. (2016). We conducted all analyses in the R environment, version 4.0.3 (R Core Team 2019), including the bipartite (Dormann et al. 2008) and vegan packages (Oksanen et al. 2019).

Data availability statement

The data are made available in Suppl. material 2.

Results

Results for the whole region

We received responses from 86 vice-counties (a return rate of 57%), reporting a total of 123 species from 782 vice-county observations. While most recorders reported 10 species, some reported fewer and, for one vice-county, eleven species were named, giving a range of one to eleven species and an average of 9.1 (s.d. = 1.96) per vice-county. There were more than 100 observations of 'massive' impact species; however, the majority of reports related to evaluations of 'major' or 'moderate' impacts (Fig. 2).

The mean coefficient of variation (CV) of impact scores per species named by at least four recorders was 32% (s.d. = 9), with a range from 17% for *Prunus laurocerasus* from 20 reports to 51% for *Gunnera tinctoria* from seven reports. The CV across all recorders was 26%, based on the average score given to all species scored per vice-county of 3.3 (s.d. = 0.85). The average scores per vice-county can be seen in Fig. 1. *Impatiens glandulifera*, *Reynoutria japonica* and *Rhododendron ponticum* were the three species considered to have the highest impacts across all vice-counties by

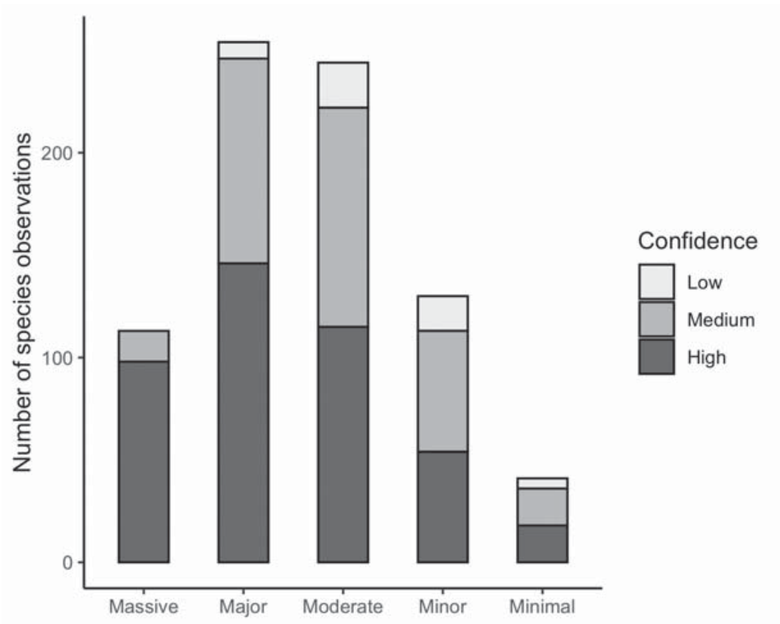

Figure 2. Frequency of impact and confidence scores received from vice-county recorders. The number of observations relates to 123 different species reported.

Table 2. Most frequently reported species with impacts ordered by the number of vice-counties (VCs) that included the species in their top 10 (N), this number as a percentage of all vice-counties (%), the mean impact score from vice-counties that reported this species (Mean VCs present), the mean impact score for all vice-counties (Mean overall), rank position when all rank scores were summed up (Rank-sum rank) and the coefficient of variation for all scores received for each species (CV).

Species	N	%	Mean VCs present	Mean overall	Rank-sum rank	CV
Impatiens glandulifera	63	73	3.62	2.65	1	31.94
Reynoutria japonica	60	70	3.28	2.29	2	30.76
Rhododendron ponticum	58	67	3.81	2.57	3	28.44
Crassula helmsii	36	42	4.00	1.67	4	21.55
Heracleum mantegazzianum	36	42	3.33	1.40	5	28.69
Picea sitchensis	23	27	3.70	0.99	6	28.77
Cotoneaster integrifolius	20	23	3.75	0.87	10	20.97
Lamiastrum galeobdolon ssp. *argentatum*	20	23	3.25	0.76	13	28.01
Prunus laurocerasus	20	23	3.60	0.84	7	16.62
Acer pseudoplatanus	19	22	3.58	0.79	8	25.19
Allium paradoxum	17	20	3.65	0.72	11	33.50
Hyacinthoides × *massartiana*	17	20	2.82	0.56	14	28.65
Lysichiton americanus	16	19	2.69	0.50	17	50.32
Symphoricarpos albus	16	19	3.06	0.57	16	18.73
Hydrocotyle ranunculoides	15	17	3.73	0.65	9	32.75
Myriophyllum aquaticum	15	17	3.00	0.52	15	43.64
Elodea canadensis	14	16	3.64	0.59	12	25.50
Azolla filiculoides	13	15	3.08	0.47	18	31.01
Petasites fragrans	13	15	3.46	0.52	19	27.95
Crocosmia × *crocosmiiflora*	12	14	2.58	0.36	22	30.70
Elodea nuttallii	12	14	3.33	0.47	23	32.19
Buddleja davidii	11	13	3.27	0.42	21	33.72
Rubus spectabilis	11	13	3.55	0.45	20	26.35

