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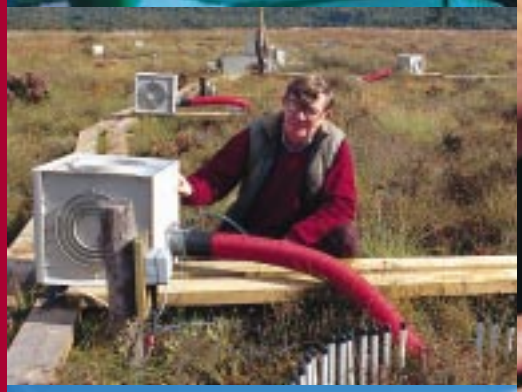

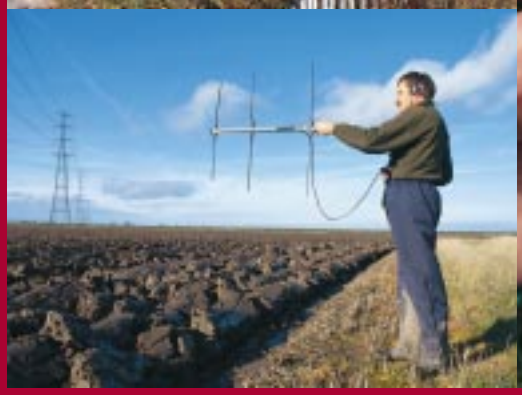

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Audit of non-native species in England

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Summary

This paper presents the results of an audit of non-native species in England, including all taxa that are found in the wild. It excludes garden plants, animals that breed only in greenhouses, pests of stored crops, human parasites, and pests of human habitation unless they also escape into the wider environment.

Data were collated by specialists from the Centre for Ecology and Hydrology (CEH), the Central Science Laboratory (CSL), the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and the Botanical Society of the British Isles (BSBI).

The main product is a tabulation listing 2721 species and hybrids, each represented by a row with 48 columns giving names and attributes. Results from this tabulation are reported here, generally concentrating on 1413 species and hybrids selected to be of most significance (the 'shorter list'). Most of the omitted species and hybrids are for rare vascular plants that are either casual or not properly naturalized, or are scarce non-clonal hybrids with little environmental significance.

An introduced species is defined as one that was either brought to the study area by humans, intentionally or unintentionally, or one that has come into the area without human intervention, but from an area in which it is non-native. Also included in the study are hybrids with a non-native parent and new species arising from such hybrids.

Flowering plants, with a total of 1798 entries, are by far the most numerous group of non-native species. The most numerous marine group is the red algae Rhodophyceae, with 12 species. On land, the most numerous animal groups were the Homoptera (bugs and aphids) with 102 species and Coleoptera (beetles) with 101 species. Next in order were Lepidoptera (butterflies and moths) with 48 species, and non-marine molluscs with 43 species.

Out of the 1413 taxa in the shorter list, 1294 have been introduced to England. There is doubt about the status of 98 others. Ten are hybrids or derive from hybrids. Nine species are former natives that have been reintroduced to England.

The major pathway of introduction for marine organisms, animals and microbes is accidental transport. Terrestrial and freshwater plants, on the other hand, are mostly escapes from cultivation.

The main continents of origin are Asia and North America for marine organisms, Europe and North America for non-marine animals, and predominantly Europe for plants.

For animal groups, the second half of the 20th century was the major period of introduction, except for fishes, with over 65% introduced by 1900. For plants, the main period of introduction was the 18th and 19th centuries.

Of the species in the shorter list, the large majority, 1177 out of 1413, are considered to be established in England. This does not reflect the overall balance in the environment, because many sporadically occurring plants ('casuals') have been deliberately excluded.

Except for vascular plants, there is a very marked difference between numbers of species recorded in the south and in the north. In the North East region, there are 91 non-native terrestrial and freshwater animals, as opposed to 278 in the South East region. The difference for vascular plants is smaller, with 514 species in the North East region, and 655 in the South East region.

Introduced freshwater and terrestrial animals occupy a wide variety of habitats, especially surface waters, woodland, and cultivated land. Plants are completely different, being strongly concentrated on cultivated, built and derelict land. Marine organisms are not concentrated in one particular habitat. The terrestrial habitats with by far the lowest number of introduced species are the wetlands - bogs, fens and marshes.

The economic and environmental effects of introduced species are generally unfavourable. Only four animals were rated as having a strongly positive economic effect, namely the quarry species common pheasant *Phasianus colchicus*, greylag goose *Anser anser* and red-legged partridge *Alectoris rufa*, and the predatory beetle *Rhizophagus grandis*, which is a biocontrol agent of the great spruce bark beetle *Dendroctonus micans*. Many plants of wild or wild-type seed origin are cultivated, especially by foresters; these have a strong positive economic impact.

Nineteen species have been identified as having strongly negative environmental impacts. The animals include six mammals, two birds and one fish. The other two are the slipper limpet *Crepidula fornicata*, and the Chinese mitten crab *Eriocheir sinensis*, which spends most of its life in freshwater and estuaries. Three pathogens were noted for their major impact. Six vascular plants were in this category, but the number could be larger if different selection criteria were applied.

The majority of non-native species are not thought to be strongly increasing or decreasing. Twenty-eight plants are strongly decreasing, all but five of which were introduced before 1500. Only two animals are strongly decreasing, Carthusian snail *Monacha cartusiana* and the giant earwig *Labidura riparia*. Thirty-six organisms are strongly increasing.

It is recommended that for the purposes of monitoring and control, the species identified as strongly increasing or with large negative impacts are given the greatest attention.

Contents

1 Introduction

Invasive non-native species are the second most significant cause of biodiversity loss on a global scale and probably the most significant cause of loss in simplified ecosystems such as oceanic islands (Williamson 1981). The threat from non-native species is increasing with the continued growth of global trade and tourism.

Most non-native species are not invasive since they do not pose a significant threat to biodiversity (Williamson 1996). Indeed, only a small minority of non-native species are invasive and threatening. To understand the magnitude of the threat in England, we need data on the flora and fauna of non-native species, including those that are currently invasive, as well as those that invaded in the past or are likely to do so in the future.

A first step is to make a list of non-native species. Indeed, monitoring the biota is seen as one of the three key stages in the process for dealing with invasive species agreed under the Convention on Biological Diversity (CBD). However, despite the generally excellent recording systems for many taxa in Great Britain, non-native species have often been under-recorded during ecological surveys and distributional inventories. Many naturalists view non-natives as not worth recording, or have recorded them systematically only in recent years.

The recognition of introduced species is often problematical, and a critical approach is needed in assessing historical trends in species frequency because of changes in recording practice. As well as problems of under-recording, data for many non-native species are held by various government agencies, county recorders, wildlife trusts, campaigning organizations and professional bodies across the UK devolved administrations. Furthermore, there are also limitations on the release of commercially sensitive data on some species (eg plant pests). These factors add to the complexity and cost of collating data.

A definitive list of non-native species in the UK does not exist. This would require an extensive audit of existing non-native species across all relevant taxa in all environments. Even if available, an audit that includes the potential risk each species poses would be needed to allow policy makers to prioritise which species require action or further research. It should also facilitate a gap analysis to identify conspicuous gaps in current knowledge or monitoring capacity. As a step in this direction, we have prepared this audit of non-native species in England.

2 Aims

The aim of the present project is to document the occurrence of non-native taxa in England, distinguishing those that are increasing or likely to increase from others that do not at present appear to be invasive. All multicellular organisms have been included, as well as a few micro-organisms.

A mere list of names and trends would be useful but would be impossible to interpret without further information. At the very least, one needs to know the taxonomic group (eg mammals, ferns, molluscs), the date and pathway of introduction, the native range and the present geographical distribution, supported by bibliographic references as to where the information was obtained.

It would be impracticable to list all non-native species and varieties present in gardens, aquaria and menageries. We have therefore included only species that either occur in the wild or which might threaten native terrestrial, freshwater and marine habitats, native fauna, commercial crops, domestic livestock or old buildings (eg termites). Excluded are pests of stored crops, human parasites, and pests of human habitation (eg thermophilous cockroaches) unless these are thought likely also to be found in the wild environment.

3 Methodologies of data collation

The main methodology of data collection was to identify non-native species in all taxonomic groups (limited as above), find a standard reference for each, and to extract the required information into a data table. A standard form was used, with headings that are listed below (Appendix 4). Spelling of names was checked against the nomenclature of the Biological Records Centre (held in an unpublished ORACLE table TAXA) and that of the National Biodiversity Network, which is available on http://www.searchnbn.net, but of which we held a copy in an Excel table.

The project was led and managed by Mark Hill (Biological Records Centre, Monks Wood). Chris Preston (BRC) and David Pearman (Botanical Society of the British Isles) collated data on vascular plants, assisted by Cassie Hoyland, who extracted data from the BRC database. At CSL, coordinated by Richard Baker, Richard Smith provided data on invertebrate terrestrial herbivores (plant pests), David Jones on plant pathogens, Niall Moore on mammals and David Parrott on birds. At CEFAS, Ian Laing and Jim Ellis provided data on marine animals and plants, Gordon H. Copp on freshwater fishes, and Matt Longshaw on diseases of freshwater organisms. Peter Chandler added data on flies. The remaining terrestrial and freshwater animals were the responsibility of Gavin Broad (BRC).

4 Data searched

For many groups there is a recent standard reference. For marine species, the review of Eno and others (1997) is a good starting point. For terrestrial and freshwater vertebrates, the older literature was well covered by Lever (1977). Non-native vascular plants, which are by far the largest category, were enumerated in detail in the *New Atlas of the British and Irish Flora* (Preston, Pearman & Dines 2002). Many species additional to those appearing in the printed *Atlas* text are included in the accompanying compact disk (CD). Several other groups are treated in atlases, for example seaweeds (Hardy & Guiry 2003), amphibians and reptiles (Arnold 1995), bryophytes (Hill, Preston & Smith 1991, 1992, 1994), some beetle groups (Alexander 2003) and fish (Davies and others 2004).

In addition to these sources, we have made much use of checklists. Web-based lists were especially useful for beetles and fungi, for which lists are published on the websites of *The Coleopterist* http://www.coleopterist.org.uk and the British Mycological Society http://194.203.77.76/fieldmycology/ . The British Ornithologists' Union also publishes the official British list of birds, including all non-native breeding species on its website. Several identification manuals were consulted, for example those of Goater (1986) for pyralid moths, Paton (1999) for liverworts and Smith (2004) for mosses.

Together with these major sources, numerous minor sources and individual papers reporting the occurrence of non-native organisms are listed in the bibliography and cross-referenced to species in the main database.

5 Assumptions and definitions used

5.1 Non-native species

The definition of a non-native species is that in the Defra (2003) *Review of non-native species policy*, namely:

> A species introduced (ie by human action) outside its natural past or present distribution.

Because of the differing mobility of species and the differing quality of evidence available for the various taxonomic groups, a uniform process of categorization has not been possible. Highly-mobile animals may appear as in England as vagrants, as well as having breeding populations derived from introductions. Their status is then less clear than that of terrestrial mammals and amphibians. The process by which we have categorized species as non-native is explained in more detail below.

5.2 Species naturalized or occurring in the wild

Several published definitions refer to species occurring 'in the wild'. The British Ornithologists' Union definitions refer to introduced species as 'naturalised'. For plant species, which may be very long-lived, it is customary to have a category 'persisting', ie released into the countryside, persisting for five or more years, but not effectively reproducing. Many such species, especially forest trees, are included in the standard floras, and they have been retained for the purposes of the audit of aliens. Effectively, a species is deemed to be naturalized if it occurs as a self-sustaining population, persisting for more than four years, not dependent on repeated reintroduction.

For animals, self-sustaining populations are those that breed. Some plants, including natives, can sustain themselves as clones that do not reproduce except vegetatively.

