The Economic Cost of Invasive Non-Native Species on Great Britain

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Executive Summary

The impact of Invasive Non-Native Species (INNS) can be manifold, ranging from loss of crops, damaged buildings, and additional production costs to the loss of livelihoods and ecosystem services. INNS are increasingly abundant in Great Britain and in Europe generally and their impact is rising. Hence, INNS are the subject of considerable concern in Great Britain, prompting the development of a Non-Native Species Strategy and the formation of the GB Non-Native Species Programme Board and Secretariat.

A number of estimates of the economic impact of INNS on various countries, including the UK, exist, but the detail in many of these estimates is lacking and the impact on different sectors of the country is largely unknown. This research estimates the current annual cost of INNS to the British economy. The report provides assessments of the economic cost of INNS to twelve sectors and the report contains detailed examples for three species (Japanese knotweed, signal crayfish and floating pennywort). Five case studies are also included to demonstrate the costs of eradication at different stages of invasion.

The report only considers negative economic impacts of INNS, although it is acknowledged that non-native species, including some invasive ones can make a positive contribution to the economy.

Various methods were used to secure data for economic estimations. References of relevance to over 500 non-native species were gathered from the scientific and grey literature as well as the internet. A detailed questionnaire was sent to key organisations, primarily to develop contacts but also to gather initial information. The collected information was used to estimate the costs, partially based on calculations for individual species, which was anonymously reviewed by selected experts from each of the sectors.

The total current annual cost of INNS to the British economy is estimated, when corrected for double counting, at £1,291,461,000 to England, £244,736,000 to Scotland and £125,118,000 to Wales. Therefore the **total annual cost of INNS to the British economy is estimated at approximately £1.7 billion**.

In this work, where solid evidence was not available, assumptions based on the biology and ecology of the species involved were used to extrapolate costs. When assumptions had to be used, the figures that were used were intentionally conservative and it has been explicitly stated that they were assumptions. In the anonymous peer review process the calculations and assumptions were challenged, corrected or accepted.

This report focused on direct costs as these could be most accurately estimated, however if indirect costs do exist to a similar extent to that found in the meta-analysis, the value of these could be very significant. However, the indirect costs have not been sufficiently explored to support or refute this suggestion.

As INNS are becoming more widespread and the economic impact is expected to increase, the effect of the extent of the invasion on control costs was investigated in five case studies (Asian long-horned beetle, carpet sea squirt, water primrose, grey squirrel and coypu). These case studies revealed an exponential increase of the cost of control as an invasion progresses, and demonstrated the benefits of intervention at an early stage, as well as the long-term cost savings if eradication is undertaken early in the invasion process.

Acronyms and Abbreviations

ADAS	Agricultural Development and Advisory Service
ALB	Asian Longhorned Beetle (*Anoplophora glabripennis*)
AINA	Association of Inland Navigation Authorities
APHIS	Animal and Plant Health Inspection Service (USA)
a.s.l.	above sea level
avg.	Average
AUS	Australia
BAA	BAA Airports Limited
BAP	Biodiversity Action Plan
BBRSC	Biotechnology and Biological Sciences Research Council
Bn	Billion (1,000,000,000)
BTCV	British Trust for Conservation Volunteers
BW	British Waterways
CAA	Civil Aviation Authority
CABI	CAB International
CBD	Convention on Biological Diversity
CCW	Countryside Council for Wales
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CLG	Communities and Local Government Department
CSL	Central Science Laboratory
Defra	Department for Environment, Food and Rural Affairs
DVC	Deer-Vehicle Collision
EA	Environment Agency
EPPO	European and Mediterranean Plant Protection Organisation
EPRSC	Engineering and Physical Sciences Research Council
EU	European Union
FAO	Food and Agriculture Organisation
FC	Forestry Commission
Fera	Food and Environment Research Agency
GB	Great Britain (England, Scotland and Wales)
GDP	Gross Domestic Product
GISP	Global Invasive Species Programme
GP	General Practitioner
FTE	Full time equivalent

ha	Hectare (10,000 m^2)
HMI	Horticultural Marketing Inspectorate
INNS	Invasive Non-Native Species
IWAC	Inland Waterways Advisory Council
JKSL	Japanese Knotweed Solutions Limited
JNCC	Joint Nature Conservation Committee
MarLIN	Marine Life Information Network
mph	miles per hour
MW	Megawatt
NBN	National Biodiversity Network
NERC	National Environmental Research Council
NHS	National Health Service
NNSS	Non-Native Species Secretariat
NZ	New Zealand
OSR	Oilseed Rape
p.a.	per annum
PACEC	Public and Corporate Economic Consultants
PHSI	Plant Health Seed Inspectorate
RAFTS	Rivers and Fisheries Trusts of Scotland
RHS	Royal Horticultural Society
RIA	Risk Impact Assessment
Rs	Rupees
RSPB	Royal Society for the Protection of Birds
SAC	Special Areas of Conservation
SEK	Swedish Krona
SEPA	Scottish Environmental Protection Agency
SNH	Scottish National Heritage
SSSI	Site of Special Scientific Interest
UK	United Kingdom
USA, US	United States of America
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VAT	Value Added Tax
WAG	Welsh Assembly Government
WTP	Willingness to Pay

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1 Introduction

Invasive non-native species (INNS) are defined by the Invasive Non-Native Species Framework Strategy for Great Britain as those species 'whose introduction and/or spread threaten biological diversity or have other unforeseen impacts' (Defra 2008). They are generally species that have been introduced by human action to areas outside their natural range, have become established in a new ecosystem, and have then been through a period of expansion in their range, a population explosion and are now firmly consolidated and have a self-sustaining population (Emerton and Howard 2008). INNS pose a huge threat to natural ecosystems, both in terms of the effect on biodiversity and the cost to human activities such as agriculture, tourism and development (Wittenberg and Cock 2001). The introduction of non-native species often occurred in past centuries, for example rabbit (*Oryctolagus cuniculus*), but there have also been recent species introductions (e.g. *Didemnum vexillum*) that could potentially cause problems in their newly invaded habitats. Past introductions may have been intentional, e.g. rhododendron (*Rhododendron ponticum*), but there have also been many cases of unintentional introductions, e.g. zebra mussel (*Dreissena polymorpha*) with ballast water. Many species that are not native to the habitat in which they now exist are not considered to be invasive. Indeed many species are very beneficial, such as most crop plants and many farmed animals, or have little impact on the habitat in the introduced range. However, the focus of this report is on those species whose presence in an ecosystem primarily has a negative effect and that are considered to be invasive in Great Britain.

An estimated 20-30% of all introduced species worldwide cause a problem (Pimentel *et al.* 2001) and the number of non-native species introductions is increasing exponentially as a result of increased travel, transport, trade and tourism (Clout and De Poorter 2005). In Europe, approximately ten new species become established each year, and there is a rising trend for invertebrates and marine fish introductions (Hulme *et al.* 2009). There often is a lag-phase prior to a non-native species becoming invasive when there is a delay between the introduction of a species and successful spread and impact. Sometimes there can be multiple lag phases, depending on species and the environment (Wangen and Webster 2006). The average lag-phase has been estimated at about 50 years, but this phase is shorter in tropical species than in species from temperate regions (Daehler 2009). Overall, the rate of invasion of a particular species is hard to predict (Melbourne and Hastings 2009). In general, however, the rate of spread of INNS is often exponential.

1.1 Economic Causes of Invasions

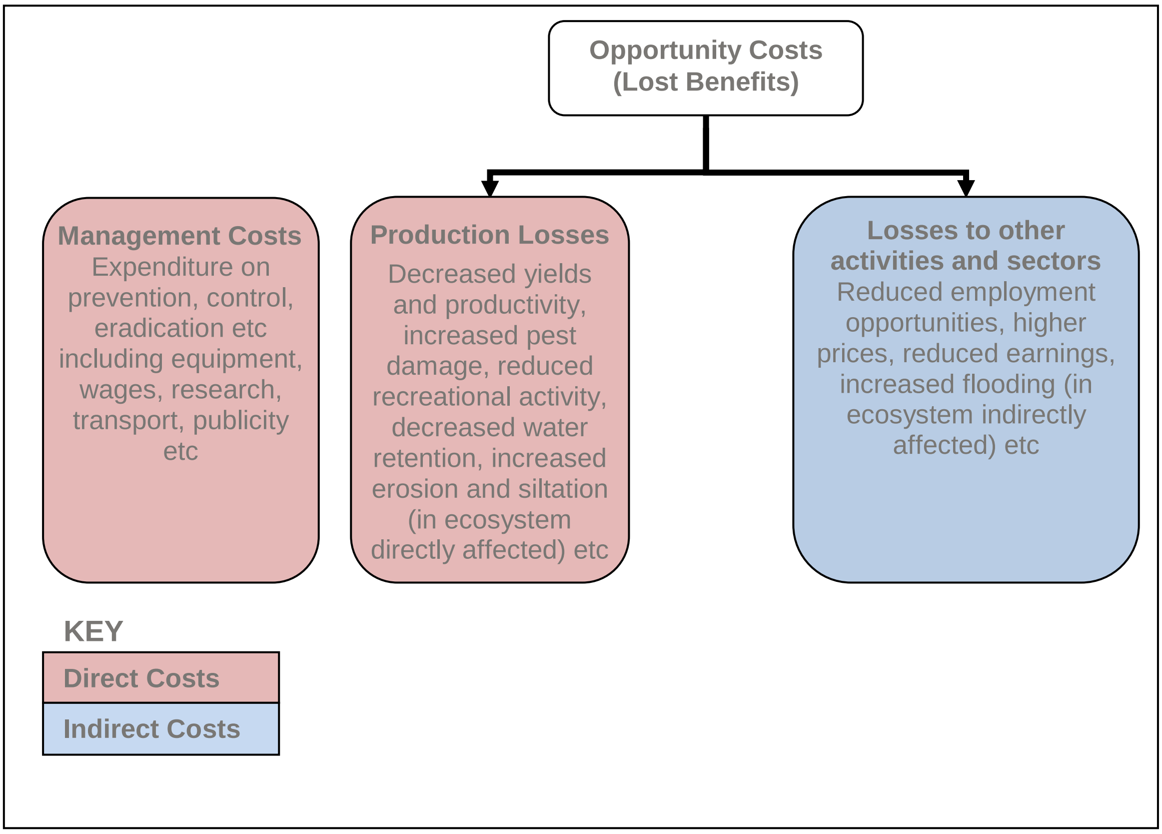
The economic reasons for species introductions can be classified as either those caused by direct human actions or those resulting from an indirect effect of human activities (Fig. 1.1, Emerton and Howard 2008). Direct economic causes can, for example be the production or consumption of goods which involve the introduction and use of an INNS and therefore can lead to its invasion into a new ecosystem. The four T's of trade, transport, travel and tourism, all direct economic activities, can also lead to new biological invasions. Species can 'hitch-hike' in travellers' luggage and clothing, in freight and packaging, be introduced through contaminated animals and plants, or through ships' ballast water and other waste material when this is dumped. There are many examples of species that have been introduced for commercial purposes such as those for agricultural plants and seeds, livestock for meat and fur, fish for aquaculture and sport fishing. While many of these species have economic benefits to a country (in particular food crops), other species have unintended consequences. This may happen when the introduction is not managed and the species becomes established in the wild, the population expands and consolidates to become invasive in the new country, as was the case with mink (*Neovison vison*). Many of the invasive weeds in Great Britain were intentionally introduced as ornamental plants, e.g. Japanese knotweed (*Fallopia japonica*).

Although introductions of new species are often caused by direct human actions, the next steps in a species becoming invasive (escape, population establishment, expansion and explosion and finally consolidation) may be attributed to indirect economic causes where the presence of INNS have a knock-on effect in different sectors of the economy. Fiscal instruments such as subsidies, taxes, trade quotas, etc. influence people's economic decisions, as does the general economic environment in which they live and work. These instruments and activities can indirectly encourage the introduction or establishment of INNS, through for example developments in the agriculture or tourism industries that encourage the use or introduction of species that may become invasive.

1.2 Economic Costs

Economic costs can arise because INNS affect the ordinary functioning of ecosystems to produce the goods and services that humans use. Many of the effects of INNS can have a direct cost to the economy (Fig. 1.1), such as control and eradication costs, structural damage to infrastructure, or loss of production due to the presence of an INNS.

Figure 1.1. A schematic representation of the division of economic costs (adapted from Emerton and Howard 2008).

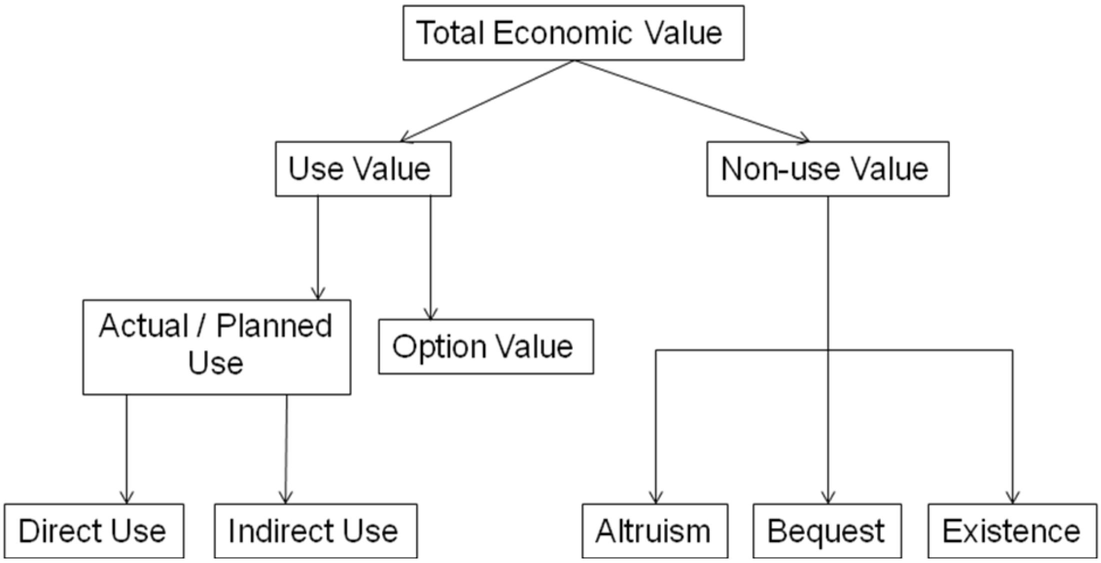


There are obvious prevention and control costs associated with INNS, as well as costs associated with repairing damage, research and publicity. Other direct costs include decreased yield and productivity, increased flooding and erosion caused directly by the presence of an INNS in a particular environment. INNS may also cause indirect costs to the economy, such as a reduction in employment opportunities or higher prices for goods as their production is affected by an INNS. For example the loss of trees due to an insect pest would have a direct cost in terms of the value of the trees, the loss of a recreational area and increased soil erosion due to reduction of root biomass in the soil. Indirectly this could also cause increased flooding downstream as the water retention capacity of the area was reduced, causing higher run off rates, meaning stream flows peaked more quickly during storm events and rivers burst their banks more frequently. The presence of the invasive insect is not directly causing the flooding, but its effects are causing subsequent effects elsewhere. However, these potential economy-wide effects are not generally incorporated into the prices or profits experienced through economic activity (Perrings *et al.* 2005), meaning that the true economic costs of INNS are not reflected in the economy.

1.3 Total Economic Value

As can be seen from the example of the insect pest in Section 1.2, the economic costs due to the presence of INNS range from the value of the lost harvested timber products and the lost recreational value, to the costs caused by increased flooding. Hence, the costs discussed above are only a portion of the costs that are attributable to the presence of INNS in a country. There are many costs that may not be immediately associated with INNS, and therefore an ecosystem services approach can be taken in order to classify the costs to the economy. This approach should include all of the costs described in Table 1.1, from direct (market) costs, to non-market costs which include the indirect costs, and the option and non-use values (Fig. 1.2), all of which can have a monetary value placed on them through environmental valuation techniques. Any negative impact on these environmental values will therefore have an associated reduction in monetary value, or an economic loss associated with it.

Figure 1.2. The total economic value of ecosystems. After Defra (2007).



- **Direct use** costs are those costs that INNS have on the use of an ecosystem service in terms of extraction of resources from the ecosystem (e.g. food production, timber extraction) or the use of the ecosystem for recreation, even though this is a non-marketable product. A reduction in production, or an increase in expenditure to maintain production caused by the presence of an INNS is an economic cost. A reduction in visitor numbers to a park, or the expenditure to remove an INNS so that native biodiversity is maintained are also direct costs to the economy attributable to the presence on an INNS.
- **Indirect use** costs are due to the effects of INNS on the ecological functions that support life. These costs could include the effects of INNS on nutrient cycling, pollination and flood attenuation. Any reduction in the functioning of these ecosystem services due to the presence of INNS will be a cost to the economy.
- **Option value** costs include the costs that INNS cause through an impact on the potential of an ecosystem to provide resources in the future. This may include new pharmaceutical discoveries from native species, new agricultural developments or tourism developments. If INNS affect the ecosystems in such a way that these services are no longer available, then the reduction of the potential value of these services is a cost of INNS to the economy.
- **Altruism values** relate to the value that people place on ensuring that an ecosystem or charismatic species are available for others to use and enjoy. Any damage to the ecosystem, reduction in species numbers, etc. caused by an INNS that means that the ecosystem is not perceived as being as valuable as it was for others to use is a cost attributable to the INNS.
- **Existence values** are the values that people place on an ecosystem, such as a forest, or a charismatic species, for example the water vole (*Arvicola terrestris*). If the existence of these values is threatened by the presence of an INNS, then the reduction in value that people place on the affected forest is a cost attributable to the INNS.
- **Bequest values** are those values that people place on ensuring that an ecosystem is still present for future generations. If the ecosystem is damaged by an INNS and the value that is placed on ensuring it is available in the future is reduced, this reduction in value is a cost caused by INNS.

These component values of the total economic value of an ecosystem are based on the willingness of individuals to pay for the goods and services provided by the earth's ecosystems, or to pay for the preservation of these goods and services so that present and future generations are able to benefit both from their existence and their use. Direct use values are the most easy to quantify as they generally have market prices. However, many ecosystem goods and services do not have direct market values and it is therefore difficult to obtain an assessment of the true value of an ecosystem. There are markets for some services and valuation techniques have been developed to address the gaps in current valuations, as discussed below. Yet, many services, such as the feeling of well-being people may obtain from experiencing nature directly, are hard to value.

1.4 Valuation Techniques

The main aim of valuation techniques is to quantify how much people are willing to pay for a certain good or service, and how any change in this good or service would affect what they are willing to pay. The current value of a good or service can also relate to how much people are willing to pay to protect it or ensure it's preservation for future generations. Alternatively, the current value can be related to the value of the loss people would feel if the good or service no longer existed. There are a number of common techniques used to value environmental goods and services in an attempt to assign a monetary value where no direct market value exists (Table 1.1). Details of the use of some techniques can be found below.

The travel cost method can be used to assign a recreational value to a habitat, such as a forest or a beach, by measuring the amount of money people are prepared to spend to reach this ecosystem. Generally, surveys are carried out that ask visitors questions related to their expenditure in visiting the site. Large datasets can be generated, and the survey may cover multiple sites. Statistical analysis of the data will reveal an amount that people are willing to pay to visit the site and this can then be used to place a value on the entire site. This method could also be used to provide a value of a nature reserve, or the value of a charismatic animal within an area.

Table 1.1. Environmental valuation techniques, after Emerton and Bos (2004).

Market-Based Techniques	**Revealed Preference Approaches**	Market Prices
		Effect on Production
	Surrogate Market Approaches	Travel Costs
		Hedonic Pricing
	Cost Based Approaches	Replacement Cost
		Mitigative and Avertive Expenditure
		Damage Costs
Stated Preference Techniques		Contingent Valuation
		Conjoint Analysis
		Choice Experiments

Contingent valuation, as a stated preference technique, directly asks people how much money they would be willing to pay for a service (e.g. to protect the water vole) or how much monetary compensation they would be willing to accept if this service was no longer available to them. This method can be used to assess people's option values for a particular ecosystem. For example, by asking how much they would pay to protect an ecosystem from invasion from a non-native species, it is possible to obtain an estimate of people's value of the ecosystem.

