Report

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Developing an indicator of the abundance, extent and impact of invasive non-native species

Final report

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Summary

This report describes an indicator of the abundance, extent and impact of invasive non-native species in Great Britain. The main ideas and options for the abundance indicator and for the impact indicator are considered. A third type of indicator, the annual rate of establishment of new non-native species, is outlined, with provisional data presented only for England.

Most of the options for the abundance indicator do not in fact measure abundance, but use either frequency in samples or frequency in recording scheme data as a substitute. An exception is the Breeding Bird Survey, for which numbers of individuals are counted. Several well-recorded groups of organisms have no non-native species (e.g. butterflies and lichens) or exceedingly few non-native species (macro-moths).

Datasets selected for the abundance indicator were the Breeding Bird Survey (birds and mammals), Countryside Survey (vascular plants), British Bryological Society data (bryophytes) and Marine Biological Society data (marine organisms). From samples of records in each species group, the non-native component was calculated as proportion of all species sampled. This provided a temporal trend in non-native proportions, which were calculated separately for England, Scotland and Wales. The GB trend was derived by combining the trends for each component country, weighted by the area of each. Finally, the overall trend was calculated as a weighted geometric mean of trends for each species group, converted to an index by dividing by a constant to start at 1 in the baseline year 1990. The weights applied were birds 20%, mammals 20%, vascular plants 30%, bryophytes 10% and marine organisms 20%. There were no suitable datasets from the freshwater environment.

No direct measure of impact could feasibly be calculated for all invasive species in Great Britain. As a substitute, an indicator based on the extent of occupation by invasive species was adopted. The methodology for the indicator was based on a scheme developed by the Belgian Forum on Invasive Species. First, a list of the most invasive species was compiled, using a simplified environmental impact assessment protocol to assign species to threat categories. Then the extent of each invasive species was scored for 1960, 1970, 1980, 1990, 2000 and 2007, on a 5-point scale ranging from 0 (absent) to 4 (present in more than half the territory). Extent scores were added to obtain the indicator.

Over the period 1990-2007, the mean indexed proportion of records of non-native species in samples of birds, mammals, plants and marine life rose by 23%. Except for mammals, the absolute proportion was still only about 1% of the total.

The assessment protocol assigned 49 species in Great Britain to the highest threat category. There were 3 marine plants, 16 marine animals, 4 freshwater plants, 8 freshwater animals, 8 terrestrial plants and 10 terrestrial animals. Over the period 1990-2007, the summed extent scores of these invasive non-native species rose by 40%. The increase of invasive species was particularly large in the freshwater and marine environments.

Although non-native species are a potential threat, they are still only a small proportion of the animals and plants to be found in most of the land area and coasts of Great Britain. Vertebrates stand out as the most invasive group.

For all groups of organisms reported here, England was the country most affected by non-native species. Scotland was the least affected. Wales was intermediate. In 2008, values of the impact indicator for the three countries were respectively 135, 73 and 95. Most species groups showed a trend over time towards an increasingly non-native biota.

If the indicator is to be developed further, the main priority is to include freshwater species in the abundance component. Because the list of invasive species depends on expert judgement, it needs to be reviewed and if necessary updated at regular intervals. Further analytical work is desirable, to improve the signal obtained from recording scheme data.

Introduction

Background and timescale of the project

Biological invasions by non-native species are recognized as a significant component of global environmental change. Under the CBD, the United Kingdom has an international obligation to address the impacts of invasive non-native species. Progress in fulfilling this obligation can be measured by an indicator. Defra, on behalf of the UK Government, invited tenders for a project to develop and present an indicator of the abundance, extent and impact of invasive non-native species. A consortium composed of the Centre for Ecology and Hydrology (CEH; lead partner), the British Trust for Ornithology, the Central Science Laboratory and the Marine Biological Association successfully tendered for the project.

Work began with a meeting of the project steering group on 13 August 2008. A consortium meeting was held at CEH Wallingford on 10 September. This identified the approach that was eventually adopted for the indicator of invasive non-native species and suggested datasets that could be used for the abundance component. A proposed methodology was presented to the UK Biodiversity Indicators Steering Group on 23 September and discussed more fully at a workshop for the project steering group, held at Nobel House on 25 November. The project was originally due to report on 8 December 2008. Sourcing and analysis of data took longer than had originally been hoped. Reporting was delayed by two months.

Objectives

The project as originally set up had two main objectives, namely to develop:

1. A measure of the abundance of non-native species in Great Britain and, where possible, the proportion which are invasive.
2. A measure of the impacts from the sub-set of non-native species that are invasive.

In addition to the two main indicators for GB, analogous indicators were required for England, Scotland and Wales.

Approach to the problem

The European Environment Agency (2007) proposed that the headline indicator on trends in invasive alien species in Europe should be composed of two parts. The first part was the cumulative number of alien species in Europe since 1900. The authors of the EEA report assert that there is a direct correlation between this number and the number of species that may become invasive. The second part of the headline indicator, which had not been calculated, was the cost of invasive alien species.

The EEA proposal, as well as others, were considered in the light of data availability. Given the short timescale of the project, the indicator could be calculated only if data could be interrogated quickly. Several guiding principles were set out at an early stage.

1. Crop species should not be included in those locations where they are cultivated; descendents of crops should be excluded unless they are part of a self-sustaining population.
2. Non-breeding species should be excluded unless they have effective clonal spread (which is for this purpose treated as reproduction).
3. Organisms that occur only in man-made, as opposed to semi-natural or natural habitats, should excluded or down-weighted.
4. A newly-arrived non-native should affect the indicator additively.
5. Indicators should reflect the current situation and not depend on what happened in the past.

Definition of non-native and invasive species

The definition of a non-native species in the Defra *Review of Non-native Species Policy* (Anon., 2003) is:-

- A species introduced (i.e. by human action) outside its natural past or present distribution.

Stated thus, the definition would include species that are native to certain parts of Britain but are outside their natural range in others - for example Welsh Poppy *Meconopsis cambrica* in Scotland, Scots Pine *Pinus sylvestris* in England and Sea-buckthorn *Hippophae rhamnoides* in Wales. For the indicator reported here, species that are native in any part of Britain are excluded. Also excluded are species such as Little Egret *Egretta garzetta* that have newly arrived by natural means.

The UK Government's *Invasive Non-native Species Framework Strategy* (UK Government, 2008) defines invasive non-native species thus:-

- Invasive non-native species are those whose introduction and/or spread threaten biological diversity or have other unforeseen impacts.

The GB indicator is required mainly for biodiversity reporting under the CBD. The definition used here therefore ignores other impacts such as effects on human health, harm to crops or damage to property.

The non-native biota of Britain

An enumeration of the non-native biota from a previous report to Defra (Hill *et al.*, 2008) provided a sound basis on which to build. If fungi, bacteria and protists are omitted, the number of non-native species in Britain is 3473 (Table 1). The grouping was adjusted from that used by Hill *et al.* (2008) to remove those vascular plants that lived in marine or freshwater environments to their proper categories. Amphibians were assigned to the freshwater category, on the grounds that they reproduce in freshwater. Insects were not reviewed; all have been treated as terrestrial animals, regardless of the medium in which they reproduce.

Methods

Possible measures of abundance

Several possible measures of abundance were considered, most of which are based on the proportion of non-native species (Table 2).

Group of species	*No.*	*Group of species*	*No.*
(a) Marine plants	**49**	**(d) Freshwater animals**	**99**
Chromista (Haptophyta)	2	Nematodes and leeches	7
Chrysomonada	1	Flatworms (Platyhelminthes)	14
Dinoflagellates (Dinophyta)	6	Crustaceans (Crustacea)	19
Flowering plants	4	Bryozoans (Ectoprocta)	1
Green algae (Chlorophyta)	2	Bony fishes (Osteichthyes)	39
Other algae (Bacillariophyta)	2	Amphibians (Amphibia)	10
Brown algae (Ochrophyta)	15	Cnidarians (Cnidaria)	1
Red algae (Rhodophyta)	17	Myxozoa	1
		Molluscs (Mollusca)	7
(b) Marine animals	**99**		
Segmented worms (Annelida)	17	**(e) Terrestrial plants**	**1851**
Crustaceans (Crustacea)	34	Flowering plants	1784
Bryozoans (Ectoprocta)	4	Gymnosperms (conifers)	39
Bony fishes (Osteichthyes)	2	Ferns (Pteridophyta)	10
Sea squirts (Tunicata)	8	Mosses and liverworts	18
Cnidarians (Cnidaria)	6		
Bryozoans (Ectoprocta)	1	**(f) Terrestrial animals**	**1353**
Goblet worms (Entoprocta)	2	Insects (Insecta)	882
Molluscs (Mollusca)	22	Other arthropods	75
Flatworms (Platyhelminthes)	1	Molluscs (Mollusca)	26
Sponges (Porifera)	2	Nematodes and Nemertea	5
		Flatworms (Platyhelminthes)	5
(c) Freshwater plants	**22**	Birds (Aves)	323
Flowering plants	21	Mammals (Mammalia)	31
Ferns (Pteridophyta)	1	Reptiles (Reptilia)	6

Table 1. Species groups included in the non-native biota of Great Britain for the purposes of the indicator; species that were introduced before 1500 are omitted from the counts

Type	*Measure of abundance*	*Comment*
1	Biomass proportion of non-native species	Data are not available for most groups; for birds one could multiply estimated density by individual mass
2	Population of non-native species as a proportion of the total	Unlikely to be available except for some vertebrates
3	Frequency as a proportion in fully-recorded units	Examples are the proportion of non-natives in quadrats in Countryside Survey or in the Rothamsted Insect Survey
4	Frequency as a proportion in incompletely recorded units	Such data typically arise from national recording schemes that do not cover the country in a single campaign
5	Geometric mean of population size for non-native species, converted to an index	Not a relative measure; geometric means are difficult to apply to rare species and newly-appearing species
6	Count of all breeding non-native species	A measure of diversity rather than abundance; it can be relativized by dividing by the total number of species

Table 2. Possible measures of abundance or frequency

The following points amplify the comments in Table 2.

1. The biomass proportion of non-native species is a measure that could in principle be applied without regard to taxonomic group. In practice, biomass data for most groups are not available and cannot readily be calculated. Furthermore, because of the pyramid of numbers, the biomass proportion would grossly favour plants over animals, even though animals may have a larger impact. Where population estimates are available, biomass can be calculated by multiplying by individual mass by the density of individuals per unit area.
2. The population of non-native species as a proportion of the total is not easily applied to plants, because many of them, including the famously invasive Japanese Knotweed *Fallopia japonica* are clonal. Indeed, Japanese Knotweed appears to be represented by a single clone in Britain and could therefore be counted as a single individual (Hollingsworth and Bailey, 2000). On the other hand, population estimates are available for some vertebrates, such as birds, so that the non-native proportion could be estimated.
3. Frequency as a proportion in fully-recorded units is available for plants in quadrats recorded by Countryside Survey (Countryside Survey Partnership, 2008). Likewise, it is available for well-recorded groups such as birds and butterflies at the hectad (10-km square) scale.
4. Frequency as a proportion in incompletely recorded units is all that is normally available from standard volunteer recording schemes. The character of volunteer data can fluctuate widely from year to year, depending on where recorders are most active at any one time. Such fluctuations can be partially corrected by giving a standard weighting to the contribution from different regions. A correction process of this type is described below.
5. Indicators based on geometric means are routinely used for reporting bird populations (British Trust for Ornithology, 2006). Noble, Newson & Gregory (2004) show how to set thresholds for new species arriving or others declining to very low numbers. There are severe difficulties in using this methodology directly for non-native species, because most have very small populations (Appendix 3).
6. A count of all breeding non-native species is in fact a measure of diversity rather than abundance. It is very close to the measure proposed by the EEA (2007), and differs only in subtracting the species that have died out. When the non-native total is calculated as a proportion of the total biota, it is analogous to a frequency proportion (i.e. a measure of type 3), where the unit sampled is the whole territory.

Choice of abundance indicator

The choice of abundance indicator was guided by the principles set out at the beginning but also depended crucially on the availability of data. No data for biomass or total population counts were readily available. Measures of type 3, based on fully-recorded units, were preferred if

possible, on the grounds that calculated proportions do not depend on the current activity of recorders. Measures of type 4, based on national recording schemes that may not make full species inventories, were used where these were suitable. Data held by the Biological Records Centre for most national recording schemes were unsuitable, either because the scheme records a group that has very few non-native species or because the data have poor temporal coverage. Although non-native insects appear as the largest group other than flowering plants in Table 1, butterflies and macro-moths, which have the most active recording schemes are remarkably lacking in non-native species. There are no non-native butterflies. Only one definitely non-native macro-moth has colonized Britain since 1900.

Taking these considerations into account, the abundance indicator was based on six major components (Table 3), comprising birds, mammals, vascular plants (in two types of location), bryophytes and marine organisms.

Species group	*Weight*	*Observation*	*Index calculated*
Birds (Breeding Bird Survey)	0.2	Counts of individuals per transect in 1-km square	Non-native count as proportion of total count
Mammals (Breeding Bird Survey)	0.2	Presence in Breeding Bird Survey (BBS) square	Mean occurrence frequency of 6 species of non-native mammals in those BBS squares with mammal records
Vascular plants, random plots (Countryside Survey)	0.15	Presence in random 14 m square quadrat ('X plot')	Frequency of non-native non-crop species as a proportion of all species recorded
Vascular plants, streamside plots (Countryside Survey)	0.15	Presence in quadrat by watercourse ('S' and 'W' plots)	Frequency of non-native non-crop species as a proportion of all species recorded
Bryophytes (BRC dataset)	0.1	Presence in hectad (10 km square)	Frequency of non-native hectad records as a proportion of all hectad records
Marine (Marine Life Information Network)	0.2	Record in database	Frequency of non-native records as a proportion of total

Table 3. Components of indicator of non-native abundance

In terms of the measures outlined in Table 2, that for birds approximates to a measure of type 2, but uses counts per transect rather than an estimate of population size. The measure for mammals is based on signs and sightings of Brown Rat, Grey Squirrel, American Mink, Reeves' Muntjac, Sika Deer and Chinese Water Deer. It is not divided by total mammal frequency. The reason for this is that most mammals, especially small mammals and (by day) bats, are cryptic, so that a reliable denominator of the total frequency of mammals is not available. The measure for vascular plants is a measure of type 3. Measures of type 4 are used for bryophytes and marine organisms. Measures of type 5 were not used directly, but the component indices were

combined by a weighted geometric mean. Specifically, let the six component indices be x_1, x_2, x_3, x_4, x_5 and x_6, with weightings (Table 3) w_1, w_2, w_3, w_4, w_5 and w_6. Then the abundance indicator A is defined as

$$A = \text{antilog}\,(w_1\log x_1 + w_2\log x_2 + w_3\log x_3 + w_4\log x_4 + w_5\log x_5 + w_6\log x_6).$$

For presentation purposes, the indicator and component indices are relativized to 1 in 1990, which is taken as the starting date.