Many naturalized species and some natives are confined to man-made habitats such as farmland, or the vicinity of buildings. Rather than define what is meant by 'in the wild', we have explicitly stated that species should occur outside buildings, captivity or cultivation. Pests of agriculture are included in the main part of the database. Garden pests such as the lily beetle *Lilioceris lilii* are included in the database but reported separately (Appendix 5).

Human activity also results in the introduction of many native plants and animals to new sites in England. Farmers sow a vast acreage of perennial ryegrass *Lolium perenne*; foresters plant large areas of pedunculate oak *Quercus robur*; gardeners plant yew *Taxus baccata* for hedging; anglers stock brown trout *Salmo trutta*; and sporting estates augment the population of grey partridge *Perdix perdix*. None of these species nor the many others that are subject to such treatment are listed in the database.

5.3 Type of non-nativeness

Most aliens are introductions. Some are reintroductions. For less well known taxa, there is often doubt as to whether a species that has newly arrived is native or alien. The category 'Newly arrived' is used for these. Two new plant species have arisen by hybridization between a native and an alien. These are listed also.

F Formerly native (extinct as a native but present as introduced populations, commonly called re-introductions; these may be deliberate or accidental and may be genetically distinct from the original population).

G Native species with large addition from domestic or non-native stock.

H Spontaneous hybrid between native and introduced taxa.

I Introduction (introduction, not present as native in post-glacial period; this includes taxa that have spread naturally to Britain from introduced populations in Europe, eg Harlequin ladybird *Harmonia axyridis*).

J Native or alien, probably or possibly introduced.

K New species derived from a spontaneous hybrid in category H (eg as an allopolyploid).

N Newly arrived (taxa with an unknown history that appear to have arrived since 1950 and from their subsequent behaviour seem likely to be introductions).

5.4 Pathway of introduction

The pathway by which aliens reach England can vary. The following categories are recognized.

D Dispersed - natural dispersal to England from introduced population elsewhere in Europe

DT Dispersed and/or transported

E Escape from captivity/gardens/agriculture/other culture

ER Escaped and/or released

ET Escaped or transported

H Hybrid - spontaneously generated hybrid, or species descended from a spontaneous hybrid

R Released - deliberate release/planting in wild

RT Released and/or accidentally transported

T Transported - accidentally transported to England

U Unknown.

5.5 Marine species

The vertebrate fauna of the British Isles is well documented, and no species of fully marine vertebrate is considered as non-native. This is largely because the British Isles are at a

biogeographical boundary between northern (boreal and boreo-Arctic) and southern (Lustitanian) provinces. Many species of fish, as well as cetaceans and sea turtles have regularly been recorded from the seas of the British Isles. These are regarded as vagrants rather than non-natives. Such vagrant species are often pelagic, and tend to be distributed either to the north, south or west of the British Isles. Their occurrences in British waters are often sporadic and may be related to hydrographic or oceanographic conditions. Such vagrants tend neither to occur throughout the year nor to establish resident populations. Their occurrence in British waters is not associated with human activities.

Within estuarine areas, there are several species of non-native vertebrate that may occur, including pikeperch *Sander lucioperca*, which in England occurs mainly in freshwaters but is physiologically able to tolerate elevated salinities (Brown and others 2001). Certain non-native estuarine gobies have successfully established populations in northern European countries, and it is likely that such species will be reported from in UK estuaries in the near future.

Several species of marine invertebrates have been introduced either deliberately (eg commercially-harvested shellfish) or accidentally (eg through being carried on ships' hulls, in ballast water, or in association with those species deliberately introduced). Many non-native marine invertebrates are restricted to ports and inshore waters, and their distributions on the coast of England are centred around major ports (eg Southampton, Thames Estuary, Plymouth). This may be either because they have limited dispersal ability in their reproductive mode or because they are estuarine. Other marine invertebrates, however, have adapted to the inshore marine environments of the British Isles and have spread more widely.

In addition to those listed in the database, three marine species have been reported from nearby waters, but are not yet reported from the waters of England. Veined whelk *Rapana venosa* was recorded off Brittany in 1997; this species is known to be major predator of commercial shellfish. Red king crab *Paralithodes camtschaticus* was introduced into the Barents Sea (Joerstad and others 2002) and has since spread into Norwegian waters. There are unconfirmed reports that it has reached Shetland. The chironomid *Telmatogeton japonicus* occurs on buoys and on the shore along the coast of Belgium and must shortly reach English waters very soon.

5.6 Terrestrial and freshwater invertebrates

5.6.1 Species newly recorded as British, or described as new to science from British specimens

Because many invertebrate groups (particularly those in very species-rich orders of insects) are poorly known in comparison with birds or plants, there are many more opportunities for species to be added to the British list with no proof that they are native British species. The presumption is that they are native. For example, Shaw & Kasparyan (2003) newly recorded 20 species of parasitic wasps in Britain, including one previously known only from Latvia. These all belong to a little-studied subfamily within a little-studied family and it is assumed that they are all native. Likewise, for other very poorly studied taxa, eg the nematodes, so little information is available that it is rarely possible to state categorically whether a species is native or non-native. However, with well-recorded groups, such as grasshoppers and crickets, recent introductions have been noticed.

5.6.2 Species known in Britain only as pests of stored products or as commensals in houses

Groups such as stored product pests and cockroaches are not included in this audit as they are not found 'in the wild' in England. Either their food resources are not present outside buildings or they cannot survive or reproduce outdoors in the English climate. For example, certain bruchid beetles, such as *Callosobruchus chinensis*, can be pests in warehouses where the larvae develop inside dried pulses. These food sources are not available in the wild in Britain and the adults could probably not survive the winter.

5.7 Freshwater fish species

The definition of non-native species as regards freshwater fishes has recently been reviewed (Copp and others 2005a). Synonyms of 'non-native' include 'non-indigenous', 'alien' or 'exotic' and 'foreign'; these refer to a species, sub-species, race or variety (including gametes, propagules or part of an organism that might survive and subsequently reproduce) that does not occur naturally in a geographical area; ie it did not previously occur there or its dispersal into the area was mediated or facilitated directly or indirectly by humans, whether deliberately or unintentionally (see also Manchester & Bullock 2000; Scalera and Zaghi 2004). In England, some non-native freshwater fish species, from a biogeographical point of view, have exceptional status under current legislation (eg common carp *Cyprinus carpio*, ide *Leuciscus idus*, goldfish *Carassius auratus*, rainbow trout *Oncorhynchus mykiss*). These species are considered by the authorities to be 'ordinarily resident' in England, which *de facto* categorizes them as being 'naturalized'. For current purposes, there is no distinction between these species and other non-native fishes that were introduced to, and became established in, English waters during the same era (eg pikeperch *Sander lucioperca,* European (wels) catfish *Siluris glanis*, pumpkinseed *Lepomis gibbosus*). For the purposes of this audit, all species not native to England are included. Of particular note as regards native/non-native status is the crucian carp *Carassius carassius*. This species was previously considered to be non-native to the British Isles (eg Maitland 1972), and indeed continues to be classed as such in rare cases (eg Maitland 2004). However, following assessment of archaeological evidence and pre-1960's distribution of freshwater fishes, Wheeler (1977, 2000) recognised as native to southeastern England. Therefore Crucian carp is excluded from this audit.

5.8 Birds

The British Ornithologists' Union (BOU) definitions for birds are given in Table 1. Categories A and B are natives. Category C corresponds to the one used here for aliens. Of the subdivisions listed there, the great majority have type of non-nativeness 'Introduction' in the system proposed here. However, category C3 'Naturalised re-establishments' corresponds to our category 'Formerly native'.

Table 1. British Ornithologists' Union categories for the official British list of birds (taken from http://www.bou.org.uk)

BOU category	Explanation, with names of subcategories for introduced species
A	Species which have been recorded in an apparently natural state at least once since 1 January 1950
B	Species which were recorded in an apparently natural state at least once up to 31 December 1949, but have not been recorded subsequently
C	Species that, although originally introduced by man, either deliberately or accidentally, have established breeding populations derived from introduced stock, that maintain themselves without necessary recourse to further introduction
C1	*Naturalised introductions* Species that have occurred only as a result of introduction. Eg Egyptian goose *Alopochen aegyptiacus*
C2	*Naturalised establishments* Species with established populations as a result of introduction by Man, but which also occur in an apparently natural state. Eg Canada goose *Branta canadensis*
C3	*Naturalised re-establishments* Species with populations successfully re-established by Man in areas of former occurrence. Eg red kite *Milvus milvus*
C4	*Naturalised feral species* Domesticated species with populations established in the wild. Eg rock dove *Columba livia*
C5	*Vagrant naturalised species* Species from established naturalised populations abroad. Eg possibly some/all ruddy shelducks *Tadorna ferruginea* occuring in Britain. There are currently no species in category C5
D	Species that would otherwise appear in Categories A or B except that there is reasonable doubt that they have ever occurred in a natural state. Category D species are included within the lists that follow. They do not form any part of the species totals, and are not regarded as members of the British List
E	Species that have been recorded as introductions, transportees or escapees from captivity, and whose breeding populations (if any) are thought not to be self sustaining. Category E species form no part of the British List

Because birds are generally very mobile and very popular, many species sit in two or more BOU categories. This is generally because (a) they have high vagrancy potential; (b) many species of birds are kept in captivity; and (c) reintroduction or augmentation programmes are more frequent than in other taxonomic groups.

'Alien' birds in Britain can be roughly divided into four categories, detailed below:

1. Species that occur in the England as part of their natural range but with feral breeding populations/attempts in England. These species, which include those in BOU categories A & C, are included from the database.
2. Species that occur naturally as vagrants but also with feral breeding populations/attempts. These species, which include those in BOU categories A & C, are included in the database.
3. Species that breed naturally in England but are also released or escape. These species are not included in the database. The species involved are osprey *Pandion haliaetus*, barn owl *Tyto alba*, grey partridge *Perdix perdix*, buzzard *Buteo buteo*, pochard *Aythya ferina*, pintail *Anas acuta*, wigeon *Anas penelope*, and mallard *Anas platyrhynchos*.
4. Species that have escaped and bred, on very few occasions. These species are not included as the potential list probably includes most birds kept in captivity in the UK, and

details are lacking at the present time. Species involved (data from the BOU website) include swan goose *Anser cygnoides*, Ross's goose *Anser rossii*, magellan goose *Chloephaga picta*, cinnamon teal *Anas cyanoptera*, northern bobwhite *Colinus virginianus*, rock partridge *Alectoris graeca*, silver pheasant *Lophura nycthemera*, purple swamp-hen *Porphyrio porphyrio* and red-headed Conure *Aratinga acuticaudata*.

5.9 Mammals, reptiles and amphibians

Non-native mammal, reptile and amphibian species are defined as species that, although originally introduced by man, either deliberately or accidentally, have established breeding populations derived from introduced stock, which maintain themselves without recourse to further introduction. Ancient introductions are omitted if there is doubt as to whether they were in fact introduced. This removes brown hare (*Lepus europaeus*) and harvest mouse (*Micromys minutus*), which are probably prehistoric introductions although possibly native. (The brown hare may even have been introduced more recently, by the Romans.)

Species that are recorded as escapes from captivity but which have not been proved breeding (eg coati, racoon) are not included. However, the red-eared terrapin *Trachemys scripta* is included, even though breeding is thought unlikely, as it has substantial populations which have been living in the wild for many years.

5.10 Vascular plants (terrestrial and freshwater)

The definition of non-native plants is that given by Preston, Pearman & Hall (2004), slightly reworded

> A non-native plant is one that was brought to the study area by man, intentionally or unintentionally, even if native to the source area or one that has come into the area without human intervention, but from an area in which it is non-native.