Some indirect costs are quantifiable through the use of these valuation techniques, but the effect of INNS on many other non-market values is not quantifiable. Values, such as the ecological functioning of an ecosystem, will not be captured by these techniques unless the role of the ecosystems is understood and there are sufficient data. Moreover, it is likely that there are functions that have yet to be identified or quantified and this lack of knowledge means the true value of ecosystem services is always likely to be underestimated (European Commission 2008). As a result of the difficulties in quantifying all the costs caused by INNS, these estimates are probably always incomplete and therefore too low. Whilst all costs have been included in this report where possible, it is evident that the vast majority of non-market costs (e.g. impacts on biodiversity) associated with the effects of INNS have not been captured in any monetary form.

1.5 Estimations of Total Economic Costs

The non-market costs of INNS often can be high in comparison to market costs (Colautti *et al*. 2006), as illustrated by estimates in published studies. Where costs have been estimated, they are often based on a relatively small number of case study species, therefore limiting the accuracy of the assessment of the costs of INNS to an economy. Holmes *et al.* (2009) suggested, however, that a conservative estimate of the economic impact can be obtained by assessing only the most influential species. They also stated that the use of historic data often leads to an underestimate of the economic costs. As the species' distribution often increases exponentially during the course of an invasion, the change in impact of a species on an economy may also be exponential. Therefore, cost estimates based on historic data need to take the stage of invasion of a species into account to ensure the estimated costs reflect the current effect of the species. The accuracy of transferring values of non-market valuation (Benefit Transfer) from one case to another creates a lot of variation in the data (Hanley *et al*. 2006), therefore in order to obtain an estimate it is necessary to ensure that data used in cost estimations are from similar ecological conditions, even if they are obtained from a different country. It is necessary to understand the existing evidence and the key assumptions and sensitivities associated with it, before deciding whether it is appropriate to use the data in cost calculations in a different context (Bateman *et al.* 2010).

1.6 Previous Studies

The total loss to the world economy as a result of invasive non-native species has been estimated at 5% of annual production (Pimentel *et al.* 2002). However, despite past work on INNS, the total cost of these species to a country's economy is generally unknown and therefore several recent studies have been undertaken to estimate the economic impact of INNS in a number of countries (summarized in Table 1.2). These studies have revealed that the cost of INNS to a country's economy can be very high, but the estimates vary widely. A review of these studies also demonstrated that in general only direct, market costs are included in studies that estimate the economic impact of INNS due to the lack of the necessary data, despite the extensive literature about the key species (Colautti *et al.* 2006).

An analysis of the effect of selected characteristics of study design and the studied countries on the estimates of the economic cost of INNS in 16 studies was carried out (Box 1). The results revealed that the inclusion of non-market costs explains a significant proportion (15.2%) of the variation between the estimates in those studies. While some of the other characteristics of the studies or the studied countries did also have a significant effect on the estimated costs, no clear trends were found. Market costs represented on average 1.7% of the total estimated annual cost of INNS to a country's economy.

The selected characteristics in our analysis explain a large amount of variation among the cost estimates, although the valuation of the non-market costs is very dependent on the methods used to assess them (Boyer and Polasky 2004) and can be very context-dependent (Boyer and Polasky 2004; Hanley *et al.* 2006). The substantial unexplained fraction of the variation is due to factors like inconsistency in the methodologies of the studies. A further reason for the variation is the inclusion of different organism groups and viruses in the different studies. The description of the studies of the economic impact of INNS often lack a clear methodology (Born *et al.* 2004), leading to speculation about the accuracy of the estimates. Indeed, the quality and interest of the published cost estimates varies widely and standardised approaches towards estimating cost are needed (Simberloff 2004).

Table 1.2. Summary of previous studies of the economic impact of INNS on various countries. Values were converted to sterling and corrected for inflation.

Country	Cost/Year	Year	2008 £ million avg.	km^2	GDP in study year (2008 £ billion)*	Organism groups	Non-market costs	Reference
Australia	AUS$3,554-4,532M	2002	2701	7617930	295	Weeds	Y	Sinden *et al.* 2004
Australia	AUS$719.7M	2004	454	7617930	445	Animals (economic and environmental impact)	N	McLeod 2004
Canada	CDN$13300-34500M	2006	14903	9984670	896	Plants and animals	Y	Colautti *et al.* 2006
China	Yuan30.9Bn	2005	3033	9640821	1,604	Forest insects and pathogens	Y	Li & Xu 2005
China	US$14,450M	2006	9391	9640821	1,855	Microorganisms, plants and animals	Y	Xu *et al.* 2006
Germany	€109-263M	2003	199	357021	1,476	Plants and animals	N	Reinhardt *et al.* 2003
India	Rs. 1.68Bn	2002	24	3287240	399	Fungal, bacterial, viral & nematode pathogens	N	Singh & Kaur 2005
New Zealand	NZ$270M	2002	141	268680	40	Vertebrates	N	Clout 2002
New Zealand	NZ$200M	2002	105	268680	40	Weeds	N	Williams & Timmins 2002
New Zealand	NZ$3,424M	2009	1479	268680	84	Plants and animals	N	Giera & Bell 2009
Sweden	SEK1600-5000M	2009	286	450295	310	Animals, plants, HIV	Y	Gren *et al.* 2009
UK	US$239M	2002	175	219000	1,162	Vertebrates	N	White & Harris 2002
UK	UK£200-300M	2002	372	219000	1,162	Plants	N	Williamson 2002
UK	US$5000M	2002	3658	219000	1,162	Arthropods and pathogens	Y	Pimentel 2002
UK	UK£19.3-29.2M	2009	24	219000	1,728	Freshwater organisms, control cost only	N	Oreska 2009
USA	US$134000M	2001	99575	9826675	8,116	Plants, animals and microbes	Y	Pimentel *et al.* 2001

* GDP figures from World Bank and International Monetary Fund

Box 1. What determines the estimated cost of INNS to the economy of a country?

The published estimates of the cost of INNS to a country's economy vary widely. An analysis of how a number of country properties and study descriptors affected the values estimated in a number of studies was conducted.

The cost estimates for various countries were obtained from studies published in the grey and scientific literature. A total of 16 studies were found from various continents that estimated the cost of a variety of organism groups. The estimates were converted to sterling using the current exchange rate and adjusted for inflation. Where a range was provided, the mean of those values was used. Further descriptors were the size of the country (in km^2), the country's GDP, the year the study was published[1], and whether non-market costs were part of the estimate. The data are presented in Table 1.3. The influence of the study descriptors on the cost estimates was analysed using an analysis of variance with cost estimates as the response variable and the descriptors listed above as explanatory variables. The cost estimates were log-transformed prior to the analysis. The analysis of variance tests determined whether the variation seen in the response variable (cost) was explained by the variation found in any of the explanatory variables (country size, GDP, year of study, inclusion of non-market costs). The test determines whether more than two population means are equal using a probability distribution function (F-distribution). A low probability (e.g. $P < 0.05$) suggests that the explanatory variable has a significant effect on the response variable.

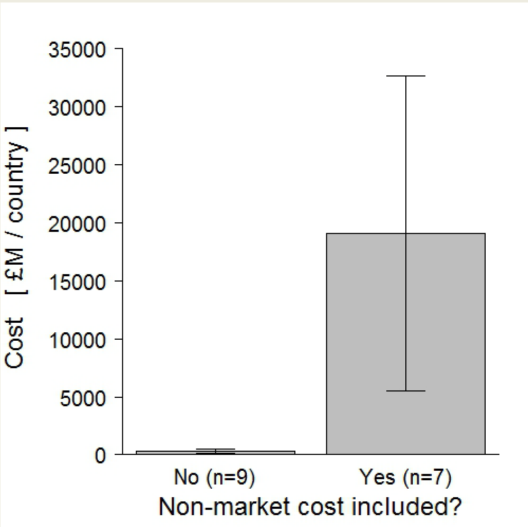
Of the descriptors, only the area of each country and the inclusion of non-market costs significantly affected the cost estimates (Table A). If non-market costs were included in the estimates of costs of INNS to the countries' economies, the estimates were on average 57 times higher than if these costs were not included as shown in Figure A. Inclusion of non-market costs explained 15.2% of all the variation among the studies. Although the size of the country had a significant effect, there was no obvious trend in the effect of a country's area on the estimated cost of INNS.

[1] Or, if mentioned, the year the numbers were standardised to.

Table A. Table summarizing the result of the statistical analysis. Indicated are the degrees of freedom, sums of squares, F-distribution and Probability values.

	Df	SS	F	*P*
Km^2	1	7.78	21.9	0.001
Year	1	0.02	0.1	0.809
GDP 2008	1	1.51	4.3	0.063
Non-market costs	1	2.18	6.2	0.031
Residuals	11	3.91		

Figure A. The effect of inclusion of non-market costs of INNS on the estimated cost of INNS to a country's economy.



The estimate provided in this report is for the economic costs of INNS to Great Britain (GB). Great Britain is a distinct geographical entity, as it is surrounded by seas that act as a natural barrier against the migration of terrestrial and freshwater species (Defra 2008). The island has been separated from mainland Europe since the end of the last Ice Age (~6,500 BC) and since then humans have introduced a large number of species, both intentionally and unintentionally, many of which have successfully become established and are now widespread. As elsewhere, most of these species either have a positive or no impact, but some have become invasive and have negative impacts on the ecology and economy of the island.

The cost of INNS to the economy of Great Britain is of increasing concern to the government (POST, 2008). Although crude estimates of the total cost of INNS to the British economy exist (e.g. Williamson 2005; White and Harris 2005; Pimentel *et al.* 2005), details of the cost of INNS to the economy of England, Scotland and Wales are lacking. This research aims to obtain a detailed estimate of the current annual economic impact of INNS to Great Britain (England, Scotland and Wales, excluding Northern Ireland, the Channel Islands and the Isle of Man). As explained in more detail below, this question has been addressed by conducting literature research, through a questionnaire sent to people working in a variety of sectors (for example industry, science, government, and conservation) and interviews with respondents of the questionnaire and specialists in Great Britain and abroad. Viruses, microorganisms and diseases of animals and humans have been excluded from this report, though plant pathogens are included. Organisms that act a vectors of plant, animal or human pathogens are included where the vector is non-native. Costs associated with quarantine and the exclusion of species (apart from animal and human pathogens) that are known to be invasive elsewhere from entering Great Britain have been included. Data of costs of INNS to other countries have been used to support estimates of costs to Great Britain where appropriate. The positive economic impacts of INNS have been excluded from these cost estimates, although it is acknowledged that non-native species, such as deer species, through recreational hunting, also make a positive contribution to the economy.

References

Bateman I, Brouwer R, Cranford M, Hime S, Ozdemiroglu E, Phang Z and Provins A (2010) Valuing Environmental Impacts: Guidelines for the Use of Value Transfer – Non Technical Summary. Economics for the Environment Consultancy, London

Born W, Rauschmayer F, Bräuer I (2004). Economic evaluation of biological invasions - a survey. UFZ, Halle Germany

Boyer T, Polasky S (2004). Valuing urban wetlands: a review of non-market valuation studies. Wetlands 24: 744-755

Clout M (2002). Ecological and economical costs of alien vertebrates in New Zealand. In: Pimentel D (ed.). Biological invasions. CRC Press, pp. 185-194

Clout, MN & De Poorter, M (2005) International initiatives against alien invasive species. *Weed technology* 19 pp 523-527

Colautti R, Bailey S, van Overdijk C, Amundsen K, MacIsaac H (2006). Characterised and projected costs of non-indigenous species in Canada. Biological Invasions 8: 45-59

Daehler CC (2009). Short lag times for invasive tropical plants: evidence from experimental plantings in Hawai'i. PLoS ONE, 4: e4462

Defra (2007) An introductory guide to valuing ecosystem services. Defra, London

Defra (2008) The Invasive Non-Native Species Framework Strategy for Great Britain. Defra, London

Emerton L, Bos E (2004). Value. Counting Ecosystems as an Economic Part of Water Infrastructure. IUCN, Gland Switzerland and Cambridge, UK

Emerton L, Howard G (2008). A Toolkit for the Economic Analysis of Invasive Species. Global Invasive Species Programme, Nairobi

European Commission (2008). The economics of ecosystems and biodiversity: an interim report. Banson Production, Cambridge, UK

Giera N, Bell B (2009). Economic costs of pests to New Zealand. MAF Biosecurity New Zealand

Gren I-M, Isacs L, Carlsson M (2009). Costs of alien invasive species in Sweden. Ambio 38: 135-140

Hanley N, Wright R, Alvarez-Farizo B (2006). Estimating the economic value of improvements in river ecology using choice experiments: an application to the water framework directive. Journal of Environmental Management 78: 183-193

Holmes T, Aukema J, Von Holl B, Liebhold A, Sills E (2009). Economic Impacts of invasive species in forests. Annals of the New York Academy of Sciences 1162: 18-38

Hulme PE, Pysek P, Nentwig W, Vila W (2009). Will threat of biological invasions unite the European Union? Science 324: 40–41

Li M, Xu H (2005). Indirect economic losses associated with alien invasive species to forest ecological systems in China. Electronic Journal of Biology 1: 14-16

McLeod R (2004). Counting the cost: Impact of invasive animals in Australia, 2004. Cooperative Research Centre for Pest Control

Melbourne BA, Hastings A (2009). Highly variable spread rates in replicated biological invasions: fundamental limits to predictability. Science 325: 1536-1539

Oreska MPJ (2009). Assessing the economic aspects of aquatic invasive species in Great Britain. Master's thesis. Cambridge University

Perrings C (2002). Biological Invasions in Aquatic Systems: The Economic Problem. Bulletin of Marine Science 70: 541-552

Perrings C, Dehnen-Schmutza K, Touza J, Williamson M (2005). How to manage biological invasions under globalization. Trends in Ecology and Evolution 20: 212-215

Pimentel D, McNair S, Janecka J, Wightman J, Simmonds C, O'Connell C, Wong E, Russel L, Zern J, Aquino T, Tsomondo T (2001). Economic and environmental threats of alien plant, animal, and microbe invasions. Agriculture, Ecosystems and Environment 84: 1–20

Pimentel D (2002). Non-native invasive species of arthropods and plant pathogens in the British Isles. In: Pimentel D (ed.). Biological invasions. CRC Press, pp. 151-158

Pimentel D, Zuinga R, Morrison D (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52: 273-288

Reinhard F, Herle M, Bastiansen F, Streit B (2003). Economic impact of the spread of alien species in Germany. German Federal Environment Agency

Simberloff D (2004). A rising tide of species and literature: A review of some recent books on biological invasions. BioScience 54: 247-254

Sinden J, Jones R, Hester S, Odom D, Kalish C, James R, Cacho O (2004). The economic impact of weeds in Australia. Cooperative Research Centre for Australian Weed Management

Singh R, Kaur J (2002). Alien plant pathogens in India. In: Pimentel D (ed.). Biological invasions. CRC Press, pp. 159-172

Wangen SR, Webster CR (2006). Potential for multiple lag phases during biotic invasions: reconstructing an invasion of the exotic tree acer platanoides. Journal of Applied Ecology 43: 258–268

White P, Harris S (2002). Economic and environmental costs of alien vertebrate species in Britain. In: Pimentel D (ed.). Biological invasions. CRC Press, pp. 113-150

Williams P, Timmins S (2002). Economical impacts of weeds in New Zealand. In: Pimentel D (ed.). Biological invasions. CRC Press. pp. 175-184

Williamson M (2002). Alien plants in the British Isles. In: Pimentel D (ed.). Biological invasions. CRC Press. pp. 91-112

Wittenberg, R and Cock, MJW (2001) Invasive alien species: A toolkit of best prevention and management practices. CAB International, Wallingford

Xu H, Ding H, Li M, Qiang S, Guo J, Han Z, Huang Z, Su H, He S, Wu H, Wan F (2006). The distribution and economic losses of alien species invasion to China. Biological Invasions 8: 1495-1500

2 Methods

The data were collected in three semi-parallel ways. A list of 523 INNS was assembled based on sources such as JNCC, NNSS, CBD, CABI's Crop Compendium, Google searches, etc. Efforts were made to obtain information about the economic impact of those species, but for most no information was found, either because the species apparently has no documented or quantified economic cost, it is not widespread, or is not perceived as a problem. For these species no records of incurred costs were found. Information on the economic impact of individual species and sectors was collected from scientific and grey literature, such as government or other reports that are not published in academic or commercial literature. Further, a questionnaire was sent to over 730 people and organisations in various sectors. Some of the recipients sent it on to colleagues, thereby increasing the potential impact. Additional information was gathered through phone calls with over 250 scientific experts, policy makers, land owners and managers, many of whom had also received the questionnaire. The draft report was divided by sector and submitted for anonymous review to over 40 sectoral experts and the comments received were addressed in the final report.

The information contained in the grey and scientific literature was assembled through searches using internet search engines, such as Google and Google Scholar, and using the CAB Abstracts database (www.cabdirect.org) and CABI's Invasive Species Compendium database. Various search terms were used to obtain information about the costs of INNS. Over 650 references of relevance were gathered from the scientific and grey literature as well as the internet. Additional information about the distribution of species, the market and non-market value of habitats, industries, etc., which was used in the calculation of the costs was also sought.

The questionnaire consisted of a number of pages, some of which were directed at respondents of different sectors (Annex 1). The questions were aimed at obtaining information about the respondent's background and expertise, and about the cost incurred per sector or per species. The questionnaire was also used to obtain further contacts. Subsequent phone calls were conducted to clarify answers provided in the questionnaire responses, to get more detail about the answers or to get into contact with people who did not respond to the questionnaire.

The information obtained using the three methods was combined and used to create an estimate of the total direct cost for each of the three countries, where applicable. If necessary, additional information was sought to fill gaps in the acquired knowledge, either through contacting specialists or internet and literature searches. Where available, estimates were used from other countries if no data from Great Britain were found. The basis for the estimates and the calculations were then summarized and the summaries for some species are included in this report to provide insight into how the cost estimates were derived from the available information. In these summaries, we have aimed to make the assumptions and estimates used in the calculations explicit. The total direct cost estimate of INNS for each of the countries and a number of sectors was derived by combining the cost of individual species (Chapters 5-15). The final sectors in the report vary from the initial sectors in the questionnaire, as the results of the data searches led to some sectors being removed and others added to reflect the costs that were being identified. All estimates are rounded to the nearest £1,000. It is important to note that some costs affect multiple sectors, and the sum of the costs of all sectors is greater than the total cost of INNS to the British economy. Any double counting between sectors was removed before the final total cost to the British economy was calculated, therefore allowing sector costs to be presented that reflect the true cost for each sector, while acknowledging that some costs may be attributable to more than one sector. The calculations for three species are presented in detail to illustrate how cost figures were obtained (Chapter 4). In five case studies, a comparison is drawn between the cost of eradication at the start of the invasion (a rapid response) and the potential costs of eradication that may be incurred if the invasion spread across the country (Chapter 16).

3 Questionnaire Responses

The questionnaire was sent out to more than 730 addressees, a total of 338 responses were received although only 91 of those responses were complete. A number of respondents indicated that they worked in more than one sector, therefore giving a higher response total in Table 3.1. Some of the low response rate may be due to the combined responses received from various organizations providing one response for the entire organisation, rather than multiple responses from individual employees. In contrast, some recipients preferred to be contacted directly and although they did not complete the questionnaire, they did provide us with information. As expected, the low response rate did not allow statistical analysis of the data. However, it provided a useful basis from which to elicit further information from respondents and was used to a limited extent in the assessment of the cost of INNS, where supported by other data. A summary of the responses from the completed questionnaires is found below, including duplicate responses where the respondent felt their work fitted into more than one category.

Table 3.1. The number of people and/or organisations targeted by the questionnaire in each of twelve sectors.