frequency, mean overall impact score and ranking, followed by *Crassula helmsii*, *Heracleum mantegazzianum* and *Picea sitchensis* in exactly the same positions by each measure (Table 2).

In comparison to the GB assessment, we found that four of the top 10 species from that assessment were also in our top 10 list (Table 3) and a further three included in our list of species reported from more than 10 vice-counties (Table 2). Just one species, *R. japonica*, was present in all British vice-counties; however, only 68% of respondents included the species in their county's top 10. Similar high presences in the top 10 list of vice-counties were only achieved by *R. ponticum* and *C. helmsii* (Table 2). Species where impacts are mainly recorded in coastal habitats, i.e. *Carpobrotus edulis*, *Cotoneaster integrifolius* and *Spartina anglica*, were only in the top 10 of a few vice-counties as these habitats are not available in inland areas. The top 10 GB list included one moss, *Campylopus introflexus*; however, the BSBI and their recorders do not record bryophytes and this was confirmed by 20 of the respondents who did not comment on the species' presence in their county, with many of them indicating that moss species are outside of their remit.

Table 3. Assessment of the top 10 GB species (Booy 2019) in the 68 vice-counties located in Great Britain. Species presence ('In top 10') in the list of 10 highest impact plants in the respective county, presence in county, but not in top 10 ('Present'), species reported as not present ('Not present') and number of respondents not answering the question (NA).

Species	In top 10	Present	Not present	NA
Azolla filiculoides	10	32	25	1
Campylopus introflexus	4	23	21	20
Carpobrotus edulis	2	10	53	3
*Cotoneaster integrifolius**	9	38	15	6
*Crassula helmsii**	39	19	9	1
*Reynoutria japonica**	46	18	0	4
Hydrocotyle ranunculoides	15	10	39	4
Myriophyllum aquaticum	12	22	30	4
*Rhododendron ponticum**	45	20	1	2
Spartina anglica	6	19	41	2

* indicates species is also in the overall top 10 list for all vice-counties.

Regional differences

Regions differed in the number of species reported (Suppl. material 1: Table S1). Looking at the frequency of individual species reported, for each region there were species in the list of species more frequently reported that were not in the overall high frequency list (Table 2). For Ireland, *Allium triquetrum* (5 counties) and *Pinus contorta* (5) were in the top 10 list of species, *Claytonia sibirica* (3) and *Tolmiea menziesii* (3) were in the top 10 list of species in the Scottish Highlands and Islands, with *T. menziesii* (5) also frequent in the Scottish Lowlands. *C. edulis* was in the top list of two of the five vice-counties participating in the region of Southwest England.

Raunkiaer plant lifeform

Most observations of species with impacts were related to phanerophytes, with more than half of these impacts considered to be 'massive' or 'major' (Fig. 3A). There was a significant difference (probability test of proportion: chi-squared = 51.5, d.f. = 5, p-value < 0.001) in the lifeform spectrum (Fig. 3B) of the species reported in the survey (excluding species with native occurrences in some parts of the study area) to all non-native plants included in the species list of the British and Irish flora (Henniges et al. 2022). The *post hoc* test of pairwise comparisons between proportions of lifeform categories found significant differences for the combined category of helophytes and hydrophytes (p < 0.001), which contribute 1.8% of the non-native flora of the British Isles, but 10.6% of the species reported to have impacts. Focusing more specifically on aquatic plants, all but three of the 14 non-native species recorded in the flora of Britain and Ireland were reported amongst the non-native species with impacts. Therophytes were the second group with significant differences in the *post hoc* test (p < 0.001) contributing 28% of all non-natives, but just 10% in our study (for all pairwise post-hoc comparisons, see Suppl. material 1: Table S2).

