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INVASION NOTE

GB Non-native Species Information Portal: documenting the arrival of non-native species in Britain

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Abstract Information on non-native species (NNS) is often scattered among a multitude of sources, such as regional and national databases, peer-reviewed and grey literature, unpublished research projects, institutional datasets and with taxonomic experts. Here we report on the development of a database designed for the collation of information in Britain. The project involved working with volunteer experts to populate a database of NNS (hereafter called "the species register"). Each species occupies a row within the database with information on aspects of the species' biology such as environment (marine, freshwater, terrestrial etc.), functional type (predator, parasite etc.), habitats occupied in the invaded range (using EUNIS classification), invasion pathways, establishment status in Britain and impacts. The information is delivered through the Great Britain Non-Native Species Information Portal hosted by the Non-Native Species Secretariat. By the end of 2011 there were 1958 established NNS in Britain. There has been a dramatic increase over time in the rate of NNS arriving in Britain and those becoming established. The majority of established NNS are higher plants (1,376 species). Insects are the next most numerous group (344 species) followed by non-insect invertebrates (158 species), vertebrates (50 species), algae (24 species) and lower plants (6 species). Inventories of NNS are seen as an essential tool in the management of biological invasions. The use of such lists is diverse and far-reaching. However, the increasing number of new arrivals highlights both the dynamic nature of invasions and the importance of updating NNS inventories.

Keywords Inventories · Non-native species · Database · Pathways · Freshwater · Terrestrial · Marine

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The Millennium Ecosystem Assessment (Anonymous 2005) ranked invasive non-native (=alien) species (INNS), alongside climate change, habitat destruction, pollution and overexploitation, as one of the main drivers of biodiversity loss. INNS are defined as species, introduced through human action outside of their native range, that have the ability to spread causing damage to the environment, the economy, our health or the way we live (Roy et al. 2012a). Over the last century there has been a dramatic increase in the movement of non-native species (NNS) around the world, as a consequence of increasing international trade and travel (Hulme et al. 2009b). NNS are being introduced into countries at unprecedented and unpredictable rates and those that become invasive threaten biodiversity by decreasing the uniqueness of ecosystems at genetic, functional and taxonomic levels (Vila et al. 2011). The Convention on Biological Diversity (CBD) suggests a three-stage hierarchical approach to invasive non-native species: prevention, surveillance and rapid response, control and eradication. This approach has been followed in the Invasive Non-Native Species Framework Strategy for Great Britain (Defra 2008a, b), which outlined nine specific aims including the requirement for improved detection and monitoring capabilities coupled with an effective decision-making framework.

Lists of NNS are seen as an essential tool in the management of biological invasions (McGeoch et al. 2012). The use of such lists is diverse and far-reaching. There have been many influential research studies based on NNS lists which have increased understanding particularly in relation to pathways of arrival (Hulme 2009) and impacts on biodiversity (Vila et al. 2011); both acknowledged as critical elements within biodiversity strategy. Indeed implementation of policy and legislation is often based on NNS lists (Lodge et al. 2006). Early warning, prevention and control measures for INNS rely on information such as identity, associated biology and distribution (McGeoch et al. 2012). Maintaining a list of NNS within Britain is essential for underpinning decision-making concerning control, mitigation and eradication of INNS (Defra 2008a).

There are a number of international agreements which recognise the negative effects of INNS and reflect the growing concerns of many people. For example, European countries now have obligations in relation to NNS and must: "strictly control the introduction of non-indigenous species" (Bern Convention on the Conservation of European Wildlife and Natural Habitats) and the EU is working towards policy for tackling invasions ('Towards an EU Strategy on Invasive Species' (COM 2008) and establishing an early warning system. The recent announcement of the European Commission proposal for a regulation on invasive alien species (http://ec.europa.eu/environment/nature/invasivealien/) further highlights the importance of underpinning policy with easily accessible and high quality information.