Sector	**No. recipients**	**No. complete responses**
Agriculture, Forestry, Horticulture	74	19
Aquaculture	26	2
Marine Fisheries	46	8
Transport	38	3
Utilities, inc. pest control	97	3
Academia/Research	111	20
Conservation/Biodiversity	341	51
Land Management		19
Construction & Development		6
Flooding		3
Tourism & Recreation		9
Not specified		1
Total	733	

52%, 17% and 16% of the respondents indicated that they work in England, Scotland and Wales respectively, and 17% throughout Great Britain. The respondents were active in a variety of sectors, with Biodiversity and Conservation named in over 60% of the responses (Fig. 3.1).

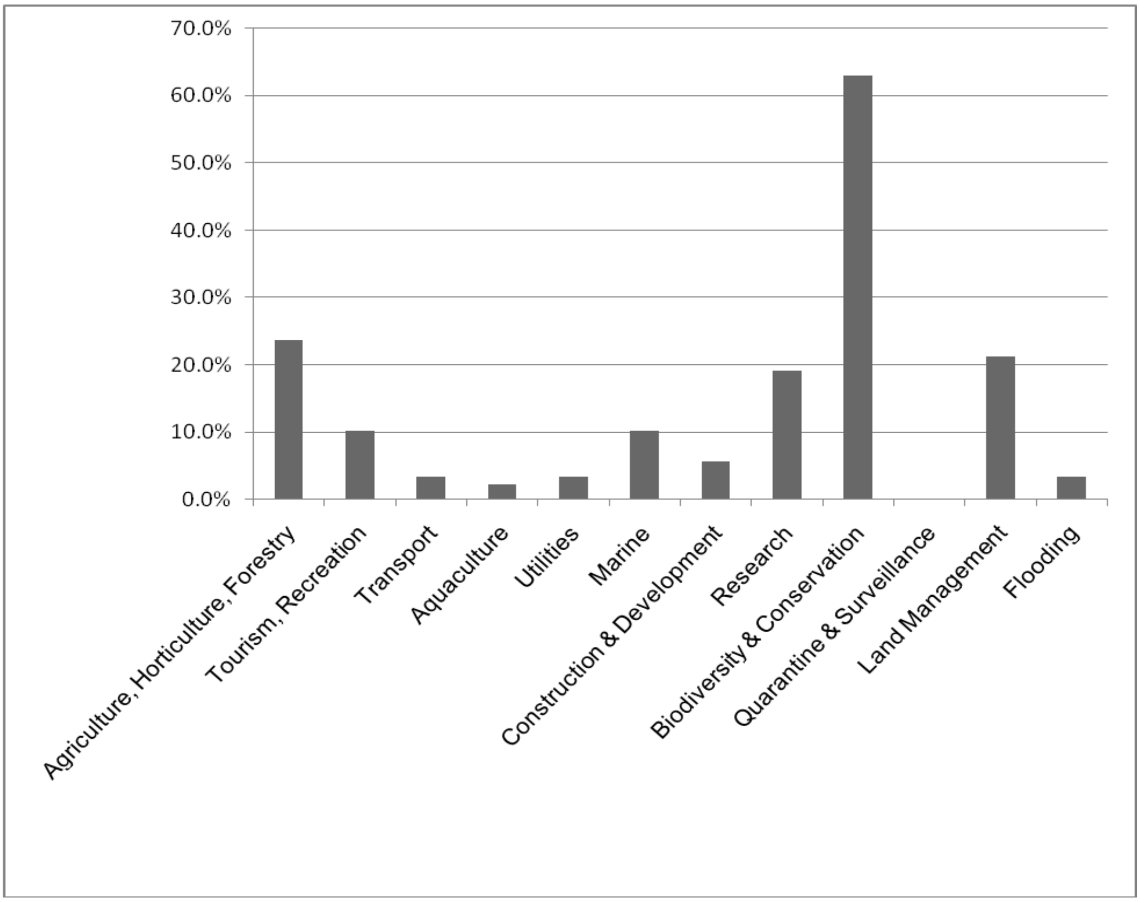


Figure 3.1. Areas of activity of the respondents to the questionnaire. More than one answer could be given in each response. 91 completed questionnaires were received.

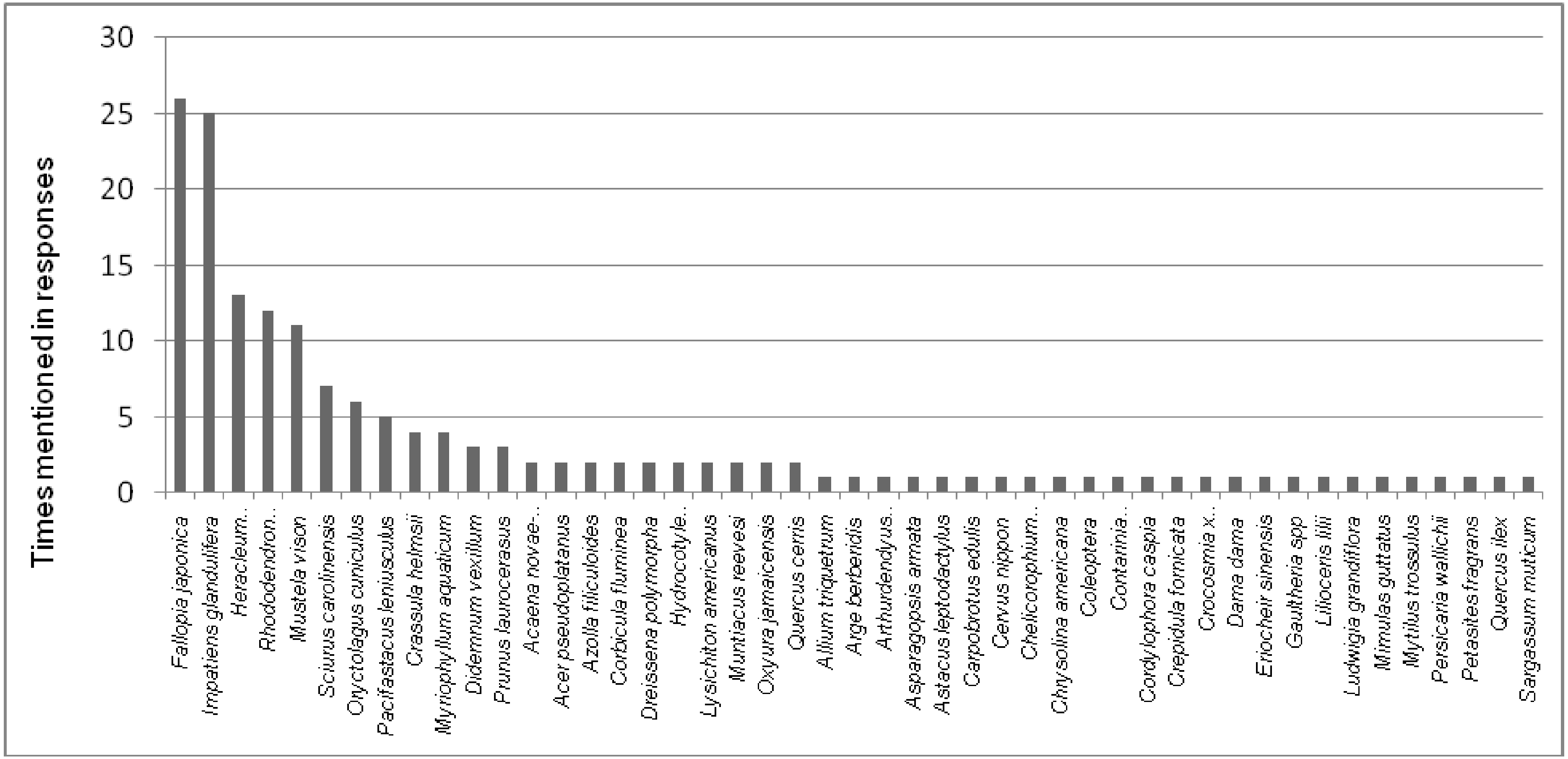


Figure 3.2. The number of times costs were provided for individual species in the questionnaire responses.

Apart from overall costs, separate costs for 47 species were provided. The most often mentioned species were Japanese knotweed, Himalayan balsam, giant hogweed, *Rhododendron ponticum*, mink, grey squirrel, rabbit and signal crayfish, which were all mentioned at least five times (Fig. 3.2). About half of the mentioned species were plants, a third were invertebrates and one eighth were mammals. One bird species was mentioned.

3.1 Research costs

Just over 40% of the respondents indicated that INNS had no direct impact on them, but that they had quantifiable knowledge about them through research or otherwise ("scientists"), while the remaining answers came from people who were directly affected by INNS. The responses from scientists indicated that their work is beneficial to all sectors, but biodiversity and conservation were each selected by approximately 42 of the respondents (Fig. 3.3).

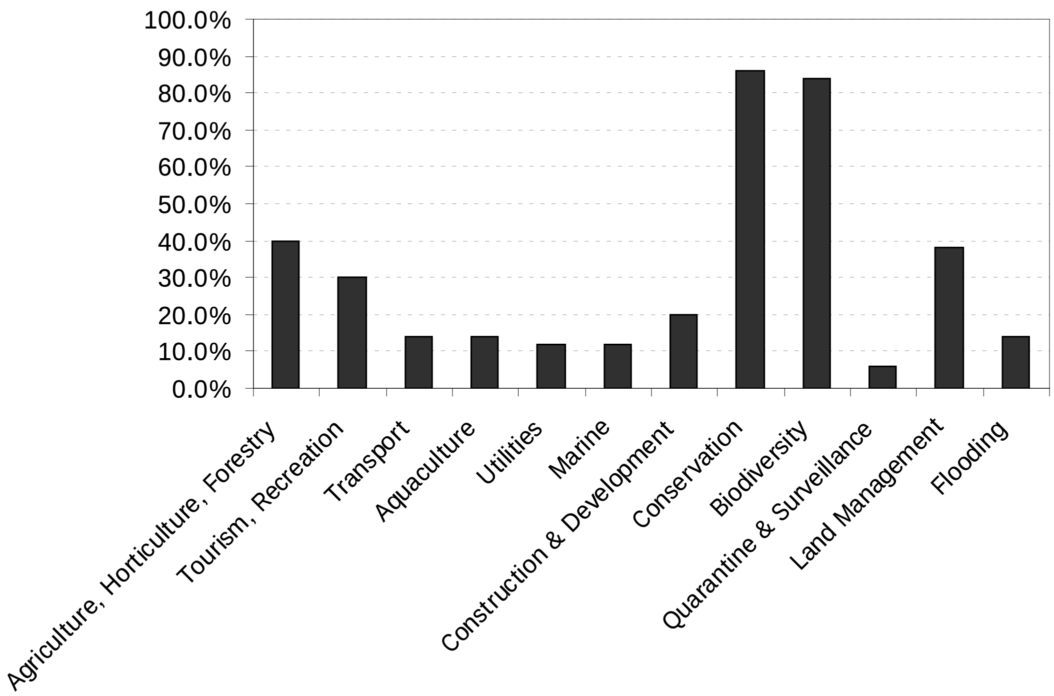


Figure 3.3. Sectors that benefit from INNS-related research. More than one sector could be selected.

The scientists that responded to the questionnaire were asked to provide estimates of the cost of INNS-related research in their research group or organization. Separate answers were given for money and labour and the results, although not precise, indicate that substantial resources are allocated to this subject every year (Fig. 3.4).

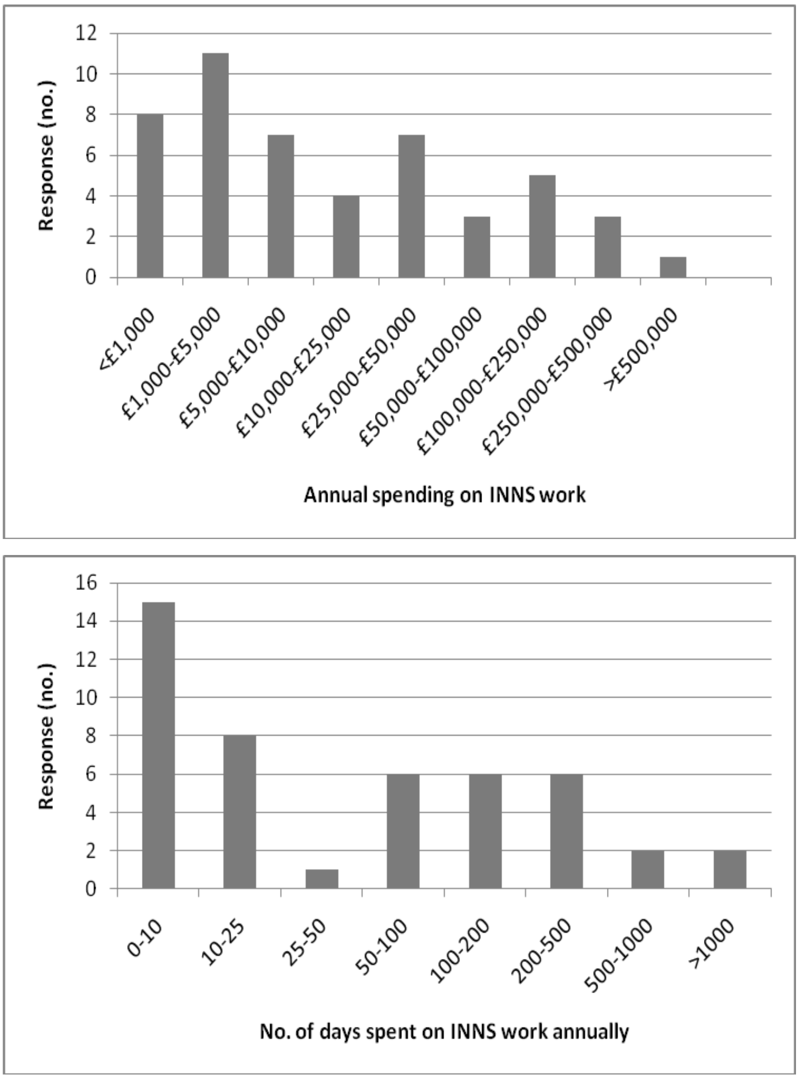


Figure 3.4. The INNS-related research costs incurred by respondents of the questionnaire.

3.2 Non-research costs

Nearly 60% of the respondents that reported on non-research costs provided data by species, while the remaining responses were overall costs. The responses about overall costs of INNS management, including the amount spent on materials, equipment, transport and labour, indicate that most people spent resources on eradication, containment and control, as well as awareness raising and desk-based tasks (Table 3.2). Costs for prevention were less often provided, but where they were given, the resources spent on it were substantial. Costs for increased infrastructure maintenance and project management were also not often provided, but respondents that did report these costs, reported relatively low costs.

The responses for the cost of management of individual species have been used in the cost estimates later in the report, where they were substantiated by other estimates, or through additional interviews with respondents.

	£1-£500	£500-£1,000	£1,000-£5,000	£5,000-£10,000	£10,000-£25,000	£25,000-£50,000	£50,000-£100,000	£100,000-£250,000	£250,000-£500,000	>£500,000
Prevention		1	2		1					1
Eradication	2	2	4	4	1		1	2		
Containment, control	4		6	1	3		2			1
Project management		1	4	1	1			1		
Restoration	2		2	2				1	1	
Awareness raising	2	4	5	1						
Increased infrastructure maintenance costs	1		2			1				
Desk based work e.g. admin, public enquiries & advice	3		7		1	1				

Table 3.2. Costs of INNS management incurred by respondents of the questionnaire, divided by activity. Numbers and shading of the cells indicate the number of responses received for each spending category.

4 Species Examples

As the majority of the costs given in this report are presented on a sector-by-sector basis, examples of the detailed costing for three individual species are presented. These illustrate the methods used and calculations worked in order to obtain cost estimates for species and sectors. The costs presented here are included in the sector-by-sector analysis and totals to ensure that each cost is included in the appropriate sector, such as costs due to Japanese knotweed in both the transport and the construction and development sector. The following species analyses are presented in detail: Japanese knotweed (*Fallopia japonica*), signal crayfish (*Pacifastacus leniusculus*) and floating pennywort (*Hydrocotyle ranunculoides)*.

4.1 Japanese Knotweed (*Fallopia japonica*)

Japanese knotweed was introduced to Britain from Japan as an ornamental garden plant in the mid-nineteenth century. It has become widespread in a range of habitats, particularly roadsides, riverbanks and derelict land, where it causes serious problems by displacing native flora and causing structural damage. It out-competes indigenous species by covering large tracts of land to the exclusion of the native flora and associated fauna. Japanese knotweed can grow more than a metre a month and is able to push through tarmac, concrete and drains.

4.1.1 Development Sites

In order to calculate the regional costs for Japanese knotweed control relating to development sites, it was necessary to estimate how many sites are affected each year and how much each site costs to treat. Swansea, a council that has been at the forefront of Japanese knotweed management, provided information about the number of planning applications received by the city council each year over the past 9 years. These data demonstrate that the proportion of planning applications with Japanese knotweed treatment requirements imposed ranged from 4.7% to 1.2%, an average of 2.95% (S. Hathaway pers. comm.). Over this 9 year period, the rate of infestation initially climbed, remained steady and fell dramatically in the last two years. This reduction was partly due to increased awareness, the use of specialist on-site contractors and the availability of the Environment Agency Code of Practice. We assumed that it is appropriate to use the average over the 9-year period for extrapolation purposes, as much of the country will be behind Swansea in Japanese knotweed management, but the data comes from a city and the infestation rates would be expected to be much lower in the countryside. However, 90.1% of people live in cities in the UK (Guardian datablog 24th Aug 2009) so a reduced estimate of 2.66% was used.

The number of planning applications received for each country were collated from the Communities and Local Government statistics for England, the last four Welsh Assembly Government Development Control Quarterly Surveys and the latest Scottish planning performance statistics (2007/8) (Table 4.1).

The costs associated with Japanese knotweed control on development sites are very variable and highly influenced by developers' timescales. A 5 x 5 m patch of Japanese knotweed costs a minimum of £20,183 and a maximum of £198,200 to treat or just over £800 m^{-2} to just under £8,000 m^{-2} (Cornwall Knotweed Forum pers. comm., adjusted to today's prices). A contractor provided costs of between £50 and £200 per square metre (pers. comm. in confidence). Treatment at some small development sites cost hundreds of pounds, whilst last year, the development at one site in Cornwall incurred an extra £2 million in costs due to the presence of Japanese knotweed. However, without any knowledge of the area of each infestation, these figures are of little use. Various contractors provided estimates per "job" and the most detailed of these used an average of 427 jobs in the past 2 years and gave a mean site cost of £5,800 +VAT (Mike Clough, JKSL pers. comm.). This compared with verbal suggestions of between £7,000 and £10,000 per site from other contractors/experts (pers. comm. in confidence). The £5,800 figure is the more robust and has been selected to represent the contractor costs. However, the true costs of Japanese knotweed to developers are diverse and include enforced delays which can result in working capital being tied up rather than being made to work either through investment and alternative profitable development projects. There are also the associated costs of legal advice, considerable communication time with many stakeholders and the indirect effect of bad press. In all, this is likely to more than double the actual fee paid to the contractor called in to deal with the issue, so a figure of £11,600 per contract was used.

By applying the estimated proportion of planning applications requiring Japanese knotweed control and multiplying this by the average cost per site, annual estimates were calculated for the three countries (Table 4.1). This estimate does not include the costs associated with developers choosing not to develop sites due to the presence of Japanese knotweed, which could be a considerable cost to a community and the developer alike.

Table 4.1. Annual costs for Japanese knotweed on development sites.

	England	Wales	Scotland	GB
No. of planning applications	458,110	24,766	4,879	
Infestation rate %	2.66	2.66	2.66	
No. of infested sites	12,186	659	130	
Cost per site £	11,600	11,600	11,600	
Total cost	£141,357,600	£7,644,400	£1,508,000	£150,510,000

Homeowners also attempt to control Japanese knotweed on their land. If the Swansea figure is used to estimate the number of properties infested, it would produce too high an estimate since this assumes housing, such as flats and terraced properties, as well as new-build houses, has the same level of infestation as land that can be developed. Therefore, the figure was reduced by half to 1.125% (Table 4.2). However, not all householders will be controlling the plant and therefore we assumed that only a tenth will tackle Japanese knotweed in any one year. The costs per year for householder control would only be £10 for the product and would involve very little time to apply, so a figure of £15 was assumed. This gave the following cost estimates and a total for British households of £447,660 p.a.