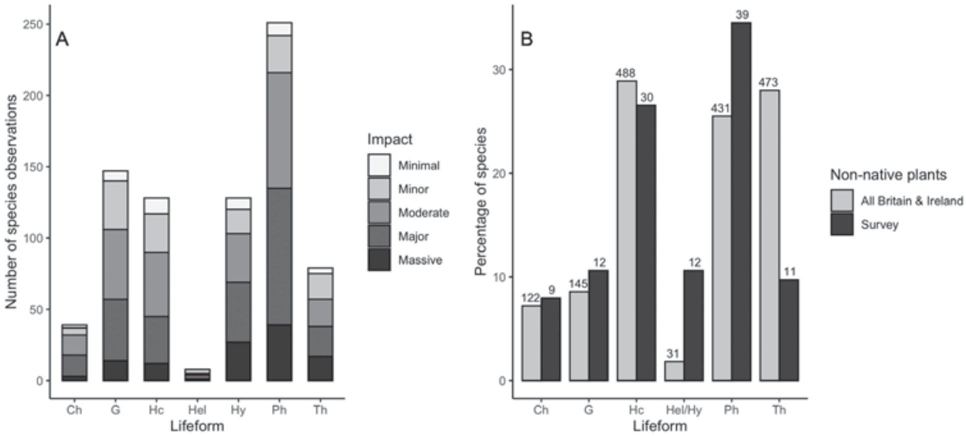

Figure 3. A number of observations and impact categories of 113 higher non-native plants reported in the survey and **B** lifeform comparison of the non-native plants with reported impacts to all 1,690 non-native plants recorded in the British and Irish flora (Henniges et al. 2022). Bars show the percentage of each sample for each lifeform, labels the number of species in each category (data for the survey in B exclude nine species that are native in some parts of the study area). Raunkiaer plant lifeforms: chamaephyte (Ch), geophyte (G), hemcryptophyte (Hc), helophyte (Hel), hydrophyte (Hy), phanerophyte (Ph), therophyte (Th).

Impacts by broad habitats and native species affected

Respondents reported the main broad habitat affected for each species when scoring the species' impacts. The highest number of species was reported for broadleaved/mixed woodlands, followed by boundary/linear features, rivers and streams and standing open waters/canals (Suppl. material 1: Table S3). Looking more closely at which species are reported from which habitats (bipartite graph Suppl. material 3: Fig. S1), we find some species predominantly reported from single broad habitat types, for example, *P. laurocerasus*, *Rubus spectabilis* and *Lamiastrum galeobdolon* subsp. *argentatum* for broadleaved/mixed woodlands or *I. glandulifera* for rivers and streams. In contrast, other species are reported to have impacts in several habitats, most notably *R. japonica*, which was found along rivers and streams, broadleaved/mixed woodlands, urban/brownfield, inland rock, littoral habitats and boundary/linear feature habitats. In boundary/linear feature habitats, we found the greatest mixture of species that are also found in other habitat types, reflecting the diverse range of habitat conditions in this category (Suppl. material 3: Fig. S1).

Additional comments provided by respondents gave further insight into individual cases of habitat impacts. For example, one respondent reported the massive impact of *Quercus ilex* on calcareous grassland that had resulted in the "*complete loss of chalk grassland*". A respondent from Ireland reported *R. spectabilis* with massive impacts in broadleaved woodlands commenting "*by far the single biggest threat to what remains of our broadleaved woodlands. Have seen woodland where this is the only ground-level species*". Further priority habitats mentioned specifically in comments include

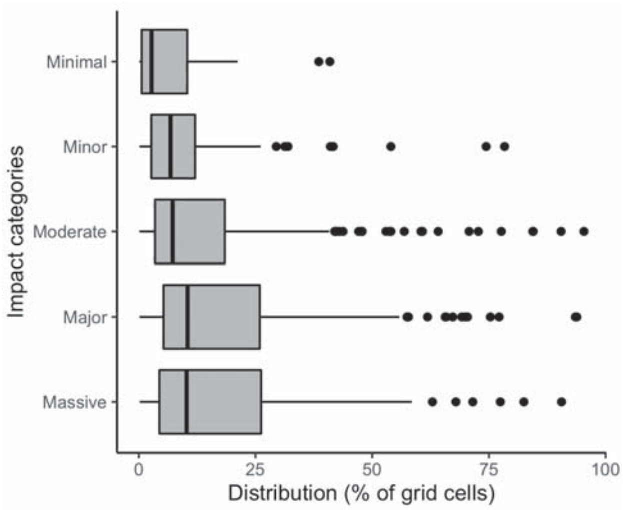

Figure 4. Distribution of reported invasive plants in vice-counties by impact category. The 2 km-scale range size of species is shown as the percentage of the total number of 2 km grid cells per vice-county.

oligotrophic lakes, limestone pavements, hedgerows, oak woodlands, blanket bogs and coastal sand dunes.

