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The role of biological records in understanding invasions

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Running title: Biological records and invasions

Abstract

The process of invasion and the desire to predict the invasiveness (and associated impacts) of new arrivals has been a focus of attention for ecologists over centuries. The volunteer recording community has made unique and inspiring contributions to our understanding of invasion biology within Britain. Indeed information on non-native species (NNS) compiled within the GB Non-Native Species Information Portal (GB-NNSIP) would not have been possible without the involvement of volunteer experts from across Britain. Here we review examples of ways in which biological records have informed invasion biology. We specifically examine NNS information available within the GB-NNSIP to describe patterns in the arrival and establishment of NNS providing an overview of habitat associations of NNS in terrestrial, marine and freshwater environments.

Monitoring and surveillance of the subset of NNS that are considered to be adversely affecting biodiversity, society or the economy, termed invasive non-native species (INNS), is critical for early warning and rapid response. Volunteers are major contributors to monitoring and surveillance of INNS and not only provide records from across Britain but also underpin the system of verification necessary to confirm the identification of sightings. Here we describe the so-called "alert system" which links volunteer experts with the wider recording community to provide early warning of INNS occurrence.

We highlight the need to increase understanding of community and ecosystem-level effects of invasions and particularly understanding of ecological resilience. Detailed field observations, through biological recording, will provide the spatial, temporal and taxonomic breadth required for such research. The role of the volunteer recording community in contributing to the understanding of invasion biology has been invaluable and it is clear that their expertise and commitment will continue to be so.

Keywords

Invasion biology, biological recording, citizen science, habitat, impact, early warning, surveillance

Introduction

Non-native species (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 (McKinney and Lockwood, 1999; Smart et al., 2006; Vila et al., 2011). The Millennium Ecosystem Assessment (Anonymous, 2005) ranked invasive non-native species (INNS), alongside climate change, habitat destruction, pollution and overexploitation, as one of the main drivers of biodiversity loss globally. The recent dramatic increase in the rate of movement of species from their native geographic regions to new regions, in which they are considered non-native, aligns with increases in globalisation and associated rises in transportation by humans (Hulme, 2009).

The process of invasion and the desire to predict the invasiveness (and associated impacts) of new arrivals has been a focus of attention for ecologists over centuries (Elton, 1958). Indeed Charles Darwin evoked the “Naturalisation Hypothesis or Conundrum” (Darwin, 1859) predicting the importance of phylogenetic relatedness in determining invasiveness such that non-native species with close relatives in the invaded range will be less invasive than those which are only distantly related to species within the recipient habitats (Daehler, 2001; Jiang et al., 2010; Thuiller et al., 2010). Such traits-based approaches continue to fascinate ecologists and provide opportunities for exploring invasions.

Recent research recognises the inherent complexity of ecological systems and the influence of the evolutionary history of the interactions between species within a population in determining invasion success of new arrivals (Thuiller et al., 2010). Furthermore, the wider community context is also likely to play an important role in the invasion process (Shea and Chesson, 2002). The recently proposed unified framework for biological invasions reconciles and integrates characteristics across a range of established invasion frameworks and eloquently outlines the invasion process and specifically the stages and barriers to invasion from transport and introduction to establishment and spread (Blackburn et al., 2011). The volunteer recording community have made unique and inspiring contributions to our understanding of invasion biology within Britain.

GB Non-Native Species Information Portal: underpinning understanding

The GB Non-Native Species Information Portal (GB-NNSIP) is an on-line information system (www.nonnativespecies.org), involving a network of people including the volunteer recording schemes and societies alongside the Biological Records Centre (BRC) and other organisations engaged in sharing information on NNS (Roy et al., 2014c). The GB-NNSIP covers species within England, Scotland and Wales (hereafter referred to as "Britain") and comprises a register of NNS, together with supporting information including country of origin, arrival pathway, establishment status, occurrence within habitats, date of first record, human impact and environmental impact. The GB-NNSIP is being updated at least annually and 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. The role of volunteers, primarily through the recording schemes and societies, in providing both information on species and occurrence data, has been invaluable. Indeed compiling the information within the GB-NNSIP would not have been possible without the contributions of volunteer experts from across Britain.

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) prioritising those species considered to be adversely affecting biodiversity, society or the economy which are termed invasive non-native species (INNS). Early warning, prevention and control measures for INNS rely on information such as identity, associated biology and distribution (McGeoch et al., 2012). Here we have examined NNS information available within the GB-NNSIP to describe patterns in the arrival, establishment and spread of non-native species within Britain.

Arrival

The arrival of a species within a new region is dependent on successful transport and introduction but survival and reproduction is essential for the species to become established (Blackburn et al., 2011). The mechanism of arrival can be difficult to determine (Eversham and Arnold, 1992). Recent advances have been made in harmonising the terminology used to describe pathways and information within the GB-NNSIP has been instrumental to these developments (CBD, 2014). Over the coming years it will be essential to prioritise research on pathways of arrival to inform strategies for preventing future INNS incursions. It is also necessary to understand the origins of NNS. Historically a large proportion of the NNS arriving in Britain were native within Europe indicative of the close transport and trade links throughout history (Preston et al., 2004). However, there has been a shift in the countries of origin of the NNS arriving within Britain which align with an increase in trade and travel from regions beyond Europe (Figure 2). Recently there has been a particular increase in the number of species arriving from temperate Asia; globalisation has facilitated and intensified the intentional and unintentional introduction of NNS (Meyerson and Mooney, 2007).

Establishment

There has been a dramatic increase in the number of species arriving and becoming established (founding reproducing populations) within Britain over the last 400 years and there is no indication of this trend slowing (Figure 2). Indeed since 1950 there have been 10.5 additional NNS arriving and establishing per year in contrast to 0.9 additional NNS per year from 1600-1799. The number of established NNS deemed to have a negative ecological or socio-economic impact (INNS) is also increasing with 1.1 of the new species per year causing an impact since 2000. There are more than 3,000 species listed within the GB-NNSIP but only 1919 are considered to be established within Britain. Plant species dominate within the GB-NNSIP; the 1,919 established NNS comprise 1,494 established non-native plants, 420 established non-native animals and 5 other species. The escalation in the rate of new arrivals is not unique to Britain and has been reported across Europe (Pyšek et al., 2010) and, indeed, globally (Meyerson and Mooney, 2007) and is widely attributed to an increase in trade and transport in recent decades (Hulme, 2009).

Spread

The invasibility of communities, habitats and ecosystems has been the focus of invasion biology research for decades (Lonsdale, 1999; Richardson and Pyšek, 2006). However, it is recognised that invasion of a region by a non-native species involves complex ecological processes driven by traits of both the invader and the invaded community (Shea and Chesson, 2002). Indeed biological invasions represent an exciting opportunity to contribute to the understanding of community ecology (Shea and Chesson, 2002). Biological records have underpinned the study of establishment and spread of non-native species within Britain (Botham et al., 2009; Eversham and Arnold, 1992; Manchester and Bullock, 2000). Non-native species occur across the British landscape (Figure 3) but a greater number of non-native species are present within England compared to either Scotland or Wales. The high number of non-native species within the south-east of England is almost certainly related to climatic factors coupled with prevalence of urban habitats and high population density; there are particularly high numbers of non-native species within urban localities.