Table 4.2. Annual costs for householder control of Japanese knotweed.

	England	Wales	Scotland	GB
No. of Households[a]	22,697,382	1,369,902	2,460,883	
% infested	1.125	1.125	1.125	
10% active	25,535	1,541	2,768	
Costs/dwelling	£15	£15	£15	
Total	£383,025	£23,115	£41,520	£447,660

[a] Taken from HM Revenue and Customs Valuation list (2009), Welsh National Council Tax Dwellings Statistics, Household estimates, gro-scotland.gov data.

4.1.2 Devaluation of Housing

The presence of Japanese knotweed close to or on people's properties has an impact on its actual and perceived value. There are recent reports of a number of mortgage applications being refused on the grounds that the homebuyers' survey has revealed the presence of Japanese knotweed (Sean Hathaway, Swansea City Council). Indeed, we are aware of one particular mortgage provider that refuses to authorise a mortgage if Japanese knotweed is identified in a neighbouring property. It is logical to assume that the presence of the plant increases the loan to value ratio that is unacceptable to the mortgage provider. It can be assumed that that this increase is at least 5%, since any less is unlikely to be enough of a concern to a lender to withhold a mortgage offer. This would equate to around £9,925 for each house using the mix-adjusted average house price in the UK for October 2009 which stood at £198,450 (not seasonally adjusted, Communities and Local Government (CLG)[2]). Over the past two years 1,759,000 houses are recorded as being sold in the UK but CLG estimate that this non-seasonally adjusted figure of properties over 40,000 misses 12% of transactions. Thus, using the last two years of figures the average number of house sales per annum is 999,432. Using the infestation rate of 1.125% derived above, the cost of housing devaluation as a result of Japanese knotweed to the country would be £111.5 million per year. However, this assumes that every Japanese knotweed patch is detected and a mortgage refused or conditions imposed. In reality this is a relatively new phenomenon and even if surveyors detect the plant and inform the buyer who demands a drop in price, this can only be assumed to be a very small percentage of cases. We believe 1% to be justifiable giving a cost of £1.12 million. This can be attributed per country using the ratio of number of houses in each country: England £962,864, Wales £56,036 and Scotland £96,752.

4.1.3 Riparian Habitats

There are various ways of estimating the extent of Japanese knotweed on rivers and canals in Great Britain. As part of the Phase 1 of the CABI Japanese Knotweed Natural Control Project, a review of Japanese knotweed in Wales and the UK was carried out by Dr Lois Child at Loughborough University (Shaw *et al.* 2001). The conclusion of that review was that of the 735 km surveyed by the Environment Agency in 2000, between 1.02% and 6.14% were impacted by Japanese knotweed (7.5 – 45 km). This would provide a mean infestation rate of 3.58%. The problem with using this to estimate the area infested nationally based on the length of rivers is that it gives much too high a figure for Scotland which has many more rivers (Raven *et al.* 2000). Raven and co-workers used the River Habitat Survey data from 5,308 sites to provide percent infestation rates for Great Britain. Assuming that the combined infestation rate for England and Wales are the same for each country, these data from Raven *et al.* and the Environment Agency provide infestation rates of 9.2% for both England and Wales and 3.1% for Scotland. In order to estimate the amount of Japanese knotweed in each country it was assumed that, where it is present, there is a 2 metre deep stand on each side of the river. In the absence of any available figures, it was also assumed that only 50% of riparian infestations are under management in any given year. Our experience suggests that the percentage of sites included in some form of management plan is probably higher

[2] http://www.communities.gov.uk/corporate/

but only those incurring spraying costs annually are considered here. Child and Wade (2000) quoted spraying costs of £1.66 m^{-2} based on a survey of users (inflated to current prices), which excluded finance costs for a three year spraying programme. The cost of Japanese knotweed control was calculated based on the Child and Wade data by using an annual cost (1.66 /3 years) of £0.5533 per m^2 and the assumptions described above (Table 4.3). The cost of revegetation has not been included because this is rarely undertaken on riparian sites. Thus, the total annual cost of Japanese knotweed control at riparian sites, excluding lakesides, in Great Britain was estimated at £5,636,698.

Table 4.3. Annual cost of Japanese knotweed control in riparian habitats.

	England	**Wales**	**Scotland**	**GB**
Length of rivers and canals (km)	33,828	4,603	50,250	
% infested	9.20%	9.20%	3.10%	
Total area infested m^2	12,448,704	1,693,904	6,231,000	
Annualised cost for 3 year programme (1.66 /3 years)	£0.55	£0.55	£0.55	
Annualised control cost	£6,888,283	£937,294	£3,447,820	
Cost for 50% under management	£3,444,141	£468,647	£1,723,910	£5,636,698

4.1.4 Road Network

An estimate of the length of road network in Great Britain[3] enables extrapolation of the regional figures (provided by respondents to the questionnaire) to national estimates. The Highways Agency indicated that their total spend on all INNS on the 30,000 ha of trunk roads in England was £228,500 (questionnaire response). They stated that "by far the largest expenditure is on knotweed control" and in the absence of exact figures we assumed that 2/3rds of the cost was on Japanese knotweed, so their annual Japanese knotweed costs for England would be £152,333. This figure was used to produce a cost per km for Japanese knotweed control on major roads of £4.32. However, using this figure to extrapolate for the rest of the country's minor roads would provide a massive underestimate, since major roads are newer and less subject to disturbance. Minor roads are also more often the subject of the problem of fly tipping, which can be a source of new Japanese knotweed infestations. A more suitable figure was derived from the actual spend of one representative council on this weed. Hampshire County Council provided the most detailed response and quoted that they spend £78,000 controlling Japanese knotweed on 9,000 km of non-trunk road, giving a cost of £8.67 per km.

[3] http://www.dft.gov.uk/pgr/statistics/

Table 4.4. Japanese knotweed control costs across the road network.

	England	Wales	Scotland	GB
Trunk roads (km)	35,266	4,305	10,678	50,249
Other roads (km)	265,700	29,552	48,964	344,216
Trunk roads (£4.32/km)	£152,349	£18,598	£46,129	£217,076
Other roads (£8.67/km)	£2,303,619	£256,216	£424,518	£2,984,353
New road construction	£1,144,459	£128,745	£226,796	£1,500,000
Total	£3,901,393	£437,416	£757,085	£5,095,894

These management costs provided do not include the extra costs to road building projects due to the presence of Japanese knotweed. We were made aware of one case where the originally preferred course of a road was changed because of a Japanese knotweed patch and one specialist (in confidence) had come across at least four other cases recently. Approximately 16 major road projects are undertaken by the Highways Agency each year on the trunk road network, in addition to those undertaken on the minor road network. In the absence of real data on the number of new road builds each year that are affected by Japanese knotweed, we have assumed that 10 road construction sites in the country are affected by Japanese knotweed per year. Given the vast expense of new road construction or widening, it was assumed that each construction site would incur additional costs of at least £150,000 based on advice from a retired consultant (in confidence). Hence, a further cost of £1.5 million p.a. was included, to give a total cost of £5,095,894 of Japanese knotweed to the road network (Table 4.4).

4.1.5 Railway Network

Network Rail spend a considerable sum on vegetation management each year, but only £300,000 of this is directly recorded as being actively spent on Japanese knotweed contracts (Neil Strong, pers. comm.). However, direct control costs are not the largest proportion of Japanese knotweed economic costs to the railway. Deferred work through restrictions on movement of contaminated ballast, and associated speed restrictions for safety reasons can be very large. For example a 50 mph speed restriction on a major line for a year would be in the region of £6 million. In addition there are costs associated with manual track inspections in daylight hours, when train numbers are at a peak. Extra safety precautions are therefore required to protect workers[4], including very detailed planning and

[4] http://londonreconnections.blogspot.com/2009/11/look-at-work-of-raib-accident-at.html

more staff time as lookouts are required. As no specific costs could be identified for these items, we estimate that a total of at least £2 million per annum is attributable to Japanese knotweed management.

4.1.6 Research

Numerous organisations, including universities and industry bodies, carry out research into Japanese knotweed control and management each year, including research into biological control measures, which have cost around £120,000 p.a. (CABI). Given, the wide variety of organisations involved in Japanese knotweed work, a conservative estimated of five other projects were assumed to be ongoing each year. Using the NERC database of projects and extracting those relating to non-native species research since 1992, 58 projects were funded to a total of £8,635,332. We assumed that each project has the usual three year lifespan the average annual cost of a project is £49,628, which for the purpose of extrapolation was rounded up to £50,000 each. Thus, the total annual research cost was estimated at £370,000.

4.1.7 Local Authorities

As well as the costs for development in council areas, local authorities also incur significant costs as a result of managing Japanese knotweed on land for which they are responsible, as well as providing advice for taxpayers on its management. So serious was the issue for Swansea City Council, that they have appointed a Japanese knotweed officer to deal with such issues full time. Caerphilly Council has also been closely involved in invasive plant species management recently and has carried out a project over a 3-year period dealing with Japanese knotweed, Himalayan balsam and giant hogweed. This cost £50,000 per year and at least 90% of that involved Japanese knotweed. After the initial work, an on-going joint management project between 5 neighbouring local authorities in the area is costing £100,000 in total (£20,000 each). Thus it can be assumed that these Welsh authorities are spending £18,000 each on Japanese knotweed each year if the spread of the costs are the same as in the initial spend. Caerphilly recorded an average of 200 enquiries relating to those invasives per year, 90% of which were to do with Japanese knotweed (180 calls). If it is assumed that each contact involves half an hour handling time, this equates to an additional £3,000 p.a. per authority. So the total for each affected local authority is £21,000 p.a. This was compared with Swansea, probably the most active local authority in Great Britain, which spent £239,000 in the 9 years up to 2001 (£26,555 p.a. average or £32,917 with inflation). Other figures are available for Cardiff, which only had £15,000 p.a. available compared with Rhondda Cynon Taf, which spends £36,000 (Cardiff Council, 2006). If it is assumed that all local authorities have similar costs to these councils, then the costs are £432,000 (£270,000 England, £66,000 Wales, £96,000 Scotland).

4.1.8 Reduction in Biodiversity

Japanese knotweed is an invader of riparian habitats. The invasion by knotweed takes place to the exclusion of most, if not all other plant species and is known to cause their local displacement and net reduction in biodiversity (Gerber *et al.* 2007). This could equate to at least 10 plant species and a further 30-50 associated fungal, invertebrate and even vertebrate species. Placing a cost on such impacts however, is extremely difficult and no appropriate data have been discovered with which to attempt to value the loss of biodiversity.

4.1.9 Impacts on leisure and tourism

Japanese knotweed is one of the many riparian and urban weeds that may have an indirect impact on leisure and tourism, but the necessary data have not been discovered to allow this impact to be quantified.

4.1.10 Other costs

It is recognised that there are many costs associated with Japanese knotweed that are not directly quantifiable and these would include, expert consultation, time spent discussing and formulating policy in each of the National Authorities, Parliamentary discussion and preparatory time. The broader issue of the impacts to ecosystem services are not estimated but could cause factorial increases in the costs. The issue of flood exacerbation has not been dealt with here, but just one flood event in a populated area attributable to dead knotweed canes causing a blockage could result in very high costs. In reality these costs are hard to separate from other riparian species. It is also recognised that in some cases development plans may be dropped once knotweed has been identified. Thus it is fair to say that the costs captured here are a conservative estimate.

Total costs for Japanese knotweed to the British economy are therefore estimated as follows:

Table 4.5. Total annual costs of Japanese knotweed

	England	Wales	Scotland	GB
Local authorities	£270,000	£66,000	£96,000	£432,000
Research	£319,000	£19,000	£32,000	£370,000
Railways	£1,726,000	£100,000	£174,000	£2,000,000
Roadsides	£3,901,000	£438,000	£757,000	£5,096,000
Riparian	£3,444,000	£469,000	£1,724,000	£5,637,000
House devaluation	£963,000	£56,000	£97,000	£1,116,000
Development	£141,358,000	£7,644,000	£1,508,000	£150,510,000
Householders	£383,000	£23,000	£42,000	£448,000
Total	£152,364,000	£8,815,000	£4,430,000	£165,609,000

4.2 Signal Crayfish (*Pacifastacus leniusculus*)

The American signal crayfish was introduced to Britain in the late 1970s primarily to farm for food. However, they quickly escaped or were deliberately released and spread rapidly across England and Wales. The distribution is currently limited in Scotland, though increasing. The signal crayfish is larger than the native white-clawed crayfish, and out-competes the native crayfish, as well as carrying a crayfish plague that kills the native species. Signal crayfish burrow into riverbanks, increasing erosion as well as affecting wild fish stocks (bullhead, stone loach, salmonids and other angling species) whose eggs are predated.

4.2.1 Management Costs

The main costs of the signal crayfish to the British economy are associated with biodiversity. The decline of the white-clawed crayfish is partly attributed to the presence of the signal crayfish through competition for resources and the spread of the fungal disease *Aphanomyces astaci*, carried by signal crayfish (Peay 2000, UKBAP, Craig Stenton, pers. comm.). Therefore, most of the white-clawed crayfish conservation costs can be attributed to the signal crayfish, in particular costs associated with ‘ark’ sites set up to protect the white-clawed crayfish. There are also limited control measures taking place with trapping activities in some areas; around 15,000-20,000 individuals were removed per year in one severely infested area in the 1990s to reduce the impact (Richard Sankey, pers. comm.). A range of these projects around England were selected and the average cost per annum was calculated at £32,574 (Table 4.6). The total number of 'ark' sites in the country is unknown (Andrew Whitehouse, Buglife, pers. comm.), as is the total number of signal crayfish or white-clawed crayfish management projects being undertaken each year, but we assumed that ten projects are carried out each year in England and the management cost can be estimated at £325,740.

Table 4.6. Costs of projects involving signal or white-clawed crayfish in England.

Lead organisation	Start Date[a]	Total budget	Duration (yrs)	Total cost p.a.	Total cost p.a.[d]
Staffordshire & Derbyshire Wildlife Trusts	2009	£35,605	2.5	£14,242	£14,242
Avon Wildlife Trust	2007	£100,000	3	£33,333	£34,662
Dorset Wildlife Trust	2009	£20,000[b]	3[c]	£3,333	£3,333
Wildlife Conservation Research Unit	2007	£159,049	3	£53,016	£55,130
Yorkshire Dales Millennium Trust	2007	£223,799	3[c]	£74,600	£77,575
South Cumbria Rivers Trust	2009	£10,500	1	£10,500	£10,500

a: Start of project or date funding was allocated
b: Estimated 50% allocated to conservation of native crayfish -£10,000
c: Duration of project is estimated
d: Corrected for inflation to today's cost

The population of white-clawed crayfish in Wales has also been significantly reduced and trapping of signal crayfish and conservation activities for native crayfish are also carried out in Welsh rivers. One example is the approximately 30,000 signal crayfish trapped in 2007, and the 6 km of habitat restored under one project (Wye & Usk Foundation 2006). A cost of £120,000 for this project covered four main UK Biodiversity Action Plan (BAP) priority species, including white-clawed crayfish. Again, the number of signal crayfish management projects in Wales is unknown, however if it is assumed that five projects are conducted each year, at an average cost of £32,574 (as in England) then, a management cost of £162,870 is estimated.

White-clawed crayfish are not native to Scotland, although there are two introduced populations in Scotland (Peay 2006). However, control measures are still undertaken for signal crayfish due to their effects on fisheries and economically important species, such as salmon. There are known populations of signal crayfish in the Upper Clyde, the Kirkcudbrightshire Dee catchment (including Loch Ken), the River Earn (Ribbens and Graham 2004) and the North Esk catchment (Peay *et al*. 2006). No specific costs could be found for control measures in these areas, although one project in Loch Ken was said to cost £90,000. (Attempts to obtain more details of the cost of signal crayfish to Loch Ken were not forthcoming.) Therefore, if it is assumed that five management projects are carried out each year at the same average cost as England (£32,574) (as this is based on a larger sample size), then management costs in Scotland can be estimated at £162,870.

In England and Wales, the Environment Agency spends approximately £500,000 per annum on controlling signal crayfish and another £500,000 on conserving the white-clawed crayfish (Trevor Renals, pers. comm.). However, some of the projects carried out by the wildlife trusts, discussed above, are partially funded by the Environment Agency (Wildlife Trusts, pers. comm.), and some of the white-clawed conservation work cannot be attributed to the presence of signal crayfish and therefore a reduction of 35% is made to the total amount spent on management work giving a total amount spent entirely by the Environment Agency of £650,000 split between England (£450,000) and Wales (£200,000).

4.2.2 Restoration Costs

The damage caused by signal crayfish burrowing into river and canal banks and causing erosion is an increasingly common problem as the range of signal crayfish expands (Simon Cain, pers. comm.). The species can be found in anything from silty river waters to canals, and will burrow into banks up to a depth of two metres. The effect of this behaviour accelerates the natural erosion process and in severe cases one metre of river bank could be lost per year (Richard Sankey, pers. comm.). In certain areas, bank restoration work has taken place. One such place is the River Lambourn, from Lambourn village to Newbury, where 800 m of restoration work was carried out following damage over a four month period. It cost £105,000, including £25,000 in kind contributions providing a cost of £131.25 m^{-1} (The River Restoration Centre 2007). For a longer length of the river (3 km) along the same waterway it was estimated that it cost around £1 million to restore the bank and a mill structure (Richard Sankey pers. comm.). The river in this case had a particularly serious problem with signal crayfish and there had been significant degradation of the banks over the last 10-15 years. Current evidence of bank restoration work due specifically to signal crayfish is very limited, though some work is undertaken that also reduces the susceptibility of the bank to signal crayfish burrowing. In addition, no data were found to suggest that bank restoration work occurred on a regular basis, and therefore it is assumed that only 20% of the cost of the major scheme described above is directly attributable to the presence of signal crayfish and an annual spend is estimated at £200,000.

4.2.3 Angling

Signal crayfish can cause a nuisance to some anglers through the loss of bait or the crayfish predating on stock (Abby Stancliffe Vaughan, pers. comm.). This can cause a significant loss of income for those businesses that rely on angling, as fishermen will go elsewhere if the fish stock is being predated. One example, from Loch Ken where signal crayfish have had a large impact of fish stocks for angling may cost about £250,000 per year in control measures and lost angling revenue (S. Peay, pers. comm.). There is also a cost caused by the need to clean equipment between fishing in different sites to prevent the spread of crayfish plague. However, these costs are expected to be minimal and there will be other reasons to ensure that equipment is clean and other causes of loss of bait, etc. Commercial fisheries may implement crayfish control programmes to reduce the impact of predation on the young fish. Even so predation may still reduce the number of fish reaching maturity, and the presence of crayfish can reduce the ability of fish farmers to supply fishing areas if they are near white-clawed crayfish populations. Again this will reduce the income of fish farmers. Specific data on the costs relating to these effects is very limited, but based on the Loch Ken estimated costs, a cost of £1,000,000 per year is estimated (£550,000 England, £325,000 Scotland, £125,000 Wales).

4.2.4 Research

In addition to the projects discussed above that concentrate on management strategies to protect white-clawed crayfish, or eradicate signal crayfish, further research projects are carried out into control methods for signal crayfish or conservation strategies for the white-clawed crayfish. At least two research projects into crayfish plague, with funding from Defra and the Environment Agency, were running in 2009 at an average cost of £37,463 per annum. Assuming that there are five research projects taking place each year, into the effects of signal crayfish and crayfish plague, an annual research cost is estimated at £187,315

4.2.5 Total Costs

Other economic costs are attributable to the presence of signal crayfish in Great Britain, such as the loss of aesthetic value related to native white-clawed crayfish and damage to river banks through burrowing. However, no data could be identified that valued white clawed crayfish or the amount of damage done to river banks, even though some figures were available on the costs of bank restoration work. The data that was available is summarised to give the following totals of annual costs to the economy due to the presence of signal crayfish.