There have been recent efforts to consolidate information into centralised European [Delivering Alien Species Inventory in Europe (DAISIE)] and regional (e.g. NOBANIS, REABIC, ESENIAS, MAMIAS, Baltic Sea Alien Species Database) databases. The Great Britain Non-Native Species Information Portal (GB-NNSIP) is an on-line information system (www.nonnativespecies.org/), involving a network of organisations engaged in monitoring and surveillance of NNS, designed to enhance national capability for detecting and reporting INNS, and thereby enabling more effective decision-making (Roy et al. 2012a). Here we describe the development of the GB-NNSIP (Fig. 1) and provide an overview of the NNS established within Britain.

Species register

The GB-NNSIP is constrained to species within England, Scotland and Wales (hereafter refered to as "Britain"). The species register comprises the basic list of NNS, together with supporting information: habitat, country of origin, arrival pathway, ecofunctional type, establishment status (for Britain and also England, Scotland and Wales separately), first record, human impact and ecological impact. The species register is dynamically linked to the National Biodiversity Network (NBN) Gateway (https://data.nbn.org.uk/) which provides maps of the distribution of the NNS within Britain. Information was collated for each species under the following categories: informal grouping (higher plant, lower plant, insect, non-insect invertebrate and vertebrate), phylum, environment (terrestrial, freshwater and marine), functional group (detritivore, algae, filter-feeder, land plant, herbivore, predator, parasite, omnivore), native range (using Taxonomic Database Working Group (TDWG http://www.tdwg.org/standards/104/) categories or country-level data where TDWG provided insufficient

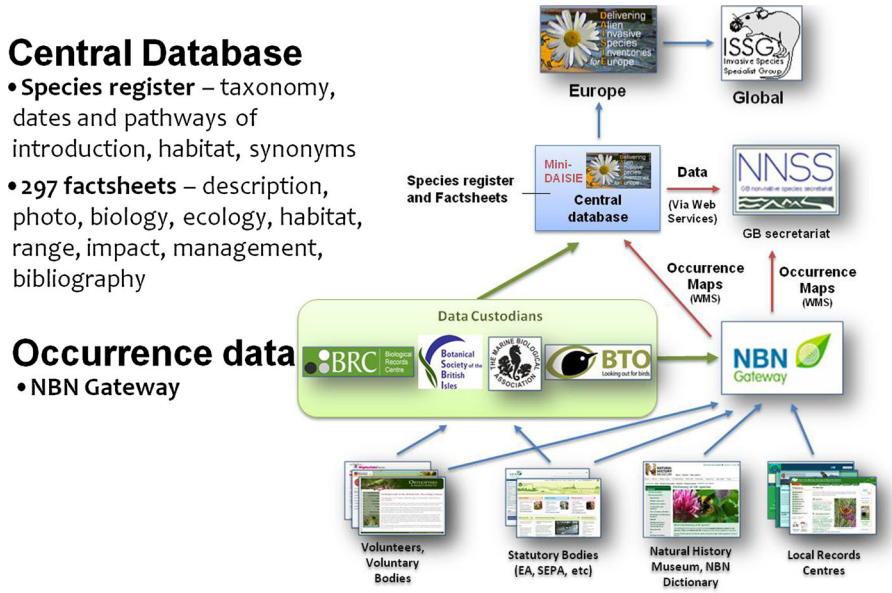

Fig. 1 Interactions between the GB-NNSIP and the wider community engaged in monitoring and surveillance of non-native species (NNS). Distributional data are collated from various organisations and bodies (statutory bodies, Local Records Centres and national schemes and societies including project collaborators BSBI, BTO and MBA) through the National Biodiversity Network (NBN) Gateway. Other information on NNS is collated in the species register within the Biological Records Centre (BRC) hosted within the Centre for Ecology and Hydrology. Data from the species register and the NBN Gateway are delivered to the GB-NNSIP and from here they can be exchanged with European initiatives (such as DAISIE) and global initiatives such as the Global Invasive Species Database (within ISSG)

resolution), habitats occupied within Britain (using Eunis categories http://eunis.eea.europa.eu/about.jsp), establishment status in Britain, England, Scotland and Wales, place and year of first record in Britain and key references.