The association of non-native species with urban habitats is widely recognised (Alston and Richardson, 2006; Botham et al., 2009; Pyšek, 1998). Indeed urban localities represent highly disturbed habitats which are also typified by high fertility and so highly suitable for ruderal species (Botham et al., 2009). Furthermore, the number of non-native species introduced into urban settlements, particularly in gardens and parks, is high and so constitutes considerable propagule pressure (Botham et al., 2009; Holle and Simberloff, 2005). Research using botanical data collected by the Botanical Society of Britain and Ireland confirms the strong association of non-native plants with urban habitats but suggests that there has been a reduction in the urban association of archaeophytes in recent decades (Botham et al., 2009). The GB-NNSIP includes information on the habitats occupied by non-native species within Britain, much of which comes from the detailed observations of the volunteer recording community. A qualitative and descriptive review of the habitat associations represented within the GB-NNSIP provides intriguing insights which stimulate the development of hypotheses for empirical testing (Figures 4, 5 and 6). The botanical information is particularly comprehensive within the GB-NNSIP and exploring the habitat associations of non-native plants in terrestrial environments against date of first record highlights changes in patterns (Figure 4I and 4II). The strong association with urban environments (EUNIS category J) is apparent and the proportion of recent arrivals within urban environments is higher than for historic invasions. Interestingly there are no clear patterns between the habitat associations of the invasive non-native plants and date of first record although association with grasslands (EUNIS category E) is strong for both non-native and invasive non-native species of plants. Previous research has highlighted the importance of fertile grasslands as recipient habitats for non-native plants, particularly disturbed and fertile components of these habitats (Maskell et al., 2006).

Habitat associations between non-native species, beyond the plants, and in non-terrestrial environments have so far received limited attention. However, a few patterns emerge from examining the habitat associations of non-native animals against date of first record which are worthy of description (Figure 4 III and 4 IV; Figures 5 and 6). Interestingly, urban habitats do not appear to be the major recipient of non-native animals and it is possible that this reflects both the capacity of animals to disperse and spread rapidly, and the range of pathways through which they arrive. There appears to be an increase in the proportion of non-native animals, particularly those considered to be invasive, associated with marine habitats (EUNIS category A). This could reflect increased intensity of recording within these habitats in recent years but it would be valuable to investigate further. Inland waters (EUNIS category C) seem to be increasingly under pressure from new invasive arrivals. The number of freshwater invertebrates arriving from the Ponto-Caspian region is a growing concern and it has been stated that Britain might be on the brink of "Ponto-Caspian invasional meltdown" (Gallardo and Aldridge, 2014). The recent arrival of the quagga mussel, *Dreissena rostriformis bugensis*, is the latest of a number of new arrivals to freshwater habitats. Recreational use of water bodies for fishing and boating are considered to be major pathways of introduction for NNS and highlight the importance of biosecurity and raising awareness through campaigns such as "Check, Clean, Dry" (Anderson et al., 2014).

Clearly there is considerable scope for research on habitat associations of non-native species. It would be particularly interesting to explore the interactions between habitat fragmentation and invasion (Hoffmeister et al., 2005). While it is apparent that urban and disturbed habitats are particular foci for invasion, it is critical to consider habitats as a heterogeneous matrix on a landscape scale. For some species habitat fragmentation might limit spread while for others the disturbance created through fragmentation might facilitate spread. It would be interesting to explore this through modelling approaches using biological records alongside life-history traits and land cover data. Investigating the vulnerability of protected areas to invasion by considering their connectivity to hot spots of invasion could provide useful insights for conservation management (Thomas et al. THIS SI).

Horizon scanning and early warning

Horizon-scanning to prioritise the threat posed by potentially new INNS which are not yet established within a region is seen as an essential component of INNS management (Copp et al., 2007; Shine et al., 2010). There have been a number of horizon-scanning exercises, based on information from the literature coupled with risk assessment frameworks or modelling approaches, for INNS in Britain involving discrete taxonomic groups, such as plants (Thomas, 2010) or animals (Parrott et al., 2009), or distinct environments such as freshwater (Gallardo and Aldridge, 2013). More recently a horizon scanning approach was developed that combined the structured approaches of literature review and risk assessment (Branquart et al., 2009) with dynamic consensus methods (Sutherland et al., 2011) to deliver a ranked list of species that are likely to arrive, become established and have an impact on native biodiversity within the next ten years (Roy et al., 2014b).

Breadth of information across taxonomic groups and environments is essential for horizon scanning and the volunteer recording community in the UK provide an excellent example of "wisdom from the crowd" (Galton, 1907; Lorenz et al., 2011; Sutherland and Woodroof, 2009) whereby the complementary expertise within this community ensures the required collective knowledge (Roy et al., 2014b). The list of non-native species on the resulting horizon scanning list included a "top ten" and four of these species (*D. rostriformis bugensis* (Mollusca: Bivalvia), *Hemigrapsus sanguineus* (Crustacea: Brachyura), *Hemigrapsus takanoi* (Crustacea: Brachyura), *Procyon lotor* (Mammalia: Carnivora) were reported within six months following publication. The quagga mussel, *Dreissena rostriformis bugensis*, was unanimously agreed to constitute the highest risk of all the species considered (Roy et al., 2014b) and in October 2014 was reported as established in a reservoir in Surrey, UK (http://www.nonnativespecies.org/alerts/index.cfm). The quagga mussel is an ecosystem engineer and has a history of becoming the dominant benthic organism within invaded systems (Sousa et al., 2009) with a wide range of direct and indirect impacts (Cross et al., 2010; MacIsaac, 1996; Schloesser et al., 2006; Sousa et al., 2009; Ward and Ricciardi, 2007).

Monitoring and surveillance

The volunteer recording community are major contributors to monitoring and surveillance of non-native species. It is essential that the species prioritised through risk assessment and horizon scanning are publicised to raise awareness and encourage reporting. Volunteers not only provide records from across Britain but also underpin the system of verification necessary to confirm the identification of sightings. The so-called "alert system" (Figure 7) promoted through the Non-Native Species Secretariat website (www.nonnativespecies.org) links to iRecord (www.brc.ac.uk/irecord), a website for managing wildlife records, and enables rapid reporting and verification of species considered as a priority for action. On-line capability enables people to register for notification of selected species of interest and ensures rapid data flow to support effective decision-making.

The alert system includes species identified as high-risk through horizon scanning (Roy et al., 2014b). The Asian hornet, *Vespa velutina*, is one such species. This species arrived in France in 2005 and spread rapidly across the country and into Spain in 2010 (Perrard et al., 2009; Villemant et al., 2011). It is a predator of pollinating insects and so poses a threat to native biodiversity (Perrard et al., 2009; Villemant et al., 2011). There has been considerable publicity through the media on this species and also targeted promotion to the beekeeping community. Consequently many people have sent sightings of concern through iRecord (374 suspect Asian hornet records) and a designated e-mail account for alert species (1,162 suspected Asian hornet records received; Figure 8). To date there have been no confirmed sightings of the Asian hornet in Britain; most of the records have been identified as European hornets, *Vespa crabro*. However, the high number of records received through the e-mail alert (Figure 8) system is encouraging and highlights the role of volunteers, expert and non-expert, in surveillance and monitoring of non-native species. The peaks in numbers of records received (September 2013 and May 2014) coincide with reports in the national press and demonstrate the importance of effective communication to raise awareness.