Table 4.7. Total annual costs of signal crayfish.

	England	Scotland	Wales	GB
Management	£776,000	£163,000	£363,000	£1,302,000
River Bank Restoration	£100,000	£50,000	£50,000	£200,000
Angling	£550,000	£325,000	£125,000	£1,000,000
Research	£112,000	£38,000	£37,000	£187,000
Total	£1,538,000	£576,000	£575,000	£2,689,000

4.3 Floating Pennywort (*Hydrocotyle ranunculoides*)

Floating pennywort was introduced into Britain from North America in the 1980s through the aquatic plant trade (Kelly 2006). There are over 150 known sites of infestation in England and Wales, although none are known in Scotland. Floating pennywort is found in slow-flowing water such as ditches, lowland rivers and on the edges of lakes, where it forms dense vegetative mats that out-compete most native aquatic plants. The species can negatively impact upon fish through restricting access to feeding and resting spaces and can contribute to localised flooding through the blocking of drainage systems. Floating pennywort has a rapid growth rate of up to 20 cm a day and is particularly difficult to control due to this rapid vegetative growth.

4.3.1 Control Costs

Dr Jonathan Newman (pers. comm.) has stated that floating pennywort is the most expensive of all aquatic weeds to control in the UK at the moment, with a cost of £1800-£2000 per km for removal. The Environment Agency (EA) estimate they have spent £510,260 on control of approximately 300 km of floating pennywort in 2009 (T Renals pers. comm.). British Waterways spend £50,000, primarily on two separate river navigations. In addition, many other bodies are known to be involved in control of this species. Ryland (2008) stated that in Pevensey Levels SSSI, Natural England pays farmers to remove floating pennywort from ditches at a rate of £2.90m^{-1} under a higher level stewardship scheme. The cost of control at that site, where about 10% of the ditches are infested (45 km), was approximately £35,000 p.a. in 2008. The range of floating pennywort is expanding and it is assumed that the cost doubled to £70,000 in that area in 2009 despite control efforts. Ryland (2008) estimated that the cost of implementing a localised control strategy at Pevensey Levels would be £150,000 per annum for the first five years. There are many other sites where floating pennywort is being managed, such as a small eradication programme in Gillingham costing £8,400 (Kelly 2006) and an infestation in Reading recently cost £20,000 to deal with[5], excluding the removal of material. The total known spending on control of floating pennywort is therefore £658,660. This does not include costs incurred by Internal Drainage Boards and private owners of lakes, fisheries and watercourses. The most recent estimate for the whole country for the control, management and disposal of *H. ranunculoides* was £1.93 million in 2008 (Newman, quoted in EPPO 2010). In 6 years, these costs had increased 7 fold.

4.3.2 Costs to Leisure and Recreation

Any shallow, slow-moving waterway that is infested with floating pennywort will rapidly become non-navigable and useless for fishing. This would certainly have been the case for much of the 400 km subject to control efforts above. We have assumed that floating pennywort is indiscriminate in its colonisation of the 400 km of waterways cleared this year and that 50% of these water bodies are used for recreation, the rest being drainage ditches etc., which are not used for recreational purposes. Floating pennywort is most prolific in lowland eutrophic water bodies, which tend to be mostly associated with larger conurbations. These watercourses would also tend to have the greatest angling, navigation and recreational use.

The British Waterways Inland Waterways Surveys provides useful data that can be used to extrapolate the recreational value of canals and rivers through the country. Their latest survey, British Waterways (2008) stated that in 2008, 3.4 million adults visited one of their waterways across their 3,540 km network in an average two-week period. This is equivalent to 2087 visitors per km per month. Therefore, on the basis that 200 km of canals are infested (see above) for a two month period this affects 834,300 visitors, of which an estimated 10% are anglers, a further 10% use the sites in other ways and the remaining 80% are general visitors.

A 1999 investigation of the benefits to anglers and other recreation users (e.g. swimming, wildlife viewing) of increasing flow rates of low-flow rivers in England gave a mean willingness to pay (WTP) value of £68.03 per year for anglers for improved fishing, brought about by low-flow alleviation. Mean WTP for other on-site recreational users was £28.22 per year and for general users the mean WTP ranged between £5.34 and £10.78 per year for an

[5] http://news.bbc.co.uk/1/hi/england/berkshire/8370140.stm

environmentally acceptable flow regime (Willis and Garrod 1999). These values related to low-flow alleviation, whereas the presence of floating pennywort would result in a complete loss of fishing. However, given the similarities in the effects of low-flow and pennywort infestation on rivers, it is assumed that the same willingness to pay values are applicable at current levels, providing values in today's prices of £88.36, £36.65 and £10.47 (using the average of the WTP of general users).

It was assumed that the negative impacts of floating pennywort are felt for a two-month period, during which there is sufficient vegetative growth to cause a problem and the control measures are being undertaken and the vegetation removed. Therefore, based on these visitor numbers above and the willingness to pay figures provided, the presence of floating pennywort costs an estimated £17,428,120 per year during the period in which its presence is a significant issue.

Floating pennywort will also cause a problem to boat users in areas of significant growth. British Waterways currently spend £50,000 on floating pennywort control, which, at an average spend of £2000 per kilometre, suggests that only 25 km of canals are infested to an extent that impedes boating. We assume that this represents at least five stretches of floating pennywort, each of which has an impact on at least five times the length of waterway that was infested. Therefore, an estimated 125 km of the canal network would not be used for boating as a result of the presence of floating pennywort. Annual tourism spending related to leisure boating has been estimated at £1.8 to £2.2 billion[6]. This gives a value of £22,553 per kilometre of river and canal and if, as above, it is assumed that the impact is felt for a two-month period, then the loss to tourism through the effects of floating pennywort on boating on canals can be estimated at £469,849. In addition, boating on rivers can also become restricted by floating pennywort (T. Renals, pers. comm.) and therefore, of the 300 km of floating pennywort controlled by the Environment Agency on rivers in England and Wales it is assumed that 50 km affects boating. Based on the same assumptions used to calculate the effect on boating on canals (each affected area is 5 km long, affecting five times that length i.e. 25 km, with 10 stretches of floating pennywort affecting boating) a total of 250 km of river will be affected by the presence of floating pennywort. At the same value of £22,553 per kilometre of river costs to boating on rivers in England and Wales can be estimated at £5,638,250, giving a total of £6,108,099.

[6] http://www.britishmarine.co.uk/upload_pub/Ec_Bens_Exec_summary.pdf

4.3.3 Total costs

Current costs of floating pennywort in terms of management and the effect on tourism are as follows:

Table 4.8. Total annual costs of floating pennywort.

	England	**Scotland**	**Wales**	**GB**
Management	£1,815,000	-	£115,000	£1,930,000
Recreation	£23,468,000	-	£69,000	£23,537,000
Total	£25,283,000	-	£184,000	£25,467,000

The ratio of the known management costs between England and Wales has been used to proportion the recreational costs between the two countries. No costs have been attributed to Scotland as no infestations of floating pennywort have been recorded there.

It is likely that floating pennywort will lead to additional flooding, both through flooding previously unaffected areas, or exacerbating flooding that is already occurring. This will have an associated economic cost. However, it is not possible to estimate this at present as no data are available to indicate where these additional flood events may take place. If they occur primarily on agricultural land, through the blocking of drainage ditches, then there may be costs due to loss crops, or lost grazing. Alternatively if the ditches or streams affected are located in built up and urban areas, then floating pennywort blocking these streams may cause houses to flood. This would again have an economic cost that could be considerable. However, no data were available to establish whether additional flooding had taken place due to the presence of floating pennywort, and if it had, whether it should be considered to be a one-off event or contribute to the annual cost of this species.

References

British Waterways (2008). British Waterways Annual Inland Waterway Visitor Survey. Quoted in A vision for 2020. British Waterways. 14pp. http://www.britishwaterways.co.uk/media/documents/BW_2020_A_Vision_for_the_Future.pdf

Child L, Wade M (2000). The Japanese knotweed manual: the management and control of an invasive alien weed. Packard Publishing, Sussex

EPPO (2010) Report of a Pest Risk Analysis for Hydrocotyle ranunculoides. European and Mediterranean Plant Protection Organisation Report Number 09-15161.

Gerber E, Krebs C, Murrell C, Moretti M, Rocklin R, Schaffner U (2008). Exotic invasive knotweeds (*Fallopia* spp.) negatively affect native plant and invertebrate assemblages in European riparian habitats. Biological Conservation 141: 646-654

Kelly A (2006). Removal of invasive floating pennywort *Hydrocotyle ranunculoides* from Gillingham Marshes, Suffolk, England. Conservation Evidence 3: 52-3

Peay S (2000) Guidance on works affecting white-clawed crayfish. Scott Wilson Resource Consultants for English Nature and Environment Agency.

Peay S (2006). Conserving the white-clawed crayfish in England and Wales, briefing notes for Wildlife Trusts. http://www.derbyshirebiodiversity.org.uk /news/files/crayfish%20conservation%20notes%20for%20wildlife%20trusts.pdf

Peay S, Hiley PD, Collen P and Martin I (2006) Biocide Treatment of Ponds in Scotland to Eradicate Signal Crayfish. Bull. Fr. Pêche Piscic. 380-381 pg 1363-1379

Raven PJ, Jolmes NTH, Naura M, Dawson FH (2000). Using river habitat survey for environmental assessment and catchment planning in the UK

Ribbens JCH, Graham JL (2004). Strategy for the containment and possible eradication of American signal crayfish (*Pacifastacus leniusculus*) in the River Dee catchment and Skyre Burn catchment, Dumfries and Galloway. Scottish Natural Heritage Commissioned Report No. 014. (ROAME No. F02LK05).

Ryland K (2008). Floating pennywort control strategy report. Dolphin Ecological Surveys. 122 pp.

Shaw RH, Child LE, Evans HC, Bailey JP (2001). The Biological Control Programme for Japanese Knotweed (Fallopia japonica) in the UK and USA. A report of the Phase 1 Research produced for the Welsh Development Agency (WDA) and US Department of Agriculture Forest Service. CABI internal report

Willis K, Garrod JD (1999). Angling and recreation values of low-flow alleviation in rivers. Journal of Environmental Management 57: 71–83

Wye and Usk Foundation (2006). http://www.wyeuskfoundation.org /projects/tubney.php

5 Agriculture and Horticulture

As mankind's staple industry worldwide, agriculture has been instrumental in the rise of civilisations and society through domestication of livestock and crops to supply sufficient, affordable food to feed its populations. In Great Britain, a small, densely populated island, agriculture today is intensive and highly mechanised and produces about 60% of the nation's food needs[7]. Society and national economies hold little tolerance for the adverse impacts of native or non-native pests and diseases on yield and quality. This is also true in the horticultural and gardening sector, with a retail turnover of over £5 billion[8].

The INNS affecting agricultural and horticultural industries in England, Wales and Scotland are diverse and represented by mammal, bird, insect, mollusc and plant taxa as well as fungi, bacteria and viruses. Disturbance is widely recognised as one of the key drivers of biological invasions (Mack *et al*. 2000), as discussed earlier, and arable fields are by their nature highly disturbed environments, presenting numerous opportunities for invasion by both native and non-native species.

Around 18.7 million ha of the UK are classified as agricultural land (Nix 2009), approximately 67% of the land area in Great Britain[9], and despite the rise of many organic farms, the repeated use of pesticides is still intrinsic in managing the threat of damage and reduced yield, ensuring ease of harvesting, preventing long-term weed build up and vectoring of pests and diseases.

5.1 Weeds

Amongst non-native grass weeds, the brome species (*Bromus* spp.), particularly sterile or barren brome (*B. sterilis)* have become increasingly important pests in British cereal and leguminous crops and may cause cereal yield losses of 45% (Peters *et al.* 1993). National studies show an average wheat yield loss of over 7% from headland infestations, rising to 11% for patch infestations and over 18% for more general infestations.

Similarly, wild oat (*Avena fatua*) has been ranked as one of the most important and competitive grass weeds of winter and spring cereals and winter rape by European scientists (Schroeder *et al.* 1993). Wild oat and wheat compete for the same resources and are

[7] https://www.cia.gov/library/publications/the-world-factbook/geos/uk.html
[8] http://www.thehta.org.uk/index.php
[9] http://www.statistics.gov.uk/STATBASE/ssdataset.asp?vlnk=7649

mutually exclusive, resulting in 5% yield loss from as few as 5 plants per m^2. Defra reported that over 750,000 ha of cereals were sprayed annually for control of wild oats in 1995, which equated to roughly 23% of cereals grown at that time (Defra final report for project PT0211). Italian ryegrass (*Lolium perenne*) is also becoming more of a problem in cereal crops as the species develops herbicide resistance. Ryegrass is widespread through the country and is found in at least 25 % of cereal fields (Bayer CropScience 2006), with some data indicating that populations of as little as 5-7 plants per m^2 can lead to yield losses of 8.5%-11%, though other data suggest that much higher infestation levels are needed to cause significant yield loss.

Of the broadleaved weeds, the Macaulay Institute Land Use report[10] on biological invasions stated that common field-speedwell (*Veronica persica*) is one of the common grain contaminants. The reported annual control costs, combined with those for wild oat, amounted to £100 million. Common field-speedwell has been recorded throughout cultivated land and gardens and is indeed one of the commonest annual weeds in the UK (Salisbury 1962). Bond *et al.* (2007) reported an average 3% incidence in cereal crops and oil seed rape in England and Scotland.

Defra's pesticide usage surveys[11] record the area of crops sprayed, taking into account multiple applications, and provide information about the main weeds that are being controlled. These surveys also provided information for the main horticultural crops in the country. Based on this information and that provided in Lutman *et al.* (2009), the percentage of weeds controlled that are non-native was estimated. Knowledge of which species were non-native was taken from the species list compiled for this research project. Herbicide costs, including application costs, for different crops were taken from The John Nix Farm Management Pocketbook (2009). The results of the calculations are presented in Table 5.1.

[10] http://www.macaulay.ac.uk/aweg/speciesinvasions.pdf
[11] http://www.fera.defra.gov.uk/plants/pesticideUsage/fullReports.cfm

Table 5.1. Estimated cost of non-native weed control

	England	Wales	Scotland	GB
Wheat	£46,479,000	£471,000	£2,734,000	£49,684,000
Winter barley	£6,886,000	£134,000	£1,147,000	£8,167,000
Spring barley	£6,216,000	£288,000	£5,112,000	£11,616,000
Oats	£1,703,000	£69,000	£347,000	£2,119,000
Rye	-	-	-	-
Triticale	£168,000	-	£11,000	£179,000
Oilseeds	£6,049,000	£33,000	£226,000	£6,308,000
Potatoes	£3,768,000	£82,000	£1,015,000	£4,865,000
Fodder crops	£5,291,000	£9,000	£45,000	£5,345,000
Total Arable	**£76,560,000**	**£1,086,000**	**£10,637,000**	**£88,283,000**
	England	**Wales**	**Scotland**	**GB**
Orchards	£189,000	£10,000	-	£199,000
Soft fruit	£81,000	£2,000	£16,000	£99,000
Outdoor vegetables	£788,000	£3,000	£83,000	£874,000
Outdoor bulbs & flowers	£41,000	-	-	£41,000
Fodder & grassland	£585,000	£114,000	£170,000	£869,000
Hardy nursery stock	£261,000	£14,000	£14,000	£289,000
Total Horticulture	**£1,945,000**	**£143,000**	**£283,000**	**£2,371,000**
Total Herbicides	**£78,505,000**	**£1,229,000**	**£10,920,000**	**£90,654,000**

Although herbicides control the majority of weeds, competition between the crop and remaining weeds does lead to some yield loss from the crop. There is a paucity of data on the yield loss experienced by crops subsequent to herbicide use. Much information available stated that weed growth was reduced to ‘a commercially acceptable level’ or that weed control was total. Oerke *et al.* (1994) state that potential yield losses in wheat and barley without weed control could amount to 17% but with control the losses are reduced to 5%. In potatoes the potential losses could be up to a 23% yield loss, but again with control this is reduced to 5%. Therefore, using this information and that from May (2003) and a Scottish Agricultural College Technical Note[12], a yield loss of 5% was assumed for all cereal crops and potatoes, 4% for oilseed crops and commercial vegetables and 3% for sugar beet and fodder crops. It was also assumed that weed control would be totally effective in preventing yield loss in plants and flowers, hardy nursery stock and fresh fruit (as the

[12] http://www.sac.ac.uk/mainrep/pdfs/tn624weedpotato.pdf

herbicides are primarily used for inter-row weeds) and therefore no additional cost due to competition with INNS was attributed for these crop groups. The yield loss figures were adjusted to account for the proportion of weeds affecting the crops that are non-native (using the same percentages used for the weed control estimates above) and the cost of the estimated losses calculated using the yield of crops grown and the market value, taken from Defra statistics[13].

Market prices for crops can vary between 1% to 30% between years depending on amongst other things, global and local output and demand, weather conditions in the growing season and the area of a crop planted. Crops that are traded on international markets are especially vulnerable to price fluctuations resulting from changing global supply and demand, e.g. the price of wheat has decreased from US$277/ton to US$179/ton within one year[14]. Due to this variability of market prices and all the factors that cause price fluctuations at any one time, including those that are demand driven, an assumption has to be made as to the effect of a small increase in crop yields in Great Britain on overall trading prices. Therefore, it is assumed that an average of a 2% decrease in market prices would occur across all crops due to the increased production in the absence of any non-native weeds. The price differential between the increased production value due to increased output at a lower unit cost, and the cost of the yield loss caused by non-native weeds at the lower unit cost is taken as the cost of yield loss attributable to the presence of non-native weeds post control. These are estimated at £102,716,995 (England £87,730,752, Scotland £1,134,194, Wales £13,852,009; Table 5.2).

Table 5.2 Yield loss due to non-native weeds.

	England	**Scotland**	**Wales**	**GB**
Cereal Crops	£54,100,286	£842,090	£8,686,024	£61,628,400
Potato	£11,352,077	£209,668	£2,962,568	£14,524,313
Oilseeds	£1,283,048	£6,765	£88,029	£1,377,842
Sugar Beet	£3,828,500	-	-	£3,828,500
Peas & beans (fodder)	£222,854	£879	£5,977	£229,710
Commercial Vegetables	£18,943,987	£74,792	£2,109,411	£21,128,190
Total	**£89,730,752**	**£1,134,194**	**£13,852,009**	**£104,716,955**

[13] https://statistics.defra.gov.uk/esg/publications/auk/default.asp
[14] http://www.igc.int/en/grainsupdate/igcexpprices.aspx

5.2 Non-native invertebrate agricultural pests.

The most common control options against insects, mites and molluscs are chemical pesticides, which are often applied as a preventative control measure. Most pesticides treat a number of species and/or groups of pests that may or may not be native, and so are likely to be used in many cases regardless of whether a particular species is present. Therefore, in order to determine the control cost of non-native pests to British agriculture, the annual spend on insecticides, acaricides and mollusicides was calculated for the main agricultural and horticultural sectors (arable, glasshouse, soft fruit, orchard and fruit stores, outdoor vegetables, outdoor bulbs and flowers and grassland, fodder crops and hardy nursery stock) using data from the Defra's pesticide usage surveys.

The total annual spend on pesticides was calculated using the data on the percentage of each pesticide formulation used on different crops, the area of crops treated, the average spray application and the price of pesticide per hectare, including application. In circumstances where only the most popular pesticides used were mentioned, the cost of the remaining pesticides used was estimated by taking the mean cost of pesticides already calculated for that specific group of crops.

In order to calculate the price of individual pesticides per hectare, the recommended dosage for the specific crops was used. Once the total annual spend on pesticides had been extrapolated for each group of crops and pesticide, the proportion of native and non-native pests was estimated based on information about the main pests of each major crop, and what non-native pests affected the major crops. The percentage of non-native pests estimated from this data was used to calculate the proportion of annual pesticide spend that was used against non-native pests. Data on key pest species published by, among other organisations, Rothamsted, ADAS and major agro-chemical companies were used. This method was used for all the crop groups discussed below.