Preston, Pearman & Hall (2004) also distinguished *archaeophytes*, which are non-native plants that became established in the study area before 1500 (discovery of Americas by Europeans) from *neophytes*, which became established more recently. Many of these are listed in the current standard flora (Stace 1997) as natives, but are treated here simply as non-natives that arrived at an early date. In addition to the non-native species defined above, the audit includes reintroduced species that were formerly native, as well as spontaneous hybrids where one parent was alien and newly-evolved species resulting from such hybrids.

It was not practicable to include data on all the vascular plants. Information on most of these has been summarized by Clement & Foster (1994) and Ryves, Clement & Foster (1996), but even so the literature is scattered. Those plants with less than 50 recorded 10-km squares in Britain and Ireland have been omitted from the database. Exceptions were made for purple dewplant *Disphyma crassifolium*, which is locally abundant on some western coasts, and for large-flowered waterweed *Egeria densa* and floating pennywort *Hydrocotyle ranunculoides*, which have spread extensively since publication of the *New Atlas* (Preston, Pearman & Dines 2002). Although a few other exceptions could be found, the majority of omitted taxa are either very rare or are absent in the wild. Many are garden escapes or rare hybrids.

5.10.1 Archaeophytes

Non-native archaeophytes are defined by the following criteria:

- There should be no fossil evidence for the presence of archaeophytes in the Holocene before the Neolithic.
- Archaeophytes, like neophytes, are likely to be restricted to man-made habitats, or much more frequent in man-made than semi-natural habitats.
- Archaeophytes should have been recorded in the wild in Britain before AD 1700.
- Archaeophytes in Britain are likely to have had stable ranges since AD 1700, or to have increased or decreased in response to environmental change or human practices, but are unlikely to have expanded rapidly into previously available habitats.
- The native range of British archaeophytes in Europe is likely to be uncertain.
- Archaeophytes are likely to have spread to North America, Australia and New Zealand.

On this basis, Preston, Pearman & Hall (2004) derived a list of archaeophytes for Britain, which is used here. All British archaeophytes that have occurred in England are considered, including those that are now extinct.

5.10.2 Neophytes

In all but a few cases, data on the first occurrence of neophytes are available from the literature. These data from the historical record are published in the *New Atlas of the British and Irish Flora* (Preston and others 2002). We list all neophytes included in the *New Atlas* and its accompanying compact disk. The database does not distinguish between archaeophytes and neophytes as the date of first occurrence is given. Newly-discovered populations that may be native, eg the fern *Cystopteris diaphana* (Murphy & Rumsey 2005), are excluded.

5.10.3 Spontaneous hybrids and derived species

Spontaneous hybrids of native and alien taxa are listed, together with species subsequently derived from them. For example, Townsend's cord-grass *Spartina x townsendii*, and its derived allopolyploid common cord-grass *Spartina anglica*, are listed.

5.10.4 Plants introduced from other parts of the British Isles

Species such as strawberry-tree *Arbutus unedo* that are native in other parts of the British Isles (in this case Ireland; Stace 2005) but introduced in England are listed.

5.10.5 Deliberately introduced populations of formerly native species

Species such as Scots pine *Pinus sylvestris*, that were formerly native in England but were extinguished and subsequently reintroduced, are listed.

5.10.6 Casuals and planted species

Casuals, that persist for less than five years, are included, provided that they were listed in the *New Atlas* (Preston, Pearman & Dines 2002). Species planted in the countryside (but not gardens) are included, provided that they were listed in the *New Atlas.*

5.11 Bryophytes

Relatively few bryophytes are thought to have been introduced to England, but there is no currently agreed list of aliens. The wide world ranges and good dispersal powers of many taxa make it more difficult to recognize recently introduced bryophytes than vascular plant neophytes. In addition, the taxonomy of apparently introduced species is not always well known in their native ranges, so that some undoubtedly introduced species have been described from Britain and are apparently endemic. The standard British and Irish checklist (Blockeel & Long 1998) does not distinguish between native and introduced taxa. Crundwell (1992) listed introduced species, but since his time, some new species of questionable status have been discovered or described; Smith (2004) also comments on whether or not species are native. For the current project we have reviewed species that have been considered in the past as introductions, using a combination of four main criteria.

- **World range**. Introductions often show discontinuous ranges which (unlike the discontinuous ranges of many native oceanic species) are not easily explicable on ecological grounds.
- **Means of introduction**. It is possible to deduce the means of introduction of some species.
- **Habitat**. Some less successful introductions occur in most or all of their localities in artificial habitats such as gardens.
- **Spread.** The most successful introductions have spread markedly during the period of bryophyte recording. Although native species have also spread, there is often (although not always) an ecological explanation for their expansion.

Species are classified as ‘native’, ‘native or introduced’ and ‘introduced’.

5.12 Fungi (including lichens)

There are about 14,000 known fungi in Britain, and about 120 are added to the list annually. ‘Many common soil and dung saprobes must have had their natural ranges extended dramatically through human activity, with the spread of domesticated animals and crop plants as well as incidentally in soil attached to shoes’ (Cannon and others 2001). In addition to the saprophytic fungi, mycorrhizal and parasitic species have been introduced with their host species. ‘It will be observed’, remarks Dennis (1995) drily, ‘that the introduction of strict plant quarantine legislation has made no difference to the steady stream of immigrant fungi’. If the true total of introduced fungi were known, it would probably exceed that of all other groups with the possible exception of the flowering plants. However, it is quite impossible to list the majority of introductions, as the ancient introductions (and many introductions in more recent times) cannot now be recognized. The numerous coprophilous fungi illustrate the problem: which of those characteristically recorded on dung of domestic animals (especially cow and horse) were introduced with those species and which were native, occurring on the dung of ancestral species or of unrelated herbivores? There is no way of knowing. In

addition, the taxonomy of many groups of fungi is poorly known, and the scattered literature is not easily accessible to a non-specialist. There are additional difficulties in deciding from sparse published records whether fungi are present 'in the wild'; these difficulties apply to ecological groups as different as saprophytes of wood chips used as garden mulch and parasites of horticultural or agricultural plants. In view of these difficulties, some insuperable, others reflecting the time available for the audit, we have concentrated on covering a sample of well-recorded groups. Glasshouse aliens and weeds of mushroom compost are excluded.

Larger fungi have been recognized as introduced by mycologists using similar criteria to those used for bryophytes, as their conspicuous nature sometimes allows introduced species to be identified directly. Microfungi which are obligate parasites of non-native genera of vascular plants (and larger species with ectomycorrhizal associations which non-native tree genera) have been listed on the assumption that the fungus was introduced with the host, although one often cannot rule out the possibility that they spread naturally to the host after the introduction of the latter. Non-native genera of vascular plants are those that are non-native to Britain, rather than England. Thus the many fungi associated with *Pinus* are not listed even though *P. sylvestris* (native in Scotland) is introduced in England. Species associated with alien species in native genera (eg with *Acer pseudoplatanus*) are usually omitted unless there is a particularly strong case for their inclusion.

Species nomenclature follows the British Mycological Society (BMS) database, available on their website http://194.203.77.76/fieldmycology/BMSFRD/bmsfrd.asp).

The following groups have been covered:

Agarics and boleti (Basidiomycetes), species treated in the published volumes of the incomplete *British Fungus Flora Agarics and Boleti* (Orton 1986; Orton & Watling 1979; Watling 1970, 1982; Watling & Gregory 1987, 1989, 1993; Watling & Turnbull 1998). At the present time only very partial coverage of Basidiomycetes is possible. A new checklist of Basidiomycetes is in preparation and when published should enable the spreadsheet to be updated.

Gasteroid fungi, formerly recognised taxonomically as gasteromycetes but now recognised as modified Basidiomycetes, are treated by Pegler and others (1995).

Hypogeous fungi, including the 'true truffles' (Ascomycetes) and the 'false truffles' (Basidiomycetes), treated by Pegler and others (1993).

Rust fungi or Uredinomycetes (Basidiomycota) are treated by Henderson (2000) in a checklist which identifies introduced species. Casual introductions on cultivated species are excluded, but as noted above it is often difficult to know whether species are 'in the wild'. Our attitude to this group (and the Ustilagomycetes) has been relatively inclusive and self-sustaining outdoor populations on common garden plants have tended to be included even if the hosts are always cultivated.

Smut fungi or Ustilagomycetes (Basidiomycota) are treated by Mordue & Ainsworth (1984). See comments on Uredinomycetes above.

The 'vast and confusing assemblage' of the Ascomycetes provides a particular difficulty. Many are microfungi which are studied only by specialists and therefore poorly recorded. In

addition, the sexual or 'perfect' stages (teleomorphs) are often associated with introduced vascular plants and might be thought to be introductions, but many have conidial stages (anamorphs) which may occur on other substrates. Traditionally the anamorphs have been named separately in a parallel taxonomic treatment of Fungi Imperfecti. Although the modern view is that a single name should attach to the species, there are very many anamorphs where the claimed association with the teleomorph is rather speculative, or completely unknown, and there is always the possibility that the teleomorph stage of the life-cycle has been lost. In view of all these factors, it is easier to ask the question 'has the fungus been introduced with the host or has it colonised the introduced host from native anamorph stages?' than it is to answer it. Nevertheless, a number of ascomycetes listed by Dennis (1981) as introduced, or with such close associations with introduced vascular plants that they seem likely to have been introduced, have been listed. Poorly-known species, including some known only from a single collection, are omitted. Names in the check-list by Cannon and others (1985) are provided if they differ from those on the BMS website.

Ascomycetes include the great majority of lichenized fungi. There is no unequivocal example of an introduced lichen in Britain, although Gilbert (2000) lists four possible introductions in England, including the widespread *Lecanora conyzaeoides*, which expanded greatly in response to atmospheric pollution.

Very few 'Fungi imperfecti' are included.

In addition to these taxonomic sources, Dennis's (1995) list of the fungi of southeast England (Surrey, Sussex, Kent) has been consulted as a source of information on introduced macrofungi and the habitat of microfungi. (Glasshouse aliens are not included within the scope of this report but Dennis's list is a useful source should these need to be identified, especially as his area includes Kew Gardens.) Distributional data for many species are provided on the British Mycological Society's website. It should be noted that it is often difficult to distinguish between records from London (Lo) and SE England (SE) as the many records from Kew Gardens are reported as Lo if the locality is available but as SE if the only information available is 'Surrey'.

5.13 Myxomycetes

A recent handbook to the British and Irish myxomycetes is available (Ing 1999). The species are dispersed by spores, often by wind, and many have very wide or even subcosmopolitan distributions. It is difficult therefore to identify as aliens even species associated with non-native habitats, as their presence may result from natural dispersal. The occasional presence as casuals of tropical species such as *Physarum javanicum* during periods of warm weather is interpreted by Ing as demonstrating the effectiveness of this dispersal. There are some hothouse casuals recorded in Britain that are clearly introduced but these are outwith the scope of this project. We have included only a single introduced myxomycete, a tan-bark casual.

6 Limitations of the data

The data compiled for this audit reflect current knowledge, which is necessarily incomplete. The difficulty of knowing whether or not a species is non-native has been noted above and is made more difficult by the different criteria used for different groups. This means that many ancient introductions must undoubtedly have been omitted. The status of several newly-

introduced species in uncertain, either because they have not been refound or because it is not known whether populations are self-sustaining. In a few cases, confirmation of a past reported occurrence was impossible due to a lack of consent (from landowners) to access the site. The lack of a full enumeration of species in some difficult groups such as nematodes and parasitic wasps means that some new arrivals must inevitably have been omitted.

In the time available for this audit, it was not possible to search all possible sources. The non-native biota for some groups such as vascular plants is well documented. In many other groups, the question of whether or not a species is native has attracted little interest. Even if a standard checklist exists it may not highlight those species that are non-native or distinguish non-natives that have established breeding populations from those which have just been intercepted at the border. For some taxa, especially those of less interest to the general public and for whom identification can only be undertaken by specialists, eg the nematodes and plant pathogens, the problem is most acute. We must undoubtedly have omitted a number of species that are known to specialists to be non-native. Fortunately, we have had advice and help from many experts, so that the number of such omissions is probably small.