Respondents also named 39 native plant species that were particularly negatively affected by the invasive plant they listed, including several species listed in the vascular plant Red Lists for Britain and Ireland, respectively (Table 4). Three species are classified as 'Vulnerable': (1) the liverwort *Southbya nigrella*, which reaches its northern distributional range on calcareous cliffs on the south coast of England with just 20 known sites on the Isle of Portland and one on the Isle of Wight (Blockeel et al. 2014), from where the local vice-county recorder reported *Buddleja davidii* having caused the "virtual loss" of the species. Similarly, the occurrence of (2) *Hydrocharis morsus-ranae* was the only known native site in a north-eastern English vice-county and was considered by the respondent to be "*possibly shaded out*" by *Lemna minuta* (with low confidence score). Lastly, (3) *Heracleum mantegazzianum* was considered responsible for the extinction of a colony of *Allium oleraceum* in the Scottish Lowlands. A further four species are of 'Near Threatened' (NT) status, including reports for *Pilularia globulifera* as threatened by *Crassula helmsii* from three vice-counties. *Pilularia globulifera* has also NT status in the European and global Red Lists of plants (Wyse Jackson et al. 2016). *Cotoneaster integrifolius* agg. was the invasive species most often associated with the direct mentioning of impacts on native species (8 cases), with reports from five vice-counties in southern England, Wales and Ireland, where it was reported to threaten the NT listed species *Gentiana verna* and *Neotinea maculata*. A further European NT species is *Najas flexilis*, for which *Elodea canadensis* was reported to be "*Likely responsible for local population extinctions of* Najas flexilis, Potamogeton rutilus (*but hard to survey these and be sure*)".Species scoring with higher impacts had generally a

Table 4. Native plant species and their threat category (for Ireland and Great Britain, respectively, depending on location of the vice-county, from Wyse Jackson et al. 2016) stated in the survey to be directly impacted by an invasive plant within the top 10 plants of highest impacts in individual vice-counties, their overall impact, confidence score and region of the vice-county. Threat categories according to IUCN standard: VU = vulnerable, NT = near threatened, LC = least concern.