Measures of impact

Several possible measures of impact were considered (Table 4). In the event, all but one of them, based on a simplified environmental impact assessment protocol developed by the Belgian Forum on Invasive Species (Branquart, 2007), proved to have insuperable difficulties. This was therefore selected.

Measure of impact	***Comment***
1. Damage to ecosystems or species	Very hard to quantify; few potentially damaging non-natives are listed as threats to BAP species
2. Impact of 20 most invasive species	Measure of impact difficult to define; likely to be too subjective
3. Extent of native species impacted upon by non-native species	Not easily measurable; the degree of impact is equally important
4. Cost of control measures	Data could not be updated regularly
5. Economic damage by species	Not relevant to biodiversity reporting
6. Modified Belgian system for rating environmental risk and species extent	Not strictly a measure of impact, but has practical advantages

Table 4. Possible measures of impact

The following points amplify the comments in the table.

1. Damage to ecosystems or species is exceedingly hard to quantify. For example, even if it were possible to measure the number of indigenous White-clawed Crayfish *Austropotamobius pallipes* that are absent as a result of the alien Signal Crayfish *Pacifastacus leniusculus*, this impact would need to be added to that of Rhododendron *Rhododendron ponticum* in obliterating moorland and replacing it by scrub. The units of measurement are simply not comparable, and incompatible units would be found across a wide range of impacts.
2. The impact of the twenty most invasive species suffers from the same problems as the more general measure of damage, considered above.
3. The extent of native species impacted upon by non-native species can in principle be measured. However, the degree of impact is important. For example, Sycamore *Acer pseudoplatanus* occurs widely in mixtures with native Ash *Fraxinus excelsior*, which is

reduced in quantity but almost never eliminated. This particular impact is therefore of much lower importance than that of the non-native crayfish.

4. The cost of control measures has the merit of using a common system of measurement, for example pounds sterling per year. However, the current cost of control measures does not necessarily reflect the damage being done to biodiversity. Indeed, some very damaging species may at present incur little or no cost because they cannot be controlled. For those species that are currently being controlled, control costs are mostly not collected.
5. Economic damage may not be relevant to biodiversity. At present, the highest control costs in Great Britain are for Japanese Knotweed *Fallopia japonica*, mainly because of economic damage in the urban environment.
6. The Belgian Forum on Invasive Species developed a system for scoring non-native species on simple numerical scales to measure environmental risk and species extent. This system is used here to define a measure of impact, based on invasiveness and extent of spread, described below.

Distinguishing invasive species

Invasive non-native species were selected by means of a short risk assessment, based on that developed by the Belgian. This was applied to the species signified as having high impact in an audit for English Nature (Hill *et al.*, 2005), as well as to the 100 European high-impact species identified by DAISIE (DAISIE, 2009).

The modified Belgian system starts by selecting the most invasive species. Each species is rated on a three-point scale in four categories:

1. Dispersal potential
2. Colonization of natural and semi-natural habitats
3. Adverse impacts on native species
4. Alteration of ecosystem function.

In each category, the species is rated on a scale of 1 (low risk) to 3 (high risk). Full definitions of these risk scales for each of the four categories are given in Appendix 1. For categories 3 and 4, the risk is divided into subcategories (Table 5). The contribution of each of these categories is calculated as the maximum risk score of its subcategories. Additional numerical scores are given to three other types of entry, namely DD (data deficient) scoring 0, unlikely (adverse impact unlikely) scoring 1, and likely (adverse impact likely) scoring 2.

In the example given, Sycamore scores 3 for dispersal potential and natural habitats. However, as pointed out above, it does not eliminate native species but mixes with them, and it does not produce any physical alteration that might not be produced by a native tree. On this basis it is seen as a potential risk but does not qualify as invasive.

Of 152 species scored in this way, 49 were in the highest threat category and therefore deemed to be invasive (Table 6). Many other species were

considered informally, but were omitted because they were clearly not in the highest threat category.

Major category	Marine invertebrate	Freshwater vertebrate	Terrestrial plant	Terrestrial vertebrate
Scientific name	*Eriocheir sinensis*	*Alytes obstetricans*	*Acer pseudo-platanus*	*Myocastor coypus*
English name	Chinese Mitten Crab	Midwife Toad	Sycamore	Coypu
1 Dispersal potential	3	1	3	3
2 Natural habitats	3	3	3	3
3.1 Predation, herbivory	3	1	-	2
3.2 Competition	3	1	2	unlikely
3.3 Disease vector	DD	2	1	likely
3.4 Genetic pollution	1	1	1	1
3 Max Species impact	**3**	**2**	**2**	**2**
4.1 Nutrient cycling	DD	1	1	3
4.2 Physical alteration	3	1	2	3
4.3 Successions	1	1	2	2
4.4 Food webs	2	2	2	likely
4 Max Ecosyst impact	**3**	**2**	**2**	**3**
Sum of 1 to 4	**12**	**8**	**10**	**11**
Risk category	**A**	**C**	**B**	**A**

Table 5. Calculation of risk category using the Modified Belgian system; species with combined score 11 or 12 are rated as invasive (A), those scoring 9 or 10 are rated as a potential risk (B) and those with lower scores are not thought likely to become invasive (C)

Extent values of invasive species summed for impact indicator

The original Belgian system of scoring species for extent used just three categories, together with zero for absence. For a larger territory such as Britain, this number was judged to be too small. Four extent categories were used for species present in the territory (Table 7). The indicator of non-native impact was then derived by summing extent values for those species that were deemed to be invasive.

Data

Breeding Bird Survey (birds and mammals)

The Breeding Bird Survey (BBS) http://www.bto.org/bbs/ is a line-transect survey based on randomly selected 1-km squares. Squares are chosen according to a stratified random design, with more squares in areas with more potential volunteers. Each BBS observer makes two early morning visits during the April–June survey period to count all birds encountered while walking two 1-km transects across their square. Birds are recorded in three distance categories, or as 'in flight'. Observers also record the habitat along the transects, and record any mammals seen during the survey. In 2007, the BBS recorded 2,783 squares in England, 409 squares in Scotland

and 263 squares in Wales. BBS data are available for birds from 1994 and for mammals from 1995.

(a) Marine plants	**(d) Freshwater animals**
Sargassum muticum (Jap Weed, Wire Weed)	*Pacifastacus leniusculus* (Signal Crayfish)
Undaria pinnatifida (Japanese Kelp, Wakame)	*Procambarus clarkii* (Red Swamp Crayfish)
Codium fragile ssp. tomentosoides (Green Sea Fingers)	*Corbicula fluminea* (Asian Clam)
	Dreissena polymorpha (Zebra Mussel)
	Pseudorasbora parva (Topmouth Gudgeon)
(b) Marine animals	*Sander lucioperca* (Pikeperch, Zander)
Tricellaria inopinata (a bryozoan)	*Lithobates catesbeianus* (American Bullfrog)
Watersipora subtorquata (a bryozoan)	*Trachemys scripta* (Common Slider Turtle)
Corophium sextonae (an amphipod)	
Gammarus tigrinus (an amphipod)	**(e) Terrestrial plants**
Elminius modestus (an acorn barnacle)	*Carpobrotus edulis* (Hottentot Fig)
Solidobalanus fallax (a barnacle)	*Disphyma crassifolium* (Purple Dewplant)
Eriocheir sinensis (Chinese Mitten Crab)	*Fallopia japonica* (Japanese Knotweed)
Rhithropanopeus harrisii (Dwarf Crab)	*Heracleum mantegazzianum* (Giant Hogweed)
Crassostrea gigas (Pacific Oyster)	*Impatiens glandulifera* (Himalayan Balsam)
Crepidula fornicata (Slipper Limpet)	*Quercus ilex* (Evergreen Oak)
Rapana venosa (Rapa Whelk)	*Rhododendron ponticum* (Rhododendron)
Anguillicola crassus (Swim-bladder Nematode)	*Rosa rugosa* (Japanese Rose)
Botrylloides violaceus (a tunicate)	
Corella eumyota (a tunicate)	**(f) Terrestrial animals**
Didemnum vexillum (a tunicate)	*Arthurdendyus triangulata* (New Zealand Flatworm)
Styela clava (Leathery Sea Squirt)	*Harmonia axyridis* (Harlequin Ladybird)
	Branta canadensis (Canada Goose)
	Oxyura jamaicensis (Ruddy Duck)
(c) Freshwater plants	*Cervus nippon* (Sika Deer)
Crassula helmsii (New Zealand Pigmyweed)	*Muntiacus reevesi* (Reeves' Muntjac)
Hydrocotyle ranunculoides (Floating Pennywort)	*Mustela vison* (American Mink)
Ludwigia grandiflora (Uruguayan Hampshire-purslane)	*Myocastor coypus* (Coypu)
Myriophyllum aquaticum (Parrot's-feather)	*Rattus norvegicus* (Brown Rat)
	Sciurus carolinensis (Grey Squirrel)

Table 6. Invasive species in the highest threat category in Great Britain; details of how these were selected are given in Appendix 2

Definition	*Interpretation*	*Extent*
Not present in territory	Absent	0
Present in territory and either not established or with established populations that have not spread more than 10 km from their source	Not or scarcely established	1
Established populations present less than 10% of territory, with some having arrived from further than 10 km from their source; or if more widespread then populations scattered and sparse	Established but still generally absent or at most occasional	2
Established populations present in 10-50% of the territory	Established and frequent in part of the territory	3
Established in more than 50% of the territory	Widespread	4

Table 7. Invasion extent of non-native species

Species introduced before 1500 were treated as native. Geese presented a problem, because several species are non-native breeders but have large wild wintering populations that are sometimes present till April and may be recorded on early BBS visits. Such birds are all treated as native, except for Barnacle Geese, which, although treated as native in Scotland, were treated as non-native in England and Wales because of their introduced breeding populations in those countries and the scarcity of wild birds there during the BBS season.

Countryside Survey (vascular plants)

Countryside survey http://www.countrysidesurvey.org.uk/ provides a unique record of plants growing in the British countryside from 1978 to the present day. In a recent report (Countryside Survey Partnership, 2008), the authors observe that 'The number of non-native or "alien" plant species recorded in Great Britain has increased greatly in the past sixty years. Most non-native species remain relatively scarce in the CS sampling plots (over 14,000 plots in this analysis), although locally they can be very abundant e.g. Rhododendron and Japanese Knotweed. Together, non-native species now account for nearly 2% of the vegetation cover of the British countryside'.

In the analysis of the 2007 Countryside Survey, crop plants were included along with other non-native species. For the purpose of the relative proportion indicator, however, crop plants (Table 8) were omitted. The argument for this is that the majority of occurrences of crop species are either as a standing crop or as first-generation descendents of such a crop. Some crop species, especially forest trees, may in future become invasive. Indeed, Corsican Pine is already invasive locally on sand dunes. However, because the great majority of its occurrences are as planted trees, it is retained in the crop category. In the other direction, sycamore is sometimes

grown as a crop, but is much more often naturalized. It is therefore not treated as a crop for the indicator.

Field crops (major)	*Field crops (minor)*	*Tree crops*
Barley	Buckwheat	Austrian Pine
Beet	Carrot	Corsican Pine
Cabbage etc.	Flax	Douglas Fir
Field bean	Garden Strawberry	European Silver-fir
Italian Rye-grass	Millet	Giant Fir
Lucerne	Pea	Grey Poplar
Maize	Phacelia	Larch (all)
Oats	Quinoa	Lawson's Cypress
Potato	Rye	Lodgepole Pine
Rape	Salsify	Noble Fir
Swede, turnip	Sunflower	Pear
Wheat	Tomato	Spruce (all)

Table 8. Crop species omitted from non-native totals in calculating a non-native indicator based on Countryside Survey

In the course of data analysis, an anomaly emerged with Pineappleweed *Matricaria discoidea* in 1978. In that year, it was recorded from 14.7% of the random (X) plots, whereas in 1990 it was found in 3.5% of these plots. It may have been confused, probably not by the original recorders, with Scentless Mayweed *Tripleurospermum inodorum*, which is unexpectedly scarce in the data for that year. There was insufficient time for us to consult the original field sheets. In an effort to correct for the discrepancy, Pineappleweed was downweighted in 1978 by assuming that it made up the same proportion of the non-natives as in 1990. On this basis records were treated as 51% native and 49% non-native. With the downweighting, it made up 27% of the 1978 non-native total.

Region	Definition	Area (km^2)	Proportion
Southern England	Vice-counties 1-34	66966	29%
Northern England	Vice-counties 36-40, 53-70	65249	28%
Scotland	Vice-counties 72-112	79972	34%
Wales	Vice-counties 35, 41-52	21161	9%
Great Britain	Vice-counties 1-70, 72-112	233348	100%

Table 9. Regions of Great Britain and their area; vice-counties are widely used for biological recording

Plots were weighted so that the contribution of each region was proportional to the area of the region. Southern England (Table 9) was for this purpose defined by Watsonian vice-counties (NBN, 2008), comprising England south of the Severn-Wash line, together with Gloucestershire. Northern England, defined as the rest of England, has a very similar area.

For example, in southern England in 2007, there were 608 random plots, in which 184 non-native occurrences were reported. Thus the mean number of non-natives was on average 184/608 = 0.303 per plot. In calculating the weighted total for all Britain, the contribution of southern England was adjusted for the area of the territory.

Southern England contribution = 0.303 * 66966 / 233348 = 0.0868 .

The weighted total of non-natives for all regions is the sum of the contributions for Southern England, Northern England, Scotland and Wales. Finally, the proportion of non-natives was calculated as the weighted total of non-natives by the weighted total species counts.

Non-native bryophytes in the BRC database

Bryophyte recording by the British Bryological Society started in 1960 with the launch of the Society's Mapping Scheme. From then onwards, systematic recording of bryophytes has provided a steady stream of records. For the purposes of calculating non-native frequency, a bryophyte record was taken to be the occurrence of a species in a 10-km square (hectad) in a year. If the same species was found twice in the hectad in a year, the occurrence is counted only once.