Understanding impacts

INNS are widely stated to be one of the major drivers of biodiversity loss (Millenium Ecosystem Assessment, 2005), however there is a lack of empirical evidence for the impacts of many non-native species which are considered to be invasive. There is a clear need to increase understanding of the effects of non-native species on other wildlife to inform risk assessment and prioritisation of management strategies. However, invasions also provide opportunities to gain unique insights to advance understanding of processes within community ecology. It is essential that impacts are quantified using experimental approaches alongside field observations. Biological recording could play a critical role in the latter, however currently the interactions between species are rarely captured within biological records. There is considerable potential to encourage recorders to include such additional information and many naturalists document interactions as comments alongside the standard information (what, when, who and where) that constitutes a record.

Biological records collated through the UK Ladybird Survey (formerly the Coccinellidae Recording Scheme) have been instrumental in providing evidence that the harlequin ladybird, *Harmonia axyridis*, is contributing to the declines in distribution of native ladybirds (Brown et al., 2011; Roy et al., 2012). Linking this research with life-history traits, climate and land cover data highlights the role of *H. axyridis* coupled with urbanisation in causing local extinctions of native ladybirds (Comont et al., 2013; Comont et al., 2012). It will be intriguing to explore the extent to which such changes in ladybird community structure affect the ecological resilience of the network of aphidophagous insects (Roy and Lawson-Handley, 2012). A high degree of biodiversity is widely considered to enhance the resilience of ecosystems to invasion (Elmqvist et al., 2003) but few studies within invasion biology have included ecosystem-scale approaches to underpin this intuitive theory. Biological records have the potential to contribute to the understanding of ecological resilience and specifically to the assessment of the state of ecosystems following perturbation. The development of methods for constructing ecological networks from biological records is an exciting prospect and worthy of prioritisation going forward.

Conclusions

The contributions made by volunteers to our understanding of invasion biology have been invaluable. The GB-NNSIP (alongside the European inventory, DAISIE) is possibly one of the most comprehensive regional databases of information on non-native species worldwide. The wealth of information on British wildlife, both native and non-native, is inspiring, and the large-scale and long-term datasets comprising biological records compiled and collated by the volunteer recording community provide a unique resource for addressing questions of major ecological importance (Roy et al., 2014a). The information available through publications on life-history traits, such as PLANTATT (Hill et al., 2004), provide additional rich resources to inform analyses.

The development of databases of life-history traits for other taxonomic and functional groups should be prioritised. Integrating detailed traits-based information with biological records across taxonomic groups and including relevant interactions will enhance understanding of biological invasions immeasurably.

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442

Figure 1. Origins of established non-native species (NNS) and the date of first record in Great Britain. The place of origin is shown at continent level, some species have a native range that covers multiple continents. The number of NNS indicates the total number of NNS within a native range including that continent and a GB first record in that date range. The innermost circle denotes the date range 1500-1549 and each further concentric circle refers to a 50 year time period with the outermost circle representing the most recent date range 1950-1999. The colour of the continent relates to the most recent time period displayed (1950-1999).

Figure 2. Number of established non-native species (black line) and the number that are designated as having a negative ecological impact, so called invasive non-native species (grey line), against date of first record.

Figure 3. Richness of invasive non-native species (number of species per 10km square).

Figure 4. Number of non-native and invasive non-native plants (I and II respectively) and non-native and invasive non-native animals (III and IV respectively) associated with terrestrial habitats against date of first record. Habitat information is included with the GB-NNSIP as EUNIS categories (www.eunis.eea.europa.eu/habitats.jsp).

Figure 5. Number of non-native and invasive non-native plants (I and II respectively) and non-native and invasive non-native animals (III and IV respectively) associated with marine habitats against date of first record. Habitat information is included with the GB-NNSIP as EUNIS categories (www.eunis.eea.europa.eu/habitats.jsp).

Figure 6. Number of non-native and invasive non-native plants (I and II respectively) and non-native and invasive non-native animals (III and IV respectively) associated with freshwater habitats against date of first record. Habitat information is included with the GB-NNSIP as EUNIS categories (www.eunis.eea.europa.eu/habitats.jsp).

Figure 7. Outline of the "alert system" in which a biological record is received either by e-mail or within iRecord. The record is checked by an expert and either confirmed (verified) or not. The database is updated and stakeholders are informed if the record is verified so that they can take appropriate action. In some cases stakeholders are notified prior to verification if rapid response is necessary.

Figure 8. Number of reports of suspected *Vespa velutina* received through the designated e-mail account for the "alert system". Date range 2011 to 2014. Note that there have been no confirmed sightings of *V. velutina* within Britain.

Supporting information: List of Invasive Non-Native Species considered to adversely affect biodiversity in Britain

Environment	Common name	Scientific name
Marine	**a bryozoans**	*Schizoporella japonica*
Marine	**a bryozoans**	*Tricellaria inopinata*
Marine	**a bryozoans**	*Watersipora subatra*
Marine	**a coelenterate**	*Cordylophora caspia*
Marine	**a crustacean**	*Dyspanopeus sayi*
Marine	**a mollusc**	*Ensis directus*
Marine	**a mollusc**	*Mytilopsis leucophaeata*
Marine	**a tunicate**	*Botrylloides diegensis*
Marine	**a tunicate**	*Botrylloides violaceus*
Marine	**a tunicate**	*Corella eumyota*
Marine	**a tunicate**	*Didemnum vexillum*
Marine	**Algae**	*Bonnemaisonia hamifera*
Marine	**Algae**	*Grateloupia turuturu*
Marine	**Algae**	*Heterosiphonia japonica*
Marine	**Algae**	*Neosiphonia harveyi*
Marine	**American sting winkle**	*Urosalpinx cinerea*
Marine	**an acorn barnacle**	*Austrominius modestus*
Marine	**an amphipod**	*Monocorophium sextonae*
Marine	**an amphipod**	*Gammarus tigrinus*
Marine	**an annelid**	*Ficopomatus enigmaticus*
Marine	**an annelid**	*Hydroides elegans*
Marine	**an annelid**	*Hydroides ezoensis*
Marine	**Chinese Mitten Crab**	*Eriocheir sinensis*
Marine	**Compass Sea Squirt**	*Asterocarpa humilis*
Marine	**Dwarf Crab**	*Rhithropanopeus harrisii*
Marine	**Green sea fingers**	*Codium fragile subsp.fragile*
Marine	**Harpoon Weed (Algae)**	*Asparagopsis armata*
Marine	**Japanese kelp, wakame**	*Undaria pinnatifida*
Marine	**Japanese Skeleton Shrimp**	*Caprella mutica*
Marine	**Leathery Sea Squirt**	*Styela clava*
Marine	**Pacific Oyster**	*Crassostrea gigas*
Marine	**slipper limpet**	*Crepidula fornicata*
Marine	**swim-bladder nematode**	*Anguillicoloides crassus*
Marine	**Wire Weed**	*Sargassum muticum*
Freshwater	**a mollusc**	*Corbicula fluminea*
Freshwater	**a polychaete**	*Hypania invalida*
Freshwater	**African clawed frog**	*Xenopus laevis*
Freshwater	**American bullfrog**	*Lithobates catesbeianus*
Freshwater	**Bloody-red mysid**	*Hemimysis anomala*
Freshwater	**Canadian Waterweed**	*Elodea canadensis*
Freshwater	**Curly Waterweed**	*Lagarosiphon major*
Freshwater	**Demon shrimp**	*Dikerogammarus haemobaphes*