5.2.1 Arable crops

Wheat yellow blossom midge (*Contarinia tritici*), wheat bulb fly (*Delia coarctata*), hessian fly (*Mayetiola destructor*), bird cherry-oat aphid (*Rhopalosiphum padi*) and oat-leaf beetle (*Oulema melanopus*) are invasive non-native arable crop pests, some of which are serious pests. The insecticide usage survey indicates that the majority of insecticides used on arable crops are targeted against cereal aphids, cabbage stem flea beetle (*Psylliodes chrysocephala*), pollen beetles, cabbage seed weevil (*Ceutorhynchus assimilis*) and orange wheat blossom midge. According to the major agrochemical companies, major pests of arable crops are: cereal aphids (predominantly native), frit flies, wheat blossom midge (predominantly the orange wheat blossom midge, which is native), leather jackets (native), hessian fly and the wheat bulb fly. It is estimated that 25% of the annual insecticide usage on arable crops is targeted against non-native arable pests, providing an annual cost of £8,725,145, which, when split between England, Scotland and Wales equates to £7,590,876, £1,047,017 and £87,252, respectively (Table 5.3).

In addition to the insecticide treatment of growing crops, cereal seeds are also treated with insecticides against wheat bulb fly and aphid species, some of which are native. It is estimated that 30% of this treatment cost is against non-native species, giving an annual cost of £11,112,325 (England £9,571,611, Wales £131,390 and Scotland £1,409,324).

Amongst the most important species of slug pests to UK agriculture, three are non-native: Spanish slug (*Arion lusitanicus*), Sicilian slug (*Deroceras panormitanum*) and Budapest slug (*Tandonia budapestensis*) (Speiser *et al.* 2001). Slugs are serious pests of arable crops. The Spanish and Budapest slug are two of the most abundant and destructive slugs on arable crops (Frank 1998), along with the native grey field slug (*Deroceras reticulatum*). Hence, it can be estimated that approximately 66% of the cost of molluscicides used on arable crops can be accredited to invasive non-native slugs. Therefore, of £1,533,061 spent annually on molluscicides, £1,011,820 is against non-natives in Great Britain, and assuming an even population distribution within the area of arable crops grown in each country, the costs are broken down to £880,284, £121,418 and £10,118 for England, Scotland and Wales, respectively.

5.2.2 Protected crops

The pest community found in protected environments, such as glasshouses, differs in structure and species composition from outdoor crops, due to both climatic conditions and types of host crops grown. The growing conditions within the protected environment tend to be highly favourable to arthropod pests that would not become established in Britain outside a glasshouse environment. Glasshouse pests are typically; thrips, whiteflies, spider mites, aphids, leafminers and several species of caterpillars (Ferguson and Murphy 2002). Major non-native glasshouse pest species include western flower thrip (*Frankliniella occidentalis*), onion thrips (*Thrips tabaci*), glasshouse whitefly (*Trialeurodes vaporariorum*), tomato leaf miner (*Liriomyza bryoniae*), tortrix carnation leafroller (*Cacoecimorpha pronubana*), scale insects & mealybugs (*Coccoidea* spp.), root weevil (*Diaprepes abbreviatus*), pyralid moth (*Duponchelia fovealis*) and a scarid fly (*Bradysia difformis*).

The use of insecticides on protected crops tends to be particularly extensive on hardy ornamental nursery stock and ornamental plants and the major pests on these plants are: vine weevils (most important species: black vine weevil (*Otiorhynchus sulcatus*; native)), whitefly, western flower thrips, two-spotted spider mites (*Tetranychus urtica*; assumed native, as native to temperate climates), scarid flies and native aphids and leafhoppers. Using this information it is estimated that 35% of the cost of insecticides on ornamental protected crops can be attributed to non-native species, giving a total annual cost of £40,408 to Great Britain. This can then be split between England (94%), Scotland (5%) and Wales (1%), according to the proportion of protected crops grown in each country (Garthwaite *et al*. 2007). This gives a total cost of pesticides used on protected ornamental crops against non-natives of £37,983, £2,020 and £405 respectively. The percentage of insecticide used against non-native pests on edible protected crops can be estimated at approximately 50%. Therefore, of the £101,388 spent annually on pesticides on edible crops in Great Britain, £50,694 can be attributed to non native pests, which gives a cost to England, Scotland and Wales of £47,652, £2,535 and £507, respectively.

Acaricide use on edible crops and ornamentals costs approximately £55,828 and £16,150 respectively. Acaricides were used predominantly against two-spotted spider mites, which are of unknown origin and thus deemed natives. Some acaricides such as Abamectin were used to protect crops again leafminers and thrips (Garthwaite *et al.* 2007). We assumed that 5% of the annual usage of acaricides can be attributed to non-native pests on both edible and ornamental crops, giving a cost of £2,791 to edible protected crops and £807 to protected ornamental crops.

The percentage of molluscicide use on protected crops targeted at non-natives is estimated at 20% giving a total annual cost of £4,689 to Great Britain, £4,408 to England and £234 to Scotland and £47 to Wales.

5.2.3 Soft fruit crops

Insecticides are predominantly used on soft fruit crops to control aphids, thrips, vine weevils, the strawberry blossom weevil, sawflies and midge species. Of these pest insects non-natives include the red currant blister aphid (*Cryptomyzus ribis*), the bishop bug (*Lygus rugulipennis*) and the recently established blueberry gall midge (*Dasineura oxycoccana*). Despite there being several non-native pests, the majority of insecticide costs can be attributed to native pests, such as the native raspberry beetle (*Byturus tomentosus*) which has been documented as being one of the main reasons for insecticide usage on soft fruit (Garthwaite *et al*. 2006). Based on this information it is reasonable to estimate that 15% of the insecticide usage on soft fruit can be attributed to non-native pest insects, costing Great Britain approximately £33,990 annually, and £27,803, £5,652, £535 to England, Scotland and Wales, respectively.

Acaricide usage on soft fruit crops in the UK has been mainly attributed to non-native blackcurrant gall mite (*Cecidophyopsis ribis*) and the native two-spotted spider mite (Garthwaite *et al.* 2006). Blackcurrant gall mite is predominately a problem on blackcurrants whilst the two spotted spider mite is a major pest of strawberries and raspberries (Garthwaite *et al.* 2006) and therefore is likely to be the cause of most pesticide use. Acaricide use on soft fruit crops was also cited as being used against the leaf curling midge (*Dasineura tetensi*) and aphids, of which one of the six major aphid pests on soft fruit is the non-native red current blister aphid. The gooseberry mite (*Cecidophyopsis grossulariae*) is the only other invasive non-native pest on soft fruit. Based on this information it is reasonable to estimate that 60% of the annual acaricide use on soft fruit crops are used to target non-native pests, costing £24,306 to Great Britain and £19,882, £4,041, £383 to England, Scotland and Wales, respectively.

None of the non-native molluscs are documented in the literature as being a major pest on soft fruit. Consequently, no cost has been estimated for control of invasive non-native molluscs on soft fruit crops in Great Britain.

5.2.4 Orchard and fruit stores

The only invasive non-native insect pests in orchards that insecticides are used against are summer fruit tortrix moths (*Adoxophyes orana*) and plum fruit moths (*Grapholita funebrana*). All of the major insect pests in orchards are native species and therefore none of the annual cost of insecticides in orchard crops is attributed to controlling non-native insects. Similarly, none of the annual cost of acaricide use in orchards and fruit stores can be attributed to non-native pests (Garthwaite and Thomas 2005).

5.2.5 Outdoor vegetables

The main non-native insect pest of outdoor vegetables that is targeted with insecticides is the asparagus beetle (*Crioceris asparagi*). Although the asparagus beetle is a major pest, there are numerous major native pests on outdoor vegetable crops which have been estimated to contribute to larger percentages of the pesticide annual use. Other non-native species such as tomato leaf miners and the leek moth (*Acrolepiopsis assectella*) that are documented as being pests on outdoor vegetables are not cited as being specific target species and thus are likely to have a negligible cost (Garthwaite *et al.* 2007). Given this information, the cost of annual insecticide usage targeted against non-native insects can be estimated as approximately 0.5% of the total, costing £36,718 to Great Britain and £33,046, £3,672 to England and Scotland, respectively. No annual cost can be attributed to Wales.

The percentage uses of mollusicides used on outdoor vegetable crops targeted at non-natives was estimated to be 20%, giving a total annual cost of £12,012 to Great Britain, £10,811 to England and £1,201 to Scotland.

5.2.6 Outdoor bulbs and flowers

The majority of pests on outdoor bulbs and flowers for which insecticides are used are native with the exception of the great bulb fly (*Merodon equestris*), which is a major pest. The cost of annual insecticide used to Great Britain can be estimated at approximately 10% of the total, giving a cost of £1,673 to Great Britain (Garthwaite *et al.* 2005a).

The percentage of mollusicides used on outdoor bulbs and flowers targeted at non-natives is negligible, as mollusicides are very rarely used on this crop (Garthwaite *et al.* 2005a).

5.2.7 Grassland & fodder crops

None of the annual cost of insecticide use on grassland and fodder crops can be attributed to non-native pests as no non-native insect is documented as being major pest on this crop (Garthwaite *et al.* 2005b).

The percentage of molluscicides used on grassland and fodder crops targeted at non-natives can be estimated at 20% giving a total annual cost of £12,114 to Great Britain, £5,330 to England, £5,209 to Scotland and £1,575 to Wales.

5.2.8 Hardy nursery stock

Insecticide use on hardy nursery stock tends to be targeted against aphids, vine weevils and caterpillars (Garthwaite and Thomas 2005). Of the total amount of insecticide applied to hardy nursery stock, 58% of it was used to target the native black vine weevil (Garthwaite and Thomas 2005). Major non-native pests on hardy nursery crops include the green spruce aphid (*Elatobium abietinum*), woolly aphid (*Eriosoma lanigerum*), and the cypress aphid (*Cinara cupressi*). The cost of annual insecticide usage targeted against non-native insects on hardy nursery stock can be estimated as approximately 35% of the total, costing £78,624 to Great Britain, £70,762 to England and £3,931 to both Scotland and Wales.

None of the annual cost of acaricides use on hardy nursery stock can be attributed to non-native pests as no non-native mites are documented as being major pest on this crop (Garthwaite and Thomas 2005).

The percentage of molluscicide use targeted at non-natives is estimated at 40% as the non-native Sicilian slug is a key pest in hardy ornamental plant nurseries. The cost of mollusicides targeted at non-natives on hardy nursery crops can be estimated at £97 for the whole of Great Britain.

5.2.9 Biocontrol Agents

As pesticide resistance has increased in insect pests so has the use of biocontrol agents as alternative methods of control for invertebrate pests. The majority of biocontrol agents are used to control pests of protected ornamental and edible crops[15], as well as some outdoor edible crops and soft fruits, while potatoes are the only arable crop where biocontrol agents are used for the control of slugs. Key pests that can be controlled by biocontrol agents include the vine weevil (non-native), thrips including *Frankliniella occidentalis* (non-native), several mites including the red or two spotted spider mite (*Tetranychus urticae*) (native), aphids (some non-native), whiteflies (some non-native), and leafminers. Many of the pests are a particular problem in the enclosed environment of glasshouses. An estimated 50% of all pests managed using biocontrol agents are estimated as non-native, and using pricing information from companies selling these beneficial species, costs are estimated at £4,892,214 (England £4,564,910, Scotland £279,239 and Wales £48,065).

The cost of pesticides and biocontrol agents used against non-native invertebrate pest species in Great Britain is summarized in Table 5.3.

[15] http://www.fera.defra.gov.uk/plants/pesticideUsage/fullReports.cfm

Table 5.3. Total cost of pesticides and biocontrol agents for control of invasive, non-native invertebrates on agricultural crops.

Crops	Pesticide	England	Scotland	Wales	GB
Arable	Insecticide	£7,590,876	£1,047,017	£87,252	£8,725,145
	Molluscicide	£880,284	£121,418	£10,118	£1,011,820
	Seed treatments	£9,571,611	£1,409,324	£131,390	£11,112,325
Protected ornamentals	Insecticide	£37,983	£2,020	£405	£40,408
	Acaricide	£807	-	-	£807
Protected edible crops	Insecticide	£47,652	£2,535	£507	£50,694
	Acaricide	£2,791	-	-	£2,791
Protected crops	Molluscicide	£4,408	£234	£47	£4,689
Soft fruit	Insecticide	£27,803	£5,652	£535	£33,990
	Acaricide	£19,882	£4,041	£383	£24,306
Outdoor vegetables	Insecticide	£33,046	£3,672	-	£36,718
	Molluscicide	£10,811	£1,201	-	£12,012
Outdoor bulbs and flowers	Insecticide	£1,673	-	-	£1,673
Grassland and fodder	Molluscicide	£5,330	£5,209	£1,575	£12,114
Hardy nursery	Insecticide	£70,762	£3,931	£3,931	£78,624
	Molluscicide	£97	-	-	£97
Biocontrol agents		£4,564,910	£279,239	£48,065	£4,892,214
Total annual cost of pesticides		**£22,870,726**	**£2,885,493**	**£284,208**	**£26,040,427**

5.2.10 Yield loss due to non-native invertebrate agricultural pests

In addition to the spending on pesticides to prevent yield loss, discussed above, growers will still experience yield losses on their crops. Yield losses experienced after pesticide usage were taken from Tatchell (1989), Duck and Evola (1997), Dent (2000) and Capinera (2001), giving average figures ranging from no losses in treated oilseeds to 12% losses in cereal crops and 16.3% losses in pea and bean crops for fodder. However not all these losses are attributable to non-native pests, and therefore the same proportions of native to non-native pests as were used in the pesticide usage calculations were used to calculate a proportion of yield loss due to non-native pests. These yield losses ranged from 0% in oilseeds to 3% in cereal crops and 3.5% in sugar beet. Annual yield figures and production values were obtained from Defra statistics[16], as were data related to production in each country. As discussed above, market prices for crops are very variable and prices can fluctuate widely.

[16] https://statistics.defra.gov.uk/esg/publications/auk/default.asp

As discussed when considering the cost of yield losses due to agricultural weeds, it is again assumed that on average a 2% decrease in market prices occurs across all crops due to the increased production levels in the absence of any non-native pests. The price differential between the increased production value due to increased output at a lower unit cost, and the cost of the yield loss caused by non-native pests at the lower unit cost is taken as the cost of yield loss attributable to the presence of non-native pests post control. These are estimated at £105,642,000 (England), £5,477,000 (Scotland) and £18,222,000 (Wales) giving a total of £129,341,000.

Table 5.4. Yield losses due to non-native invertebrate agricultural pests.

	Value of yield loss			
	England	**Scotland**	**Wales**	**GB**
Cereals	£52,613,000	£850,000	£8,772,000	£62,235,000
Potato	£11,312,000	£209,000	£2,952,000	£14,473,000
Oilseeds	-	-	-	-
Sugar Beet	£3,933,000	-	-	£3,933,000
Peas & beans (fodder)	£232,000	£1,000	£6,000	£239,000
Commercial Vegetables	£19,314,000	£76,000	£2,151,000	£21,541,000
Plants and flowers	£3,989,000	£855,000	£855,000	£5,699,000
Hardy nursery stock	£7,436,000	£1,593,000	£1,593,000	£10,622,000
Fresh fruit (orchard and soft)	£6,813,000	£1,893,000	£1,893,000	£10,599,000
Total	**£105,642,000**	**£5,477,000**	**£18,222,000**	**£129,341,000**

5.2.11 Sprayer water

An additional cost that should be considered as part of the cost of control of weeds and invertebrate pests is that of the amount of water needed to apply the herbicides, insecticides etc. While it may be possible to apply some herbicides and insecticides together, therefore reducing the amount of water needed, there are still considerable amounts of water used to apply the chemicals. Average water use for an arable crops application is approximately 150l/ha[17], while potato crops can use an average of 180l/ha. Outdoor vegetable crops need considerably more water for the application of the necessary agro-chemicals at the appropriate doses, using approximately 250l/ha for crops such as brassicas, peas and

[17] http://www.fera.defra.gov.uk/plants/pesticideUsage/fullReports.cfm

beans. At an average commercial use price of 0.084p/l[18] the cost of water used for spraying agro-chemicals to control non-native species can therefore be estimated at £757,548 (England £671,739, Wales £8,402 and Scotland £77,408).

5.2.12 Control of Non-native Invertebrate Storage Pests

A number of beetles, mites and moths ruin grain and fodder crops when stored on farms or commercially. The majority of storage pests found in Great Britain are non-native pests[19,20] such as *Oryzaephilus surinamensis* (saw-toothed grain beetle), *Ahasverus advena* (foreign grain beetle), and *Cryptolestes ferrugineus* (rust-red grain beetle). Therefore assuming that all pesticide usage in stores is for control of INNS and based on the tonnage of crops stored both on farms[21] and in commercial grain stores[22] and the amount treated, and a cost of £4 per tonne treated (Dr J Knight, pers. comm.), costs for control were estimated at £5,506,301 for England, £1,005,697 for Scotland and £23,913 for Wales, a total of £6,535,911 per annum.

Other stored crops, such as fruits and potatoes, are also treated in storage, but with fungicides or to suppress sprouting respectively. Drying methods are generally used to control fungi, many of which may be native, and therefore no cost is included here. However, the use of cooling as a control method is entirely attributable to the presence of INNS (Maureen Wakefield pers. comm.) and therefore all associated costs are included here. Based on the tonnes of crop stored (as above) and using the average of the rate of manual cooling (at 50p per tonne) and automatic cooling (at 29p per tonne)[23], cooling costs were estimated (Table 5.5).

Table 5.5 Estimated cooling costs to control non-native storage pests

	England	Scotland	Wales	GB
Cereals	£8,665,583	£1,072,942	£54,593	£9,793,118
Oilseeds	£585,079	£39,531	-	£624,610
Pulses	£451,860	£3,668	£6,632	£462,160
Other	£6,375	£256	-	£6,631
	£9,708,897	£1,116,397	£61,225	£10,886,519

[18] http://www.ofwat.gov.uk/nonhousehold/yourwaterbill/hownonhousehold/large
[19] http://www.hgca.com/document.aspx?fn=load&media_id=463&publicationId=896
[20] http://www.hgca.com/cms_publications.output/2/2/Publications/Publication/Grain%20Storage%20Guide%20-%202nd%20Edition.mspx?fn=show&pubcon=820
[21] http://www.fera.defra.gov.uk/plants/pesticideUsage/fgs2003.pdf
[22] http://www.fera.defra.gov.uk/plants/pesticideUsage/cgs2003.pdf
[23] http://www.hgca.com/document.aspx?fn=load&media_id=4817&publicationId=4811

In addition to treatment costs in storage facilities, there are likely to be some further treatment costs at points further along the processing chain. However no data could be located to ascertain the amount of treatment required, what type of treatments were used and which pests were being treated. Therefore no cost has been estimated here.

A further cost is associated with the rejection of loads that are infested with pests. Rejection of a load can cost £20 per tonne, including the costs of treatment and transport[24] with less than 1% of loads being rejected due to infestation in normal years (Wilkin 2003). However in warmer years up to 5% or 10% of loads can be lost. If it is assumed that 1% of loads are lost per year, and that a load consists of 25 tonnes (based on the size of the lorry), then assuming all stored grain is transported, a total of 11,024 loads are lost each year at a cost of £220,487 (£196,636 England, £22,611 Scotland and £1,240 Wales; Table 5.6).

Table 5.6. Total costs associated with INNS storage pests.

	England	Scotland	Wales	GB
Pesticides	£5,506,301	£1,005,697	£23,913	£6,535,911
Cooling	£9,708,897	£1,116,397	£61,225	£10,886,519
Load rejection	£196,636	£22,611	£1,240	£220,487
Total	**£15,411,834**	**£2,144,705**	**£86,378**	**£17,642,917**

5.2.13 New Zealand Flatworm

The New Zealand flatworm (*Artioposthia triangulata*) and Australian flatworm (*Austaloplana sanguinea*) are terrestrial planarians, which have become very widely distributed in garden centres, botanic gardens, nurseries and domestic gardens in Scotland. The New Zealand flatworm is reputed to have a geographic distribution encompassing over 90% of the Scotland land area (Boag *et al.* 1997), as well as being found in northern England. However, they are not considered to be an issue on agricultural land (Fera, undated), rather they are found mainly in botanical and domestic gardens (Cannon *et al.* 1999) and may be spread through nursery plants. No control methods are known at present, but good hygiene at nurseries and horticultural suppliers are recommended to control the spread of the worm[25]. As most nurseries will practice good hygiene measures as standard, no additional costs are include here.