For well known groups, species' geographical distribution and economic and environmental impact are already documented, though some of these accounts made be based on anecdotal information. For species that are rare and apparently have little economic or environmental significance, our knowledge is often scanty. In tabulating economic and environmental impact, and sometimes in documenting current trends, we have in many cases had to rely on expert judgement. Although the experts would all agree, for example, that the Chinese muntjac deer *Muntiacus reevesi* has had a large negative environmental impact, the effects of other introductions such as sycamore *Acer pseudoplatanus* or European catfish *Silurus glanis* are harder to judge. Their effects are both positive and negative.

7 Key findings in terms of the numbers and impacts of non-native species on biodiversity

7.1 Totals in major categories

In all, 2721 non-native species were entered in the database (Table 2). Terrestrial plants are by far the largest category. Indeed, flowering plants (angiosperms) make up fully 1798 species, ie 73% of the total. Many more angiosperms could have been listed if we had based the enumeration on the standard catalogues of alien plants (Clement & Foster 1994; Ryves, Clement & Foster 1996) rather than the *New Atlas* (Preston, Pearman & Dines 2002). Marine species are a relatively small proportion of the total, 2.7% in all.

A very interesting category consists of animals and fungi that exist in gardens and towns but are not known to have spread to the wild (Table 3; Appendix 5). Several of these are polyphagous herbivores elsewhere in their range, and therefore have the potential to switch host in Britain. At least one species, the rapidly-increasing horse chestnut leaf miner *Cameraria ohridella*, was in this category until 2004, but since then it has been found in woods removed from human habitation. The species in Appendix 5 are omitted from the statistics set out in Tables 4 to 14, but some of them are likely in future affect wild plants in England.

When garden animals and fungi and the rarer alien vascular plants are excluded, the total number of species falls to 1413 (Table 4), about half the number in the full enumeration. Results for this subset are analysed in more detail below.

Table 2. Numbers of alien species in major taxonomic groups

Taxonomic group	Number	Taxonomic group	Number
marine sponges	-	insects - butterflies and moths	48
marine coelenterates	3	insects - caddis flies	-
marine molluscs	10	insects - crickets and grasshoppers	1
marine crustaceans	12	insects - damselflies & dragonflies	-
diadromous crustaceans	1	insects - true bugs	102
marine annelids	9	insects - true flies	52
echinoderms	-	insects - other insects	9
marine bryozoans	1	amphibia	8
tunicates and cephalochordates	2	reptiles	4
other marine invertebrates	1	freshwater fishes	33
marine and estuarine fish	-	diadromous fishes	5
marine and estuarine mammals	-	birds	38
Rhodophyceae	12	non-marine mammals	20
Phaeophyceae	2	non-marine algae	3
Chlorophyceae	3	stoneworts	-
Xanthophyceae	-	mosses	10
other marine plants	8	liverworts and hornworts	8
non-marine molluscs	43	pteridophytes	11
non-marine crustaceans	20	conifers and ginkgo	37
myriapods	7	flowering plants	1798
arachnids	33	Basidiomycota	89
non-marine annelids	-	Ascomycota, non-lichenized	99
non-marine invertebrates, other	32	lichens or lichenicolous fungi	-
insects - ants, bees and wasps	26	other fungi	10
insects - beetles	101	bacteria and viruses	10
		Total	2721

Table 3. Species of animals and fungi found only in gardens and other highly artificial man-made habitats (see Appendix 5 for a full enumeration)

Taxonomic group	Number	Taxonomic group	Number
non-marine crustaceans	2	insects - true flies	12
myriapods	1	insects - other insects	2
arachnids	1	reptiles	1
non-marine invertebrates, other	6	freshwater fish	1
insects - ants, bees and wasps	1	Basidiomycota	36
insects - beetles	3	Ascomycota, non-lichenized	25
insects - butterflies and moths	3	other fungi	2
insects - true bugs	24	Total	120

Table 4. Numbers and proportions of non-native species in major categories

Major category	Number	Proportion
Marine & estuarine invertebrates	39	2.8%
Marine & estuarine plants	25	1.8%
Insects	294	20.8%
Invertebrate non insect	124	8.8%
Vertebrates	106	7.5%
Lower plants	21	1.5%
Vascular plants	659	46.6%
Fungi	135	9.6%
Microbes	10	0.7%
Total	1413	100.0%

7.2 Types of non-nativeness

The large majority of species included here are almost certainly introduced (Table 5). The next largest category is of hybrids between introduced and native species. These hybrids are all flowering plants, and the great majority are of little environmental significance. An exception, not included in the main list because it is too rare, is the rhizomatous saltmarsh grass *Spartina x townsendii*. Not only did this spread round the coast of Britain, but it gave rise to one of the two newly derived species, common cord-grass *Spartina anglica*. The other new species is York groundsel *Senecio eboracensis*, which arose from a hybrid between the introduced *Senecio squalidus* and the native *S. vulgaris*.

Table 5. Types of non-nativeness in marine and terrestrial groups

Code	Type of non-nativeness	Marine	Animals	Plants	Fungi & microbes	Total
I	Introduced	52	432	667	142	1294
J	Native or introduced (not known which)		59			59
N	Newly-arrived (by natural means or introduced)	12	24	1	3	39
H	Hybrid native x introduced			10		10
K	New species derived from hybridization			2		2
F	Reintroduced, formerly native		9			9
	Total	64	524	680	145	1413

Species with non-nativeness code J or N, are species that are doubtfully non-native, being possibly native (code J) or possibly naturally arrived (code N). No vascular plants are in this category, because native or introduced plants have been treated for this enumeration as native. Newly-arrived vascular plants are normally assumed to be introduced. The large majority of species in the 'native or introduced' category are either non-marine molluscs (21 species) or beetles (13 species). The 'newly arrived' species are more mixed, including 6 species of marine phytoplankton, and 8 species of Homoptera, mostly aphids.

7.3 Pathway of introduction

There are two major pathways of introduction (Table 6). The largest is accidental transport, which is strongly predominant for marine organisms and fungi and is also the major pathway for animals. Terrestrial and freshwater plants, on the other hand, are mostly escapes from cultivation. This result is well known. Crop plants and former crop plants are relatively few; the main source of alien plants is ornamental gardening (Crawley, Harvey & Purvis 1996). It is notable that no plants are signified as 'released', whereas this is a substantial pathway for animals, eg ornamental varieties of freshwater fish (Copp and others 2005b). Plants have frequently been planted or sown into the wild, but this is rarely used as a means of introduction. In Scotland, several non-native alpine plants such as *Homogyne alpina* were planted into the wild; some orchids have been introduced in this way to England but did not persist.

There is a large predominance of vertebrates among deliberately released animals. Most of these were released by enthusiasts who would like to see their pets or potential quarry species established in the wild. There were also several reintroductions of formerly native species, among which the large blue *Maculinea arion* and red kite *Milvus milvus* have been notable successes. Successful introductions of biocontrol agents have been relatively few. The database lists the greenhouse mite *Neoseiulus californicus*, which occurs outdoors but is possibly not established there, the parasitic wasp *Psyllaephagus pilosus* used to control blue gum psyllid *Ctenarytaina eucalypti*, and *Rhizophagus grandis*, a predatory beetle introduced with great success to contol the great spruce bark beetle *Dendroctonus micans*.

Table 6. Pathways of introduction in marine and terrestrial groups

Code	Pathway of introduction	Marine	Animals	Plants	Fungi & microbes	Total
D	Dispersed from introduced pop.	8	2			10
DT	Dispersed and/or transported		2		1	3
E	Escape from captivity or cultiv.		21	424		445
ER	Escaped and/or released		34	1		35
ET	Escaped or transported			9		9
H	Hybrid - native x alien			13		13
R	Released - deliberate release	5	65	7		77
RT	Released and/or transported		2			2
T	Transported - accidentally	47	316	215	143	721
U	Unknown.	4	82	11	1	98
	Total	64	524	680	145	1413

7.4 Continent of origin

It is hardly a surprise that marine introductions mostly do not originate from Europe. European species can generally reach England by natural dispersal and would establish populations in suitable conditions. The one exception is *Mytilicola intestinalis*, a parasitic copepod introduced from the Mediterranean. At the other extreme, almost exactly two-thirds of plant species are of European origin. For terrestrial and freshwater species, North America is the next most frequent continent of origin, though for freshwater fishes an approximately equal number of species originate from North America and the European/Asian Continent. A special feature of plants is that 35 species are signified as having their origin in agriculture or horticulture. In principle, the same could be said (with obvious changes of wording) for feral

cat, ferret and goat. Almost all the other animals, however, have been little modified by domestication, although at least some of those released may be of clearly modified forms, for example melanistic pheasants. There is a marked contrast between plants and animals in relation to Australasia, which is the source of 38 animals but only 9 plants.

Table 7. Continent of origin for marine and terrestrial groups; where more than one continent is signified in the database, the first one named has, for this analysis, been treated as unique

Continent of origin	Marine	Animals	Plants	Fungi & microbes	Total
Europe	1	226	441	9	677
Africa	-	11	11	2	24
Asia	25	51	44	7	127
North America	17	78	69	7	171
South America	1	13	31	4	49
Australasia	2	38	9	5	54
Oceanic islands	3	1	-	-	4
Widespread	1	2	2	-	5
Agriculture or Horticulture	-	-	35	-	35
Unknown or data lacking	14	104	38	111	267
Total	64	524	680	145	1413

7.5 Date of introduction

Table 8. Dates of introduction for marine and terrestrial groups. The dates are calculated from the database by choosing the date of introduction if known, or the end of the date-range where an exact date is not known. If neither of these dates is available, the date is that of the first record from the wild.

Date range	Marine	Animals	Plants	Fungi & microbes	Total
BC	-	3	39	-	42
1st millennium	-	12	56	-	68
1000-1499	-	9	72	-	81
1500-1549	-	-	19	-	19
1550-1599	-	-	57	-	57
1600-1649	1	-	42	-	43
1650-1699	-	2	37	-	39
1700-1749	-	1	44	-	45
1750-1799	-	5	73	1	79
1800-1849	1	32	97	8	138
1850-1899	4	55	64	11	134
1900-1949	17	94	50	15	176
1949-1999	39	193	29	42	303
2000-2004	2	42	-	2	46
Blank (no data)	-	76	1	66	143
Total	64	524	680	145	1413

The dates when species were introduced are rarely known exactly. Even for the much-studied Oxford ragwort *Senecio squalidus* the dates are not known more accurately than the range 1700-1702 (Harris 2002). Overall, however, the record for plants is now well

documented. It is based on archeological evidence (Preston, Pearman & Hall 2004) combined with written information from herbals and floras from about 1500. The record for animals other than vertebrates is much less complete. Temporal trends in the arrival of plant pests are discussed by Smith and others (2005). The archeological and post-glacial fossil record is useful for snails and beetles, but most animals have left few remains, so that the equivalent of archaeophytes cannot be known.

There is a clear difference between the dates of introduction for plants and animals. For animal groups, the second half of the 20th century was the major period of introduction. The selection procedure for plants was such that a very recent introduction could not be included. For those that have become widespread, the main period of introduction was the 18th and 19th centuries. These were the great centuries of botanical exploration, and the main pathway to England was through gardens.

7.6 Persistence

The majority of species included in the database now have at least one established populations in England (Table 9). This is not because most introduced species persist. Indeed they do not (Williamson & Fitter 1996). Inevitably the record of those that appeared and then failed is poor, unless they were repeatedly introduced or are well known to gardeners or naturalists. The list of failed and successful introductions of freshwater fishes is perhaps more complete than that of some other taxonomic groups; only 43% of species listed in the present audit are known or believed to be established (none of these is diadromous). For these reasons, the results in Table 9 are not a good basis for comparing the processes of introduction and establishment in different taxonomic groups.