A NNS list compiled for England (Hill et al. 2005) formed the basis of the species register with additional species extracted from DAISIE, the Biological Records Centre database and updates from experts. The list excluded garden plants, cultivated crops, pests of stored crops, human parasites and pests of human habitation unless they were thought likely to be found in the wild. Microorganism (with the exception of a small number of marine phytoplankton) and macrofungi were also not included. The NNS information summarised here relates to all NNS arriving prior to 2012, although the GB-NNSIP is being updated at least annually.

Information for the 1958 established[1] NNS is summarized in this paper.

The term "in the wild" is widely used and generally encompasses both natural and semi-natural habitats in both rural and urban environments (i.e. beyond the curtilage of residential, public and commercial buildings). However, this and preceding projects (Hill et al. 2005, 2008) have not attempted to define the term "in the wild" but have only included species that occur outside buildings, captivity or cultivation. In this report we align with the definition provided by Natural England with respect to "the wild" (http://www.defra.gov.uk/publications/2011/05/26/pb13535wildlife-countryside-act/):

> The diverse range of natural and semi-natural habitats and their associated wild native flora and fauna in the rural and urban environments in general. This can also be broadly described as the general open environment.

The term "established" is used for self-sustaining (i.e. reproducing) populations. A species is deemed to be "established" if it occurs as a self-sustaining population, persisting for more than 4 years, not dependent on repeated reintroduction, and usually spreading away from the point of introduction. However, it is useful to include the term "persisting" for species such as ornamental or commercial trees

[1] Species established and persisting in the wild.

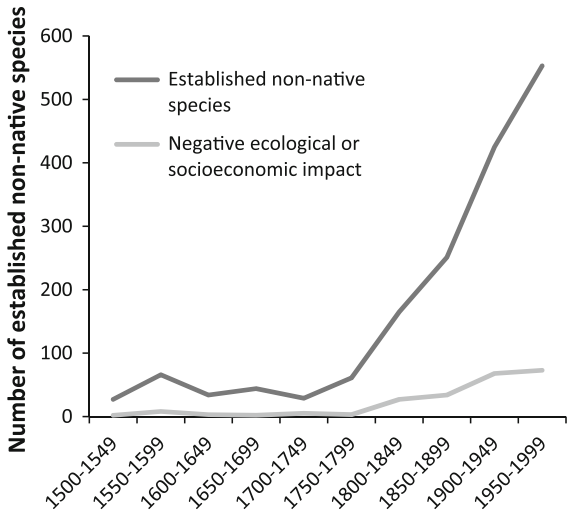

Fig. 2 Number of established NNS and the number that are designated as having a negative ecological or socioeconomic impact against date of first record. It should be noted that a further 125 species have arrived between 2000 and 2010 (that is in the first fifth of the current half century). Only 45 of these are known to have established and 14 of these are considered to have a negative impact. There are 239 established NNS for which there is no date within the species register

and shrubs that persist for more than 4 years but are not successfully reproducing (i.e. surviving but not regenerating). In most cases these are treated as a subset of "established" because it is often impossible to know the extent to which they are regenerating.

Factsheets

Species experts were asked to provide expanded contextual information for 297 species as factsheets including the following categories: brief description of the species, invasion history (including origin, first record, pathway and method of arrival, species status), ecology (including dispersal mechanisms, reproduction, known predators or herbivores, resistant stages, habitat occupied in Britain), distribution within Britain and impact (including environmental, economic, health and social) and references. The factsheets are made available for download through the GB-NNSIP.

Established NNS in Britain

By 2012 there were 1958 established NNS within Britain including 54 NNS established indoors only.