As with vascular plants in Countryside Survey, Great Britain was divided into four regions, each of which was weighted in proportion to its area. In each of the component regions (Southern England, Northern England, Scotland, Wales) counts of non-native records and of total records were summed over five years. Calculated proportions are therefore 5-year running means. The non-native proportion for Great Britain was calculated as the weighted mean of the proportions for component regions. Specifically, let A_{SE}, A_{NE}, A_S, A_W be the areas of Southern England, Northern England, Scotland and Wales, and let p_{SE}, p_{NE}, p_S, p_W be the corresponding proportions of non-native records. Then the non-native proportion for Great Britain is calculated as

$$p_{GB} = (p_{SE}A_{SE} + p_{NE}A_{NE} + p_SA_S + p_WA_W) / A_{GB}$$

where A_{GB} is the area of Great Britain and

$$A_{GB} = A_{SE} + A_{NE} + A_S + A_W$$

Taxonomic group	*Dataset*	*Custodian*
(a) Datasets used for indicator		
Marine shore and seabed species	Data Archive for Seabed Species and Habitats (DASSH)	MBA
Vascular plants	Countryside Survey	CEH
Bryophytes	British Bryological Society national recording scheme	BRC
Birds	Breeding Bird Survey	BTO
Mammals	Breeding Bird Survey	BTO
(b) Other datasets		
Marine plankton	Continuous Plankton Recorder Database (Sir Alister Hardy Foundation for Ocean Science)	SAHFOS
Crayfish	No single compilation	EA and others
Fish	No regular recording; EA have data for a few, including Topmouth Gudgeon	EA and others
Amphibians and reptiles	National Amphibian and Reptile Recording Scheme (NARRS)	Herpetological Conservation Trust
Aquatic plants	BSBI vascular plant database	BRC
Riparian plants	River Habitat Survey	EA
Butterflies	Butterflies for the New Millennium	BC
Macro-moths	The Rothamsted Insect Survey	Rothamsted Research
Macro-moths	Moths Count recording scheme	BC
Orthoptera and allies	Orthoptera recording scheme	BRC
Aphids	The Rothamsted Insect Survey	Rothamsted Research
Terrestrial vascular plants	BSBI vascular plant database	BRC

Table 10. Datasets with information on non-native species

Marine organisms

Data from biological survey of Britain's seas and coasts are relatively sparse. Many areas of the coast and seabed are under-surveyed. DASSH (Data Archive for Seabed Species and Habitats) and the NBN Gateway hold marine life datasets for Great Britain. For the frequency indicator, data from NBN Gateway and DASSH within 12 nautical miles (22 km) of the British coast were combined. Most of the data on the NBN Gateway originated from the Marine Nature Conservation Review. There was no discrimination between taxonomic groups but some groups of species were not represented. Records were mainly of benthic and intertidal plants and animals. Records of absence were excluded.

Starting with a fuller set of data, including records from further out to sea, the 12 nautical mile limit was imposed using ESRI ArcGIS software.

Records were assigned to England, Scotland and Wales, using national boundaries supplied by Defra. The data were then transferred from an ArcGIS geodatabase to a series of MySQL database tables and queried via a web-interface using a PHP-based script. The script extracted the number of records and the number of non-natives recorded for each given time period for England, Scotland, Wales and Great Britain.

The list of non-native marine species was derived from the DAISIE list of marine aquatic species for Great Britain, with some additions based on expert knowledge and the scientific literature. The list included 96 marine, diadromous and brackish species from 11 phyla.

Other datasets

The search for data revealed several national datasets that could in principle be used (Table 10). Those that were eventually selected were chosen because they covered all of Great Britain and were readily available to the consortium. The Environment Agency, Rothamsted Research and the Herpetological Conservation Trust were approached, and expressed a willingness in principle to supply data. However, the short time-scale of the project meant that data could not be used unless fully compiled in an easily-searchable database. This was not the case with the first two sources. An additional problem with the Environment Agency data is that Scotland is excluded. Herpetological Conservation Trust data may well have been suitable, but there was insufficient time to pursue the matter more fully with them. Butterflies and macro-moths are well recorded groups. However, there are no established non-native butterflies, and very few non-native macro-moths. The newly-introduced Oak Processionary Moth *Thaumetopoea processionea* and the reintroduced Gypsy Moth *Lymantria dispar* (which may by now have been exterminated) are possibly the only introduced species to have become established since 1900.

The NBN Gateway was a particularly useful resource for checking the spread of invasive species.

Results

Non-native birds in Breeding Bird Survey

The graphs in this section show the proportion of birds counted on BBS squares that were of non-native species. Values for 2008 are based on roughly two thirds of the expected final sample.

Proportions of non-native birds in England were first assessed separately for the nine Government Office regions. The proportion of non-natives in London has been rising fast, and since 2003 has exceeded that in other regions. In 2007-8 it was about 3%, fully twice the average for all England. Many of the London birds were Rose-ringed Parakeets, which are not widely distributed elsewhere. The lowest proportion of non-natives was in the North East, where values were similar to those in Scotland and Wales.

Because of regional differences in the density of BBS squares, trends for England and GB were compiled by first weighting the count values for each region by the reciprocal of the density of BBS squares surveyed there. Weighted counts were added, and the proportion calculated from these.

The proportion of non-native birds in England was roughly three times that in Wales. Scotland had the lowest non-native proportion (Figure 1). The trend was upward in all three countries, with England passing 1% non-native in 2000. GB reached the 1% level in 2007 but, on provisional 2008 data, has subsequently fallen.

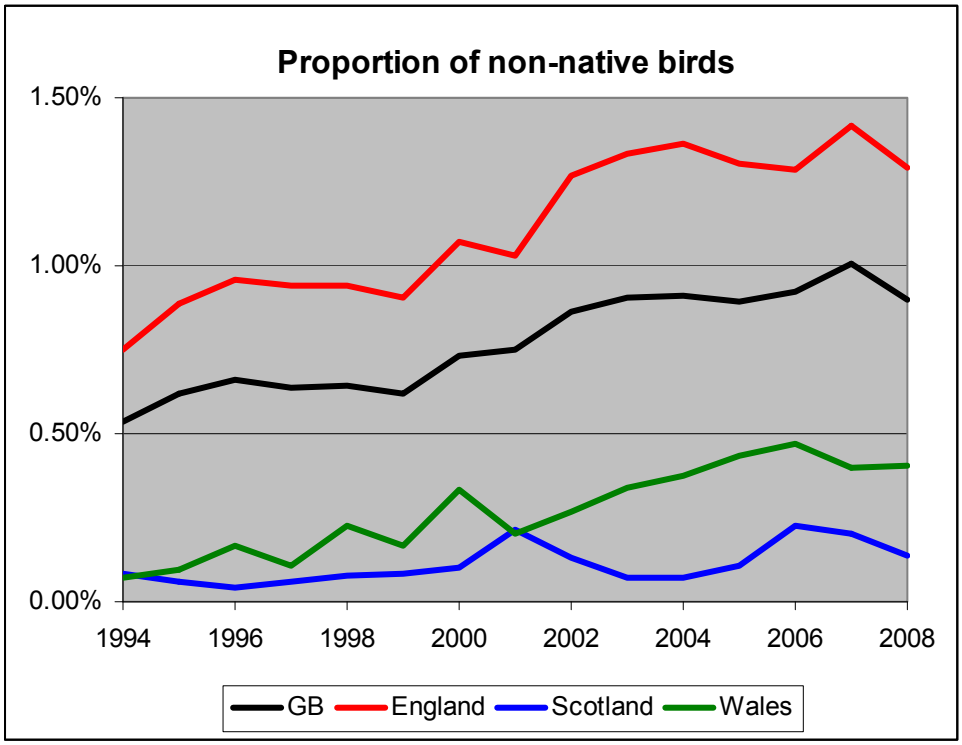

Figure 1. Proportion of non-native birds in countries of Great Britain

Non-native mammals in Breeding Bird Survey

BBS data were used to investigate trends for six of the seven mammal species deemed to be invasive in Britain. The seventh, Coypu, was exterminated during the 1980s, before BBS mammal recording began in 1995.

More than 80% of BBS observers record mammals, despite this being an optional part of the survey. Most make no special efforts, however, and record only what is noted on bird-counting visits to the square. Many BBS mammal records refer to presence of field signs or to local knowledge that a species was present, rather than to counts of live animals.

All species are under-recorded, but to differing extents. It is not therefore possible to compare native and non-native species, as was done for birds.

Instead, the proportion of sites (1-km squares) occupied was investigated over time, separately for each of the six invasive species. A square was registered as occupied on the strength of BBS evidence from any source: counts on BBS visits, other sightings of live or dead animals, field signs, or local knowledge.

Trends were first assessed separately for the nine Government Office regions. The 'rough and ready' nature of the data did not warrant any weighting procedure when the data were combined into larger regions. Data for 2008 were drawn from less than 20% of the expected final sample. Proportions for 2001 are biased because of access restrictions following a major outbreak of Foot & Mouth Disease. In that year, much farmland was inaccessible. In the GB indicator, value of the mammal index for 2001 was interpolated as the average of those for 2000 and 2002.

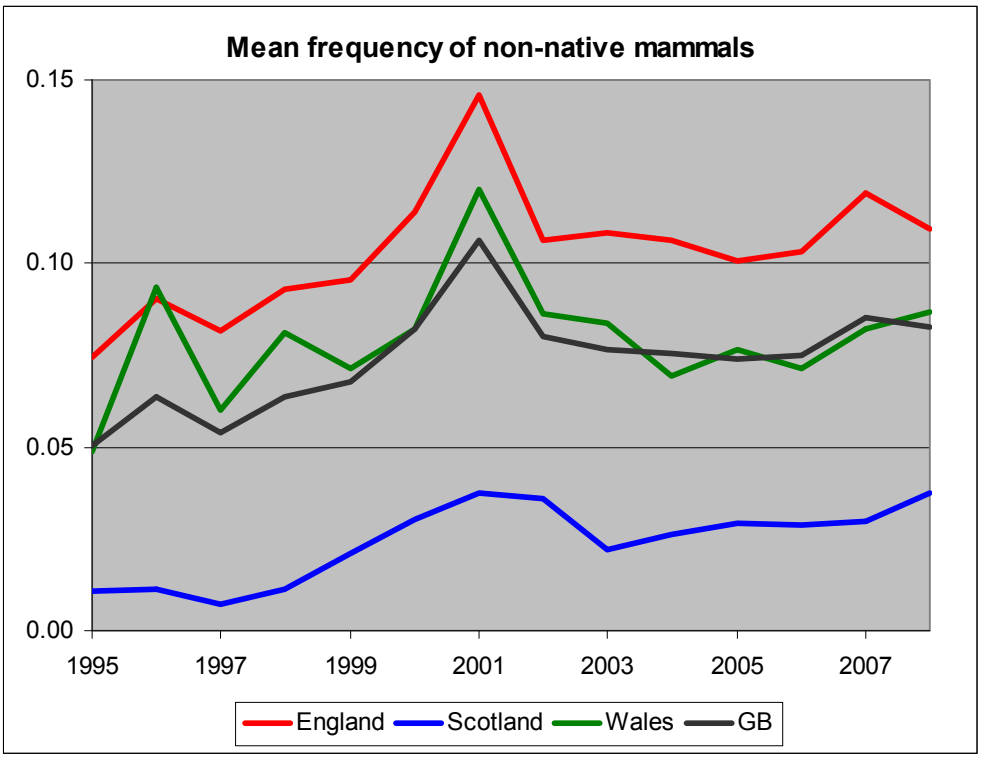

Figure 2. Mean frequency of six non-native mammal species in Breeding Bird Scheme squares; the peak in 2001 is due to many rural sites being inaccessible in England and Wales during an outbreak of Foot and Mouth Disease

Trends of most species are upward. The spread of Muntjac is shown clearly in data for the East of England, but is less clear in other regions and on broader scales. Other analyses of BBS mammal data have used different approaches (British Trust for Ornithology, 2008).

Non-native plants in Countryside Survey

Taken over all time periods, the top 10 non-native plants in Countryside Survey account for 82% of all 2443 non-native occurrences in the random

(X) and stream (S and W) plots in the data (Table 11). Japanese Knotweed is not even one of the top ten in the countryside; it is in 11th place.

Scientific name	English name	Total	Random	Stream
Acer pseudoplatanus	Sycamore	644	263	381
Matricaria discoidea	Pineappleweed	459	415	44
Veronica persica	Common Field-speedwell	432	416	16
Impatiens glandulifera	Indian Balsam	122	5	117
Epilobium brunnescens	New Zealand Willowherb	97	11	86
Mimulus guttatus	Monkeyflower	70	1	69
Rhododendron ponticum	Rhododendron	65	33	32
Epilobium ciliatum	American Willowherb	63	20	43
Claytonia sibirica	Pink Purslane	32	1	31
Aesculus hippocastanum	Horse-chestnut	27	17	10
Total of top 10 species		2011	1182	829
Total of all NNNCS		2443	1426	1017
Top 10 as % of all NNNCS		82.3%	82.9%	81.5%
Total no. of plots		16884	9513	7371
Mean no. of NNNCS per plot		0.14	0.15	0.14

Table 11. Counts of occurrence in sample plots for the 10 most frequent non-native non-crop species (NNNCS) in Countryside Survey (all Countryside Surveys 1978-2007).

The proportion of non-native species in England, and therefore in Britain, fell markedly between 1978 and 1990 (Figs 3 and 4). While this is at first sight a surprising result, it is not implausible, because the main contributors to the non-native total in random plots are arable weeds. If crops were being more effectively weeded with selective herbicides after 1978, then the non-native proportion could have fallen.

The lower proportion of non-natives in streamside plots than in random plots applies only in England. In Wales and Scotland, streamside plots had a slightly higher proportions of non-natives than random plots (Figs 4, 5). The discrepancy is particularly marked in southern England, where about 2% of the flora was non-native in random plots, compared with about 1% in streamside plots.

Non-native bryophytes in the BRC database

Scotland had overall a much lower proportion of non-native species than England (Table 12; Fig. 6). Northern England, on the other hand, had a higher non-native proportion than southern England. This probably reflects that fact that the top three non-native bryophytes (Table 13) are all calcifuges, which are relatively scarce in calcareous or intensively farmed countryside.