Impacted species	Threat cat.	Invasive plant	Impact	Confidence	Region
Alchemilla spp.		*Alchemilla mollis*	Moderate	Low	Northern England
Allium oleraceum	VU	*Heracleum mantegazzianum*	Major	High	Scottish Lowlands
Allium ursinum	LC	*Allium paradoxum*	Major	Low	Scottish Lowlands
Allium ursinum	LC	*Lysichiton americanus*	Massive	Medium	Scottish Lowlands
Butomus umbellatus	LC	*Crassula helmsii*	Major	High	Southeast England
Cardamine amara	LC	*Lysichiton americanus*	Massive	Medium	Scottish Lowlands
Carex remota	LC	*Allium paradoxum*	Major	Low	Scottish Lowlands
Carex remota	LC	*Lysichiton americanus*	Massive	Medium	Scottish Lowlands
Cerastium spp.		*Smyrnium olusatrum*	Massive	High	Southeast England
Chrysosplenium oppositifolium	LC	*Allium paradoxum*	Major	Low	Scottish Lowlands
Chrysosplenium oppositifolium	LC	*Lysichiton americanus*	Massive	Medium	Scottish Lowlands
Dryas octopetala	LC	*Cotoneaster integrifolius* agg.	Major	High	Ireland
Elatine hexandra	LC	*Hydrocotyle ranunculoides*	Major	High	Southeast England
Fraxinus excelsior	LC	*Acer pseudoplatanus*	Major	High	Scottish Lowlands
Gagea lutea	LC	*Allium paradoxum*	Massive	High	Scottish Lowlands
Gentiana verna	NT	*Cotoneaster integrifolius* agg.	Major	High	Ireland
Gentianella amarella	LC	*Cotoneaster integrifolius* agg.	Massive	Medium	Southeast England
Helianthemum nummularium	LC	*Cotoneaster integrifolius* agg.	Massive	Medium	Southeast England
Helianthemum spp.		*Cotoneaster integrifolius* agg.	Major	Medium	Wales
Helosciadium inundatum	LC	*Crassula helmsii*	Major	High	Southeast England
Hyacinthoides non-scripta	LC	*Hyacinthoides* × *massartiana*	Moderate	Medium	Scottish Lowlands
Hyacinthoides non-scripta	LC	*Lamiastrum galeobdolon* subsp. *argentatum*	Massive	High	Scottish Lowlands
Hydrocharis morsus-ranae	VU	*Lemna minuta*	Major	Low	Northern England
Hypericum elodes	LC	*Crassula helmsii*	Major	High	Southeast England
Hypericum elodes	LC	*Hydrocotyle ranunculoides*	Major	High	Southeast England
Lamiastrum galeobdolon subsp. *montanum*	LC	*Lamiastrum galeobdolon* subsp. *argentatum*	Major	High	Midlands
Lysimachia nemorum	LC	*Allium paradoxum*	Major	Low	Scottish Lowlands
Medicago spp.		*Smyrnium olusatrum*	Massive	High	Southeast England
Najas flexilis	LC	*Elodea canadensis*	Major	High	Scottish Highlands & Islands
Neotinea maculata	NT	*Cotoneaster integrifolius* agg.	Massive	High	Ireland
Neotinea maculata	NT	*Cotoneaster integrifolius* agg.	Major	High	Ireland
Pilularia globulifera	NT	*Crassula helmsii*	Moderate	Low	Wales
Pilularia globulifera	NT	*Crassula helmsii*	Major	Medium	Wales
Pilularia globulifera	NT	*Crassula helmsii*	Major	Medium	Midlands
Potamogeton rutilus	LC	*Elodea canadensis*	Major	High	Scottish Highlands & Islands
Potamogeton praelongus	NT	*Elodea canadensis*	Major	High	Scottish Highlands & Islands
Ranunculus baudotii	LC	*Azolla filiculoides*	Massive	High	Southwest England
rare calcicoles		*Quercus cerris*	Major	Medium	Wales

Impacted species	Threat cat.	Invasive plant	Impact	Confidence	Region
Rubus dasyphyllus		*Rubus armeniacus*	Massive	High	Northern England
Salicornia spp.		*Spartina anglica*	Massive	High	Southeast England
Salix spp.		*Rubus spectabilis*	Major	High	Scottish Highlands & Islands
Sambucus nigra	LC	*Sambucus racemosa*	Minor	Medium	Scottish Lowlands
Micranthes nivalis	LC	*Epilobium brunnescens*	Moderate	High	Scottish Highlands & Islands
Sedum anglicum	LC	*Sedum album*	Moderate	High	Northern England
Southbya nigrella	VU	*Buddleja davidii*	Major	High	Southeast England
Thymus spp.		*Cotoneaster integrifolius* agg.	Massive	Medium	Southeast England
Trifolium spp.		*Smyrnium olusatrum*	Massive	High	Southeast England
Ulmus glabra	LC	*Acer pseudoplatanus*	Major	High	Scottish Lowlands

higher distribution in the vice-county where they were scored than species with lower distributions (Fig. 4), (ANOVA, F(4)= 7.90, $p < 0.001$). Furthermore, across all vice-counties, species that were included in a county's top 10 list were recorded from an average of 15.5% of the county's total number of grid cells, whereas in vice-counties where the species were not included in the top list, they were recorded on the average of 10.1% grid cells (two sample t-test, t = -7.96, $p < 0.001$).

Discussion

Our results demonstrate the value of local experts' contributions to impact assessments of non-native species. This is the first study bringing together assessments by local volunteer experts, based on their own field experience with a national assessment conducted by researchers relying mainly on published evidence. The analysis confirms the results of the national assessment, but also adds a new level of evidence which will be relevant for future national assessments, as well as local and regional management decisions. Here, we discuss how our approach could complement and feed into comprehensive impact assessments, how the results compare to previous assessments in Britain and Ireland and how our local experts' contributions go beyond the identification of species to include information on impacts on habitats and native species.