Table 1 Non-native species eradicated in Britain

Scientific name	English name	Notes
Hystrix brachyura	Hodgson's Porcupine	Small colony was briefly established in Devon but successfully eradicated.
Leptinotarsa decemlineata	Colorado Beetle	Probably introduced with potato (or other) shipments, though possibly an immigrant from continental Europe.
Mesocricetus auratus	Golden Hamster	First record from Bath in 1958.
Misgurnus mizolepis	Chinese Weatherfish	A reproducing loach population in a pond in Essex (since eradicated) was found to be *M. mizolepis*.
Myocastor coypus	Coypu	First brought to England to stock fur farms in 1929. Escapes occurred mainly in the 1930s.
Ondatra zibethicus	Muskrat	Escaped from fur farms
Bemisia tabaci	Tobacco Whitefly	First reported on *Poinsettia* cuttings, which have since been main source of interceptions/outbreaks.

There has been a dramatic increase in the rate of species arriving and those becoming established since 1800 and there is no indication of this trend slowing (Fig. 2).

Most of these are established in the wild with a few occupying habitats in buildings. The dramatic increase in the arrival and establishment of NNS within Britain from 1800 is comparable to patterns of arrival and establishment across Europe (Hulme 2009), albeit confounded with advances in transport and taxonomic knowledge. The apparent decline in the proportion of NNS considered having a negative ecological or human impact in recent years could be a reflection of a lag phase in which impacts have not yet been identified or a greater tendency in recent decades to record casual species.

A total of seven NNS have been contained (only present in quarantine or other contained facilities) or exterminated in Britain over the last 100 years (Table 1). Muskrat (*Ondatra zibethicus*) and tobacco whitefly (*Bemisia tabaci*) are the only species eradicated from all constituent countries within Britain, the others being more restricted in their distributions.

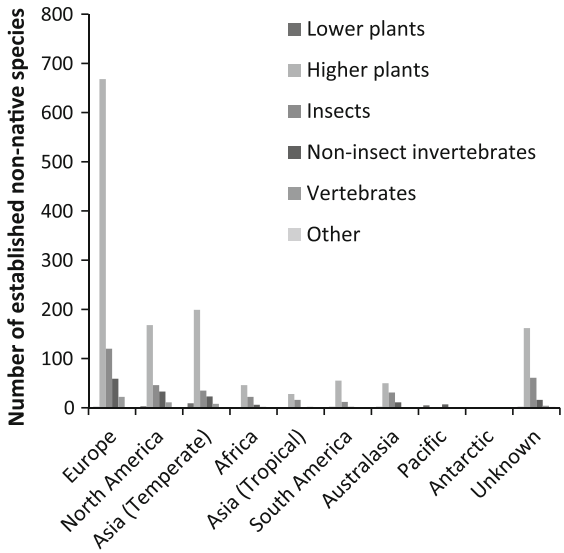

Fig. 3 Number of established NNS (plants, insects, non-insect invertebrates, vertebrates and other) in Britain originating from different geographic regions

Geographic origin of established NNS

Most of the NNS that are established within Britain originate from Europe (Fig. 3). It is interesting to note that NNS originating from Europe began to arrive and establish in high numbers from the eighteenth century, whereas NNS originating from temperate Asia and North America have seen a rapid escalation since the nineteenth century (Fig. 4).

It is intuitive that species in close proximity to Britain would arrive earlier than those from greater distances because of the close transport and trade links throughout history (Preston et al. 2004). The patterns in date of first arrival for NNS originating from different regions are consistent with the increase in long-distance trade subsequent to the discovery of the Americas. In particular the importation of higher plants for both commercial and ornamental purposes from North America and temperate Asia from the eighteenth century onwards (Hulme 2009; Preston et al. 2004). It is apparent the rate of new species arriving from Europe to Britain is slowing, in striking contrast to the dramatic rate of new arrivals from temperate Asia. Hulme (2009) highlighted the importance of understanding invasions as spatial processes which can inform action rather than simply identifying the scale of the problem. Interestingly, within the marine environment the NNS originate much more evenly from a number of regions with Asia (temperate), North America and the Pacific region dominating (Fig. 5). Perhaps the low number of marine NNS from the marine environment is beause of the ease with which these species can naturally colonise a new region.