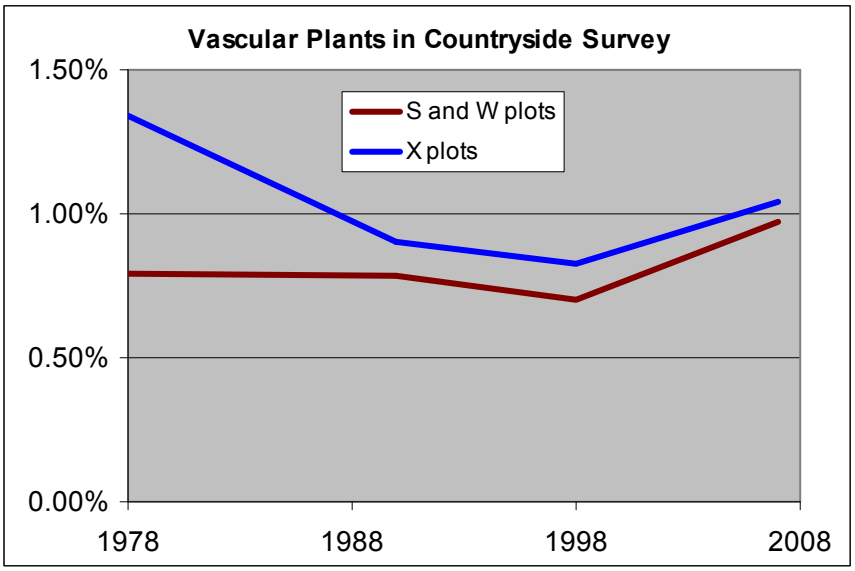

Figure 3. Great Britain proportions of non-native vascular plant species in random (X) and streamside (S and W) plots in Countryside Survey

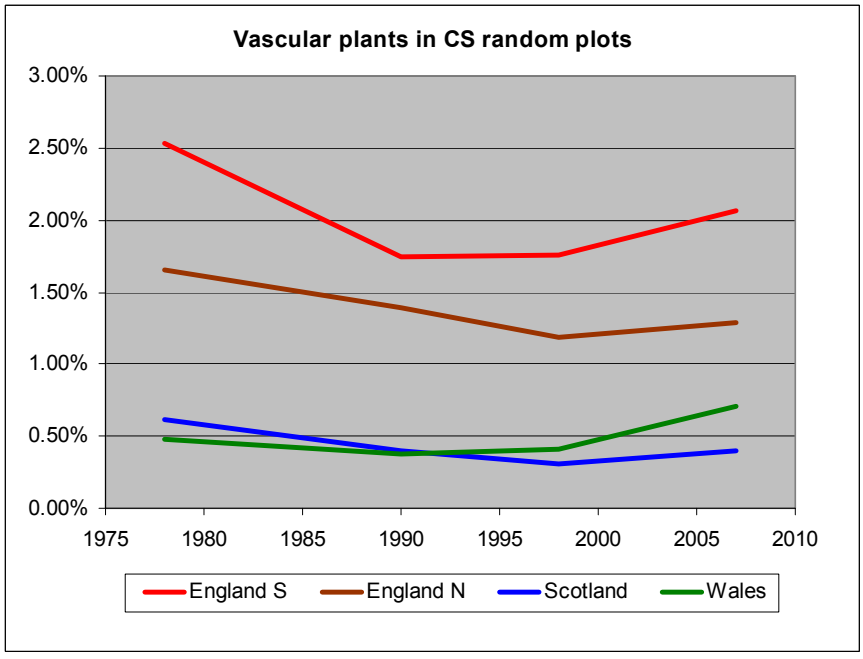

Figure 4. Country proportions of non-native vascular plant species in random (X) plots in Countryside Survey; southern England is defined as in Table 9

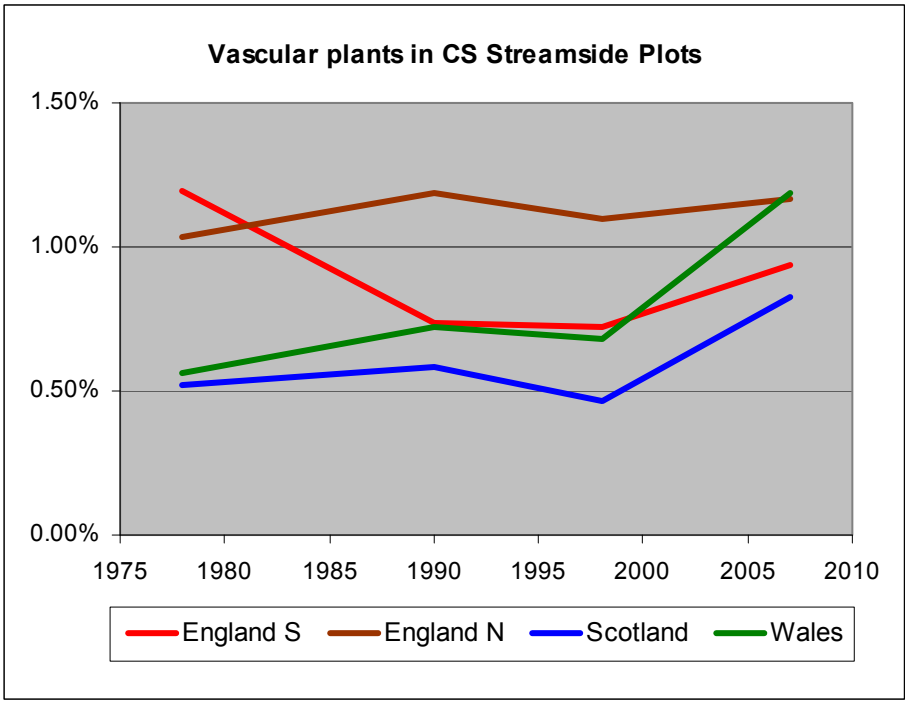

Figure 5. Country proportions of non-native vascular plant species in streamside (S and W) plots in Countryside Survey; southern England is defined in Table 9

The early phase of increasing non-native proportion, to 1976 (Fig. 6), corresponds to the time when *Campylopus introflexus* was still increasing. Since then, two liverworts from the Southern Hemisphere, *Lophocolea bispinosa* and *L. semiteres*, have begun to spread rapidly. If they soon become widespread throughout Great Britain, then the overall non-native proportion will show a second period of increase in the near future.

Region	*Area (km^2)*	*Total NNS*	*Total all spp.*	*Proportion NNS*	*Proportion 1960-89*	*Proportion 1990-2008*
Southern England	66966	2702	235043	1.15%	0.87%	1.42%
Northern England	65249	2248	155746	1.44%	1.10%	1.83%
Scotland	79972	680	234632	0.29%	0.23%	0.43%
Wales	21161	752	103952	0.72%	0.65%	0.76%
Total GB	233348	6382	729373	0.87%		
Weighted GB proportion				0.90%	0.70%	1.14%

Table 12. Counts of occurrence of non-native bryophyte species in 10-km squares (hectads) of the National Grid, 1960-2008; weighted GB proportions are calculated from regional proportions, weighted by the areas in Table 9

Non-native Bryophyte	Total	1960-1990	1990-2008
Campylopus introflexus	3209	1029	2180
Orthodontium lineare	2436	1093	1343
Atrichum crispum	228	139	89
Hennediella stanfordensis	158	95	63
Hennediella macrophylla	107	80	27
Lophocolea semiteres	95	17	78
Tortula freibergii	45	19	26
Lophocolea bispinosa	33	15	18
Riccia crystallina	17	8	9
Riccia rhenana	16	12	4
Chenia leptophylla	14	6	8
Telaranea murphyae	11	8	3
Calyptrochaeta apiculata	9	6	3
Telaranea tetradactyla	8	6	2
Syntrichia amplexa	6	1	5

Table 13. Counts of non-native bryophyte records; each occurrence in a distinct 10-km square (hectad) and year counts as a separate record

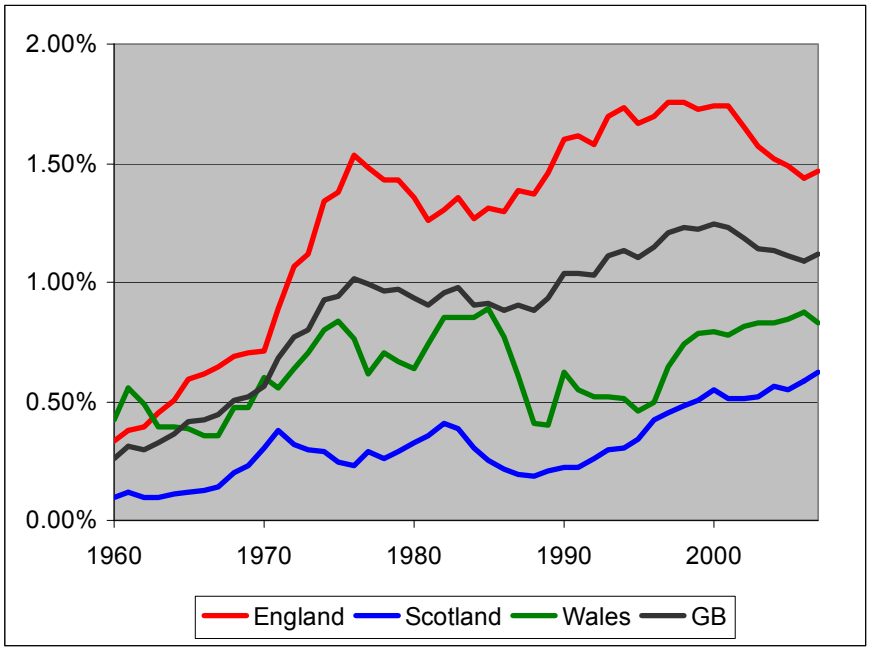

Figure 6. Proportion of bryophyte records that are of non-native species (running means based on 5-year totals); values for GB are derived from those from the separate countries, weighted by their land area.

Marine life

Marine organisms are not only far more diverse than any of the terrestrial groups, but marine records came from a wider range of habitats. They were not collected as part of a recording scheme, and therefore also show much larger year-to-year variation in numbers (Table 14). During the 1980s, most

marine records came from Scotland. During the early 1990s, English records were the most numerous. During the late 1990s and early 2000s, Welsh records were most numerous. From 2005 records have come more evenly from England and Wales, but Scottish records were much fewer.

The proportion of non-native records (Figure 7) was much more consistent than the intensity of recording, at least after 1983. Both in England and Scotland, it has fallen since the mid 1980s. The Welsh proportion has varied but does not show this trend.

Period	*England*	*Scotland*	*Wales*
1980-84	3838	8547	4658
1985-89	12546	20360	2625
1990-94	25978	18159	3841
1995-99	9335	12506	15499
2000-04	7450	7084	10034
2005-07	12912	5808	10729

Table 14. Average numbers of marine records per year in England, Scotland and Wales, 1980-2007

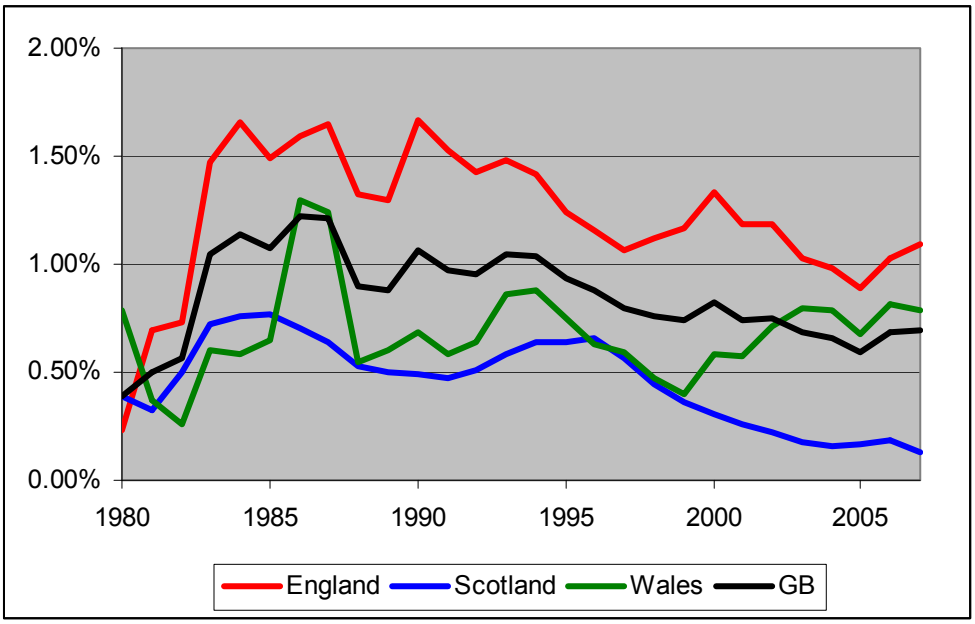

Figure 7. Proportion of marine records that are of non-native species (running means based on 5-year running totals); values for GB are derived from those from the separate countries, weighted by the square root of their land area

Summed extent of invasive non-native species

The summed extent of invasive species (Fig. 8) differed between countries in a similar way to the proportions of non-natives, discussed above. There

were marked differences between the three environments, with marine and freshwater species increasing faster than those on land. Trends for Scotland and Wales were very similar except for marine species, for which Wales was intermediate between Scotland and England. The difference between Scotland and England is particularly marked in the freshwater environment. It should be noted, however, that many English freshwater fish are considered to be invasive in Scotland.

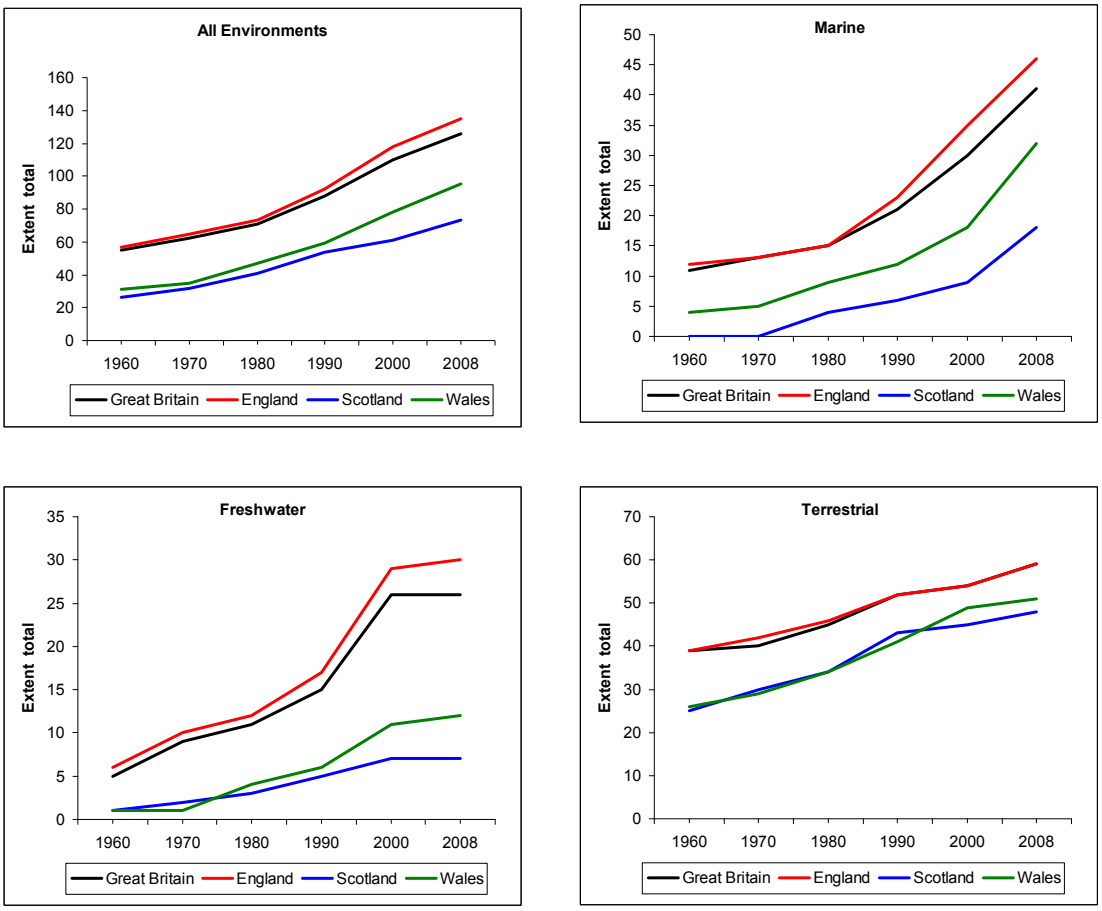

Figure 8. Summed extent of invasive non-native species in countries within Great Britain; one diagram shows totals summed over all environments, the others show totals for marine, freshwater and terrestrial species separately.