[24] http://www.fwi.co.uk/Articles/2004/11/26/25747/Avoid-16320t-Rejections-by-Regularly-Checking-Stores.htm
[25] http://www.fera.defra.gov.uk/plants/publications/plantHealth/documents/flatwormsCop.pdf

5.2.14 Nematodes

There are many species of nematode in Great Britain which affect crop species, but the origin of the majority of these species is unknown (S Hockland pers. comm.). One nematode however that is known to be non-native, originating from South America, that causes significant yield and economic losses is the potato cyst nematode. There are two species that are commonly referred to as a potato cyst nematode, *Globodera pallida* (the white or pale potato cyst nematode) and *G. rostochiensis* (the yellow or golden potato cyst nematode). The nematodes infect the roots of the potato plant and severe infection can cause severe root damage or even death. Any new root growth is also likely to be affected. The reduction in root growth caused by both species also causes reduced foliar growth and a significant reduction in tuber yield. Yield losses have been estimated as at least 10% annually[26] with costs of nematicides estimated at approximately £9 million annually in product costs alone (Clayton *et al.* 2008). Further costs will include application costs as well as costs associated with crop rotation, a main control method for potato cyst nematodes. Estimated yield loss was valued at £43 million in 1998 (Haydock and Evans 1998) and the total cost of potato cyst nematodes has been estimated as between £50 million - £60 million (S Hockland pers. comm.) in the UK. Therefore, excluding Northern Ireland, costs are estimated at £50 million per year in Great Britain, which once divided by the area of potato grown in each country (as used in calculations above) then costs are England £38,605,000, Wales £841,000 and Scotland £10,554,000. It is expected that some of the other nematode species that cause economic crops losses are non-native, but as stated earlier the origin of most nematodes is unknown so no additional costs are estimated here.

5.2.15 Varroa Mite

The Varroa mite (*Varroa destructor)* is considered a serious pest to honey bee (*Apis mellifera*) hives in Great Britain. It was first identified in Devon in 1992, and is now established in England and Wales and found in Southern and Central Scotland as well[27]. The mite contributes to the spread of viruses and is thought to be one of the many factors contributing to colony collapse disorder, although present research has not established the exact contribution of the varroa mite (Hendrikx *et al.* 2009, Aston *et al.* 2009) to colony collapse. The most appropriate control methods for the varroa mite depend on the level of infestation, and include chemical control and mechanical methods that primarily have an associated labour cost. Due to developing resistance to chemical control, mechanical

[26] www.dowagro.com/uk/potato/nematode.htm
[27] https://secure.fera.defra.gov.uk/beebase/public/BeeDiseases/historyVarroa.cfm

methods are more common now, included general hive manipulation and sugar dusting (C Deaves, British Beekeepers' Association, pers. comm.). The main associated costs are the extra time spent managing the hives through the months between March and September, estimated at an extra 10 minutes per hive per week. On the assumption that half the hives are properly managed (C Deaves, pers. comm.), and that a skilled beekeeper, if charging for their services could earn £7.04 per hour (recommended wage for a skilled farm worker[28]), then the cost of managing hives to control varroa mite can be estimated at £4,673,973. Some of these hives will be in Northern Ireland, therefore the cost is reduced to £4,440,275 (England £2,220,137, Scotland £1,110,069 and Wales £1,110,069).

The British Beekeepers' Association (Aston *et al*. 2009) states that there are 240,000 hives in the UK, each contributing £600 p.a. to the economy, while the Arthur Rank Centre estimates that there are approximately 274,000 hives[29], honey production is valued at £10-30 million and pollination of crops at £200 million. Using an average 257,000 hives and a total value to the economy of £220 million p.a. then each hive is worth £856. There is great variation in the reported percentage loss of hives, from an estimated 30% loss in the winter of 2007-2008 in England (Aston *et al.* 2009), to losses in England and Wales of 11% in 2006, 11% in 2007, 12% in 2008 and 6% in 2009 (Hendrikx *et al.* 2009) and a loss of 26% in Scotland between 2000 and 2009 (Hendrikx *et al.* 2009). These losses include the average 10% annual loss experienced each winter anyway (Hendrikx *et al.* 2009). Due to the ongoing research into the contribution of the varroa mite to hive death, no data were available stating how many hives were lost due to the presence of varroa in Great Britain. However the majority of extra hive deaths experienced each winter are considered to be due to varroa mite, or the diseases they transmit (C Deaves, pers. comm.), therefore, if it is assumed that 90% of the extra hive deaths (i.e. 90% of the 8% averaged loss figures from above, excluding the 10% normal winter death) each winter are caused or partly caused by the presence of the varroa mite then 18,504 hives are lost in the UK at a cost of £856 each, giving a cost of £15,839,424 each year. Some of these hives will be in Northern Ireland, therefore the cost is reduced to £15,047,453 (England £7,523,727, Scotland £3,761,863 and Wales £3,761,863).

In addition both Fera and the Scottish Government undertake work on bee health. Of the figures provided (Jean Waddie, Fera, pers. comm.) approximately 92% was spent on delivery and 8% was spent on research into bee health. This gives a total spending on bee health delivery in England and Wales of £2,568,000 and £173,283 in Scotland. However

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[28] http://www.defra.gov.uk/foodfarm/farmmanage/working/agwages/pdf/awo09.pdf
[29] http://www.arthurrankcentre.org.uk/projects/rusource_briefings/rus09/827.pdf

this will also include work on native species and therefore an estimated 50% of these costs are attributed to non-native bee health issues giving a cost of £1,284,000 in England and Wales and £86,642 in Scotland, a total of £1,370,642.

Total costs attributable to varroa mite are therefore England £13,837,205, Scotland £6,523,745 and Wales £6,758,103, a total of £27,119,053.

5.3 Plant Pathogens

The importance of plant pathogens (fungi, nematodes, bacteria, viruses etc) has long been recognised in Great Britain (Ainsworth, 1969) and the economic impact of plant diseases probably first became apparent when plants were cultivated as crops (Carlile, 1995). Many of the fungal pathogens causing plant diseases in Great Britain today are non-native or exotic species that have been introduced either accidentally or deliberately from other countries. The most historic and infamous example of a non-native pathogen causing significant crop loss is late blight of potato caused by *Phytophthora infestans.* During the 1840s, potato crops were completely destroyed by this oomycete pathogen and gave rise to the great Irish famine.

Invasive non-native species are currently receiving increasing attention in the literature (Manchester and Bullock 2000). However, non-native plant pathogens are far less well-studied than plants, vertebrates, insects, etc. and are under-represented in the scientific literature (Desprez-Loustau *et al*. 2007).

A recent, comprehensive analysis of available data for introduced non-native plant pathogens in Great Britain by Jones and Baker (2007) found that 234 pathogens were recorded between 1970 and 2004. Of these, 67% (157) were fungi, 11.5% (27) were oomycetes, 11% (26) were viruses, 10% (23) were bacteria and <0.5% (1) were phytoplasmas. Approximately 53% of these were first recorded on ornamentals, 16% on horticultural crops, 15% on wild native plants, 12% on agricultural crops, 2% on pasture plants and 2% on forestry tree species. Interestingly, 47% of these non-native pathogens introduced into Great Britain could be traced back to the Netherlands, 16.7% to New Zealand, 13.9% to France and 11.1% to the USA. This study also analysed the regional distribution of non-native pathogen introductions within Great Britain: 81% in England, 15% in Scotland and 4% Wales. Jones and Baker (2007) believe that the number of non-native pathogens introduced into Great Britain does not appear to be increasing and consider 45 of the 234 (19%) non-native pathogens to be of importance because of economic or environmental losses (Table 5.7).

Table 5.7. Plant pathogens numbers affecting selected crops.

Plant	**Number of important non-native pathogens**
Tomato *(Lycopersicon esculentum*)	6
Lettuce *(Lactuca sativa)*	5
Camellia (*Camellia japonica*)	5
Sugar beet (*Beta vulgaris*)	4
Potato (*Solanum tuberosum*)	4
Wheat (*Triticum aestivum*)	3
Barley (*Hordeum vulgare*)	3
Onion (*Allium cepa*)	3
Cucumber (*Cucumis sativus*)	3
Blackberry (*Rubus fruticosus*)	3
Pelargonium (*Pelargonium* spp.)	3
Corsican pine (*Pinus nigra* subsp. *laricio*)	3

Sixteen of the 157 fungi and 10 of the 27 oomycetes listed affecting ornamentals, agricultural crops and horticultural crops are considered to be important (Table 5.8). Most important of these are the oomycete pathogens *Phytophthora kernoviae* and *P. ramorum* which are currently affecting the native flora of Great Britain.

Table 5.8. Economically important non-native pathogens (fungi and oomycetes) introduced into Great Britain between 1970 and 2004 (adapted from Jones and Baker 2007).

Pathogen	**Disease**	**Host**
Fungi		
Ciborinia camelliae	Petal Blight of camellia	*Camellia japonica*
Coniothyrium lavendulae	Dieback of lavender	*Lavandula angustifolia*
Cylindrocarpon parva	Stem rot of pelargonium	*Pelargonium* sp.
Cylindrocarpon buxicola	Box blight	*Buxus microphylla*
Discula destructive	Anthracnose of dogwood	*Cornus florida*
Erysiphe azalea	Powdery mildew of rhododendron	*Rhododendron* sp.
Fusarium oxysporum f.sp. *radicis-lycopersici*	Fusarium crown rot of tomato	*Lycopersicon esculentum*

Pathogen	Disease	Host
Fusarium trichothecioides	Dry rot/gangrene of potato	*Solanum tuberosum*
Kabatiella zeae	Eyespot of maize	*Zea mays*
Oidium neolycopersici	Powdery milder of tomato	*Lycopersicon esculentum*
Podosphaera verbenae	Powdery mildew of verbena	*Verbena lasiostacys*
Pseudocercosporella anguioides	Eyespot of wheat	*Triticum aestivum*
Puccinia distinct	Rust of daisy	*Bellis perennis*
Ramularia collo-cygni	Leaf spot of spring barley	*Hordeum vulgare*
Sclerotium hydrophilum	Leaf spot of giant water lily	*Nymphaea gigantea*
Stemphylium sp.	Leaf spot of hebe	*Hebe albicans*
Oomycetes		
Peronospora hariotii	Downy mildew of buddleia	*Buddleja globosa*
Phytophthora alni	Root and collar rot of alder	*Alnus glutinosa*
Phytophthora infestans (A2 mating type)	Late blight of potato	*Solanum tuberosum*
Phytophthora fragariae var. *rubi*	Root rot of raspberry	*Rubus idaeus*
Phytophthora idaea	Root rot of raspberry	*Rubus idaeus*
Phytophthora ilicis	Twig dieback of holly	*Ilex* sp.
Phytophthora kernoviae	Trunk canker of beech	*Fagus sylvatica*
Phytophthora ramorum	Sudden oak death, dieback of viburnum	c 130 host species, including Rhododendron, Viburnum, Camellia, Vaccinium, *Larix kaemferi, Quercus* spp*, Fagus* etc
Plasmopara obducens	Downy mildew of impatiens	*Impatiens balsamina*
Pythium tracheiphilum	Stem infection of lettuce	*Lactuca sativa*

According to Hill *et al.* (2005), 135 species of non-native fungi have been identified in England outside the somewhat artificial environment of the urban garden, which corresponds to 9.6% of the total number of recorded non-native species. Three of these pathogens, *Ophiostoma novo-ulmi* (Dutch elm disease), *Phytophthora alni* (dieback of alder) and *P. ramorum* (sudden oak death), were noted for their major impact. A further 10 species of microbes were identified, 0.7% of the total. However, Hill *et al.* (2005) also note that of the 14,000 known fungi in Great Britain the origin of many of the species is unknown, and may never be known. It is possible that many plant pathogens arrived with the plant they are a pathogen of, but for species introduced a long time ago, such as cultivated cereals (e.g. wheat, barley) or potatoes, it may not be possible to establish the origin of the pathogen. No data on the percentage of plant pathogens found in Great Britain that are non-native has been found, but given that many crop species are non-native it is likely that their pathogens are also non-native. Therefore a figure of 40% for arable and vegetable crops and 50% for protected crops has been estimated.

In the USA at present, crop loss due to invasive non-native plant pathogens is estimated at $21 billion per year, greater than that caused by non-native insects (Rossman, 2008). One non-native pathogen of particular economic importance is the potato (late) blight. *Phytophthora infestans* (Mont.) de Bary is an oomycete pathogen that causes the serious potato and, to a lesser extent, tomato disease known as late blight or potato blight. The origin of *P. infestans* can be traced to a valley in the highlands of central Mexico and was introduced into Europe in 1845 (Grünwald and Flier, 2005). The disease destroyed potato crops throughout Europe and was responsible for the Irish famine that occurred between 1845 and 1852.

Despite numerous control methods (fungicides, resistant varieties, management practices), potato blight still remains an important plant pathogen today. Potato blight is estimated to cost the global potato industry £3.5 billion every year[30] due to crop failure and the cost of fungicides, with outbreaks varying depending on climatic conditions: 2007 was one of the worst years for late blight in the UK, when a particularly wet summer saw an unprecedented 300 outbreaks[31].

5.3.1 Control Costs

The main control costs of plant pathogens relate to the control of fungal diseases. Viruses and bacteria cannot be controlled through the use of chemicals, although biological control can be effective by controlling the insect vectors that spread some of these pathogens. These costs are included in the agriculture sector.

According to Defra's pesticide usage survey report for arable crops in Great Britain (Garthwaite *et al.* 2008), fungicides accounted for 38% of the total pesticide-treated area of arable farm crops grown in Great Britain in 2008. The two most extensively-used fungicide formulations applied as sprays were chlorothalonil (used on all crops with the exception of rye, triticale and sugar beet) and epoxiconazole (used on cereals). In 2009, according to

[30] http://www.farmersguardian.com/news/arable/defra-considers-gm-potato-trial/30434.article

[31] http://www.new-ag.info/focus/focusItem.php?a=531

industry data, the average cost of fungicide is £76/ha[32], with prices varying from £25 per hectare per rotation in sugar beet to £255 per hectare per rotation in potatoes (Nix 2009).

Based on the areas of crops grown, the prices above and assuming that 40% of fungi affecting arable and vegetable crops and 50% of fungi affecting protected crops are non-native (see above), the cost of fungicides to control non-native fungi was estimated to be £118,236,000.

Table 5.9. Annual control cost of non-native fungi.

	England	**Scotland**	**Wales**	**GB**
Arable crops	£96,788,000	£13,797,000	£1,407,000	£111,992,000
Vegetable crops	£3,438,000	£273,000	£10,000	£3,721,000
Edible crops	£59,000	£3,000	£1,000	£63,000
Ornamental crops	£27,000	£1,000	£1,000	£29,000
Soft fruit crops	£581,000	£118,000	£12,000	£711,000
Top fruit	£1,617,000	£86,000	£17,000	£1,720,000
Total	£102,510,000	£14,278,000	£1,448,000	£118,236,000

5.3.2 Yield Loss

In addition to the cost of control, plant pathogens can still cause yield loss even after control measures have been taken. Oerke *et al*. (1994) have estimated the percentage yield loss caused by plant diseases, without distinguishing between native and non-native diseases, at 7% in wheat 7% in barley and 9% in potatoes, after control measures had been undertaken. Using the same cropping areas, and percentage of non-native fungi as above, and adjusting the price obtained for crops to account for the increased production levels, a cost of yield loss caused by non-native plant diseases is estimated at £281,903,000.

[32] http://www.fwi.co.uk/Articles/2010/03/03/120146/VIDEO-How-much-fungicide-can-you-afford-to-use.htm

Table 5.10 Cost of yield loss due to non-native plant pathogens

	England	**Scotland**	**Wales**	**GB**
All grains	£130,885,000	£21,910,000	£2,182,000	£154,977,000
Potato	£28,575,000	£7,812,000	£623,000	£37,010,000
Oilseeds	£3,324,000	£123,000	£18,000	£3,465,000
Sugar Beet	£9,614,000	-	-	£9,614,000
Peas & beans (fodder)	£555,000	£18,000	£4,000	£577,000
Commercial Vegetables	£47,641,000	£5,305,000	£188,000	£53,134,000
Plants and flowers	£4,004,000	£213,000	£43,000	£4,260,000
Hardy nursery stock	£6,939,000	£386,000	£386,000	£7,711,000
Fresh fruit (orchard and soft)	£7,019,000	£439,000	£3,697,000	£11,155,000
Total	£238,556,000	£36,206,000	£7,141,000	£281,903,000

5.3.3 Research

However there is considerable additional research work carried out on agricultural plant pathogens that is funded by government institutions as well as privately, in particular by the agrochemical companies.

The Scottish Crop Research Institute receives funding of approximately £15 million each year from government and commercial contracts[33]. This funds their four main science programmes and a further four themes, one of which focuses on plant pathogens, but no details were available as to spending on plant pathogens in particular. Rothamsted Research has spent £2.4 million over seven years on plant pathogen research (Knight and Turner 2009), which equates to approximately £343,000 per year. Again assuming that 40% is spent on non-native pathogen research, this gives an annual spend of £137,200 at Rothamsted. Knight and Turner (2009) estimate that this forms about 33%-40% of the total independent research effort on plant pathogens, and therefore annual spend at independent research institutes is estimated at £392,000 per year. However, there is also considerable spending on agricultural pathogens by commercial companies which is said to be substantial (Knight and Turner 2009). No data on this was available due to commercial confidences, but it is assumed that agrochemical companies spend at least three times as much on research, giving a total research spend on agricultural non-native pathogens of approximately £1,568,000 p.a.

[33] http://www.scri.ac.uk/aboutus/faqs

5.3.4 Total Costs

The total cost of non-native plant pathogens, excluding some research and biological control costs is estimated at £401,707,000 per annum, though this figure is very dependent of the percentage of pathogens that are considered to be non-native. This figure excludes the costs of general quarantine and surveillance measures undertaken against plant pathogens, and therefore does not truly present the total costs of plant pathogens to the economy. It was not possible to separate the costs of plant pathogens from other plant health issues and therefore these costs are only included in the quarantine and surveillance sector and not included here.

Table 5.11. Total costs of non-native fungi to British agriculture and horticulture.

	England	Scotland	Wales	GB
Control Costs	£102,510,000	£14,278,000	£1,448,000	£118,236,000
Yield Loss	£238,556,000	£36,206,000	£7,141,000	£281,903,000
Research	£862,000	£470,000	£236,000	£1,568,000
Total	**£341,928,000**	**£50,954,000**	**£8,825,000**	**£401,707,000**

5.4 Vertebrate pests

5.4.1 Deer

Damage caused by deer mainly consists of browsing damage and tends to be very localised, concentrated in fields adjacent to woodland. Farmers consider deer damage to be much lower than that caused by other mammal species (White *et al.* 2004), such as rabbits and foxes, and what damage there is, is primarily caused by native roe and red deer species. Muntjac (*Muntiacus* spp.), sika deer (*Cervus nippon*) and Chinese water deer (*Hydropotes inermis*) are thought to do relatively little damage, though in areas of high density, muntjac do cause damage to cereal crops, vegetables, soft fruit including berries, and garden plants. The damage is likely to still remain low due to their small size and inability to graze fully grown cereal crops, when deer could do most damage (White *et al.* 2004). Fallow deer are known to cause some damage to cereal crops, but this does vary on a regional basis, with most damage occurring in eastern and southwest England. They are also known to damage root crops and fruits, but on a much lower level.