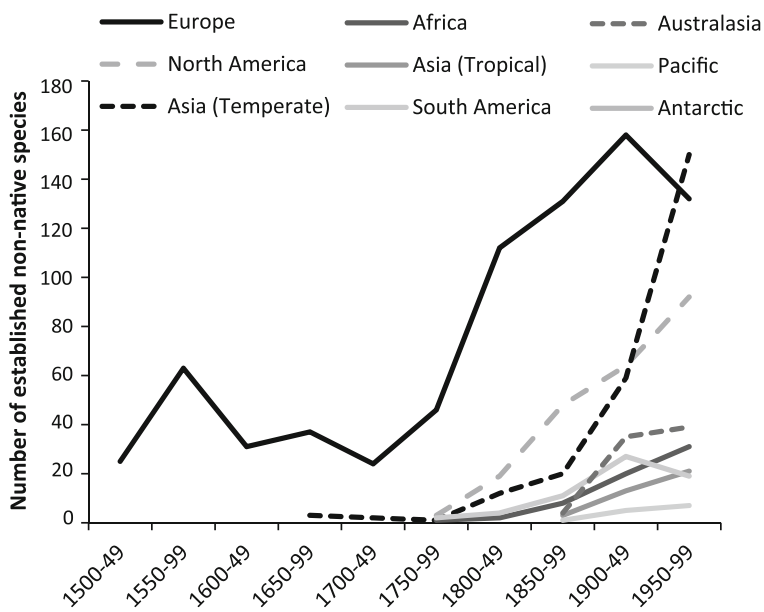

Fig. 4 Number of established NNS originating from different geographic regions and arriving in Britain against date of first record

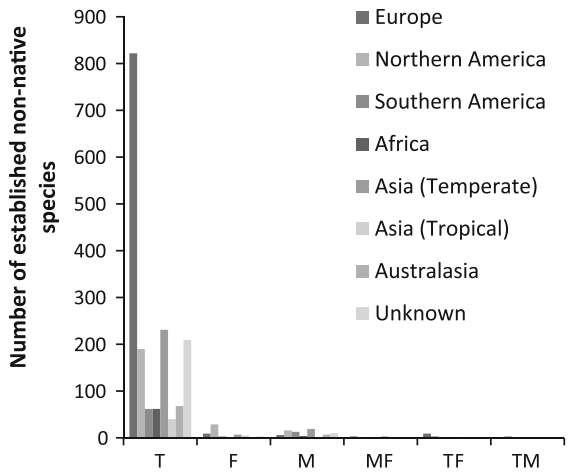

Fig. 5 Number of established NNS originating from different regions for different environments (*T* Terrestrial, *F* freshwater, *M* marine, *TF* terrestrial-freshwater, *TM* terrestrial-marine, *MF* marine-freshwater)

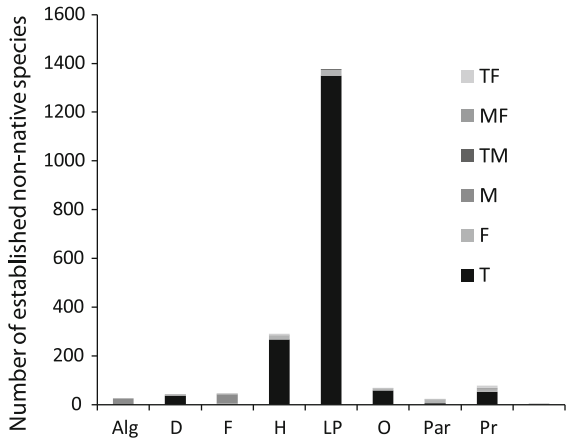

Fig. 6 Number of established NNS within different functional groups (*Alg* alga, *D* detritivore, *F* filter feeder, *H* herbivore, *LP* land plant, *O* omnivore, *Par* parasite, *Pr* Predator) for different environments (*T* Terrestrial, *F* freshwater, *M* marine, *TF* terrestrial-freshwater, *TM* terrestrial-marine, *MF* marine-freshwater)

Established NNS within broad taxonomic groups and environmental categories

Primary producers (algae and most land plants) represent the majority of established NNS, followed by primary consumers (filter-feeders, herbivores and omnivores) with secondary consumers (parasites and predators) occuring in low proportions in all systems (Fig. 6). The majority (1,376 species) of known established NNS are higher plants (Table 2; Figs. 3, 6). This is consistent with patterns reported for Europe (Pysek et al. 2009). Trade in exotic ornamental plants has increased over time and the UK market is based on more than 73 000 plant species and cultivars (Perrings et al. 2005). This trade is globally recognized as a major source of NNS (Perrings et al. 2005). In the Czech Republic 53 % of established non-native plants arrived as ornamental plants (Pysek et al. 2002).