Discussion

The non-native biota of Great Britain

The non-native biota of Great Britain is moderately well known, but there is also a steady turn-over of species. Except for birds, breeding in the wild is not always well documented. Many non-native birds that breed in the wild fall in category E of the British Ornithologists' Union, namely 'Species that have been recorded as introductions, human-assisted transportees or escapees from captivity, and whose breeding populations (if any) are

thought not to be self-sustaining'. The difficulties of constructing an index from rare and possibly non-established non-native birds are discussed in Appendix 3.

Plants present difficulties of a different kind, in that many species escape from gardens or occur as casuals by docks, but most of them do not become properly established. They may persist at a site for a long time or may be repeatedly reintroduced. Moreover, in field surveys, the origin of shrubs and trees planted in the countryside may not be at all obvious.

These difficulties apply mainly to species that are scattered and rare. In most surveys, the identity of the native flora and fauna is well known, so that non-native species can be separated from others in reported data. Furthermore, good lists of non-native species are available from DAISIE (2009) and earlier enumerations by British authors (Hill *et al.*, 2008, Hill *et al.*, 2005).

It is possible to use the English audit (Hill *et al.*, 2005) to show rates of arrival for major groupings over time (Fig. 9). The dates in the English audit are mostly in fact British first records, because separate dates for establishment in England were not available. The low value for plant arrivals in the 1850s followed a period of very high rates of arrival. The trend for all groups except plants is for increasing rates of arrival in the late 20th century. A similar result for Europe is shown by Hulme *et al*. (2009).

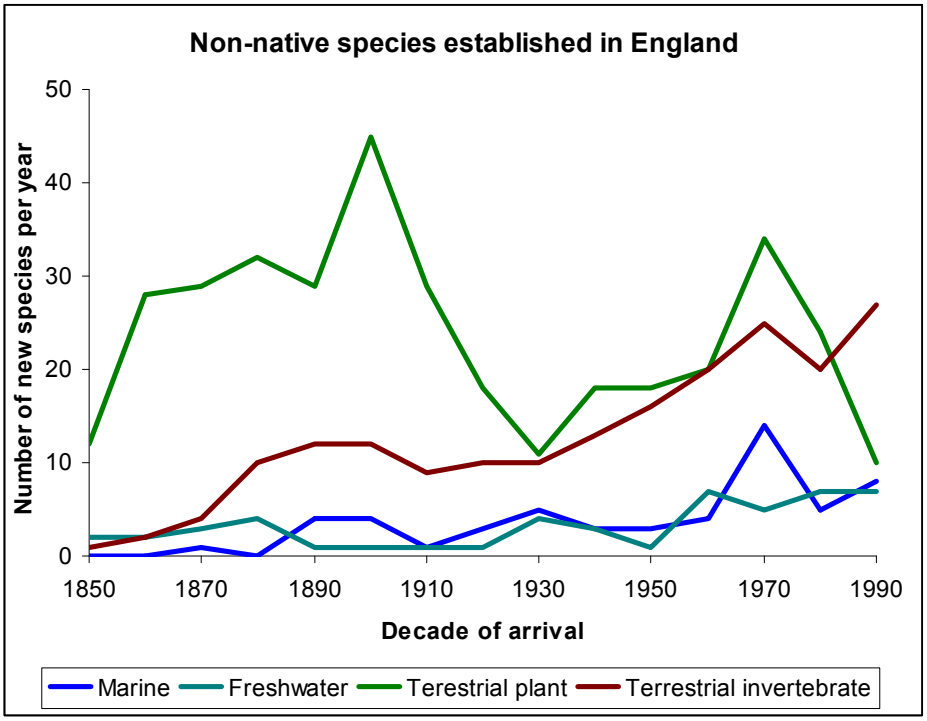

Figure 9. Rate of arrival of non-native species that subsequently became established in England; terrestrial plants include bryophytes

Defining the invasive species

The definition of invasive species employed here is that used in the Convention on Biological Diversity, namely 'Invasive alien species (IAS) are species whose introduction and/or spread outside their natural past or present distribution threatens biological diversity'. This is not the same as the definition used by McGeoch, Chown & Kalwij (2006), who define invasive merely as 'naturalized species that produce reproductive offspring in very large numbers and are able to spread over a considerable area'. They use the term 'transformers' for the subset that also cause harm.

	GB non-native risk assessment mechanism	***Modified Belgian system***
Web source	http://www.nonnativespecies.org/	http://ias.biodiversity.be/
Basis of risk assessment	EPPO risk assessment method	Belgian Forum environmental impact assessment
Impacts considered	Environmental, Economic and Social	Environmental
Impact scoring	Impact 1 (low) to 5 (high)	Impact 1 (low) to 3 (high)
Uncertainty	Low (0), Medium (1) or High (2)	Not assessed
Format	Excel spreadsheet (soon to be web-based format)	Excel spreadsheet
Speed of assessment	Slow	Rapid
Risk assessor	Expert opinion coupled with risk analysis panel	Expert opinion
Information sources listed	Yes	No (but details available)
Consultation and peer review	Yes	No

Table 15. Comparison of the methods used by the GB non-native risk assessment mechanism and the modified Belgian system used here.

The 'modified Belgian system' for selecting invasive species is, in effect, a risk assessment mechanism, and can be compared with the full GB risk assessment scheme (Table 15). In January 2009, seven species had been assessed by the GB non-native risk assessment mechanism. The results were compared (Table 15).

The GB risk assessment scheme (Baker *et al.*, 2008) is divided into two sections. In the first section (A) the species is screened by means of 14 questions to decide whether a detailed risk assessment is required. High-risk organisms, capable of causing unacceptable economic, environmental or social impacts, are considered further in section B. Section B contains 51 questions. There are six key questions relating to impact and if these score as 'massive impact' or 'very likely impact' then evaluation of subsidiary questions is not necessary. Every score in section B is linked to a written

comment. The risk analysis is in Excel format. Assessments are peer-reviewed.

The two systems produced comparable final scores and highlighted the same species as high risk (Table 16). It is possible that a few invasive species were missed by the screening process used for the indicator. A system for picking them out in future is required.

The modified Belgian system as applied here addresses impacts only on biodiversity. The GB non-native risk assessment mechanism is comprehensive and rigorous. It is vastly more time-consuming. The modified Belgian system was the best available for screening large numbers of species in a short project.

Species	***Risk (GB)***	***Certainty (GB)***	***Risk (Belgian)***
Chinese Mitten Crab *Eriocheir sinensis*	High	Low	A (high)
Chipmunk *Tamias sibiricus*	Medium	Medium	B (medium)
Monk Parakeet *Myiopsitta monachus*	Medium	Low	B (medium)
Red Swamp Crayfish *Procambarus clarkii*	High	Low	A (high)
Rose-ring Parakeet *Psittacula krameri*	Medium	Low	B (medium)
Signal Crayfish *Pacifastacus leniusculus*	High	Low	A (high)
Spiny-cheek Crayfish *Orconectes limosus*	Medium	Medium	B (medium)

Table 16: Comparison of results obtained from the GB non-native risk assessment mechanism and the modified Belgian system.

Other possible indicators

According to McGeoch *et al.* (2006), the only regional indicator developed at that time was the cumulative number of alien species in Europe since 1900. Such an indicator takes no account of the fact that many non-natives are not persistent.

A more recent major overview of ecosystem indicators in the United States (The H. John Heinz III Center for Science, 2008) suggests using established non-native species as one of 13 core national indicators. Within that category, they propose (p. 52) three possibilities:

1. The number of new non-native species that become established over time;
2. The area with different numbers of established non-native species; and
3. The area with different proportions of established non-native species, as a percentage of total species.

The first of these has already been discussed, and is plotted above for England (Fig. 9). It is essentially the rate of change of the regional indicator proposed by McGeoch *et al.* (2006).

The second of the Heinz Center's proposals amounts to charting the non-native species density for selected areas. They give an example (p. 182) for non-native fish, where the number of non-native species per catchment is mapped, without dividing by the total number of species. A measure of this type could be constructed for British fish using 10-km squares of the National Grid and the data in Davies *et al*. (2004). Such a measure is similar to those of type 4 in Table 1, and could be applied to any group for which species mapping is considered to be complete. It does not, however, result in an overall summary of trend.

The third of the Heinz Center's indicators is a relativized value, like those used above for the abundance indicator. A map showing this proportion for vascular plants is presented by Preston, Pearman & Dynes (2002) and shows a strong increase from north to south, except for the Scottish lowlands between Glasgow and Edinburgh, where the proportions are similar to those in southern England.

Various possible measures of impact are discussed in the methods section above. The Heinz Center report (p. 52) also suggested the area of forests damaged by non-native pests, and the amount of native vegetation displaced by non-native plants. McGeoch *et al.* (2006) recommend calculating the number of invasive (in their sense) and transformer species. The summed extent of invasives, used here, is similar in principle to the summed number of invasives. If the 4-point extent scale for extent were reduced to a 1-point scale, then the two would be the same.

A separate point, which is not addressed at all in this report, is that some species such as Hottentot Fig *Carpobrotus edulis* are invasive in southwest England, but are not invasive in Scotland. Likewise, many species such as *Acacia dealbata* that are invasive in southern Europe, are cultivated as tender garden plants in England where they show no tendency to spread.

Choice of datasets and weighting

The proportion of non-natives depends greatly on the scale of sampling. It rises as the plot or sample size increases, because non-native species are mostly rarer than natives. Sampling for the indicator was at widely differing scales, including individual records (marine life), quadrats with area 200 m^2 (vascular plants) encounters in 1-km squares (birds and mammals) and frequency in records from 10-km squares (bryophytes). These scales were defined not so much by consideration of what would be best for the indicator, but by the availability of data. However, the fact that non-native proportions were about 1% in all of these meant that they could be combined in an index based on broadly comparable values. Mammals were an exception. In 2006, the three commonest non-native mammals, Brown Rat, Grey Squirrel and Reeves's Muntjac made up 9% of counted

individuals and 18% of the summed frequency of mammals in BBS squares (British Trust for Ornithology, 2008).

Although we are fortunate in Britain to have a wealth of data from biological recording, many existing datasets could not be used. The most frequent reason was that they were for a group such as butterflies, lichens and macro-moths in which the non-native species are either absent or too few to be suitable for inclusion in an indicator. With other groups such as aphids, national data are collected but are not yet in a form where they can rapidly be interrogated.

Weights (Table 2) for the geometric mean were selected to give equal weighting (0.4 and 0.4) to terrestrial plants and animals and to give a moderate weighting (0.2) to marine life. This is arbitrary, but was intended to be equitable between plants and animals, while at the same time including marine organisms. If comparable data had been available for the freshwater environment, the freshwater component also would have been given weight 0.2.

Weights (Table 8) for the regions of Great Britain were used as a means to ensure that the whole territory was evenly represented. This was particularly important for bryophytes and marine organisms, for which recording was in some years very unevenly distributed between England and Scotland. As the proportion of non-natives was markedly different in these two countries, the overall proportion for Great Britain was found to be very unstable without such a weighting. Marine data were weighted not by the area of each region, but by the square root of its area. This was intended as a crude measure of the amount of coastline.

Trends and differences between countries

For all groups of organisms reported here, England was the country most affected by non-native species. Scotland was the least affected. Wales was intermediate. Most species groups showed a trend over time towards an increasingly non-native biota.

A remarkable exception was vascular plants in Countryside Survey, which had a higher non-native proportion in 1978 than at any later time. The likely explanation is that in 1978 arable fields were weedier than they were in later years. Because two of the commonest non-native plants are arable weeds, this resulted in a decrease in the value of the indicator.

Equally remarkable is the decreasing proportion of non-native marine records over the period since 1983. This may not reflect a genuine decrease in non-native species. One possible explanation is that the later records were based on a larger number of taxonomic groups, including those groups that lacked non-native taxa. Another possible explanation is that earlier records were concentrated near ports and harbours, and that they therefore exaggerated the representation of non-natives. It is also possible that in later years, there was less interest in recording non-native

species, though this seems unlikely. These hypotheses could readily be tested, but this was not possible in the time-scale of the project.

Conclusions and further developments

Over the period 1990-2007, the mean indexed proportion of records of non-native species in samples of birds, mammals, plants and marine life rose by 23% (Fig. 10). Except for mammals, the absolute proportion was still only about 1% of the total.

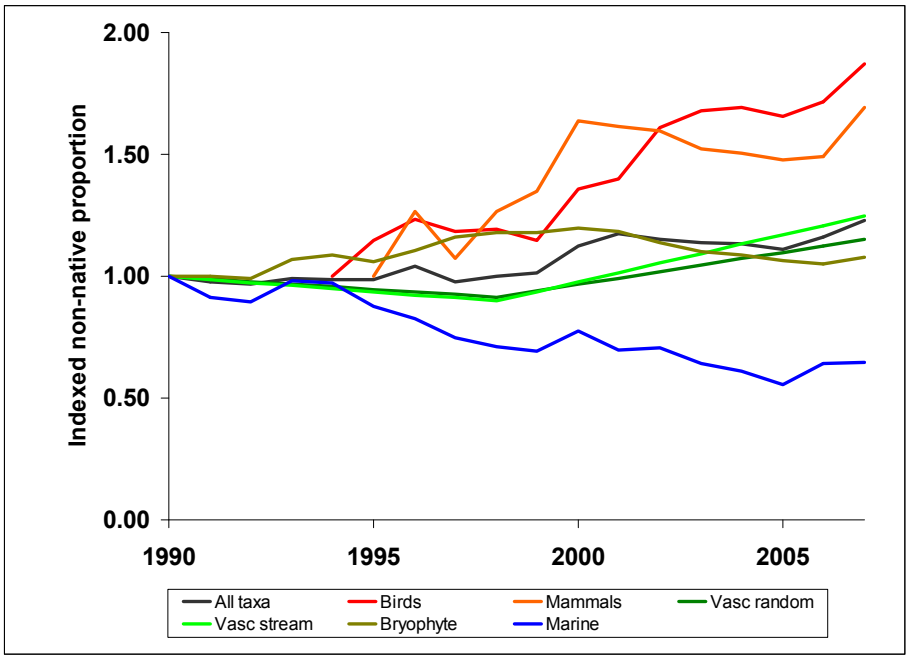

Figure 10. Trends in the proportion of non-native species in samples of birds, mammals, plants and marine organisms, 1990-2007

Over the same period, the summed extent of invasive non-native species rose by 40% (Fig. 11). The increase of invasive species was particularly large in the freshwater and marine environments.