Freshwater	**Duck-potato**	*Sagittaria latifolia*
Freshwater	**Floating pennywort**	*Hydrocotyle ranunculoides*
Freshwater	**Goldfish**	*Carassius auratus*
Freshwater	**Italian Alpine Newt**	*Icthyosaura alpestris*
Freshwater	**Italian crested newt**	*Triturus carniflex*
Freshwater	**Jenkins' spire snail**	*Potamopyrgus antipodarum*
Freshwater	**Killer shrimp**	*Dikerogammarus villosus*
Freshwater	**Large-flowered Waterweed**	*Egeria densa*
Freshwater	**Least Duckweed**	*Lemna minuta*
Freshwater	**Marsh frog**	*Pelophylax ridibundus*
Freshwater	**New Zealand pigmyweed**	*Crassula helmsii*
Freshwater	**Northern River Crangonyctid**	*Crangonyx pseudogracilis*
Freshwater	**Nuttall's Waterweed**	*Elodea nuttallii*
Freshwater	**Parrot's Feather**	*Myriophyllum aquaticum*
Freshwater	**Pumpkinseed**	*Lepomis gibbosus*
Freshwater	**Quagga mussel**	*Dreissena bugensis*
Freshwater	**Rainbow trout**	*Oncorhynchus mykiss*
Freshwater	**Red swamp crayfish**	*Procambarus clarkii*
Freshwater	**Signal crayfish**	*Pacifastacus leniusculus*
Freshwater	**Spinycheek crayfish**	*Orconectes limosus*
Freshwater	**Sunbleak**	*Leucaspius delineatus*
Freshwater	**Topmouth gudgeon**	*Pseudorasbora parva*
Freshwater	**Turkish crayfish**	*Astacus leptodactylus*
Freshwater	**Uruguayan Hampshire-purslane**	*Ludwigia grandiflora*
Freshwater	**Virile crayfish**	*Orconectes virilis*
Freshwater	**Water Fern**	*Azolla filiculoides*
Freshwater	**Wels catfish**	*Siluris glanis*
Freshwater	**White river crayfish**	*Procambarus acutus*
Freshwater	**Zander**	*Sander lucioperca*
Freshwater	**Zebra mussel**	*Dreissena polymorpha*
Terrestrial	**a flatworm**	*Australoplana sanguinea*
Terrestrial	**a flatworm**	*Kontikia ventrolineata*
Terrestrial	**Aesculapian snake**	*Zamensis longissimus*
Terrestrial	**Alexanders**	*Smyrnium olusatrum*
Terrestrial	**American mink**	*Mustela vison*
Terrestrial	**American Skunk-cabbage**	*Lysichiton americanus*
Terrestrial	**an ant**	*Lasius neglectus*
Terrestrial	**Arrow Bamboo**	*Pseudosasa japonica*
Terrestrial	**Austrian Pin**	*Pinus nigra*
Terrestrial	**Bear's-breech**	*Acanthus mollis*
Terrestrial	**Berberis sawfly**	*Arge berberidis*
Terrestrial	**Bermuda-buttercup**	*Oxalis pes-caprae*
Terrestrial	**Biliary parasite**	*Pseudamphistomum truncatum*
Terrestrial	**Billard's Bridewort**	*Spiraea alba x douglasii = S. x billardii*

Terrestrial	**Black rat**	*Rattus rattus*
Terrestrial	**Black-bindweed**	*Fallopia convolvulus*
Terrestrial	**Bladder-senna**	*Colutea arborescens*
Terrestrial	**Blotched Monkey Flower**	*Mimulus luteus*
Terrestrial	**Bluebell**	*Hyacinthoides non-scripta x hispanica = H. x massartiana*
Terrestrial	**Brazilian Giant-rhubarb**	*Gunnera manicata*
Terrestrial	**Bridewort**	*Spiraea salicifolia*
Terrestrial	**Broad-leaved Bamboo**	*Sasa palmata*
Terrestrial	**Brown rat**	*Rattus norvegicus*
Terrestrial	**Buddleia**	*Buddleja davidii*
Terrestrial	**Canada Goose**	*Branta canadensis*
Terrestrial	**Canadian Goldenrod**	*Solidago canadensis*
Terrestrial	**Cherry Laurel**	*Prunus laurocerasus*
Terrestrial	**Common Michaelmas-daisy**	*Aster novi-belgii x lanceolatus = A. x salignus*
Terrestrial	**Comon Wall lizard**	*Podarcis muralis*
Terrestrial	**Confused Bridewort**	*Spiraea salicifolia x douglasii = S. x pseudosalicifolia*
Terrestrial	**Dump fly**	*Hydrotaea aenescens*
Terrestrial	**Dutch Rose**	*Rosa Hollandica*
Terrestrial	**Eagle Owl**	*Bubo bubo*
Terrestrial	**Eastern Gray Squirrel**	*Sciurus carolinensis*
Terrestrial	**Edible Dormouse**	*Glis glis*
Terrestrial	**Egyptian Goose**	*Alopochen aegyptiacus*
Terrestrial	**Entire-leaved Cotoneaster**	*Cotoneaster integrifolius*
Terrestrial	**European rabbit**	*Oryctolagus cuniculus*
Terrestrial	**Evergreen Oak**	*Quercus ilex*
Terrestrial	**Fallow Deer**	*Dama dama*
Terrestrial	**False-acacia**	*Robinia pseudoacacia*
Terrestrial	**Feral Cat**	*Felis catus*
Terrestrial	**Feral Goat**	*Capra hircus*
Terrestrial	**Ferret**	*Mustela furo*
Terrestrial	**Few-flowered Garlic**	*Allium paradoxum*
Terrestrial	**Garden Lady's-mantle**	*Alchemilla mollis*
Terrestrial	**Giant Hogweed**	*Heracleum mantegazzianum*
Terrestrial	**Giant Knotweed**	*Fallopia sachalinensis*
Terrestrial	**Giant-rhubarb**	*Gunnera tinctoria*
Terrestrial	**Great Brome**	*Anisantha diandra*
Terrestrial	**Green Alkanet**	*Pentaglottis sempervirens*
Terrestrial	**Hairy Bamboo**	*Sasaella ramosa*
Terrestrial	**Harlequin Ladybird**	*Harmonia axyridis*
Terrestrial	**Heath Star Moss**	*Campylopus introflexus*
Terrestrial	**Himalayan Balsam**	*Impatiens glandulifera*
Terrestrial	**Himalayan Cotoneaster**	*Cotoneaster simonsii*
Terrestrial	**Himalayan Knotweed**	*Persicaria wallichii*
Terrestrial	**Horse chestnut scale**	*Pulvinaria regalis*