Following higher plants, insects are the next most numerous group (344 species) followed by non-insect invertebrates (158 species), vertebrates (50 species), algae (24 species) and lower plants (6 species). Flowering plants (1,336 species) represent the most numerous taxonomic category of established NNS (Table 2). Birds (15 species) and terrestrial mammals (17 species) are the most species-rich vertebrate taxa. Insects are the most numerous of all the established invertebrate NNS with Hemiptera (bugs) and Coleoptera (beetles) dominating. Indeed the list of NNS arriving over the last decade has been dominated by insects and other invertebrates (78 species). A number of these species have received considerable interest from the media and consequently a high profile primarily because of their potentially negative effects on the environment. One such species is the harlequin ladybird, *Harmonia axyridis*, native to Asia and first recorded in the south of England in 2004 (Roy et al. 2012b). This species is known to have spread at 100 km yr^{-1} and implicated in the decline of native ladybirds (Roy et al. 2012b; Brown et al. 2008a, b). In marine environments algae (24 species) and crustaceans (15 species) are the most numerous of all established NNS. There are also a reasonable number of established non-native crustaceans (12 species) within freshwater environments.

The overwhelming majority of known established NNS are found in terrestrial environments (Table 2) and flowering plants are the most numerous NNS within the terrestrial environment. In contrast invertebrates are the dominant NNS in freshwater and marine environments, although a high proportion of NNS higher plants in the freshwater environment tend to be invasive. Freshwater species are reported to have a higher intrinsic dispersal ability compared to terrestrial species (Gherardi et al. 2009) and this, coupled with the strong effect of human disturbance on

Table 2 Total number of established NNS in broad taxonomic groups and associated informal groups for different environments

Broad group	Informal group	F	M	MF	T	TF	TM	Total
Algae			24					24
Lower plants					6			
Lower plants total			24		6			30
Higher plants	Flowering plant	22			1311		3	1336
	Conifer				29			29
	Fern	1			8			9
	Other				2			2
Higher plants total		23			1350		3	1376
Insects	Beetle (Coleoptera)	1			123			124
	Bug (Hemiptera)				104			104
	Moth (Lepidoptera)	7			45			52
	Bee, wasp or ant (Hymenoptera)				22			22
	Thrip (Thysanoptera)				12			12
	Booklouse (Psocoptera)				10			10
	True fly (Diptera)				4		2	6
	Cockroach (Dictyoptera)				5			5
	Stick insect (Phasmida)				5			5
	Grasshopper or cricket (Orthoptera)				2			2
	Flea (Siphonaptera				1			1
	Silverfish (Thysanura)				1			1
Insects total		8			334		2	344
Vertebrate	Mammal				17			17
	Bird				7	8		15
	Fish	6		1				7
	Amphibian					8		8
	Reptile				3			3
Vertebrates total		6		1	27	16		50
Non-insect invertebrate	Mollusc	8	11	2	23			44
	Crustacean	12	15	3	2			32
	Spider				20			20
	Annelid	2	12					14
	Mite				8			8
	Tunicate		6					6
	Bryozoan		4	1				5
	Tapeworm	4						4
	Trematode	3				1		4
	Coelenterate	1	2	1				4
	Centipede				3			3
	Flatworm	2			1			3
	Millipede				2			2
	Ribbon worm				2			2
	Roundworm			1	1			2
	Other		2		3			5

Table 2 continued

Broad group	Informal group	F	M	MF	T	TF	TM	Total
Non-insect invertebrate total		32	52	8	65	1		158
Overall total		69	76	9	1776	17	5	1,952