Table 9. Categories of persistence of introduced species in marine and terrestrial groups

Date range	Marine	Animals	Plants	Fungi & microbes	Total
Persisting, not reproducing	7	22	24	2	55
Established	55	378	608	136	1177
Casual	2	55	42	3	102
Extinct		29	6	2	37
Deliberately extirpated		6			6
Unknown or data lacking		34		2	36
Total	64	524	680	145	1413

An interesting category is the species that have been deliberately extirpated. Only six species are noted for this in the database. Three are vertebrates, namely the mammals coypu *Myocastor coypus* and musk rat *Ondatra zibethicus*, and the Chinese weatherfish *Misgurnus mizolepis*. One hundred and sixty-three outbreaks of Colorado beetle (*Leptinotarsa decemlineata*) have been eradicated (Bartlett 1979), and the termite *Reticulitermes lucifugus* has been eliminated from Devon. The map butterfly *Araschnia levana* is also thought to have been deliberately exterminated, although the colonies might well not have persisted in any case. Efforts are being made to exterminate ruddy duck *Oxyura jamaicensis*, but have not yet achieved their aim. Topmouth gudgeon *Pseudorasbora parva* is being subjected to selective extermination.

The category of species that are extinct through natural causes is a small one. It is obviously hard to distinguish from the casual category. A casual is a species whose populations become extinct wherever they occur in England, but which is repeatedly reintroduced. In general, it is difficult or impossible to know whether a species is likely to be reintroduced. An exception is the Large copper butterfly *Lycaena dispar*. Efforts to re-establish it were so consistently unsuccessful that one may conjecture that it will not be the subject of further attempts, at least until there is a much larger area of undrained fenland in eastern England.

7.7 Numbers of species according in geographical regions

For most groups of organisms, and especially for introduced species, which tend to be more adapted to conditions in southern UK (Williamson & Fitter 1996), it is to be expected that there will be greater species richness in the south than the north. The trend is much greater for animals than plants (Table 10), with only about 33% as many animal species in the North East as in the South East, compared to 78% of plant species. It is possible that the method of selection of plant species has weakened the north-south difference, because those introduced plants in at least 50 10-km square may have had multiple introductions and reintroductions, many of which did not produce persistent populations in the north, but were recorded there nevertheless.

Table 10. Numbers of species in regions for marine and terrestrial groups. Marine species were attributed to English Nature regions for species of estuaries and ports, and to ICES regions for most other taxa.

English Nature Region	Marine	Animals	Plants	Fungi & microbes
North East	5	91	514	42
North West	2	152	603	40
Yorkshire & the Humber	2	138	606	71
East Midlands		126	604	59
West Midlands		132	621	72
East of England	8	202	637	82
South East	20	278	655	112
South West	26	192	656	85
London	1	137	594	26
ICES Region				
Central North Sea	16			
Southern North Sea	21			
Eastern English Channel	26			
Western English Channel	17			
Bristol channel	11			
Celtic Sea North	10			
Celtic Sea South	9			
Irish Sea (part near England)	10			

7.8 Habitats of introduced species

The introduced marine species are well distributed between habitats, with no one habitat being predominant (Table 11). Of the four introduced vascular plants that occur in marine habitats, two cord-grasses, *Spartina alterniflora* and its allopolyploid derivative *Spartina*

anglica, are strictly confined to the intertidal zone. For hoary cress *Lepidium draba* and Michaelmas daisies *Aster* spp., on the other hand, the intertidal is only a minor habit. The main habitats for these two species are artificial, especially by roads for hoary cress and by railways for Michaelmas daisies.

Introduced freshwater and terrestrial animals occupy a wide variety of habitats, especially surface waters (still and running), woodland, and cultivated land. Plants are completely different, being strongly concentrated on cultivated, built and derelict land. Of the plants whose habitat is EUNIS type F (heathland, hedgerows and scrub), 85 out of the 101 species are found in hedgerows. The habitat with the fewest introduced species is EUNIS D, mires, bogs and fens. Only for the large copper butterfly *Lycaena dispar* and swamp meadow-grass *Poa palustris* are wetlands the principal habitat; for the remaining six species they are a secondary habitat.

Table 11. Habitats recorded for marine and terrestrial groups; a fuller list of EUNIS habitats is given in Appendix 3

Code	Name of EUNIS habitat	Marine	Animals	Plants	Fungi & microbes	Total
A1	Littoral rock & hard substr.	22	0	0	0	22
A2	Littoral sediment	16	0	4	0	20
A3	Infralittoral rock etc.	14	0	0	0	14
A4	Circalittoral rock etc.	7	0	0	0	7
A5	Sublittoral sediment	21	0	0	0	21
A7	Pelagic water column	8				8
B	Coastal habitats	0	36	57	2	95
C	Inland surface waters	1	141	48	1	191
D	Mires, bogs and fens	0	5	3	0	8
E	Grasslands etc.	0	45	47	3	95
F	Heathland, hedgerows & scrub	0	35	101	24	160
G	Woodland & forest	0	166	86	79	331
H	Inland unveg. or sparsely veg.	0	4	60	0	64
I1	Arable land & market gardens	0	52	148	15	215
I2	Cultivated gardens and parks	0	142	197	50	389
J	Constructed, industrial, etc.	5	60	232	6	303
	Blank (no habitat in database)	11	115	214	50	390

7.9 Economic and ecological impacts

The large majority of introduced species have no marked effect, either economic or environmental. Only four species were rated strongly positive, namely the quarry species common pheasant *Phasianus colchicus*, greylag goose *Anser anser* and red-legged partridge *Alectoris rufa*, and the predatory beetle *Rhizophagus grandis*, which is a biocontrol agent of the great spruce bark beetle *Dendroctonus micans*. Several other animals have a partially or moderately beneficial effect, but the effect is often mixed. The story for plants is quite different, because many crop plants and valued garden plants also occur as escapes in the wild. These have a strongly positive economic impact. Two introduced plants, sweet chestnut *Castanea sativa* and butterfly-bush *Buddleja davidii* are considered to have strongly positive environmental effects. Butterfly-bush also has a major negative economic effect, because of the cost of herbicide applications to railway lines.

Table 12. Economic and ecological environmental effects of introduced species

Effect	Marine	Animals	Plants	Fungi & microbes	Total
Economic impact					
Strongly negative	3	33	7	24	67
Negative	9	83	14	15	121
Positive	4	11	151	1	166
Strongly positive		4	51		56
No effect	48	277	457	105	887
Blank (no data)		116			116
Environmental impact					
Strongly negative	2	10	6	3	19
Negative	8	41	48	5	103
Positive		3	36		39
Strongly positive			2		2
No effect	54	419	588	137	1199
Blank (no data)		51			51

The twenty-one species with strongly negative environmental effects are listed in Table 13. There is inevitably much subjectivity about this list, especially for plants, regarding which there was no clear consensus among the audit team. For example, *Crassula helmsii* is not included because the two botanical specialists were sceptical of its harmful effects, although they were well aware that it is normally treated as very harmful. Of the animals, the coypu has been extirpated. The topmouth gudgeon is subject to a recently-initiated eradication programme, which would seem particularly relevant given the species's recently-discovered disease threat to native fishes (Gozlan and others 2005), but the extent of its distribution and its invasive character suggest that it will be difficult to extirpate completely. The ruddy duck *Oxyura jamaicensis* may be eradicated, depending on the political will to pursue the extermination programme. The other species are all well established, and there is no expectation that they will ever be eradicated from England.

7.10 Current and future trends in range and abundance

Many more animal species are currently increasing than decreasing, but a larger number show little change (Table 14). The two animals that are thought to be strongly decreasing are the Carthusian snail *Monacha cartusiana* and the giant earwig *Labidura riparia*. One species that is known to be increasing rapidly is topmouth gudgeon, with exponential expansion in range since its introduction in the mid-1980s (R.E. Gozlan, CEH-Dorset, personal communication). Many more plants are known to be strongly decreasing. All but five of these are archaeophytes, mainly cornfield weeds. Of the five neophytes, false cleavers *Galium spurium* and annual vernal-grass *Anthoxanthum aristatum* are also cornfield weeds. crimson clover *Trifolium incarnatum* subsp. *incarnatum* is no longer sown as a fodder plant, and both it and motherwort *Leonurus cardiaca* now rarely occur as seed contaminants. The cause of decline in small melilot *Melilotus indicus* is more puzzling, but may reflect that fact that it is still mainly found on rubbish tips and – unlike the three common melilots – has failed to spread from this habitat to the wider countryside.

Table 13. Animals and diseases with demonstrated major negative environmental effects

Major group	Scientific name	Common name	Mode of environ impact
Marine mollusc	*Crepidula fornicata*	Slipper limpet	Habitat modification
Diadromous crustacean	*Eriocheir sinensis*	Chinese mitten crab	Habitat modification
Freshwater crustacean	*Pacifastacus leniusculus*	Signal crayfish	Competitor; disease vector
Freshwater fish	*Pseudorasbora parva*	Topmouth gudgeon	Predator and competitor
Bird	*Branta canadensis*	Canada goose	Habitat eutrophication, competition, herbivory
Bird	*Oxyura jamaicensis*	Ruddy duck	Introgression with White-headed Duck in Spain
Mammal	*Muntiacus reevesi*	Chinese muntjac	Consumption of desired species; habitat modification
Mammal	*Mustela vison*	American mink	Predator
Mammal	*Myocastor coypus*	Coypu	Destructive herbivore; habitat modification
Mammal	*Oryctolagus cuniculus*	European rabbit	Destructive herbivore, also with positive effects
Mammal	*Rattus norvegicus*	Brown rat	Predator
Mammal	*Sciurus carolinensis*	Eastern grey squirrel	Predator; destructive herbivore
Flowering plant	*Acer pseudoplatanus*	Sycamore	Competitor; aesthetically bad
Flowering plant	*Carpobrotus edulis*	Hottentot-fig	Competitor; aesthetically bad
Flowering plant	*Fallopia japonica*	Japanese knotweed	Competitor; aesthetically bad
Flowering plant	*Heracleum mantegazzianum*	Giant hogweed	Competitor; human health hazard; aesthetically bad
Flowering plant	*Quercus ilex*	Evergreen oak	Competitor
Flowering plant	*Rhododendron ponticum*	Rhododendron	Competitor; aesthetically bad
Ascomycete	*Ophiostoma novo-ulmi*	Dutch elm disease	Disease of valued species
Other fungus	*Phytophthora alni*	Dieback of alder	Disease of valued species
Other fungus	*Phytophthora ramorum*	Sudden oak death	Parasite

Table 14. Trends in range and abundance for marine and terrestrial groups

Trend	Marine	Animals	Plants	Fungi & microbes	Total
Current trend					
Strongly decreasing		2	28		30
Decreasing	1	15	56	1	73
No change	43	112	375	16	546
Increasing	9	79	190	12	290
Strongly increasing	1	17	16	2	36
No data	10	299	15	114	407
Future trend					
Decreasing		8	79	1	88
No change	35	138	415	19	607
Increasing	7	59	181	10	257
Strongly increasing		3	4		7
No data	22	316	1	115	423

Strongly-increasing animals, plants and fungi (Table 15) are not necessarily a threat to wildlife. Many of them are them are restricted to introduced species or man-made habitats. In one case, the great spruce bark beetle *Dendroctonus micans*, the animal attacks non-native species and has now been controlled by a predator, so that its increasing phase is over. Undoubtedly, however, the list includes many organisms that may adversely affect the environment.

Future trends are necessarily speculative, and compilers' dislike of speculation may account for the fact that in general they predicted less change in the next twenty years than at present.