Terrestrial	**Hottentot-fig**	*Carpobrotus edulis*
Terrestrial	**House mouse**	*Mus domesticus*
Terrestrial	**Japanese Knotweed**	*Fallopia japonica*
Terrestrial	**Japanese Rose**	*Rosa rugosa*
Terrestrial	**Juneberry**	*Amelanchier lamarckii*
Terrestrial	**Late Michaelmas-daisy**	*Aster laevis x novi-belgii = A. x versicolor*
Terrestrial	**Lesser Knotweed**	*Persicaria campanulata*
Terrestrial	**Lesser Periwinkle**	*Vinca minor*
Terrestrial	**Mandarin duck**	*Aix galericulata*
Terrestrial	**Maritime Pine**	*Pinus pinaster*
Terrestrial	**Monk parakeet**	*Myiopsitta monachus*
Terrestrial	**Montbretia**	*Crocosmia aurea x pottsii (C. x crocosmiiflora)*
Terrestrial	**Narrow-leaved Michaelmas-daisy**	*Aster lanceolatus*
Terrestrial	**New Zealand Flatworm**	*Arthurdendyus triangulatus*
Terrestrial	**Oak Processionary**	*Thaumetopoea processionea*
Terrestrial	**Pheasant**	*Phasianus colchicus*
Terrestrial	**Pirri-pirri-bur**	*Acaena novae-zelandiae*
Terrestrial	**Pitcherplant**	*Sarracenia purpurea*
Terrestrial	**plant hybrid**	*Fallopia japonica x sachalinensis = F. x bohemica*
Terrestrial	**Portugal Laurel**	*Prunus lusitanica*
Terrestrial	**Potato aphid**	*Macrosiphum euphorbiae*
Terrestrial	**Purple Dewplant**	*Disphyma crassifolium*
Terrestrial	**Red-legged Partridge**	*Alectoris rufa*
Terrestrial	**Red-osier Dogwood**	*Cornus sericea*
Terrestrial	**Reeve's muntjac**	*Muntiacus reevesi*
Terrestrial	**Rhododendron**	*Rhododendron ponticum*
Terrestrial	**Rhododendron Leafhopper**	*Graphocephala fennahi*
Terrestrial	**Rose-ringed parakeet**	*Psittacula krameri*
Terrestrial	**Rosy Garlic**	*Allium roseum*
Terrestrial	**Ruddy duck**	*Oxyura jamaicensis*
Terrestrial	**Rum Cherry**	*Prunus serotina*
Terrestrial	**Russian-vine**	*Fallopia baldschuanica*
Terrestrial	**Shallon**	*Gaultheria shallon*
Terrestrial	**Sika**	*Cervus nippon*
Terrestrial	**Snowberry**	*Symphoricarpos albus*
Terrestrial	**Spartina planthopper**	*Prokelisia marginata*
Terrestrial	**Spiraea**	*Spiraea*
Terrestrial	**Steeple-bush**	*Spiraea douglasii*
Terrestrial	**Thorn-apple**	*Datura stramonium*
Terrestrial	**Tree-of-heaven**	*Ailanthus altissima*
Terrestrial	**Turkey Oak**	*Quercus cerris*
Terrestrial	**Virginia-creeper**	*Parthenocissus quinquefolia*
Terrestrial	**Wall Cotoneaster**	*Cotoneaster horizontalis*
Terrestrial	**Water Deer**	*Hydropotes inermis*
Terrestrial	**Western green lizard**	*Lacerta bilineata*

Terrestrial	**White Butterbur**	*Petasites albus*
Terrestrial	**Winter Heliotrope**	*Petasites fragrans*
Terrestrial	**Wireplant**	*Muehlenbeckia complexa*
Terrestrial	**Yellow archangel**	*Lamiastrum galeobdolon subsp. argentatum*

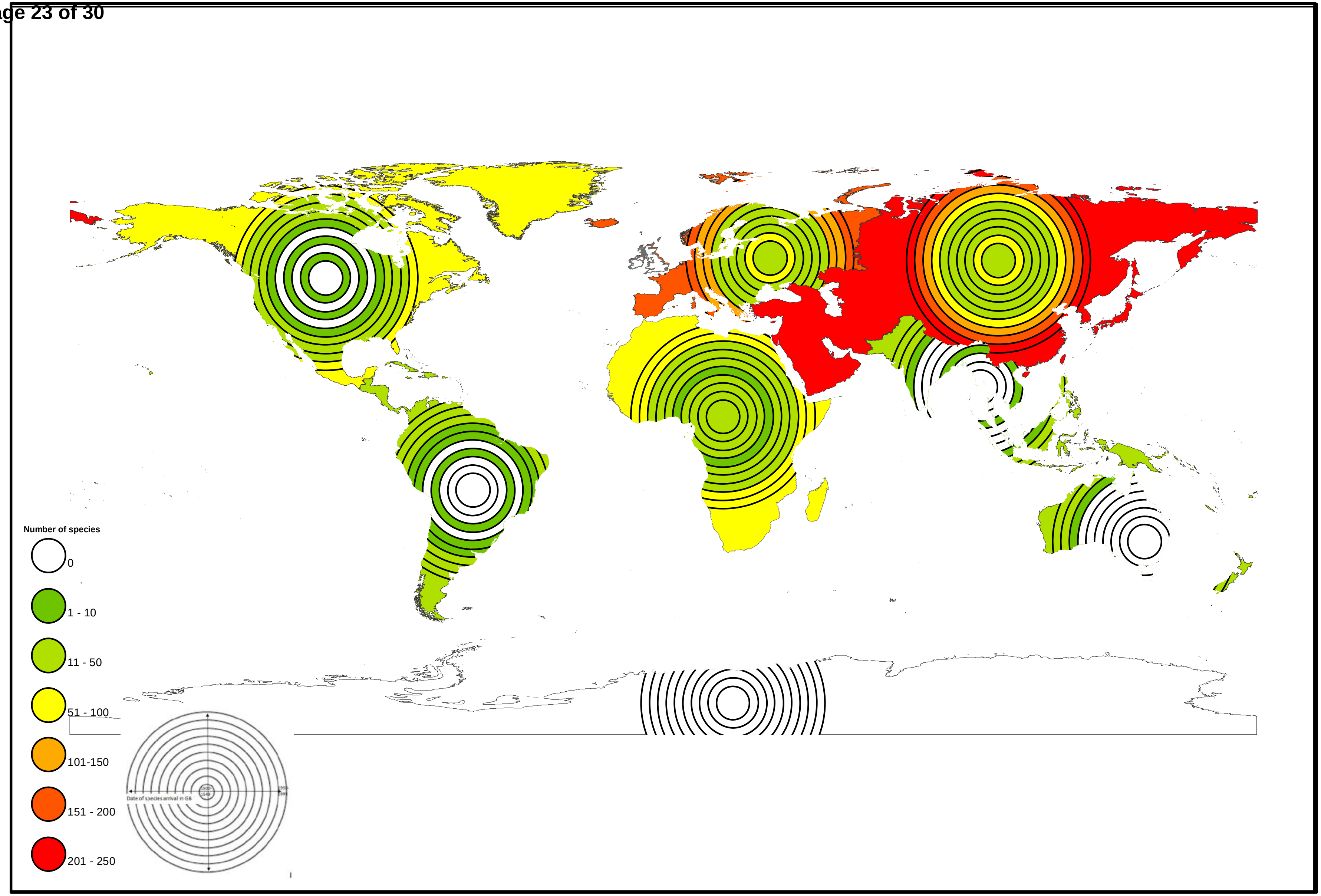
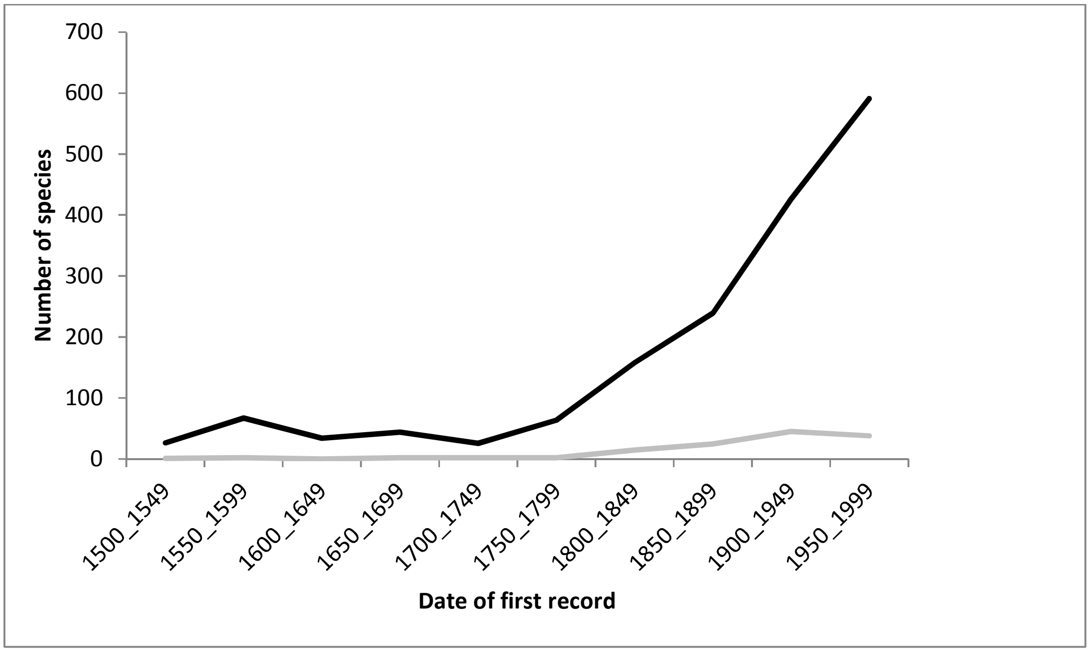