Although non-native species are a potential threat, they are still only a small proportion of the animals and plants to be found in most of the land area and coasts of Great Britain. Vertebrates stand out as the most invasive group.

There are three main areas that deserve further development. The first is to secure sources of additional data, especially freshwater data – e.g. on fish. The second is to make a regular review of the list of invasive species, checking for new arrivals, omissions and species that have lost their harmful character. The third is to improve the analysis of species from recording schemes that do not make a full survey. This is particularly desirable for marine life, where the falling proportion of non-native species in the records did not accord with expectations, and needs confirmation.

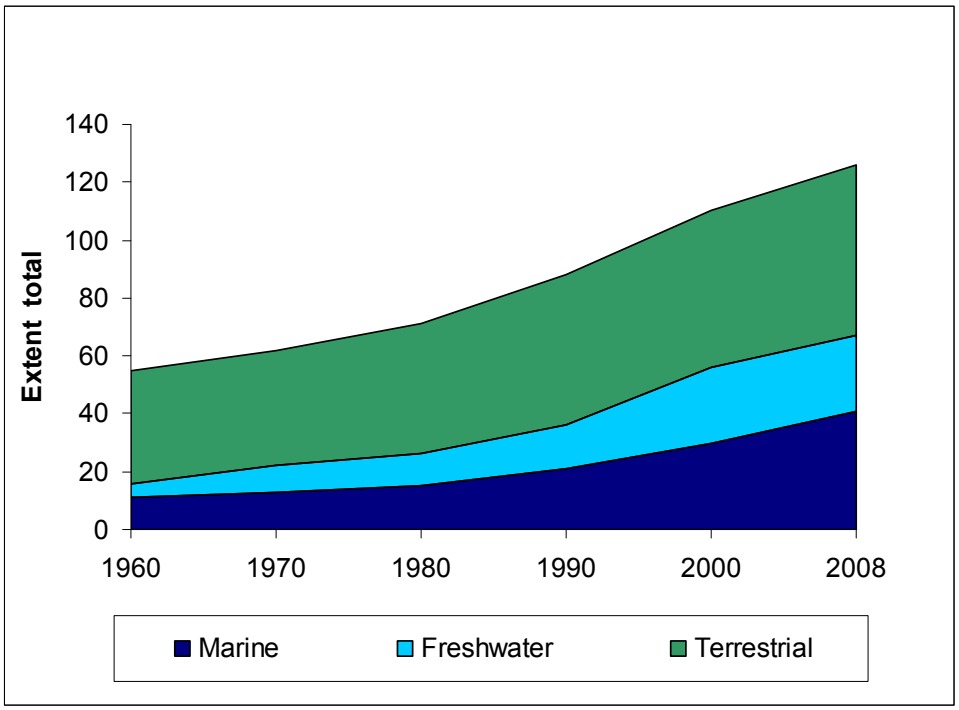

Figure 11. Trends in the summed extent of invasive non-native species in marine, freshwater and terrestrial environments, 1960-2008

Updating of the abundance indicator will be facilitated in future by the existence of a central data repository (CDR) for non-native species in Great Britain. This will increase the flow of records from the marine environment. It will establish a flow of records for species that breed in freshwater, such as amphibians, fish and crayfish. It will maintain the flow of records for terrestrial vertebrates. It will not allow for more rapid recording of vascular plants through Countryside Survey, but may increase the capacity of voluntary sector plant recording to the point where an alternative vascular plant indicator could be introduced. Bryophyte recording will not be enhanced by the CDR, but the flow of bryophyte records is already adequate. Annual updates for birds, mammals and bryophytes should be available without a large amount of work.

The CDR should allow for more-or-less automatic updates of the extent to which the high-risk invasive species have spread. The risk register will need to be revised at intervals, both to account for species that have newly arrived or become invasive, and for species that may have lost their invasive character. Such a review could be undertaken in 2010, towards the end of the process of establishing the CDR, and would probably need about 12 days of staff time, at a cost of about £5,000. It is not included in current costings for the CDR. The year 2010 would be timely, as the impacts indicator was calculated at decadal intervals except for 2008.

If the abundance indicator were extended to include other taxonomic groups, or to allow for substantial reanalysis of data for existing groups, the costs would be more substantial. This is partly because the CDR will record

the presence of non-native species, but does not allow for recording of native species. All but the mammal component of the abundance indicator were derived by dividing non-native totals by native totals. Costs of reanalysing existing data, for example to find the cause of the paradoxical fall in proportion of non-native species in marine data, would also be appreciable. Worthwhile extensions to the existing indicator along these lines would probably cost about £10,000 to set up, but thereafter the running costs might be quite low.

Given that the establishment and spread of non-native species are relatively slow processes, annual updates to the indicator are unlikely to show much change. Intervals of about five years would be sufficient.

Finally, an indicator based on the rate of establishment of non-native species deserves further consideration. Such an indicator could be reported in other European countries. It would not be so dependent on extensive data sources as the indicators developed here. Even so, it would require substantial further work to determine which species are in fact established.

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List of abbreviations

BBS	Breeding Bird Survey
BOU	British Ornithologists' Union
BRC	Biological Records Centre
BTO	British Trust for Ornithology
CBD	Convention on Biological Diversity
CEH	Centre for Ecology and Hydrology
CS	Countryside Survey
DAISIE	Delivering Alien Invasive Species Inventories for Europe
DASSH	Data Archive for Seabed Species and Habitats
EA	Environment Agency
EEA	European Environment Agency
EPPO	European and Mediterranean Plant Protection Organization
GB	Great Britain
IAS	Invasive Alien Species
JNCC	Joint Nature Conservation Committee
MBA	Marine Biological Association
NBN	National Biodiversity Network
NNS	Non-native Species
RBBP	Rare Breeding Birds Panel
SAHFOS	Sir Alister Hardy Foundation for Ocean Science

Appendix 1. Definitions for impact scoring

Invasion potential is rated in 4 categories, namely Dispersal potential, Colonization of natural and semi-natural habitats, Adverse impacts on native species and Alteration of ecosystem function. As explained in Appendix 2, two of the categories are subdivided, and the maximum impact for each of the subdivisions is taken as the score for the category.

Table A1. Dispersion potential

Definition	Mnemonic	Score
Low risk. The species does not spread in the environment because of poor dispersal capacity or low reproductive potential.	Species does not spread naturally	1
Medium risk. Unlikely to colonize remote places. Natural dispersal rarely exceeds more than 1 km per year, and species is not regularly transported within the territory by humans. The species can however become locally invasive because of a strong reproductive potential.	Species spreads up to 1 km per year	2
High risk. The species is highly fecund, can easily disperse by active or passive means over distances >1 km per year and initiate new populations. Means of dispersal include wind, water, animal movements, translocation by humans or accidental transport by human agency.	Species spreads naturally or by human agency >1 km per year	3

Table A2. Colonization of natural and semi-natural habitats

Definition	Mnemonic	Score
Low risk. Populations of the non-native species are restricted to man-made habitats (low conservation value).	Restricted to man-made habitats	1
Medium risk. Populations of the non-native species are usually confined to habitats with low or medium conservation value and may occasionally colonize natural and semi-natural habitats.	May occasionally colonize natural and semi-natural habitats	2
High risk. The non-native species often colonizes natural or semi-natural habitats (i.e. many sites of at least one natural or semi-natural habitat could be readily colonized by the species when source populations are present in the vicinity).	Often colonizes natural or semi-natural habitats	3

Table A3. Adverse impacts on native species

Definition	Mnemonic	Score
Low risk. Data from invasion histories suggest that any negative impact on native populations is negligible.	Negative impact on native populations negligible	1
Medium risk. The non-native species is known to cause local changes (< 80%) in population abundance, growth or distribution of one or several native species. This effect is thought to be reversible, or the affected species are either common or ruderal or both.	Causes reversible changes of < 80% in population abundance of native species	2
High risk. The non-native species can cause local severe (> 80%) population declines of valued or rare species, or may reduce local species richness. At a regional scale, it may cause species decline. When such non-native species are established, their impacts on native biodiversity are unlikely to be reversible.	Often causes changes of > 80% in population abundance of native species, including rare species	3

Table A4. Alteration of ecosystem function

Definition	Mnemonic	Score
Low risk. The impact on ecosystem processes and structures is considered as negligible.	Ecosystem impact negligible	1
Medium risk. The impact on ecosystem processes and structures is moderate and considered as easily reversible.	Ecosystem impact moderate, reversible	2
High risk. The impact on ecosystem processes and structures is strong and difficult to reverse.	Ecosystem impact strong, difficult to reverse	3

Note: When the impact is variable, depending on the type of ecosystem, one should consider the effect on those ecosystems that are most vulnerable.

Appendix 2. Scoring species for invasiveness

Species are rated in the categories specified in Table 3, using the scoring system outlined in Appendix 1. In addition to the standard scores, the following conversions were used:

D	data deficient	score 0
U	adverse impact unlikely	score 1
L	adverse impact likely	score 2.

Column headings are shown as numbers as follows:

1 Dispersal potential
2 Colonization of natural and semi-natural habitats
3.1 Adverse impacts on native species: predation and herbivory
3.2 Adverse impacts on native species: competition
3.3 Adverse impacts on native species: disease vector
3.4 Adverse impacts on native species: genetic pollution
3 Adverse impacts on native species: maximum of 3.1, 3.2, 3.3, 3.4
4.1 Alteration of ecosystem function: nutrient cycling
4.2 Alteration of ecosystem function: physical alteration
4.3 Alteration of ecosystem function: successions
4.4 Alteration of ecosystem function: food webs
4 Alteration of ecosystem function: maximum of 4.1, 4.2, 4.3, 4.4

The column labelled Sum is the sum of columns 1, 2, 3 and 4. The column labelled Category assigns a threat category in accordance with the sum:

A	invasive	Sum = 11 or 12
B	potential threat	Sum = 9 or 10
C	low threat	Sum = 8 or less.

Table A5. Scoring for invasiveness: marine organisms

Scientific name	English name	Group	1	2	3.1	3.2	3.3	3.4	3	4.1	4.2	4.3	4.4	4	Sum	Category
(a) Marine plants																
Sargassum muticum	Jap Weed/ Wire Weed	brown alga	**3**	**3**	-	3	D	1	**3**	2	3	3	2	3	**12**	**A**
Undaria pinnatifida	Japanese Kelp/ Wakame	brown alga	**3**	**2**	-	3	D	1	**3**	2	2	3	2	3	**11**	**A**
Codium fragile ssp. *tomentosoides*	Green Sea Fingers	green alga	**3**	**3**	-	3	D	D	**3**	2	3	3	2	3	**12**	**A**
(b) Marine animals																
Tricellaria inopinata	(a bryozoan)	bryozoan	**3**	**2**	1	3	1	D	**3**	2	2	2	3	3	**11**	**A**
Watersipora subtorquata	(a bryozoan)	bryozoan	**3**	**2**	1	3	1	D	**3**	2	3	3	2	3	**11**	**A**
Corophium sextonae	(an amphipod)	crustacean	**3**	**3**	D	3	D	D	**3**	2	2	D	D	2	**11**	**A**
Elminius modestus	(an acorn barnacle)	crustacean	**3**	**3**	1	3	D	1	**3**	1	2	2	2	2	**11**	**A**
Eriocheir sinensis	Chinese Mitten Crab	crustacean	**3**	**3**	3	3	D	1	**3**	D	3	1	2	3	**12**	**A**
Gammarus tigrinus	(an amphipod)	crustacean	**3**	**3**	2	3	D	D	**3**	D	1	1	2	2	**11**	**A**
Rhithropanopeus harrisii	Dwarf Crab	crustacean	**3**	**3**	2	2	3	D	**3**	D	2	2	2	2	**11**	**A**
Solidobalanus fallax	(a barnacle)	crustacean	**3**	**3**	1	3	D	D	**3**	D	2	2	D	2	**11**	**A**
Crassostrea gigas	Pacific Oyster	mollusc	**3**	**3**	1	2	D	1	**2**	2	3	3	3	3	**11**	**A**
Crepidula fornicata	Slipper Limpet	mollusc	**3**	**3**	1	3	D	1	**3**	2	3	2	3	3	**12**	**A**
Rapana venosa	Rapa Whelk	mollusc	**3**	**2**	3	2	2	1	**3**	1	1	1	3	3	**11**	**A**
Anguillicola crassus	Swim-Bladder Nematode	nematode	**3**	**3**	3	1	3	D	**3**	D	1	1	2	2	**11**	**A**
Botrylloides violaceus	(a tunicate)	tunicate	**3**	**3**	1	3	D	1	**3**	2	2	2	2	2	**11**	**A**
Corella eumyota	(a tunicate)	tunicate	**3**	**3**	1	3	D	1	**3**	2	2	2	3	3	**12**	**A**
Didemnum vexillum	(a tunicate)	tunicate	**3**	**3**	1	3	D	1	**3**	2	2	3	3	3	**12**	**A**
Styela clava	Leathery Sea Squirt	tunicate	**3**	**2**	1	3	D	1	**3**	2	3	2	2	3	**11**	**A**