Table 15. Species that were strongly increasing in the 20 years to 2005

Name of major group	Scientific name	Common name
marine crustaceans	*Elminius modestus*	a barnacle
non-marine molluscs	*Boettgerilla pallens*	Worm slug
non-marine molluscs	*Deroceras panormitanum*	Caruana's or Sicilian sSlug
non-marine molluscs	*Hygromia cinctella*	Girdled snail
non-marine molluscs	*Physa* (alien spp.)	
beetles	*Dendroctonus micans*	Great spruce bark beetle
beetles	*Harmonia axyridis*	Harlequin ladybird
beetles	*Rhizophagus grandis*	a predatory beetle
butterflies and moths	*Blastobasis decolorella*	
butterflies and moths	*Cameraria ohridella*	Horse chestnut leaf miner
butterflies and moths	*Ectoedemia heringella*	a leaf-miner on holm oak
true bugs	*Floria variegata*	a psyllid
freshwater fish	*Pseudorasbora parva*	Topmouth gudgeon
birds	*Anser anser*	Greylag goose
birds	*Branta canadensis*	Canada goose
birds	*Phasianus colchicus colchicus*	Common pheasant
mammals	*Muntiacus reevesi*	Chinese muntjac
mammals	*Oryctolagus cuniculus*	European rabbit
flowering plants	*Amsinckia micrantha*	Common fiddleneck
flowering plants	*Brassica napus*	Rape
flowering plants	*Buddleja davidii*	Butterfly-bush

Name of major group	Scientific name	Common name
flowering plants	*Conyza sumatrensis*	Guernsey fleabane
flowering plants	*Cotoneaster integrifolius*	Entire-leaved cotoneaster
flowering plants	*Cotoneaster microphyllus* agg.	
flowering plants	*Crassula helmsii*	New Zealand pigmyweed
flowering plants	*Hirschfeldia incana*	Hoary Mustard
flowering plants	*Hydrocotyle ranunculoides*	Floating pennywort
flowering plants	*Lamiastrum galeobdolon* subsp. *argentatum*	a garden form of a native plant
flowering plants	*Lemna minuta*	Least duckweed
flowering plants	*Leucanthemum lacustre x maximum (L. x superbum)*	Shasta daisy
flowering plants	*Linum usitatissimum*	Flax
flowering plants	*Myriophyllum aquaticum*	Parrot's-feather
flowering plants	*Polypogon viridis*	Water bent
flowering plants	*Valerianella carinata*	Keeled-fruited cornsalad
Basidiomycota	*Amanita inopinata*	
Basidiomycota	*Stropharia aurantiaca*	Readlead roundhead

8 Conclusions

The audit of aliens shows that they are very mixed group, occurring in a wide range of habitats. To take the work forward, a more detailed evaluation of those species that are increasing rapidly and those with large negative environmental effects is required. Such an evaluation is beyond the scope of this audit, whose main purpose was to bring the primary data together. It would need to be informed by a team with clear view of nature conservation priorities.

The audit has shown the need for a definitive list of British species, against which to judge past and future changes. Such a list is being compiled by the National Biodiversity Network, but it needs to give more information about native status. Newly-appearing species are of concern primarily because they are new. The question of whether they reached our shores by introduction or by natural colonization is hardly relevant. What matters is the effect that they have on our environment and crops.

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Appendix 1. Categories for species listing

The categories have been loosely based on the species categories listed on the NBN Gateway http://www.searchnbn.net . They are, for convenience of reading, separated into marine, and terrestrial and freshwater.

Table A1. Marine and estuarine plants and animals

		invertebrates - marine and estuarine
11	m sponge	marine sponges
12	m coelent	marine coelenterates
13	m mollusc	marine molluscs
14	m crustac	marine crustaceans
14.1		diadromous crustacean
15	m annelid	marine annelids
16	m echino	Marine echinoderms
17	m bryzo	marine bryozoans
18	m tunic	tunicates and cephalochordates
19	m inv - other	other marine invertebrates
		marine vertebrates (excluding birds)
21	m fish	marine fish
22	m mammal	mammals - marine and estuarine
		marine plants
31	rhodoph	Rhodophyceae
32	phaeoph	Phaeophyceae
33	chloroph	Chlorophyceae
34	xanthoph	Xanthophyceae
35	m plant - other	Other marine plants

Table A2. Terrestrial and freshwater animals

		invertebrates - (incl. Collembola, Thysanura, excl, insects)
41	ft mollusc	non-marine molluscs
42	ft crustac	non-marine crustaceans
43	myriapod	myriapods (including millipedes and centipedes)
44	arachn	arachnids (chelicerates, including spiders, mites and scorpions)
45	ft arthro - other	other freshwater and terrestrial arthropods (including Collembola)
46	ft annelid	non-marine annelids
47	ft inv - other	other terrestrial and freshwater invertebrates
		insects
51	hymenopt	insects - ants, bees and wasps
52	coleopt	insects - beetles
53	lepidopt	insects - butterflies and moths
54	trichopt	insects - caddis flies
55	orthopt	insects - crickets and grasshoppers
56	odonata	insects - damselflies and dragonflies
57	hemipt	insects - true bugs
58	diptera	insects - true flies
59	insect - other	insects - other insects
		vertebrates
61	amphib	amphibia
62	reptile	reptiles
63	fw fish	freshwater fishes
64	ddr fish	diadromous fishes
65	bird	birds
65	ft mammal	mammals - terrestrial and freshwater

Table A3. Terrestrial and freshwater plants and fungi

		plants
71	ft algae	non-marine algae
72	charoph	stoneworts
73	moss	mosses
74	liverwort	liverworts and hornworts
75	pteridoph	Lycopsida, Equisetopsida, Ophoglossopsida, Polypodiopsida
76	conifer	conifers and ginkgo
77	angiosp	flowering plants
		fungi
81	basidio	Basidiomycota
82	asco	ascomycetes (non-lichenized)
83	lichen	lichens or lichenicolous ascomycetes
84	fungi - other	other fungi

Appendix 2. Terrestrial and marine regions of England

Table A4. Numbering of terrestrial regions in relation to Watsonian vice-counties

Abbreviation	Region	Definition	Vice-counties
NE	North East	Northumberland, Durham	66, 67, 68
NW	North West	Cheshire, Lancashire, Cumbria	58, 59, 60, 69, 70
Yo	Yorkshire & the Humber	Yorkshire (and N. Lincolnshire)	61, 62, 63, 64, 65
EM	East Midlands	Lincolnshire, Derbyshire, Nottinghamshire, Leicestershire, Northamptonshire	32, 53, 54, 55, 56, 57
WM	West Midlands	Shropshire, Staffordshire, Herefordshire, Worcestershire, Warwickshire	36, 37, 38, 39, 40
E	East of England	Norfolk, Suffolk, Essex, Cambridgeshire, Hertfordshire, Bedfordshire	18, 19, 20, 25, 26, 27, 28, 29, 30, 31
SE	South East	Kent, Sussex, Surrey, Hampshire, Isle of Wight, Berkshire, Oxfordshire, Buckinghamshire	10, 11, 12, 13, 14, 15, 16, 17, 22, 23, 24
SW	South West	Devon, Cornwall, Somerset, Dorset, Wiltshire, Gloucestershire	1, 2, 3, 4, 5, 6, 7, 8, 9, 33, 34
Lo	London	Middlesex (and N. Surrey)	21

Table A5. Numbering of English Nature marine natural areas, with approximate ICES equivalents; ICES divisions are used in the database for marine species, but many estuarine species have been assigned to the terrestrial regions of Table A4.

M1	Mid North Sea	IVb	Central North Sea (southern part)
M2	Southern North Sea	IVc	Southern North Sea
M3	Eastern Channel	VIId	Eastern English Channel
M4	South Western Peninsula	VIIe + VIIf	Western English Channel + Bristol Channel
M5	Western Approaches	VIIg + VIIh	Celtic Sea North + Celtic Sea South
M6	Irish Sea	VIIa	Irish Sea (part near England)

Table A6. ICES divisions surrounding the Great Britain.

ICES Div	Abbreviation.	Area and boundaries
IVa	[not England]	Northern North Sea (east of 4ºW, between latitudes 57º30'N and 62ºN)
IVb	CN	Central North Sea (between latitudes 53º30'N and 57º30'N)
IVc	SN	Southern North Sea (between latitudes 51ºN and 53º30'N)
VIId	EC	Eastern English Channel (from 2ºW to the Dover Strait, 51ºN)
VIIe	WC	Western English Channel (westerly boundary extends westwards from Cornwall at 50ºN, to 50ºN, 7ºW, south to 49º30'N, 7ºW, east to 49º 30'N 5ºW, and south to France, eastern boundary along 2ºW)
VIIf	BC	Bristol Channel (extends southwards from Pembrokeshire at 5ºW to 51ºN, 5ºW, west to 51ºN, 6ºW, south to 50º30'N, 6ºW, west to 50º30N, 7ºW and south to 50ºN)
VIIg	NC	Celtic Sea North (Pembrokeshire, from east of 5ºW to 52ºN)
VIIa	IS	Irish Sea (between 52ºN and 55ºN)
VIa	[not England]	North-west Scotland (from 55ºN to 4ºW)

Table A7. Cross-reference between English vice-counties and regions

Vice-county	Region	Vice-county	Region	Vice-county	Region
1	SW	21	Lo	53	EM
2	SW	22	SE	54	EM
3	SW	23	SE	55	EM
4	SW	24	SE	56	EM
5	SW	25	E	57	EM
6	SW	26	E	58	NW
7	SW	27	E	59	NW
8	SW	28	E	60	NW
9	SW	29	E	61	Yo
10	SE	30	E	62	Yo
11	SE	31	E	63	Yo
12	SE	32	EM	64	Yo
13	SE	33	SW	65	Yo
14	SE	34	SW	66	NE
15	SE	36	WM	67	NE
16	SE	37	WM	68	NE
17	SE	38	WM	69	NW
18	E	39	WM	70	NW
19	E	40	WM		
20	E				

Appendix 3. EUNIS typology of habitats (level 2)

The typology is that recommended by the European Environment Agency. It includes marine, freshwater and terrestrial habitats. http://eunis.eea.eu.int/habitats.jsp.

A Marine habitats
- A1 Littoral rock and other hard substrata
- A2 Littoral sediment
- A3 Infralittoral rock and other hard substrata
- A4 Circalittoral rock and other hard substrata
- A5 Sublittoral sediment
- A6 Deep-sea bed
- A7 Pelagic water column
- A8 Ice-associated marine habitats

B Coastal habitats
- B1 Coastal dunes and sandy shores
- B2 Coastal shingle
- B3 Rock cliffs, ledges and shores, including the supralittoral

C Inland surface waters
- C1 Surface standing waters
- C2 Surface running waters
- C3 Littoral zone of inland surface waterbodies

D Mires, bogs and fens
- D1 Raised and blanket bogs
- D2 Valley mires, poor fens and transition mires
- D3 Aapa, palsa and polygon mires
- D4 Base-rich fens and calcareous spring mires
- D5 Sedge and reedbeds, normally without free-standing water
- D6 Inland saline and brackish marshes and reedbeds

E Grasslands and lands dominated by forbs, mosses or lichens
- E1 Dry grasslands
- E2 Mesic grasslands
- E3 Seasonally wet and wet grasslands
- E4 Alpine and subalpine grasslands
- E5 Woodland fringes and clearings and tall forb stands
- E6 Inland salt steppes
- E7 Sparsely wooded grasslands

F Heathland, scrub and tundra
- F1 Tundra
- F2 Arctic, alpine and subalpine scrub
- F3 Temperate and mediterranean-montane scrub
- F4 Temperate shrub heathland
- F5 Maquis, arborescent matorral and thermo-Mediterranean brushes
- F6 Garrigue

F7 Spiny Mediterranean heaths (phrygana, hedgehog-heaths and related coastal cliff vegetation)

F8 Thermo-Atlantic xerophytic scrub
F9 Riverine and fen scrubs
FA Hedgerows
FB Shrub plantations

G Woodland, forest and other wooded land

G1 Broadleaved deciduous woodland
G2 Broadleaved evergreen woodland
G3 Coniferous woodland
G4 Mixed deciduous and coniferous woodland
G5 Lines of trees, small anthropogenic woodlands, recently felled woodland, early-stage woodland and coppice

H Inland unvegetated or sparsely vegetated habitats

H1 Terrestrial underground caves, cave systems, passages and waterbodies
H2 Screes
H3 Inland cliffs, rock pavements and outcrops
H4 Snow or ice-dominated habitats
H5 Miscellaneous inland habitats with very sparse or no vegetation
H6 Recent volcanic features

I Regularly or recently cultivated agricultural, horticultural and domestic habitats

I1 Arable land and market gardens
I2 Cultivated areas of gardens and parks

J Constructed, industrial and other artificial habitats

J1 Buildings of cities, towns and villages (including demolition sites)
J2 Low density buildings
J3 Extractive industrial sites
J4 Transport networks and other constructed hard-surfaced areas
J5 Highly artificial man-made waters and associated structures
J6 Waste deposits

Appendix 4. Headings in database

The database has 48 columns. Explanations are either given below or, if not, are referenced.