T terrestrial, *F* freshwater, *M* marine, *TF* terrestrial-freshwater, *TM* terrestrial-marine, *MF* marine-freshwater

freshwater systems, has ensured that NNS are major drivers of degradation within aquatic systems (Sala et al. 2000). The most successful species among aquatic invaders are the crustaceans (Haenfling et al. 2011). The impacts of non-native crustaceans can be substantial, due to the complex trophic roles of these species leading to cascading effects throughout the invaded ecosystems (Haenfling et al. 2011). These NNS have the potential to cause changes in ecosystem function by altering energy flux and nutrient cycles which together affect critical ecosystem services such as biodiversity, fisheries yield and water quality (Haenfling et al. 2011). There are numerous crustacean NNS within freshwater environments in Britain. Two species of crayfish have arrived and established over the last 10 years: *Orconectes limosus*, spiny-cheek crayfish (2001), and *Orconectes virilis*, virile crayfish (2004). Both species are native to North America. The arrival of these two crayfish brings the total number of established non-native crayfish in Britain to seven. *Pacifastacus leniusculus*, signal crayfish, which was first recorded in Britain in 1975 is a major threat to the native *Austropotamobius pallipes*, white-clawed crayfish, and is causing declines in diversity and richness of aquatic communities.

Established NNS within habitat categories

Habitat factors are considered to be major determinants influencing the invasion process (Cadotte et al. 2006; Pysek et al. 2009). NNS occupy a diverse range of habitats within Britain and these are reflected across the different environments. Marine NNS are distributed reasonably evenly between littoral rocks, sediment and infralittoral rock habitats but are limited in other marine habitats, perhaps an indication of the logistical difficulties of sampling within subtidal habitats (Table 3). Indeed, species could remain largely undiscovered in pelagic zones where it is difficult to determine whether species are introduced because the natural movement and connectivity by ocean currents results in a cosmopolitan and transitory nature of species in these open water habitats. Terrestrial and freshwater NNS also occupy diverse habitats (Table 3). There are a number of habitats which have more than 100 established NNS (Table 3) including: woodlands and forest habitats, inland surface waters (including for example riparian species), domestic habitats (including cultivated gardens and parks) and constructed, industrial habitats. This reflects the dominance of plants within the species register. Mires and bogs have a very low number of NNS (only seven species).

More than 40 % of terrestrial established NNS are found within grassland habitats; a consequence of the high number of plants which occur in ruderal tall-herb communities (categorised by EUNIS as grasslands but specifically on disused urban or agricultural land, by watercourses, at the edge of woods, invading pastures, bracken stands, margins of standing waters and rivers, etc.). Indeed industrial and urban habitats harbour a high proportion of NNS and could be considered non-native habitats themselves. This pattern is reflected in the pan-European studies derived from DAISIE (Hulme et al. 2009a; Pysek et al. 2009). It should also be noted that there is a very large reservoir of casual species, particularly plants, repeatedly being introduced but failing to establish within these disturbed habitats. Some of these NNS are highly likely to become established and potentially invasive in the future particularly as the environment changes. Therefore, surveillance and monitoring for early warning is a critical component of invasive species management.

Conclusions

The threat posed by INNS to biodiversity and ecosystems is one of the greatest issues for European conservation (Vila et al. 2010). The pan-European

Table 3 Number of established NNS occurring in different habitats (EUNIS categories in brackets) across different environments