Table A6. Scoring for invasiveness: freshwater organisms

Scientific name	English name	Group	1	2	3.1	3.2	3.3	3.4	3	4.1	4.2	4.3	4.4	4	Sum	Category
(c) Freshwater plants																
Azolla filiculoides	Water Fern	plant	**3**	**2**	-	2	1	1	**2**	2	3	3	3	3	**10**	**B**
Crassula helmsii	New Zealand Pigmyweed	plant	**3**	**3**	-	3	1	1	**3**	2	2	2	2	2	**11**	**A**
Elodea canadensis	Canadian Waterweed	plant	**3**	**3**	-	2	1	1	**2**	2	2	2	2	2	**10**	**B**
Elodea nuttallii	Nuttall's Waterweed	plant	**3**	**3**	-	2	1	1	**2**	2	2	2	2	2	**10**	**B**
Hydrocotyle ranunculoides	Floating Pennywort	plant	**3**	**2**	-	3	1	1	**3**	2	3	2	2	3	**11**	**A**
Lemna minuta	Least Duckweed	plant	**3**	**3**	-	2	1	1	**2**	1	2	2	2	2	**10**	**B**
Ludwigia grandiflora	Uruguayan Hampshire-Purslane	plant	**3**	**3**	1	3	1	1	**3**	3	3	3	1	3	**12**	**A**
(d) Freshwater animals																
Orconectes limosus	Spiny Cheeked Crayfish	crustacean	**3**	**3**	1	1	2	1	**2**	1	2	1	2	2	**10**	**B**
Pacifastacus leniusculus	Signal Crayfish	crustacean	**3**	**3**	2	2	3	1	**3**	1	3	2	1	3	**12**	**A**
Procambarus clarkii	Red Swamp Crayfish	crustacean	**3**	**3**	1	3	3	1	**3**	1	3	1	1	3	**12**	**A**
Corbicula fluminea	Asian Clam	mollusc	**3**	**3**	1	2	1	1	**2**	1	2	1	3	3	**11**	**A**
Dreissena polymorpha	Zebra Mussel	mollusc	**3**	**3**	1	3	1	1	**3**	2	3	2	2	3	**12**	**A**
Carassius auratus	Goldfish/Prussian Carp	fish	**2**	**2**	1	3	3	3	**3**	1	1	1	2	2	**9**	**B**
Lepomis gibbosus	Pumpkinseed	fish	**2**	**3**	3	2	1	1	**3**	1	1	1	1	1	**9**	**B**
Misgurnus fossilis	European Weatherfish	fish	**2**	**2**	1	1	1	1	**1**	1	1	1	1	1	**6**	**C**
Pseudorasbora parva	Topmouth Gudgeon	fish	**2**	**3**	3	3	3	1	**3**	1	1	1	3	3	**11**	**A**
Salvelinus fontinalis	Brook Trout	fish	**1**	**3**	3	3	1	3	**3**	2	2	2	2	2	**9**	**B**
Sander lucioperca	Pikeperch (Zander)	fish	**3**	**3**	3	3	1	1	**3**	1	1	1	2	2	**11**	**A**
Silurus glanis	European (Wels) Catfish	fish	**2**	**2**	3	3	3	1	**3**	1	1	1	3	3	**10**	**B**
Alytes obstetricans	Midwife Toad	amphibian	**1**	**3**	1	1	2	1	**2**	1	1	1	2	2	**8**	**C**
Lithobates catesbeianus	American Bullfrog	amphibian	**2**	**3**	3	3	3	1	**3**	1	1	1	3	3	**11**	**A**
Triturus carnifex	Italian Crested Newt	amphibian	**2**	**3**	1	1	1	3	**3**	1	1	1	1	1	**9**	**B**
Xenopus laevis	African Clawed Frog	amphibian	**1**	**2**	3	2	2	1	**3**	1	1	1	2	2	**8**	**C**
Trachemys scripta	Common Slider Turtle	reptile	**2**	**3**	3	3	2	1	**3**	1	1	1	3	3	**11**	**A**
Trechemys scripta elegans	Red Eared Terrapin	reptile	**2**	**3**	1	D	2	1	**2**	1	1	1	1	1	**8**	**C**

Table A7. Scoring for invasiveness: terrestrial plants

Scientific name	English name	Group	1	2	3.1	3.2	3.3	3.4	3	4.1	4.2	4.3	4.4	4	Sum	Category
(e) Terrestrial plants																
Acaena novae-zelandiae	Pirri-Pirri-Bur	plant	**2**	**3**	-	3	1	1	**3**	2	2	1	1	2	**10**	**B**
Acer pseudoplatanus	Sycamore	plant	**3**	**3**	-	2	1	1	**2**	1	2	2	2	2	**10**	**B**
Ailanthus altissima	Tree Of Heaven	plant	**2**	**3**	-	3	1	1	**3**	2	2	2	2	2	**10**	**B**
Allium paradoxum	Few-Flowered Garlic	plant	**3**	**2**	-	2	1	1	**2**	1	1	2	1	2	**9**	**B**
Allium triquetrum	Three-Cornered Garlic	plant	**3**	**2**	-	2	1	1	**2**	1	1	2	1	2	**9**	**B**
Ambrosia artemisiifolia	Common Ragweed	plant	**2**	**1**	-	1	1	1	**1**	1	1	1	1	1	**5**	**C**
Buddleja davidii	Butterfly-Bush	plant	**3**	**2**	-	2	1	1	**2**	1	2	2	2	2	**9**	**B**
Carpobrotus edulis	Hottentot Fig	plant	**3**	**3**	-	3	1	1	**3**	3	3	3	2	3	**12**	**A**
Cornus sericea	Red-Osier Dogwood	plant	**2**	**2**	-	3	1	1	**3**	2	2	2	2	2	**9**	**B**
Cortaderia selloana	Pampas Grass	plant	**3**	**3**	-	2	1	1	**2**	2	2	2	2	2	**10**	**B**
C. x crocosmiiflora	Montbretia	plant	**3**	**2**	-	2	1	1	**2**	1	1	2	1	2	**9**	**B**
Disphyma crassifolium	Purple Dewplant	plant	**3**	**3**	-	3	1	1	**3**	2	2	2	2	2	**11**	**A**
Fallopia japonica	Japanese Knotweed S.L.	plant	**3**	**2**	-	3	1	2	**3**	2	3	2	2	3	**11**	**A**
Gaultheria shallon	Shallon	plant	**2**	**3**	-	3	1	1	**3**	1	1	2	1	2	**10**	**B**
Heracleum mantegazzianum	Giant Hogweed	plant	**3**	**3**	-	3	1	2	**3**	2	2	2	2	2	**11**	**A**
Hyacinthoides hispanica	Spanish Bluebell	plant	**2**	**3**	-	2	1	3	**3**	1	1	1	1	1	**9**	**B**
Impatiens glandulifera	Himalayan Balsam	plant	**3**	**3**	-	2	1	1	**2**	2	3	2	2	3	**11**	**A**
Myriophyllum aquaticum	Parrot's-Feather	plant	**3**	**2**	-	3	1	1	**3**	2	3	2	2	3	**11**	**A**
Oxalis pes-caprae	Bermuda Buttercup	plant	**3**	**2**	-	2	1	1	**2**	1	1	1	2	2	**9**	**B**
Paspalum paspalodes	Knotgrass	plant	**2**	**2**	-	2	1	1	**2**	2	2	2	2	2	**8**	**C**
Persicaria wallichii	Himalayan Knotweed	plant	**3**	**2**	-	3	1	1	**3**	2	2	2	2	2	**10**	**B**
Petasites fragrans	Winter Heliotrope	plant	**2**	**2**	-	3	1	1	**3**	2	2	2	2	2	**9**	**B**
Prunus serotina	Black Cherry	plant	**2**	**2**	-	2	1	1	**2**	2	2	3	2	3	**9**	**B**
Quercus cerris	Turkey Oak	plant	**3**	**3**	-	2	2	1	**2**	2	2	2	2	2	**10**	**B**
Quercus ilex	Evergreen Oak	plant	**3**	**3**	-	3	1	1	**3**	1	2	2	2	2	**11**	**A**
Rhododendron ponticum	Rhododendron	plant	**2**	**3**	-	3	1	1	**3**	3	3	3	2	3	**11**	**A**
Rosa rugosa	Japanese Rose	plant	**2**	**3**	-	3	1	1	**3**	2	3	2	2	3	**11**	**A**

Table A8. Scoring for invasiveness: terrestrial animals

Scientific name	English name	Group	1	2	3.1	3.2	3.3	3.4	3	4.1	4.2	4.3	4.4	4	Sum	Category
(f) Terrestrial animals																
Arthurdendyus triangulata	New Zealand Flatworm	flatworm	**2**	**3**	3	D	U	U	**3**	L	L	1	3	3	**11**	**A**
Anoplophora chinensis	Citrus Longhorn Beetle	insect	**2**	**2**	3	D	U	U	**3**	1	L	1	1	2	**9**	**B**
Harmonia axyridis	Harlequin Ladybird	insect	**3**	**3**	3	3	1	1	**3**	1	1	1	L	2	**11**	**A**
Thaumetopoea processionea	Oak Processionary Moth	insect	**2**	**3**	3	D	U	U	**3**	1	1	1	1	1	**9**	**B**
Agapornis roseicollis	Rosy-Faced Lovebird	bird	**3**	**3**	U	L	D	D	**2**	U	1	U	U	1	**9**	**B**
Aix galericulata	Mandarin Duck	bird	**3**	**3**	1	L	D	1	**2**	1	1	1	1	1	**9**	**B**
Aix sponsa	Wood Duck	bird	**3**	**3**	U	L	D	1	**2**	1	1	1	1	1	**9**	**B**
Alectoris chukar	Chukar Partridge	bird	**3**	**2**	2	L	D	1	**2**	1	1	1	1	1	**8**	**C**
Alectoris rufa	Red-Legged Partridge	bird	**3**	**2**	2	L	D	1	**2**	1	1	1	1	1	**8**	**C**
Alopochen aegyptiaca	Egyptian Goose	bird	**3**	**3**	1	2	D	1	**2**	2	2	1	L	2	**10**	**B**
Anas cyanoptera	Cinnamon Teal	bird	**3**	**3**	U	U	D	1	**1**	1	1	1	1	1	**8**	**C**
Anas discors	Blue-Winged Teal	bird	**3**	**3**	U	U	D	2	**2**	1	1	1	1	1	**9**	**B**
Anser albifrons	Greater White-Fronted Goose	bird	**3**	**3**	1	1	D	1	**1**	1	1	1	1	1	**8**	**C**
Anser brachyrhynchus	Pink-Footed Goose	bird	**3**	**3**	1	1	D	1	**1**	1	1	1	1	1	**8**	**C**
Anser cygnoides	Swan Goose	bird	**3**	**3**	D	2	D	2	**2**	D	D	D	D	0	**8**	**C**
Anser erythropus	Lesser White-Fronted Goose	bird	**3**	**3**	1	1	D	1	**1**	1	1	1	1	1	**8**	**C**
Anser fabalis	Bean Goose	bird	**3**	**3**	1	1	D	1	**1**	1	1	1	1	1	**8**	**C**
Anser indicus	Bar-Headed Goose	bird	**3**	**3**	1	L	D	1	**2**	D	D	D	D	0	**8**	**C**
Aratinga acuticaudata	Blue-Crowned Parakeet	bird	**3**	**3**	L	L	1	U	**2**	1	L	1	L	2	**10**	**B**
Athene noctua	Little Owl	bird	**3**	**3**	2	2	D	1	**2**	1	1	1	2	2	**10**	**B**
Branta canadensis	Canada Goose	bird	**3**	**3**	2	2	L	2	**2**	3	2	L	L	3	**11**	**A**
Branta leucopsis	Barnacle Goose	bird	**3**	**3**	2	1	D	2	**2**	L	1	1	1	2	**10**	**B**
Branta ruficollis	Red-Breasted Goose	bird	**3**	**3**	1	1	D	1	**1**	D	D	D	D	0	**7**	**C**
Bubo bubo	Eurasian Eagle-Owl	bird	**3**	**3**	2	2	D	1	**2**	1	1	1	L	2	**10**	**B**
Buteo jamaicensis	Red-Tailed Hawk	bird	**3**	**3**	L	L	D	2	**2**	1	1	1	1	1	**9**	**B**
Cairina moschata	Muscovy Duck	bird	**3**	**2**	1	L	D	1	**2**	1	1	1	1	1	**8**	**C**
Chen caerulescens	Snow Goose	bird	**3**	**3**	1	L	D	1	**2**	D	D	D	D	0	**8**	**C**
Chen canagica	Emperor Goose	bird	**3**	**3**	1	D	D	1	**1**	D	D	D	D	0	**7**	**C**
Chen rossii	Ross's Goose	bird	**3**	**3**	1	L	D	1	**2**	D	D	D	D	0	**8**	**C**

Table A8 (continued). Scoring for invasiveness: terrestrial animals

Scientific name	English name	Group	1	2	3.1	3.2	3.3	3.4	3	4.1	4.2	4.3	4.4	4	Sum	Category
Chloephaga picta	Upland Goose	bird	**3**	**3**	1	L	D	1	**2**	1	1	1	1	1	**9**	**B**
Chrysolophus amherstiae	Lady Amherst's Pheasant	bird	**3**	**3**	2	1	D	1	**2**	1	2	1	1	2	**10**	**B**
Chrysolophus pictus	Golden Pheasant	bird	**3**	**3**	2	1	D	1	**2**	1	2	1	1	2	**10**	**B**
Colinus virginianus	Northern Bobwhite	bird	**3**	**2**	1	1	D	1	**1**	1	1	1	1	1	**7**	**C**
Cygnus atratus	Black Swan	bird	**3**	**3**	D	L	D	2	**2**	2	1	1	1	2	**10**	**B**
Cygnus buccinator	Trumpeter Swan	bird	**3**	**3**	D	L	D	L	**2**	1	1	1	1	1	**9**	**B**
Gallus gallus	Red Junglefowl	bird	**3**	**3**	1	1	D	1	**1**	1	1	1	1	1	**8**	**C**
Garrulax formosus	Red-Winged Laughingthrush	bird	**3**	**3**	1	L	D	1	**2**	1	1	1	L	2	**10**	**B**
Lophura nycthemera	Silver Pheasant	bird	**3**	**3**	2	1	D	1	**2**	1	2	1	1	2	**10**	**B**
Melopsittacus undulatus	Budgerigar	bird	**3**	**3**	2	2	D	1	**2**	1	1	1	L	2	**10**	**B**
Myiopsitta monachus	Monk Parakeet	bird	**3**	**3**	L	L	1	U	**2**	1	L	1	L	2	**10**	**B**
Netta rufina	Red-Crested Pochard	bird	**3**	**3**	1	1	D	1	**1**	1	1	1	1	1	**8**	**C**
Numida meleagris	Helmeted Guineafowl	bird	**3**	**2**	1	1	D	1	**1**	1	1	1	1	1	**7**	**C**
Nycticorax nycticorax	Black-Crowned Night Heron	bird	**3**	**3**	U	U	D	1	**1**	D	D	D	D	0	**7**	**C**
Oxyura jamaicensis	Ruddy Duck	bird	**3**	**3**	1	1	D	3	**3**	1	1	1	L	2	**11**	**A**
Pavo cristatus	Indian Peafowl	bird	**3**	**3**	1	1	D	1	**1**	1	1	1	1	1	**8**	**C**
Psittacula eupatria	Alexandrine Parakeet	bird	**3**	**3**	L	L	1	U	**2**	1	L	1	L	2	**10**	**B**
Psittacula krameri	Rose-Ringed Parakeet	bird	**3**	**3**	2	2	2	U	**2**	1	2	1	2	2	**10**	**B**
Syrmaticus reevesii	Reeves's Pheasant	bird	**3**	**3**	L	1	D	1	**2**	1	1	1	1	1	**9**	**B**
Tadorna ferruginea	Ruddy Shelduck	bird	**3**	**3**	1	L	D	1	**2**	D	D	D	D	0	**8**	**C**
Alopex lagopus	Arctic Fox	mammal	**2**	**3**	3	L	L	2	**3**	1	1	1	L	2	**10**	**B**
Capra ibex	Ibex	mammal	**1**	**2**	2	L	L	2	**2**	1	1	2	L	2	**7**	**C**
Cervus canadensis	Wapiti	mammal	**2**	**3**	3	L	L	3	**3**	2	2	2	L	2	**10**	**B**
Cervus nippon	Sika Deer	mammal	**3**	**3**	3	L	L	3	**3**	2	2	2	L	2	**11**	**A**
Cynomys ludovicianus	Black-Tailed Prairie Dog	mammal	**1**	**2**	3	L	L	1	**3**	2	2	2	L	2	**8**	**C**
Glaucomys sp.	Flying Squirrel	mammal	**2**	**2**	2	L	L	1	**2**	1	1	1	L	2	**8**	**C**
Glis glis	Fat Dormouse	mammal	**2**	**2**	2	L	L	1	**2**	1	1	1	U	1	**7**	**C**