Integration of local knowledge into larger scale impact assessments and working with EICAT

The aim of our study was not to conduct an impact assessment following the full EICAT framework process. Our study was based on local volunteer experts reporting non-native species relying on their observations of the impacts of species in areas they are familiar with. In contrast, the EICAT approach is based on experts assessing published evidence on species' impacts including impact mechanisms (Hawkins et al. 2015). Our respondents' scoring of impacts was based on their observations and individual perceptions and lacks the rigour underlying published evidence. However, both approaches connect through using the EICAT assessment categories and criteria. The value of our approach lies in that it taps into a pool of knowledge that would often not make it into the published evidence assessed in the EICAT process. Species with impacts may thus be recognised earlier, because it is usually local experts that will notice changes in their environment first. Many of these records may take a long time from there to a professional investigating and publishing these impacts or may not be reported at all. This is illustrated by the number of species reported in our study that have not been considered in the GB national assessment. Studies such as ours could, therefore, be useful to feed into full EICAT assessments at national levels, not just for plants, but also for other species groups where local experts are involved in recording and monitoring. Future studies could also benefit by including a question on impact mechanisms as in the EICAT assessment, although there is always a risk that, if responding to a survey takes too much time, the response rate is likely to decrease.

Our results showed that the EICAT impact categories could be well communicated to local experts and were well-suited to be used by them. We, therefore, argue that our results are, to some extent, comparable to impact assessments using the same categories and criteria and we have confirmed this by comparing our results to the GB national level expert assessment. Ranking of species in the order they were submitted (highest impact species first) produced very similar results to the scoring using the assessment criteria. We would, nevertheless, not conclude that similar studies should just ask for a ranked list of species without providing impact definitions, as these will have guided respondents in their choice of species. However, the ranking is useful considering different interpretation of the criteria in the assessment scheme, as well as in the perceptions of impacts by individual respondents.

Comparison to the national level GB scoring and previous assessments for Ireland

We achieved a remarkably similar list to the species list in the expert assessment at GB national level. Species absences in our top list are explained by the fact that coastal habitats are not present in many areas from which we received responses (in the case of *Spartina anglica*) or because they were outside the taxonomic scope of vice-county recorders (e.g. *Campylopus introflexus* was outside the scope of most recorders). The study also identified species that were not included in the top list of species in the national impact scoring scheme, for example, *Picea sitchensis*, *Lamiastrum galeobdolon* subsp. *argentatum* and *Prunus laurocerasus* all ranked highly in our study, but did not achieve higher scores in the GB scoring, with *P. laurocerasus* ranked 'moderate' and the other two species 'minor'. However, the GB national assessment also asked reviewers to score the potential maximum impact (an option which was not offered in our project), defined as the impact a species "would be expected to have in GB if it were established in all parts that are suitable (i.e. based on current biotic and abiotic conditions)" (Booy 2019) and all three species were scored 'major'. This result could indicate that the evidence used in the GB scoring was out-of-date and the species' more extensive impacts have not been documented so far or accessible to the national evaluators, who, nevertheless, realised the potential for higher impacts of these species in their potential maximum impact score.

For Ireland, the survey reported 12 species on the list of 16 high impact species identified by Kelly et al. (2013), based on risk assessments and nine of the species listed by Gioria et al (2018), based on a literature review of terrestrial plants. Species included in these two sources, but not reported in our survey for Ireland, include *Reynoutria sachalinensis*, *Hydrocotyle ranunculoides*, *Carpobrotus edulis* and *Crassula helmsii*. Species reported in our survey with 'massive' impacts, but missing in Kelly et al. (2013) are *Picea sitchensis*, *Rubus spectabilis* and *Cotoneaster integrifolius*, with the latter two being also identified by Gioria et al. (2018). Furthermore, two species included in the top ten list of species reported from Ireland in our survey, *Allium triquetrum* and *Pinus contorta*, are not included in either of these two references.