Figure 1. Origins of established non-native species (NNS) and the date of first record in Great Britain. The place of origin is shown at continent level, some species have a native range that covers multiple continents. The number of NNS indicates the total number of NNS within a native range including that continent and a GB first record in that date range. The innermost circle denotes the date range 1500-1549 and each further concentric circle refers to a 50 year time period with the outermost circle representing the most recent date range 1950-1999. The colour of the continent relates to the most recent time period displayed (1950-1999).

Figure 2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600
500
400
300
200
100
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Number of species
1500_1549
1550_1599
1600_1649
1650_1699
1700_1749
1750_1799
1800_1849
1850_1899
1900_1949
1950_1999
Date of first record

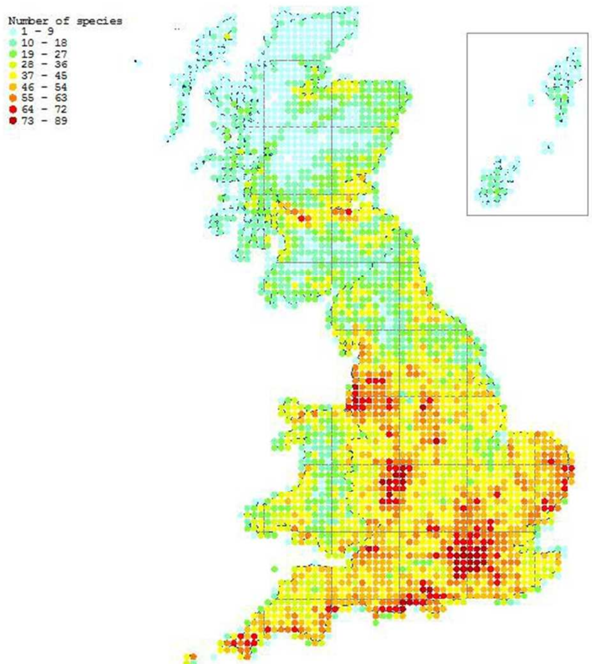

Figure 3. Richness of invasive non-native species (number of species per 10km square).
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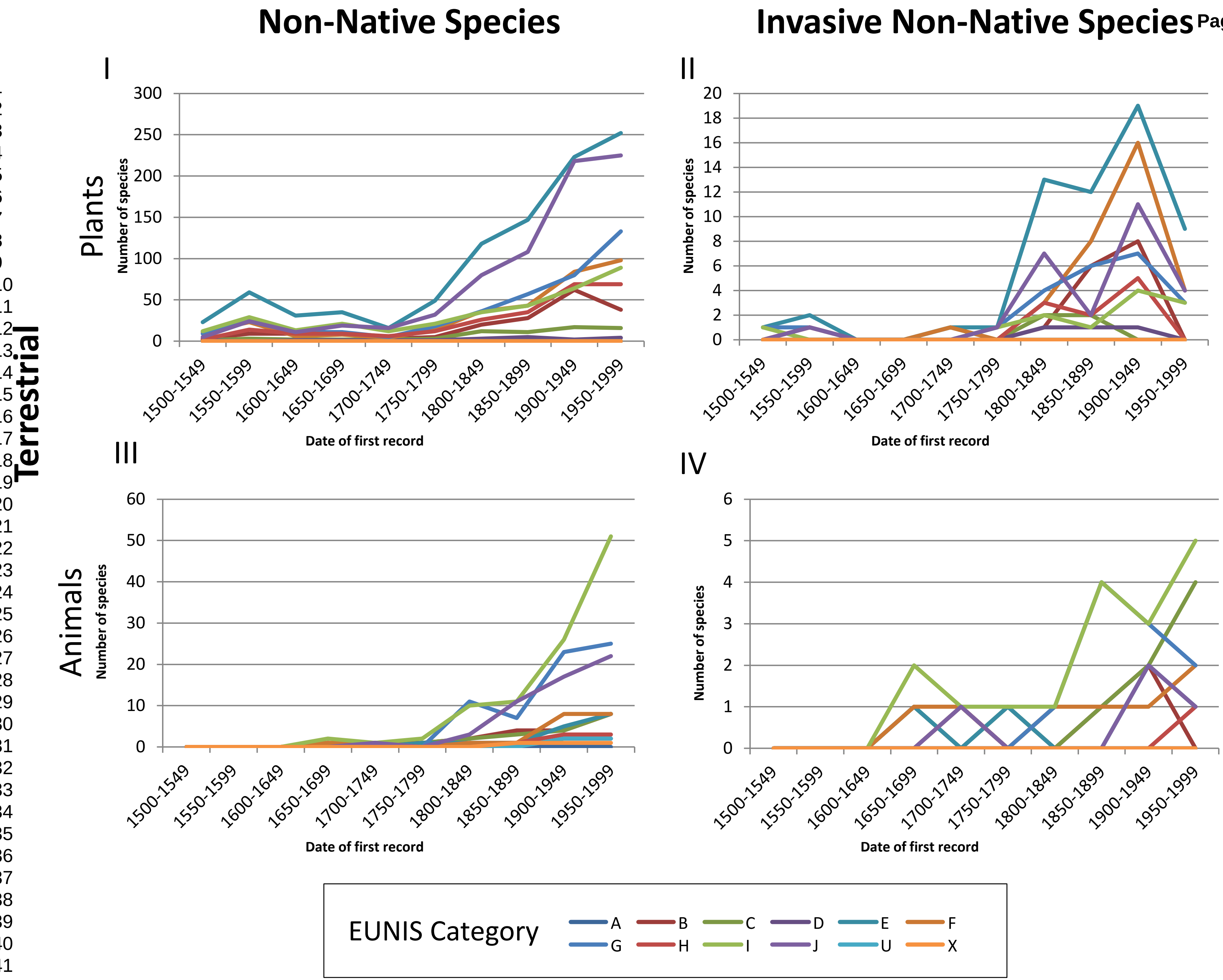
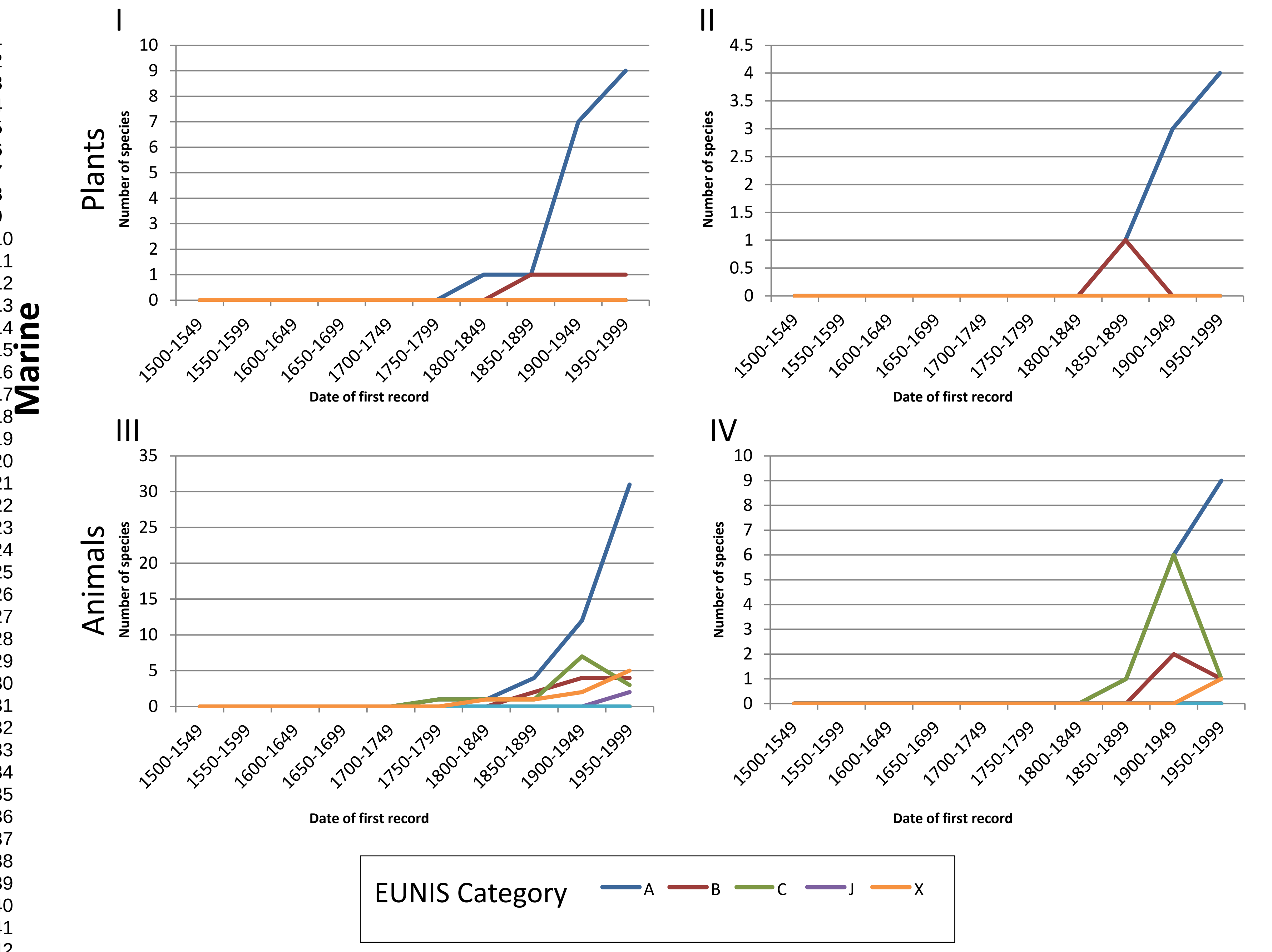
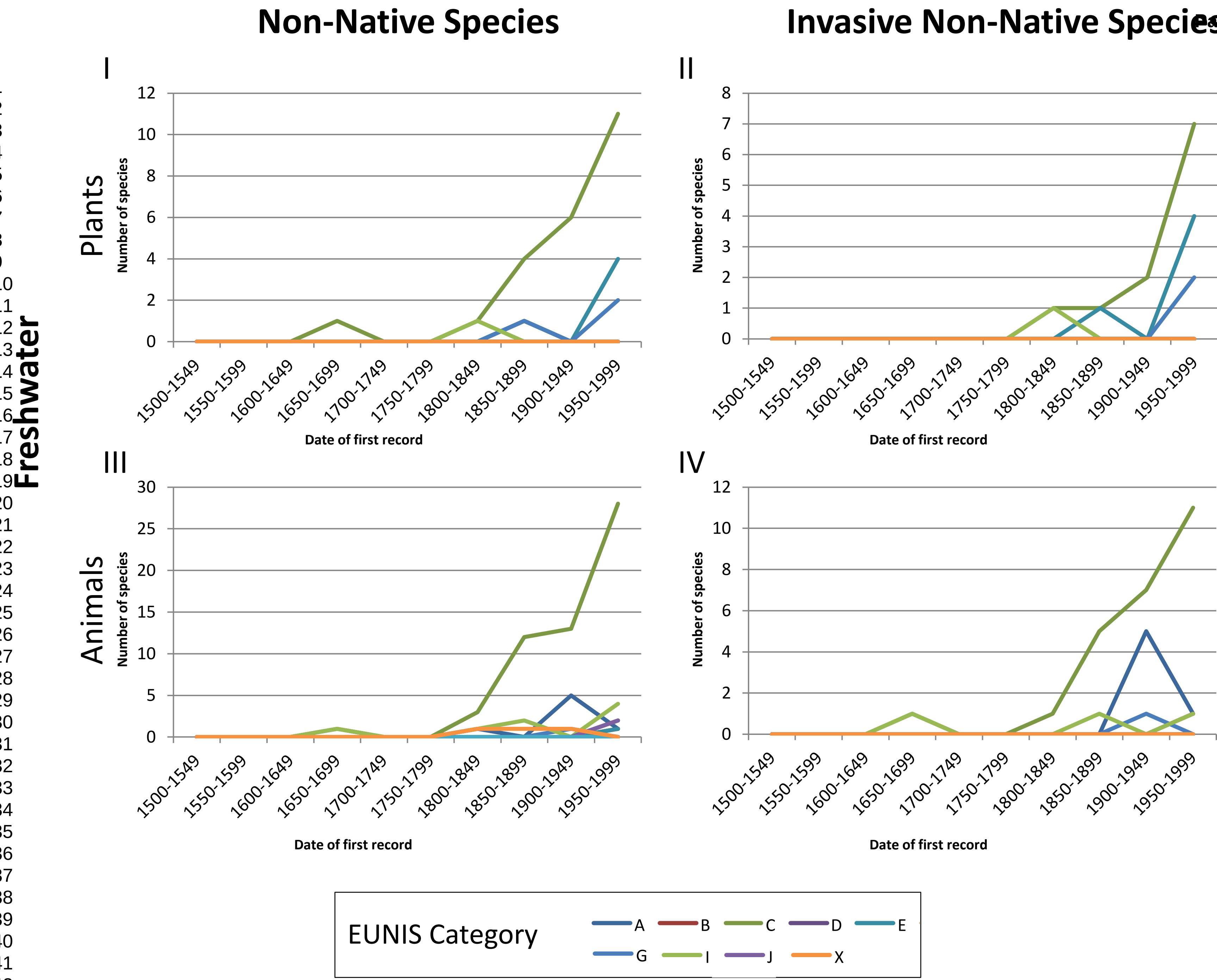