Table A8 (continued). Scoring for invasiveness: terrestrial animals

Scientific name	English name	Group	1	2	3.1	3.2	3.3	3.4	3	4.1	4.2	4.3	4.4	4	Sum	Category
Hemitragus jemlahicus	Himalayan Tahr	mammal	**1**	**2**	2	L	L	1	**2**	1	1	2	L	2	**7**	**C**
Hydropotes inermis	Chinese Water Deer	mammal	**3**	**3**	2	L	L	1	**2**	1	2	2	L	2	**10**	**B**
Hystrix brachyura	Hialayan Porcupine	mammal	**1**	**2**	2	L	L	1	**2**	1	2	1	L	2	**7**	**C**
Hystrix cristata	Crested Porcupine	mammal	**1**	**2**	2	L	L	1	**2**	1	2	1	L	2	**7**	**C**
Lepus californicus	Black-Tailed Jack Rabbit	mammal	**2**	**2**	2	L	L	1	**2**	1	2	2	L	2	**8**	**C**
Macropus rufogriseus	Red Necked Wallaby	mammal	**2**	**2**	1	L	U	1	**2**	1	1	1	L	2	**8**	**C**
Meriones unguiculatus	Mongolian Gerbil	mammal	**2**	**1**	1	U	L	1	**2**	1	1	1	U	1	**6**	**C**
Mesocricetus auratus	Golden Hamster	mammal	**2**	**2**	1	U	L	1	**2**	1	1	1	U	1	**7**	**C**
Moschus moschiferus	Siberian Musk Deer	mammal	**1**	**3**	2	L	L	1	**2**	1	1	2	L	2	**8**	**C**
Muntiacus muntjak	Common Muntjac	mammal	**2**	**3**	2	L	L	1	**2**	1	1	2	L	2	**9**	**B**
Muntiacus reevesi	Reeve's Muntjac	mammal	**3**	**3**	2	L	L	1	**2**	1	1	3	3	3	**11**	**A**
Mustela vison	American Mink	mammal	**3**	**3**	3	L	L	1	**3**	1	1	1	L	2	**11**	**A**
Myocastor coypus	Coypu	mammal	**3**	**3**	2	U	L	1	**2**	3	3	2	L	3	**11**	**A**
Nyctereutes procyonoides	Raccoon Dog	mammal	**1**	**3**	2	L	L	1	**2**	1	1	1	L	2	**8**	**C**
Odocoileus virginianus	White Tailed Deer	mammal	**1**	**3**	2	L	L	1	**2**	1	1	2	L	2	**8**	**C**
Ondatra zibethicus	Musk Rat	mammal	**2**	**3**	2	L	L	1	**2**	3	3	3	L	3	**10**	**B**
Pecari tajacu	Collared Peccary	mammal	**1**	**2**	3	L	L	1	**3**	1	3	2	L	3	**9**	**B**
Procyon lotor	Raccoon	mammal	**2**	**3**	3	L	L	1	**3**	1	1	1	L	2	**10**	**B**
Rangifer tarandus	Reindeer	mammal	**1**	**2**	2	L	L	1	**2**	1	1	1	U	1	**6**	**C**
Rattus norvegicus	Brown Rat	mammal	**3**	**3**	3	L	L	1	**3**	1	2	1	L	2	**11**	**A**
Sciurus carolinensis	Grey Squirrel	mammal	**3**	**3**	3	L	L	1	**3**	1	1	1	L	2	**11**	**A**
Sigmodon hispidus	Cotton Rat	mammal	**2**	**2**	2	L	L	1	**2**	1	1	1	U	1	**7**	**C**
Sylvilagus floridanus	Easter Cottontail	mammal	**2**	**2**	2	L	L	1	**2**	1	2	2	L	2	**8**	**C**
Tamias sibiricus	Siberian Chipmunk	mammal	**3**	**3**	2	L	L	1	**2**	1	1	1	L	2	**10**	**B**
Tamias striatus	Eastern Chipmunk	mammal	**2**	**2**	2	L	L	1	**2**	1	1	1	L	2	**8**	**C**

Appendix 3. Possible indicators for birds

Species to be included

About 350 species of birds have been noted as introductions to Great Britain, mostly as occasional escapes of individual birds from captivity. For the purpose of producing an indicator this list of species can be substantially reduced, using the following criteria.

- Birds that have not laid eggs in the wild in Britain are excluded.
- Birds that are native anywhere in the UK are excluded.
- Birds noted as non-native breeding birds prior to 1500 are excluded (Mute Swan, Common Pheasant).
- Reintroduced species (Capercaillie, White-tailed Eagle, Goshawk, Great Bustard) are excluded.

Species that have formed mixed pairings are listed if they have paired with a native species (Blue-winged Teal, Red-tailed Hawk).

There are 45 species that meet these criteria (Table A9). Canada Goose and Red-legged Partridge have been breeding since the late 1600s and are the earliest post-1500 introductions. Several of these species have bred only sporadically, or were once established but now extinct. Northern Bobwhite is not listed by the BOU, but this is presumably an oversight, since there were established populations for a number of decades, although these are now extinct. (Budgerigar, listed by the BOU, is a comparable example).

Approaches to building an indicator – parametric

Most indicators developed so far for birds draw on population indices that are set to the same base year. The geometric mean index value is then taken, across the species that form the indicator, year by year, to create an indicator from the average index values. A similar numerical approach would be possible for non-native birds, although only for ten species for which suitable numerical data are available (Fig A1). The main source for these data is the Breeding Bird Survey, which started in 1994.

Where BBS index values are available, no further processing is needed. For a few species, a better measure of population change can be obtained by calculating the total number of birds counted on BBS squares in a year and dividing by the total number of squares counted. The resulting data may contain zeros that are not compatible with taking a geometric mean.

Species	*Scientific name*	*BOU categories*
Helmeted Guineafowl	*Numida meleagris*	E*
Northern Bobwhite	*Colinus virginianus*	
Chukar Partridge	*Alectoris chukar*	E*
Red-legged Partridge	*Alectoris rufa*	C1E*
Red Junglefowl	*Gallus gallus*	E
Silver Pheasant	*Lophura nycthemera*	E*
Reeves's Pheasant	*Syrmaticus reevesii*	E*
Golden Pheasant	*Chrysolophus pictus*	C1E*
Lady Amherst's Pheasant	*Chrysolophus amherstiae*	C6E*
Indian Peafowl	*Pavo cristatus*	E*
Black Swan	*Cygnus atratus*	E*
Trumpeter Swan	*Cygnus buccinator*	E
Swan Goose	*Anser cygnoides*	E*
Pink-footed Goose	*Anser brachyrhynchus*	AE*
Bean Goose	*Anser fabalis*	AE
Greater White-fronted Goose	*Anser albifrons*	AE*
Lesser White-fronted Goose	*Anser erythropus*	AE*
Bar-headed Goose	*Anser indicus*	E*
Snow Goose	*Chen caerulescens*	AC2E*
Ross's Goose	*Chen rossii*	E*
Emperor Goose	*Chen canagica*	E*
Canada Goose	*Branta canadensis*	C2E*
Barnacle Goose	*Branta leucopsis*	AC2E*
Red-breasted Goose	*Branta ruficollis*	AE*
Upland Goose	*Chloephaga picta*	E*
Egyptian Goose	*Alopochen aegyptiaca*	C1E*
Ruddy Shelduck	*Tadorna ferruginea*	BDE*
Muscovy Duck	*Cairina moschata*	E*
Wood Duck	*Aix sponsa*	E*
Mandarin Duck	*Aix galericulata*	C1E*
Blue-winged Teal	*Anas discors*	AE
Cinnamon Teal	*Anas cyanoptera*	E*
Red-crested Pochard	*Netta rufina*	AC2E*
Ruddy Duck	*Oxyura jamaicensis*	C1E*
Black-crowned Night Heron	*Nycticorax nycticorax*	AE*
Red-tailed Hawk	*Buteo jamaicensis*	E
Budgerigar	*Melopsittacus undulatus*	E*
Rosy-faced Lovebird	*Agapornis roseicollis*	E
Alexandrine Parakeet	*Psittacula eupatria*	E*
Rose-ringed Parakeet	*Psittacula krameri*	C1E*
Blue-crowned Parakeet	*Aratinga acuticaudata*	E*
Monk Parakeet	*Myiopsitta monachus*	E
Eurasian Eagle-Owl	*Bubo bubo*	E*
Little Owl	*Athene noctua*	C1
Red-winged Laughingthrush	*Garrulax formosus*	E*

Table A9. Breeding non-native bird species in Great Britain; BOU categories (BOU, 2009) are as follows:- A naturally occurring since 1950; B naturally occurring but not since 1950; C established introductions; D doubtful; E non-native, not established.

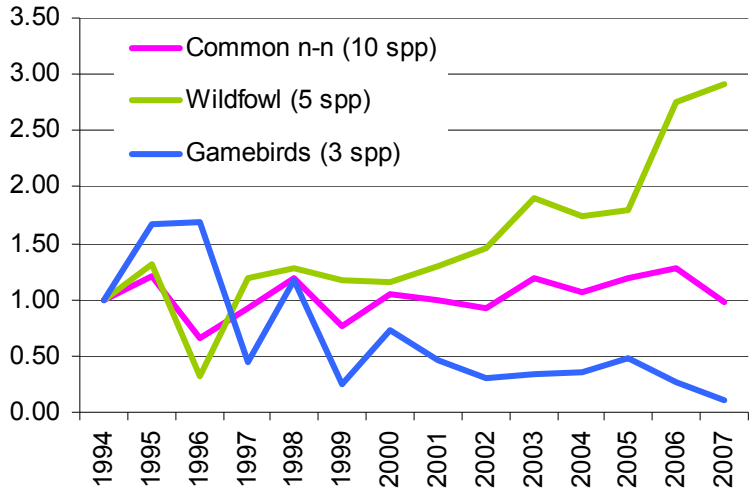

Figure A1. Indexed geometric mean frequencies of ten common non-native breeding birds in Great Britain

A further 25 or so species can also be given a numerical treatment, based not on population index values but on actual estimates of breeding numbers assembled by the Rare Breeding Birds Panel. These data cover the years 1996 to 2005, with figures for later years not yet published. The species that can be included are those for which RBBP recorded nesting at least once during their period of recording, but for which no better trend estimates are available (e.g. through BBS). In general they are species that nested either sporadically or in numbers less than ten pairs. The approach taken is to sum all the pairs of the relevant species across each year, and then to scale these totals to 1 in an arbitrary datum year – this ensures that every species has equal weight in the indicator. Results are shown in Fig A2.

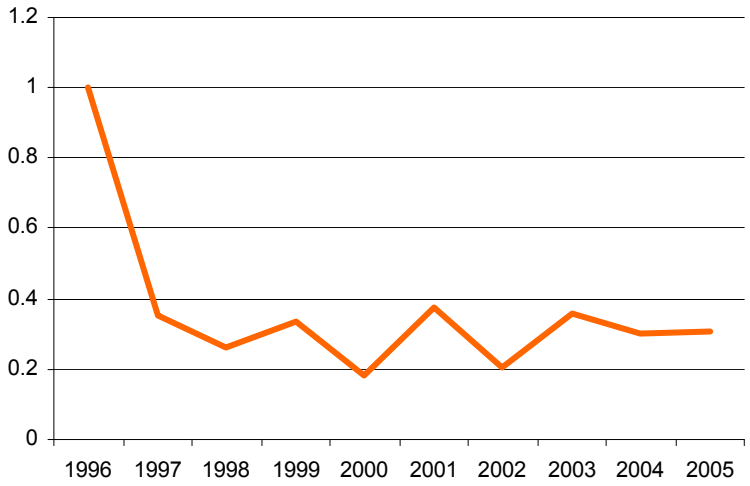

Figure A2. Indexed total of non-native breeding birds in Great Britain, drawn from annual estimates of population size (mostly from RBBP)

Species that did not breed during the timespan of the indicator and those are data deficient (Red Junglefowl) are necessarily excluded. The high initial value of this indicator is due to high counts of Snow Goose, Red-crested Pochard and Black-crowned Night-heron in 1996.

Reliability of data varies considerably between species. Any species for which data were considered unreliable would be excluded from the indicator, but the species to be excluded on this criterion might change between years, making it difficult to maintain consistency over time.

Approaches to building an indicator – non-parametric

A variety of indicators are possible that demand less of the data, for example the total of species known to have bred in each year, or each decade. This would use data from the full list of 46 species (together with any additions in future years), but would not reflect population change (Fig. A3). Such an indicator could span many decades. It would show relatively low annual values before 1996, when RBBP began reporting records of non-native breeding species, but decadal values would be less affected.

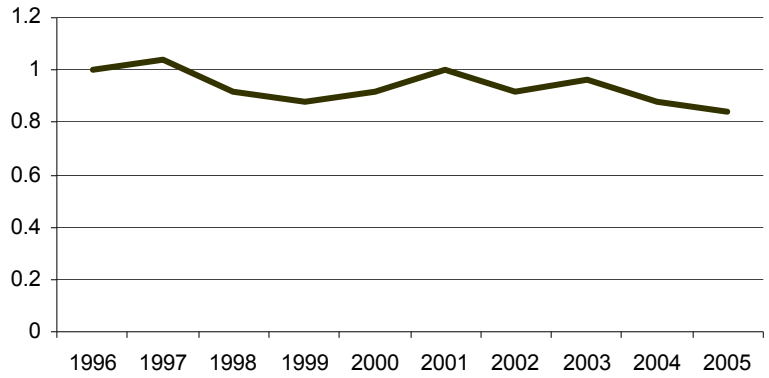

Figure A3. Index of species richness of rare breeding non-native birds in Great Britain, 1996–2005