	T	F	M
Marine (A)	0	3	38
Littoral rock (A1)	0	0	8
Littoral sediment (A2)	9	1	5
Infralittoral rock (A3)	0	0	19
Circalittoral rock (A4)	0	0	1
Sublittoral sediment (A5)	0	0	2
Pelagic water column (A7)	0	1	1
Total marine	9	5	74
Coastal (B)	2	0	3
Coastal dunes (B1)	123	0	0
Coastal shingle (B2)	14	0	1
Cliffs (B3)	64	0	2
Total coastal	203	0	6
Inland waters (C)	0	2	3
Surface standing water (C1)	28	61	1
Surface running water (C2)	11	16	0
Littoral zone of inland waterbodies (C3)	47	2	0
Total inland waters	86	81	4
Raised and blanket bogs (D1)	4	0	0
Valley mires, poor fens, transition mires (D2)	1	0	0
Sedge and Reedbeds (D5)	2	0	0
Total mires, bogs and fens	7	0	0
Grasslands (E)	1	0	0
Dry grasslands (E1)	51	0	0
Mesic grasslands (E2)	232	0	0
Seasonally wet grasslands (E3)	18	0	0
Subalpine grasslands (E4)	2	0	0
Woodland fringes and tall-herb stands (E5)	502	0	0
Sparsely wooded grasslands (E7)	17	0	0
Total grasslands	823	0	0
Subalpine scrub (F2)	1	0	0
Temperate scrub (F3)	18	0	0
Temperate shrub heathland (F4)	16	0	0
Riverine and fen scrubs (F9)	1	0	0
Hedgerows (FA)	43	0	0
Shrub plantations (FB)	2	0	0
Total scrub	81	0	0
Woodland (G)	7	0	0
Broadleaved deciduous (G1)	80	0	0
Broadleaved evergreen (G2)	2	0	0
Coniferous woodland (G3)	43	0	0
Mixed woodland (G4)	16	0	0
Lines of trees (G5)	3	0	0
Total woodland	151	0	0
Sparsely vegetated habitats (H)	1	0	0
Inland cliffs (H3)	22	0	0
Inland sparsely vegetated habitats (H5)	26	0	0
Total sparsely vegetated habitats	49	0	0
Cultivated land (I)	4	0	0
Arable land (I1)	48	0	0
Cultivated areas of gardens and parks (I2)	122	0	0
Total cultivated land	174	0	0
Constructed and artificial habitats (J)	7	0	0
Buildings (J1)	83	0	0
Low-density buildings (J2)	54	7	0
Industrial sites (J3)	2	0	0
Transport networks (J4)	30	0	0
Waste deposits (J6)	4	0	0
Total artificial habitats	180	7	0
Habitat complexes (X)	7	0	0
Estuaries (X01)	0	1	5
Domestic gardens (X25)	3	0	0
Brackish coastal lagoons (X3)	0	1	1
Pasture woods (X9)	1	0	0
Total habitat complexes	11	2	6

T terrestrial, *F* freshwater, *M* marine

inventory of alien species compiled within DAISIE has increased the awareness of the impact of biological invasions in Europe (Hulme et al. 2009a). Additionally not only is DAISIE an invaluable source of information on alien species across Europe but the infrastructure established through DAISIE can be used for national databases (Hulme et al. 2009a). The development of the GB-NNSIP was informed by the DAISIE infrastructure and reliance on experts for compilation of species information.

The identity and associated biology of NNS are critical for underpinning management policy and strategies (McGeoch et al. 2012). The GB-NNSIP provides information on all NNS known to be established in Britain. The infra-structure of the pan-European inventory DAISIE has informed the development of the GB-NNSIP and demonstrates the relevance of flow of information between such information systems. The challenge is to maintain and update NNS inventories with the rapidly increasing number of new arrivals. The

GB-NNSIP receives funding from Defra and this, coupled with the coordination provided by the Non-Native Species Secretariat and associated Programme Board, is critical for maintaining and developing the GB-NNSIP. Both the GB-NNSIP and DAISIE rely on evidence from expert natural historians who often collate information on NNS in a voluntary capacity. Britain has a rich culture of natural history with more than 80 biological recording schemes and societies representing a diverse range of taxonomic groups (Preston et al. 2012). More than 100 volunteer experts from the biological recording community in Britain contributed information to the GB-NNSIP and many continue to do so. This highlights the importance of biological recording in general and the need to improve and enhance flow of biological information, including that of NNS, through emerging on-line systems such as iRecord (http://www.brc.ac.uk/irecord/) and the NBN Gateway. The contribution that volunteers provide in enhancing understanding of biological invasions cannot be overstated.

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