Columns in the database

Listing category – see below
Major group – see Appendix 1
Scientific name
Common name
Type of non-nativeness of English population – explained under 'Assumptions and definitions used', in the main text
Pathway of introduction – explained under 'Assumptions and definitions used', above
Pathway details – text explanation of the pathway
Native range (continent) – see below
Native range (area) – see below
Comments – remarks giving extra background, eg host plant
References – references for the occurrence of the species in England; these are in the bibliography
Place first record outside captivity or cultivation – see below
Date of introduction (1) – see below
Date of introduction (2) – see below
Date first wild report – see below
Persistence in wild – see below
Distr_NE_CN – distribution; see below and Appendix 2
Distr_NW_SN – distribution; see below and Appendix 2
Distr_Yo_EC – distribution; see below and Appendix 2
Distr_EM_WC – distribution; see below and Appendix 2
Distr_WM_BC – distribution; see below and Appendix 2
Distr_EE_NC – distribution; see below and Appendix 2
Distr_SE_SC – distribution; see below and Appendix 2
Distr_SW_IS – distribution; see below and Appendix 2
Distr_Lo – distribution; see below and Appendix 2
English as proportion – see below
Habitat 1 – see below and Appendix 3
Habitat 2 – see below and Appendix 3
Habitat 3 – see below and Appendix 3
Habitat 4 – see below and Appendix 3
Current trend – see below
Direct economic value – see below
Economic impact – see below
Mode of economic impact – see below
Conservation status – conservation value in England; see below
Environmental impact – see below
Mode of environmenatal impact
Population trend (20 yr) – see below
Control methods – see below
Other information – mostly taxonomic, giving family or other group; not filled in systematically

BRC number – taxon code in the BRC database (TAXON table)
NBN system number – taxon code in NBN numbering system
Date1 – simplified form of 'Date of introduction (1)', converted to a number for data processing
Date2 – simplified form of 'Date of introduction (2)', converted to a number for data processing
Date2 – simplified form of 'Date first wild repor', converted to a number for data processing
Date – a single date for each species; see below and legend for Table 8
Compiler – initials of compilers; see below
Institution – institution to which the compiler was affiliated

Listing category

A	Species considered for the main analysis
B	Species confined to gardens and other highly artificial habitats (Appendix 5)
VD	Vascular plants included only on the CD of the *New Atlas* (Preston, Pearman & Dynes 2002)
VE	Microspecies of *Hieracium* and *Rubus* excluded from the *New Atlas*
VN	Species with no records on the CD of *New Atlas*
Z	Excluded species (not included in the main database but retained in another table for future reference)

Native range (continent)

Eur	Europe in the broad sense (including Mediterranean area, N Africa and SW Asia); the 'Western Palaearctic' of the ornithologists, including Russia east to the Urals – this is subdivided in the next field if better information available
As	Asia outside Western Palaearctic
Afr	Africa south of the Sahara
NAm	N America (including Mexico)
SAm	S America (including C America)
Aus	Australasia
Oce	Oceanic islands
Unk	Unknown
AgrHort	No wild range, taxa of agricultural/garden origin

Native range (area)

If range within continent of origin is both known and relatively restricted, then this was indicated in this text field, eg Alps; Cape province, S. Africa; New Zealand.

Place first record outside captivity or cultivation

Text entry for place of first record, with vice-county or ICES division. This ought in principle to be knowable for most species, but there are many for which the information was not readily available.

Date of introduction to England (two fields)

Date when first brought to England. For taxa first brought as captive animals, garden plants or seeds, this is date of this introduction. Vague dates are specified by limits with Date1

(earliest) and Date 2 (latest). Prehistoric dates are indicated with BC and (for convenience of sorting) an underscore, not with negative numbers, eg _2580 BC. Pest species and others that were found on an imported consignment but destroyed would not ordinarily be included; however, if they subsequently escaped, then the date of the first occurrence that resulted in establishment of a population outside captivity or containment is given. If the pest was subsequently eliminated but then established, this may not be the same as the first date in the wild, which refers to the current population. If the date of introduction is not known exactly, then the range of possible dates was indicated, using two fields. For example, Oxford ragword *Senecio squalidus* was introduced between 1700 and 1702, so 1700 is written in the first field and 1702 in the second.

Date of first report outside buildings, captivity or cultivation in England

Date of first report in the wild (ie outside buildings, gardens and parks) in England. Dates may be approximate, indicated 1910C, a date of publication rather than discovery, indicated 1897P, or a latest possible but unknown date, indicated 1899<. Animals and fungi that are at present known only from gardens have the date when they were reported in this habitat; an animal in a garden is effectively wild if it can readily move to the next garden. Garden animals and fungi were less systematically sought, but are listed where thought to be of relevance to English wildlife. Animals and plants that are still in captivity or cultivation and not naturalized may be listed if they are of interest and likely to escape; these are given the date -1.

Persistence in the wild (ie outside buildings, gardens and parks)

This describes *current* persistence in the wild (ie outside buildings, gardens and parks)

C Casual taxa dependent on repeated introduction, and not persisting for more than four years

D Deliberately extirpated introductions

E Established taxa reproducing vegetatively or sexually and thus present as self-sustaining populations

P Persisting - released into the countryside, persisting for five or more years, but not effectively reproducing; would include all non-reproducing trees and hedge plants that are planted in the wider countryside

U Unknown – applies to obscure taxa where it is not known whether they persist

X Other extinct introductions.

English distribution

Distribution in English regions (refer to Appendix 2 for definitions). For this project, regions were defined in terms of vice-counties or ICES divisions approximateinf English Nature regions. Terrestrial regions are those of Defra htp://www.defra.gov.uk/erdp/docs/regchapsindex.htm . English Nature marine areas http://www.english-nature.org.uk/pubs/publication/PDF/MNA1.pdf are cross-referenced to ICES divisions (details in Appendix 2). Note that columns of the database used for terrestrial regions were also be used for ICES divisions.

Table A8. Abbreviations used for English distribution; the left of the table lists ICES divisions, the right lists Defra regions

Abbreviation	ICES division	Abbrev	Region
CN	Central North Sea (southern part)	NE	North East
SN	Southern North Sea	NW	North West
EC	Eastern English Channel	Yo	Yorkshire & the Humber
WC	Western English Channel	EM	East Midlands
BC	Bristol Channel	WM	West Midlands
NC	Celtic Sea North	EE	East of England
SC	Celtic Sea South	SE	South East
IS	Irish Sea (part near England)	SW	South West
		Lo	London

English distribution as proportion of native range

Blank English population less than 10% of world population, and not relevant to conserving the species, being either a small proportion of population in native range, or of world population if species is widely established elsewhere

1 English distribution a significant proportion (10-50%) of that in other places, including native range

2 English population greater than that elsewhere in its world range, but species not threatened in native range

3 English population greater than that elsewhere in its world range, species threatened or extinct in native range

4 English population a significant part of British distribution, species not known from outside Britain, but almost certainly introduced

Habitat

EUNIS level 2 habitats (Appendix 3). The habitat (if known) was listed whether or not there is an impact. There are four habitat columns in the database. For a few very wide-ranging species there may have been more habitats; only the most significant were selected.

Current trend in range and abundance

That this field specifies the *current* (not historic) trend in the taxon's range and abundance.

GG Growth (expansion) strong

G Growth (expansion) moderate

0 Minor or no change

D Decrease moderate

DD Decrease strong

nd no data – trend not known

Direct economic value

Valued animals and plants are those for which the trade costs or rearing expenses exceed £10,000 p.a., eg rainbow trout, cats, goats, red-legged partridge.

0 none
1 occasional crop, horticultural, livestock, pet, quarry or fishery species
2 valued crop, horticultural, pet, livestock, quarry, or fishery

Economic impact (including effects on human and livestock health)

As a rule of thumb, large impact starts at £10,000 p.a. All pests causing damage of this value or more have a large negative impact.

NN strong negative impact (pest etc.)
N negative impact
0 slight or no impact
P postive impact
PP strong positive impact
U Unknown

Mode of economic impact

Letters signify the mode of impact. For example, Japanese knotweed *Fallopia japonica* modifies urban habitats, and can be very costly to remove. Its effect is therefore indicated by H. Costs resulting from conservation activities – eg killing rhododendron – do not count as economic, but as environmental.

A aesthetic/recreational
C competition
D disease or other health effect
F food source for humans or livestock
H habitat modification
I introgression
P predator or parasite
V vegetation eater (herbivory)
W wood or other biomass production

Conservation value in England

For species that are listed by JNCC, the IUCN categories for Britain are employed. These are particularly relevant to archaeophyte plants and reintroduced animals. Many arable plants are subject to informal conservation, eg through farmers leaving unsprayed parts of fields to encourage them, at least locally. These should be distinguished. Note that species only qualify when it is that particular species that is subject to conservation measures.

0 No conservation status and not likely to be conserved, even informally
1 No conservation status but an actual or possible subject for informal conservation (eg common poppy *Papaver rhoeas*)
EX Extinct
EW Extinct in the wild
CR Critically endangered
EN Endangered
VU Vulnerable

NT Near threatened
DD Data deficient

Environmental impact

Codes are as for economic impact. Ruddy duck is scored I for introgression, although the impact is not in England. Clearly, introgression from English birds has had an impact.

Mode of environmental impact

Codes are as for economic impact.

Population trend

Population trends in next 20 years. This is necessarily a speculative item for many species, but for some that are about to show a large increase having newly arrived, or which have now peaked, was possible to make a well informed prognostication.

G growth (increasing by factor of 2 or more)
0 not changing by more than a factor of 2
D decrease (by factor of 2 or more)
nd no information

Control methods

B biological - release of control organism
C chemical - pesticides or herbicides
D direct – trapping, shooting, fishing, weeding, clear-felling, cutting
E environmental – mowing or grazing to make habitat unsuitable, drainage of ponds
0 no control attempted

Date

A single date for each species. The date is calculated from the database by choosing the date of introduction if known, or the end of the date-range where an exact date is not known. If neither of these dates is available, the date is that of the first record from the wild.

Compiler

The following initials appear in the database.

CDP Preston
DP Parrott
DRJ Jones
GHC Copp
GRB Broad
HRA Arnold
IL Laing
JRE Ellis
ML Longshaw
MOH Hill
NG-D Greatorex-Davies

NM Moore
PJC Chandler
RH Hammon
RHAB Baker
RMS Smith

Institution

The institutional affiliations of compilers are given. Peter Chandler contributed as a private individual.