Scoring consistency and suitability of the approach for future assessments

We found scoring consistency differed for individual species between vice-county recorders. This can be attributed to differences inherent to individual respondents and how they interpreted and applied the assessment criteria. Vice-county recorder may be in their roles for various lengths of time and may have different levels of commitment and experience, which could influence their scoring. Similar, their perception of the impacts of species in their vice-counties and of invasive species, in general, could influence how they scored, with underlying factors not studied in our analysis informing individual people's perceptions (Shackleton et al. 2019). However, it is also likely that these differences can, to some extent, be explained by different introduction and spread histories of the species and/or the availability of habitats in different vice-counties. González-Moreno et al. (2019) investigated patterns of consistencies in scoring between different assessors for several invasive species and impact assessment schemes including EICAT and found, on average, a coefficient of variation (CV) of 40%. In comparison, the 32% variation for the impact score of invasive plants in our study is lower, which could be the result of higher numbers of scores for most species (i.e. between 4 to 63, compared to 5 to 8 in Gonzáles-Moreno et al. 2019), but it is also reassuring to see a comparable level of agreement at the species level, despite the fact that respondents reported from different local areas. However, we also found clear differences in scoring between different respondents, ranging from one respondent reporting 10 species all with 'massive' impacts for their vice-county to another one who had scored just one species (*Allium paradoxum*) as 'moderate', with the remaining nine all as either 'minor' (3 species) or 'minimal' (6). Overall, variation between recorders was 25% (CV).

Habitats and species affected

While most records of non-native plants in Europe and the British Isles are from human-made habitats (i.e. industrial habitats and arable land, parks and gardens) (Lambdon et al. 2008; Stace and Crawley 2015), impacts of species in our survey were most frequently associated with woodlands. This seems reasonable, given that we asked respondents to consider environmental impacts only, which will have excluded many impacts of invasive species in human-made habitats. Linear features and boundaries were the second most mentioned habitat type; however, this habitat is more difficult to interpret as it encompasses a wide range of different linearly-arranged landscapes elements according to the UK broad habitat classification, ranging from hedgerows, tree lines and walls to dry ditches (Jackson 2000). Nevertheless, linear features are recognised to play an important role in supporting biodiversity and ecosystem services (Holland et al. 2016; Phillips et al. 2020) and the high number of impacting non-native species are a reason for concern. Equally concerning are the high number of species reported from freshwater and wetland habitats combined with the fact that 11 of the 14 aquatic species in the non-native flora of the British Isles have been reported. Urban and brownfield sites, many of which are also well known to support biodiversity (Harrison and Davies 2002; Venn et al. 2013), feature less species, but this could also be the result of these habitat types not specifically mentioned in the UK broad habitat type categorisation and, therefore, not included in our survey design.

Conclusions

Our study provides evidence that local experts can make highly valuable contributions to the assessment of impacts associated with invasive non-native species. This contribution lies not only in the confirmation of results from national assessments, but also in identifying less well documented, but widely distributed species, as well as species with limited occurrences and high impacts locally.

Our assessment gained in value by adding a question in our survey about the main habitat type and native species affected. This information will further help to understand invasive species' impacts and guide management, in particular, at more local levels. Furthermore, the results provide a valuable baseline which can be followed up by surveys in regular intervals (for example 5–10 years) to document changes in the spectrum of species, as well as the reported impacts and habitats and native species affected. For this purpose, it is also important to have used the internationally recognised EICAT impact categories as a standard which will help to maintain a good level of consistency at the temporal scale in the future and integration into national impact assessments.

Our results will also be useful to provide information for national and local planning and policies, risk assessments and management actions, as well as directing future research.

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Supplementary material 1

Survey and Tables S1–S3

Authors: Katharina Dehnen-Schmutz, Oliver L. Pescott, Olaf Booy, Kevin J. Walker

Data type: Questionnaire form.

Explanation note: **Part 1**: Questionnaire survey text **Part 2**: Table S1 (Diversity at regional levels), Table S2 (results of the post-hoc row wise Fisher test comparing the proportions of lifeform), Table S3 (number of observations of invasive plants affecting different habitats as reported in the survey).

Link: https://doi.org/10.3897/neobiota.77.89448.suppl1

Supplementary material 2

Table S2

Authors: Katharina Dehnen-Schmutz, Oliver L. Pescott, Olaf Booy, Kevin J. Walker

Data type: Csv file.

Explanation note: Survey results and species information.

Link: https://doi.org/10.3897/neobiota.77.89448.suppl2

Supplementary material 3

Figure S1

Authors: Katharina Dehnen-Schmutz, Oliver L. Pescott, Olaf Booy, Kevin J. Walker

Data type: Image.

Explanation note: **Figure S1**. Bipartite graph illustrating which species have been reported to have impacts in which habitats weighted by the sum of the impacts of each species reported for the respective habitat. Littoral habitat categories have been combined.

Link: https://doi.org/10.3897/neobiota.77.89448.suppl3