Non-Native Species
Invasive Non-Native Species
Terrestrial
Plants
Animals
I
II
III
IV
Number of species
Date of first record
1500-1549
1550-1599
1600-1649
1650-1699
1700-1749
1750-1799
1800-1849
1850-1899
1900-1949
1950-1999
EUNIS Category
A
B
C
D
E
F
G
H
I
J
U
X

Non-Native Species   Invasive Non-Native Species




Non-Native Species
Invasive Non-Native Species
Freshwater
I
II
III
IV
Plants
Animals
Number of species
Date of first record
1500-1549
1550-1599
1600-1649
1650-1699
1700-1749
1750-1799
1800-1849
1850-1899
1900-1949
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E
G
I
J
X

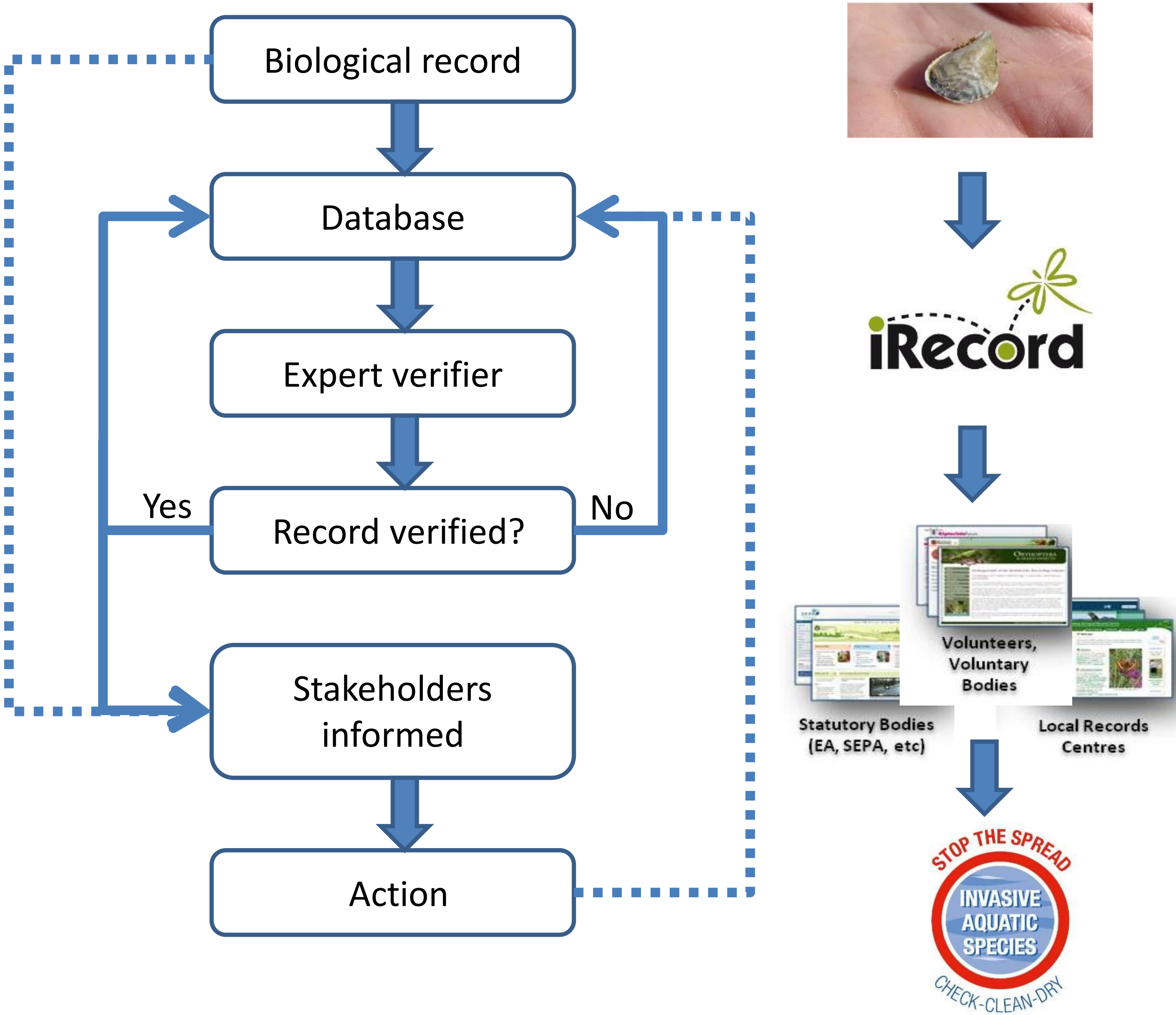
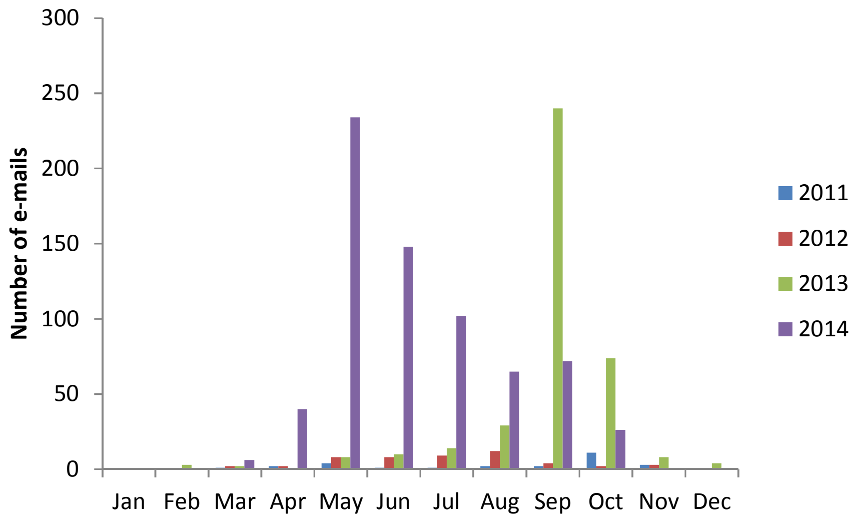

Biological record
Database
Expert verifier
Yes
Record verified?
No
Stakeholders informed
Action
iRecord
Volunteers, Voluntary Bodies
Statutory Bodies (EA, SEPA, etc)
Local Records Centres
STOP THE SPREAD
INVASIVE AQUATIC SPECIES
CHECK-CLEAN-DRY

Figure 8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Number of e-mails
Jan
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Mar
Apr
May
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Jul
Aug
Sep
Oct
Nov
Dec
2011
2012
2013
2014