BRC Biological Records Centre (a unit within the Natural Environment Research Council's Centre for Ecology and Hydrology)

CEFAS Centre for Environment, Fisheries and Aquaculture Science (an executive agency of the UK government's Department for Environment Food and Rural Affairs)

CSL Central Science Laboratory (an executive agency of the UK government's Department for Environment Food and Rural Affairs)

Appendix 5. Species found only in gardens

The species listed in Tables A9 and A10 are those that have been found only in gardens and other highly artificial habitats. Many of them are no doubt also present in the wider environment, but we have not traced records of their occurrence there. Counts of the numbers of species in each category are given in Table 3.

Table A9. Animal species found in gardens and other highly artificial habitats but not yet known in the wild in England

Scientific name	Common name	Comments
Daphnia ambigua	a water flea	Kew Gardens and Regent's Park
Metatrichoniscoides leydigi	a woodlouse	Woodlouse found in a garden centre (away from glasshouses)
Unciger foetidus	a millipede	In a garden in Dersingham
Tegenaria domestica	a spider	Synanthropic, occasionally outdoors
Antiponemertes pantini	a ribbon worm (Nemertinea)	Gardens on Isles of Scilly
Paratrichodorus renifer	Stubby-root Nematode	Associated with *Rhododendron* spp.
Pratylenchus bolivianus	Root Lesion nematode	On *Alstroemeria* spp. in Britain; in S America also on oats and potatoes
Proteocephalus osculatus	a tapeworm	On *Silurus glanis* in a fish farm
Tylenchorhynchus claytoni	Stunt nematode	On *Rhododendron* spp.
Urocleidus principalis	Monogenean platyhelminth	Parasite of *Micropterus salmoides*
Arge berberidis	Berberis sawfly	On Berberidaceae
Lilioceris lilii	Lily Beetle	Pest of *Lilium, Fritillaria*
Luperomorpha xanthodera	Rose flea beetle	On rose cultivars, *Astilbe* spp., *Erysimum* sp.
Rodolia cardinalis	Vedalia ladybird	Introduced elsewhere as a biocontrol agent
Argyresthia cupressella	Cypress tip moth	On cultivated Cupressaceae including *Juniperus*
Athrips rancidella	Cotoneaster webworm	Suburban gardens but wide-ranging and polyphagous in Europe
Gelechia sabinellus	a moth	Feeds on junipers
Acyrthosiphon auriculae		Aphid on garden primulas
Aonidia lauri	Laurel scale	On *Laurus nobilis* in one garden
Aspidiotus nerii	a mealybug	Gardens on Isles of Scilly; common in greenhouses
Bemisia afer	a whitefly	Breeding in Britain on *Laurus nobilis*; polyphagous elsewhere
Brachycaudus amygdalinus	an aphid	On almond
Cinara cedri	a Lachnid aphid	Feeds on *Pinus* and *Cedrus*; single site in England
Cinara curvipes	a Lachnid aphid	On *Cedrus atlantica*; single site in England
Coccus hesperidum	a mealybug	Common in greenhouses, often surviving outdoors on evergreen leaves
Crypturaphis grassii	an aphid	On *Alnus*
Eulecanium excrescens	Wisteria Scale	Recorded mainly on *Wisteria* in Britain; broadly polyphagous elsewhere
Eupulvinaria hydrangea	Hydrangea scale	On *Hydrangea* in England, polyphagous elsewhere
Leucaspis podocarpi	a scale insect	On *Podocarpus* in Abbey Gardens, Scilly
Paracolopha morrisoni	a root aphid	Root aphid on bamboos

Scientific name	Common name	Comments
Planococcus vovae	a mealybug	On Cupressaceae, especially *Cupressus macrocarpa*
Pseudococcus calceolariae	Citrus Mealybug	In Britain only in gardens
Saissetia oleae	a mealybug	On *Aloe* in the Abbey Gardens, Tresco
Stephanitis takeyai	Andromeda lacebug	On Ericaceae, particularly *Pieris* spp. in England
Takecallis arundicolens	a bamboo aphid	On bamboos
Takecallis arundinariae	a bamboo aphid	On bamboos
Takecallis taiwanus	a bamboo aphid	On bamboos
Toxoptera aurantii	an aphid	On *Camellia* in Britain, polyphagous elsewhere
Trichosiphonaphis polygonifoliae	an aphid	On *Lonicera tatarica*, found only once
Trionymus diminutus	a mealybug	On *Phormium tenax*, established on Tresco
Trioza alacris	Bay sucker	On *Laurus nobilis*
Asphondylia borzi	a gall midge	Recorded once on *Rhamnus alaternus*
Braula schmitzi	a 'bee louse' (fly)	Wingless cleptoparasite of honeybees
Contarinia quinquenotata	a gall midge	On *Hemerocallis fulva*, sometimes a pest
Dasineura gleditchiae	a gall midge	On *Gleditsia triacanthos*
Dasineura rhododendri	a gall midge	On *Rhododendron ferrugineum*
Dohrniphora cornuta	a phorid fly	Subtropical, established outdoors in sewage filters
Hydrotaea aenescens	The dump fly	A predator of housefly larvae in rubbish
Leia arsona	a fungus gnat	Casual in England but established in nurseries in Netherlands
Leptocera caenosa	a sphaerocerid fly	Mostly indoors but also established outdoors in sewage filters
Phytomyza hellebori	a leaf-mining fly	Leaf-miner on *Helleborus* spp.
Rhopalomyia chrysanthemi	a gall midge	On garden chrysanthemums, last record 1955
Tephritis praecox	a picture-winged fly	On *Calendula officinalis*
Heliothrips haemorrhoidalis	a greenhouse thrips	On *Laurus* at Kew, *Arbutus* at Chelsea Physic garden, various genera on Tresco, Isles of Scilly
Sipyloidea sipylus	Pink-winged stick-insect	
Trachemys scripta	Red-eared Terrapin	Not known to breed in the wild
Pimephales promelas	Fathead Minnow	Reproducing population in garden pond

Table A10. Fungus species found in gardens and other highly artificial habitats but not yet known in the wild in England

Scientific name	Common name	Comments
Agrocybe putamium	a basidiomycete	On wood-chip mulch, London, Kew, Wisley
Collybia biformis	a basidiomycete	On wood-chip mulch, Wisley
Endophyllum sempervivi	Houseleek rust	Parasitic on *Sempervivum* spp.
Entyloma calendulae	Calendula Smut	On cultivated *Calendul*a, common in SW England.
Entyloma compositarum	Gaillardia smut	On *Gaillardia* cultivars
Entyloma dahliae	Dahlia smut	Widespread and common on cultivated *Dahlia*
Gastrosporium simplex	Steppe truffle	Only record is from a domestic garden
Geastrum campestre	Field earthstar	Associated with *Cedrus* trees
Gymnosporangium juniperi-virginianae	a rust	Parasitic on apple
Hydnangium carneum	a basidiomycete	Found wherever *Euclayptus* is planted
Ileodictyon cibarium	Basket fungus	Well established in small area of SE England
Lysurus cruciatus	Lizard's claw	Gardens, stable refuse, greenhouses

Microstroma juglandis	a smut	On *Juglans* and *Carya* throughout their wild and cultivated ranges
Mikronegeria fagi	a rust	Parasitic on *Nothofagus*
Phragmidium fusiforme	a rust	Parasitic on introduced roses (*Rosa glauca*, *R. pendulina*)
Puccinia antirrhini	Antirrhinum rust	Arrived 1930s, now generally distributed
Puccinia cyani	Centaurea rust	Parasitic on *Centaurea cyanus*
Puccinia gentianae	a rust	Parasitic on cultivated gentians (*Gentiana acaulis*, *G. verna*)
Puccinia gladioli	a rust	Parasitic on cultivated *Gladiolus*
Puccinia horiana	Chrysanthemum white rust	On cultivated chrysanthemums; spread rapidly after first discovery
Puccinia kusanoi	a rust	On bamboo *Arundinaria fastuosa*, not seen recently
Puccinia ljulinica	a rust	Parasitic on *Smyrnium perfoliatum*
Puccinia longicornis	a rust	Parasitic on bamboos (*Pseudosasa japonica, Sasa veitchii*)
Puccinia pazchkei var. pazchkei	Saxifrage rust	Parasitic on cultivated *Saxifraga* spp. in gardens
Puccinia pelargonii-zonalis	Pelargonium rust	Parasitic on *Pelargonium zonale* and hybrids
Puccinia prostii	a rust	Parasitic on *Tulipa australis*
Queletia mirabilis	Quélet's stalk puffball	Very few world records, all from spent tan-bark, most in Europe
Stropharia percevalii	a basidiomycete	On wood-chip mulch
Suillus placidus	a basidiomycete	Confined to Bedgbury Pinetum
Urocystis gladiolicola	Gladiolus smut	Parasitic on cultivated *Gladiolus*
Urocystis syncocca	a smut	Parasitic on cultivated *Hepatica* species
Uromyces aecidiiformis	a rust	Parasitic on *Lilium* spp.
Uromyces colchici	a rust	Parasitic on *Colchicum*, including *C. autumnale*
Uromyces dianthi	Carnation rust	On cultivated carnations, mainly in greenhouses
Uromyces erythronii	Erythronium rust	Parasitic on *Erythronium dens-canis*
Zaghouania phillyreae	a rust	Parasitic on *Phillyrea latifolia*, last seen 1907
Aglaospora profusa	an ascomycete	On *Robinia pseudoacacia*
Anthostomella trachycarpi	an ascomycete	On *Trachycarpus*
Aulographina eucalypti	an ascomycete	On Eucalyptus
Botryotinia draytonii	an ascomycete	On *Gladiolus*
Cryptodiaporthe robergeana	an ascomycete	On *Staphylea*
Diaporthe oncostoma	an ascomycete	On *Robinia pseudoacacia*
Diaporthe skimmiae	an ascomycete	On *Skimmia*
Didymella lycopersici	Tomato stem and fruit rot	On *Capsicum, Cucumis* and *Lycopersicon*
Elsinoë ampelina	Grape anthracnose	Foliar parasite on *Vitis* and *Parthenocissus*
Erysiphe euonymi-japonicae	an ascomycete	On *Euonymus japonicus*
Erysiphe necator	Vine powdery mildew	Common mildew on *Vitis vinifera*; also on other cultivated Vitaceae
Erysiphe rayssiae	an ascomycete	On *Spartium junceum*
Erysiphe syringae	an ascomycete	On *Syringa vulgaris*, few records from *Ligustrum*
Eupropolella arundinariae	an ascomycete	On culms of bamboos
Leptosphaeria lunariae	an ascomycete	On *Lunaria*
Lichenopeltella fimbriata	an ascomycete	On dead leaves of *Chamaecyparis* and *Cupressus*
Mycosphaerella chrysanthemi	Chrysanthemum ray blight	On cultivated chrysanthemums
Neobulgaria undata	an ascomycete	On stems of tree ferns
Oidium hortense	an ascomycete	On *Hydrangea macrophylla*

Paurocotylis pila	an ascomycete	Records on mossy soil may not all be gardens
Pseudonectria pachysandricola	an ascomycete	On *Pachysandra*
Sphaerotheca verbenae	an ascomycete	Parasitic on cultivated *Verbena* plants
Stromatinia gladioli	an ascomycete	On *Gladiolus*
Taphrina deformans	Peach leaf curl	Parastic on *Prunus dulcis, P. persica*
Xenomeris nicholsonii	an ascomycete	On *Prunus lusitanica*
Circinotrichum britannicum	anamorphic fungus	Saprophyte on *Laurus nobilis* leaves
Colletotrichum acutatum	anamorphic fungus	On *Lupinus* and *Fragaria*

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Front cover photographs:
Top left: Using a home-made moth trap.
Peter Wakely/English Nature 17,396
Middle left: Co_2 experiment at Roudsea Wood and Mosses NNR, Lancashire.
Peter Wakely/English Nature 21,792
Bottom left: Radio tracking a hare on Pawlett Hams, Somerset.
Paul Glendell/English Nature 23,020
Main: Identifying moths caught in a moth trap at Ham Wall NNR, Somerset.
Paul Glendell/English Nature 24,888