Data about the economic damage caused by deer to agricultural crops is sparse, but in areas of high deer densities yield loss could range between 1-5% (White *et al.* 2004). Wilson *et al*. (2009) estimated damage to cereal crops in the south west of England to be so minimal as to be insignificant, and to amount to a 15% dry matter yield loss on grassland. However, this damage was caused by native red deer. The majority of farmers in lowland England estimate annual costs of less than £500 per annum on holdings of over 500 hectares (Scott and Palmer 2000). In 2003 the cost of damage was estimated at approximately £4.3 million (Wilson 2003), with £1 million each in east and southwest England. This estimate included the cost of damage caused by deer to cereal crops, grassland, root, fruit and vegetable crops. However the data in the 2003 report were based on costs of damage to cereal alone and extrapolated to other crop types, including vegetable and fruit crops, as no data were available of the costs of damage to other crop types. No current data on the amount of damage done by deer to horticultural crops were available to improve the estimate of £4.3 million. Therefore, if it is assumed that the damage caused by non-native deer is in proportion to their percentage of the total deer population in England (66% of c. 304,600 deer), Scotland (8% of c. 543,500 deer) and Wales (68% of c. 10,251 deer) (A Ward pers. comm.), then agricultural damage can be estimated at £1,473,838 at today's prices (England £1,184,498, Wales £41,339, Scotland £248,001).

As deer have no natural enemies in Great Britain, population numbers are managed by culling. Non-native deer make up approximately 29% of the total deer population, out of a total estimated population of c. 858,351 (A Ward pers. comm.). Given this population and the variability of deer populations throughout the country with high concentrations in the east and south-west of England in particular (White *et al.* 2004) it is assumed that culling would still take place even if there were no non-native deer present. An estimated 350,000 deer are culled annually in the UK (Anon. 2009) and the cost of culling per animal has been estimated at £105 (£121 today). Therefore, assuming that the proportion of native and non-native deer that are culled is the same as their proportion of the entire deer population in each country, then culling costs are £9,897,361 in England, £2,072,229 in Scotland and £345,421 in Wales, giving a total of £12,315,011. As the main reasons for culling deer appear to be due to their impact on agriculture and forestry, 47% of this cost is attributed to agriculture, providing an annual culling cost of £5,788,055.

Total costs to agriculture of deer are therefore estimated at £7,261,893, (England £5,836,258, Scotland £1,221,949, Wales £203,686)

5.4.2 Rabbit

The European rabbit (*Oryctolagus cuniculus*) causes widespread damage to a range of agricultural crops, both at their growing stage and at the end marketable product. Their primary impact is on grasslands and cereals resulting in major damage to both the growth and yield of these crops (Rural Development Service Wildlife Management Team 2001). Winter wheat, barley and oats are the most vulnerable crops. Rye and triticale suffer smaller losses and spring barley appears to be the least susceptible to rabbit damage (Natural England 2007). There is less damage to grassland and pasture than cereals and high value crops. In addition to grazing damage, the quality of pasture can be further reduced by burrowing, which can lead to the establishment of problematic weeds such as nettles, thistles and ragwort (Natural England 2007). The current rabbit population in Britain is estimated at 40 million (Smith *et al*. 2007), and is increasing at approximately 2% per annum (Rural Development Service Wildlife Management Team 2001).

Studies into the effect of rabbit grazing on yields have indicated losses of £3.40 per rabbit at 1998 prices on grass used for silage (Dendy *et al.* 2003). Winter wheat yield losses are about 1% per rabbit per hectare at densities of up to 40 per ha, which represents a loss of £7.50 per rabbit (McKillop *et al.* 1997) and spring barley, £2.00 per rabbit (Dendy *et al.* 2005). Therefore, it can be estimated that at today's prices the cost per rabbit on grass, winter wheat and spring barley crops is £4.48, £10.23 and £2.72, respectively. These figures were used to extrapolate the cost of rabbits to agriculture by multiplying the number of rabbits on each crop by the individual cost of a rabbit. The cost used for winter wheat (£10.23) was assumed for winter barley and oats. A value for rye, triticale, oil seed rape, linseed and sugar beet crops was taken to be an average of the highest and lowest costs per rabbit, £4.75 per rabbit. In addition, rabbits are known to feed on vegetable crops and hardy nursery crops, so an average of known costs of rabbit on all crops was used to give a cost of £5.48 per rabbit.

An array of opposing rabbit densities for the three countries and on individual crops are given in the literature and it was not possible to obtain a definitive answer as to the density per crop. Therefore, these calculations assume that rabbit population densities are consistent on all crops and between all countries and regions. In addition, the estimate of yield loss may be overestimated as all rabbits were assumed to graze agricultural land and no reduction in rabbit numbers were made for those animals that inhabit other areas, such as recreational grassland, archaeological sites and golf courses.

Using the figures for yield loss per rabbit per hectare on different crops/ groups of crops from studies, and the area of each crop under cultivation (Garthwaite *et al.* 2007), the total damage cost for rabbits in Britain was estimated at £183,277,000 p.a. (Table 5.12).

Table 5.12. The estimated annual yield loss due to rabbit damage in Great Britain.

	England	**Wales**	**Scotland**	**GB**
Grass crops	£47,766,000	£14,032,000	£49,292,000	£111,090,000
Spring barley crops	£1,578,000	£79,000	£1,432,000	£3,089,000
Outdoor vegetable crops	£6,000	£154,000	£1,387,000	£1,547,000
Wheat, oats & barley	£51,927,000	£646,000	£4,301,000	£56,874,000
Rye, triticale, OSR, linseed, sugar beet	£9,962,000	£40,000	£546,000	£10,548,000
Hardy nursery crops	£91,000	£5,000	£5,000	£101,000
Protected (edible & ornamental) crops	£25,000	£1,000	£2,000	£28,000
Total	£111,355,000	£14,957,000	£56,965,000	£183,277,000

Farmers and land managers control the rabbit population in order to reduce the population numbers to an economically acceptable level. There are numerous control options including traps and fencing, gassing, shooting, ferreting and repellents, all with varying degrees of success and costs. The most effective form of control is gassing supplemented by habitat management (Rural Development Service Wildlife Management Team 2001).

The total cost of rabbit control in Great Britain was previously estimated at approximately £5 million per annum in 2007 (Smith *et al.* 2007). At today's prices, this equates to £5,200,000 p.a. However, this cost relates to land under forestry, as well as agriculture and horticulture, and so was reduced in line with the land area under each land use, to give a total control cost for agriculture and horticulture of £4,344,000 per annum (England £2,322,000, Wales £424,000 and Scotland £1,598,000). Table 5.13 summarizes the total costs of rabbits to British agriculture.

Table 5.13. The estimated annual cost of rabbits to agriculture in Great Britain.

	England	**Wales**	**Scotland**	**GB**
Yield loss	£111,355,000	£14,957,000	£56,965,000	£183,277,000
Management costs	£2,322,000	£424,000	£1,598,000	£4,344,000
Total Cost	£113,677,000	£15,381,000	£58,563,000	£187,621,000

5.4.3 Grey Squirrel

Damage costs of grey squirrels (*Sciurus carolinensis*) are difficult to estimate, because the data about damage are scarce. In addition, no records are currently kept of the numbers culled each year or the impact the culling has on population dynamics (Dr. Shuttleworth, pers. comm.). While no accurate population estimates exist, various sources have suggested that the current population is between 2 million and 3.3 million. Squirrels live in areas of deciduous and mixed forests, parks and gardens and feed on fruits, nuts, tree shoots, flowers and cereals. The impact could be significant to the agricultural sector, particularly in market gardens, orchards and arable crops if they are located favourably for grey squirrel habitats, and their other food sources are in short supply (Gurnell and Hare, 2008). However, a study in Italy, where grey squirrel are a recent INNS, concluded that there was very little damage to agricultural crops (Signorile and Evans 2007). Most damage was done to maize crops, but even then less than 1% of fields showed any sign of damage. The National Farmers' Union had no data concerning squirrel damage to farms. It therefore appears that squirrel damage to crops is not considered a significant issue in this country. There may be damage to farm buildings however, which is considered with general pest control costs in the infrastructure chapter.

5.4.4 Rats

The Norway or brown rat (*Rattus norvegicus*) is the main rural rat found in Britain. A study reported that 70% of a tonne of wheat was spoilt by 10 to 26 rats during a 12 to 28 week period, although only 4.4% had been eaten (Buckle 2007). On farms, damage to the electrical wiring of vehicles and equipment is a common cause of breakdown and the need for expensive repairs with rats said to cause 50% of electrical fires (Richards 1989). Diseases carried by rats have an impact on livestock milk yields and fertility. Proofing of buildings, especially grain stores and food warehouses, to prevent rodent ingress is well documented (Jensen, 1979) and a Fera report estimated associated costs of repairs and maintenance alone in the region of £100,000 to £1 million per year (Fera, undated). In 2007, Buckle estimated the cost of damage caused by rats to the UK farming industry at £21 million per annum. This included costs due to consumed and spoilt stored crops and animal feed, damage due to electrical fires as well as some crop damage while still in the field. Therefore, adjusting the 2007 figure to today's prices, costs are estimated to amount to £10,915,000 in England, £4,366,000 in Wales and £6,549,000 in Scotland, giving a total of £21,830,000 per annum.

5.4.5 Mink

Considerable control efforts are undertaken to protect poultry flocks from predators including mink (*Neovison vison*). However the majority of these costs are due to predation from native species such as fox and therefore, only costs associated with loss of poultry due to mink kills are included here. The introduction of mink in Lewis and Harris is known to have reduced the number of crofts keeping poultry from approximately 90% of 4,000 crofts to less than 10%. The average flock size was 10 birds, and therefore net annual cost to two islands was estimated at £586,000 (MacDonald *et al.* 2000) or £739,260 today. Mink are also known to predate on free-range poultry stock, including chicken and game birds. Data on the number of free-range poultry farms with more than 50 birds, and the number of birds are available[34], but no data on the number of mink attacks could be established. Although there is anecdotal evidence that one mink can kill up to 100 birds, again no firm data were available to confirm this. Dunstone (2000) considered that the economic loss due to mink predating on domestic poultry was negligible, though acknowledges that those who experience the loss are unlikely to agree with this assessment. However, if it is assumed that 1,000 premises throughout England, Scotland and Wales are predated each year, and that each attack kills 10 birds, then 10,000 birds may be killed each year. Some of the killed poultry may not be eaten by mink, but it will still not be possible to sell the killed poultry due to the damage caused by the mink. We assumed that 2/3^{rds} of these birds were chicken and ducks and 1/3rd were turkey and geese, that chicken and ducks have the same live weight at slaughter (2.46 kg[35]), as do turkey and geese (12.24 kg) and that the live weight to carcass weight ratio for chicken and ducks is 0.73[36] and for turkey and geese it is 0.8. Using an average carcass weight price of £1.50[37] for chicken and ducks and £3.76 for turkey and geese, a value of chicken and ducks predated by mink was calculated at £17,800 and turkey and geese at £121,474. This provided a total cost of £139,294. Data concerning the number of free-range poultry farms also indicates their distribution, with the highest densities found in England. Therefore this cost is divided between England (£77,506), Scotland (£37,859) and Wales (£23,929). Once the cost of lost poultry production in the Western Isles is included the total cost to Scotland is therefore £111,785.

Mink are also a threat to fish farms (MacDonald *et al.* 2000, White *et al*. 2000) and they are known to take small fish, in particular smolts. Smolts are particularly vulnerable as they are still small enough to be predated by mink, and are generally the smallest stage of fish to be

[34] http://www.defra.gov.uk/foodfarm/farmanimal/diseases/vetsurveillance/poultry/
[35] https://statistics.defra.gov.uk/esg/statnot/ppntc.pdf
[36] http://www.oecd.org/dataoecd/35/1/32366025.htm
[37] https://statistics.defra.gov.uk/esg/publications/auk/2008/AUK2008CHAPTER5_AUK.pdf

reared in sea cages. Earlier growth stages are reared indoors (Areal and Roy 2009). There is a general belief that mink predation on fish farms has a serious economic impact on the fish farms, but there is very little data available on the numbers of incidents, or the costs incurred. One reported incident in the Western Isles stated that mink caused the release of 14,500 smolts from one farm, costing £11,600 at the time (Moore *et al.* 2000). However, no further evidence of the specific economic cost caused by mink predation on fish farms could be discovered. Therefore, no annual cost has been added to this estimate of the cost of mink and the figure presented here is an underestimate of the true situation.

5.4.6 Geese and Swans

There are several species of non-native geese in Great Britain of which Canada geese (*Branta canadensis*), Egyptian geese (*Alopochen aegyptiaca*) and barnacle geese (*Branta leucopsis*) have the highest population numbers[38]. Barnacle geese are both migratory (over-wintering in Great Britain) as well as having a resident population from escaped and released birds, which can be considered to be non-native. Greylag geese (*Anser anser*) are native to Great Britain, with a resident and a winter migratory population in Scotland, and a re-established population in southern and eastern England. Mute swans (*Cygnus olor*) were introduced to Great Britain and are included here with Canada, Egyptian and barnacle geese.

Geese damage crops such as cereals, oilseed rape, root crops and spring pastures through grazing (Parrot and Watola 2007). Flocks of geese have a detrimental effect on farming through competition with livestock on grassland and trampling vegetation, compacting the soil creating a ‘hard pan’ that prevents new growth (Conover 1991), therefore reducing carrying capacity on pasture land. In addition, they feed in stubble fields, on roots crops and on newly sprouted winter cereals (Allan *et al.* 1995), which can result in significant yield losses. For example, Simpson (1991) cites instances of yield losses in the UK on winter cereals continuously grazed by Canada geese at 20%. In the EU, Canada geese cause yield losses on cereals between 0%-56% and on grass between 0%-40%. An annual loss to individual farmers has been estimated as up to £402 per hectare in 1992 (Wetlands International 2005). A problem in using figures such as these in calculating the total cost damage by geese is, however, that individual farmers are disproportionately affected by the geese, due to their high degree of gregariousness and a tendency to repeatedly utilise individual fields (Kirby *et al.* 1998). In addition the level of damage is dependent on the timing of grazing of the crop. Earlier grazing, when the crop is young causes less yield loss

[38] http://www.wwt.org.uk/research/monitoring/species/non_native.asp

than grazing at later stages of crop growth. Therefore a weighted average of damage per goose has been estimated at £12.74 (MacMillan *et al.* 2004) with a further estimate of £13.30 per goose. An average of these two prices, inflated to today's prices (£14.90) is therefore used as a damage cost for all geese species, as no specific damage costs could be found for barnacle geese.

The UK population of Canada geese was estimated as 88,866 in 2000 (Austin *et al.* 2007). The distribution of Canada geese is widespread in England but localised in Scotland and Wales (British Association for Shooting & Conservation 2009). In Scotland, Canada geese do not cause a significant impact on agricultural production (Cope *et al.* 2006). Canada geese's limited distribution in Wales and lack of documentation in the literature also implies they also have a limited impact on agriculture. It can therefore be assumed most agricultural damage and cost occurs in England. Therefore with a population of 88,866 and a cost of damage of £14.90 per goose, a cost of £1,324,103 is attributed to England.

Population numbers of Egyptian geese are estimated at 700 breeding pairs[39] (1400 geese) and 1,011 resident barnacle geese, all in England. Therefore, with the estimated total number of geese at 2,411, and using the same damage cost of £14.90 per goose, the additional damage cost caused by geese to England is £35,924.

Mute swan population numbers are estimated at 31,700[40] with the population spread between Scotland and England and a smaller number found in Wales. Mute swans are mainly found on inland waters, but are also found on agricultural land, especially in the winter months when an estimated 3% of the population will graze on arable crops (Rees *et al.* 1997). They are found mainly on oilseed rape (Rees *et al.* 1997, Parrot and Watola 2007) and yield loss on these fields due to the presence of mute swans has been estimated to vary between 18% and 24% (Parrot and Watola 2007). At a price of £813 ha^{-1} (based on average yield and crop prices per tonne (Nix 2009)) for oilseed rape, this is equivalent to a loss of £146-£195 ha^{-1}. However only three out of nine fields included in the study experienced significant damage and with field sizes of 7.2 ha, 10.0 ha and 10.2 ha and damage of 18%, 23% and 24% respectively this equates to £1021, £1870 and £1989 of damage caused by mute swan. This damage level was caused by large flock sizes of 51, 62 and 67 individuals respectively and therefore the cost of damage per swan can be estimated at £20.02, £30.16 and £29.69, an average of £26.62 damage per swan. Therefore based on

[39] http://www.wwt.org.uk/research/monitoring/species/non_native.asp
[40] http://www.wwt.org.uk/research/monitoring/species/2008/mute_latest2008.asp

3% of the mute swan population grazing on arable fields in winter, (Parrot and Watola 2007), an estimated 951 swans cause £25,316 of damage per annum (£10,126 England, £10,126 Scotland and £5,064 Wales).

In addition to these damage costs, control measures are undertaken to prevent both geese and swans grazing. A common method is through human harassment and assuming as for swans that geese only graze on arable fields in the winter months (November to February), then control is only needed for a total of 126 days per year. Assuming that harassment is undertaken every day for two hours per day, at a cost of £6.40 per hour (Nix 2009) then the cost of harassment can be estimated at £1613 per annum for each location. Parrott and Watola (2007) reported that the three fields in which grazing damage was experienced due to swans were grazed by flock of over 50 birds. If as with mute swans, only 3% of Canada geese and barnacle geese graze arable fields, then an estimated 2,666 Canada geese and 72 barnacle geese cause damage. This equates to 53 flocks of Canada geese (at 50 birds per flock), 1 barnacle geese flock and 19 mute swan flocks. Therefore assuming as before that only flocks this size cause damage that it is worth trying to control then control costs can be estimated at £85,489 for Canada geese, £1,613 for barnacle geese and £30,647 for mute swans. As with damage costs, all the control costs for Canada geese and barnacle geese are attributed to England, while costs for mute swan are proportion based on estimated swan populations and hectares of crop grown, giving a cost of £12,259 England, £12,259 Scotland and £6,129 Wales.

This gives a total damage cost of all four species at £1,503,092 (£1,469,514 England, £22,385 Scotland and £11,193 Wales).

5.4.7 Parakeets

Fletcher & Askew (2007) reviewed incidences of damage to agriculture in England by the rose ringed parakeet (*Psittacula krameri*) and found conflicts occurring in the urban/rural fringe areas for orchard growers of apples, plums and pears. Extensive damage was also reported in vineyards and grow-your-own apple orchards in England with loss of crop estimated at £5000 and additional costs (e.g. bird scarers) of £2,000 per year. Despite isolated and localised incidents causing significant costs to some growers, there are relatively few reports of damage to crops by either monk parakeets (*Myiopsitta monachus*) or rose ringed parakeets. Parakeets could transmit diseases to poultry flocks, but no evidence was found, which suggests that this is currently not an issue. Due to the limited number of reports of damage by these birds, the cost to agriculture is estimated to be £10,000 per year in total for both parakeet species, through mainly caused by rose ringed parakeets. This cost is entirely attributed to England as there are no populations of parakeets established in Wales or Scotland.

5.5 Total Costs of INNS to Agriculture and Horticulture

The total cost to British agriculture as a result of INNS is estimated at £1,066,692,000 (Table 5.14).

Table 5.14. Total estimated annual costs of non-native species to agriculture.

	England	Wales	Scotland	GB
Herbicides	£78,505,000	£1,229,000	£10,920,000	£90,654,000
Yield loss - weeds	£89,731,000	£13,852,000	£1,134,000	£104,717,000
Pesticides	£22,871,000	£284,000	£2,885,000	£26,040,000
Yield loss - invertebrates	£105,642,000	£18,222,000	£5,477,000	£129,341,000
Sprayer water	£672,000	£9,000	£77,000	£758,000
Storage pests	£15,412,000	£86,000	£2,145,000	£17,643,000
Nematodes	£38,605,000	£841,000	£10,554,000	£50,000,000
Varroa mite	£13,837,000	£6,758,000	£6,524,000	£27,119,000
Plant pathogens	£341,928,000	£8,825,000	£50,954,000	£401,707,000
Deer	£5,836,000	£1,222,000	£204,000	£7,262,000
Rabbit	£113,677,000	£15,381,000	£58,563,000	£187,621,000
Rats	£10,915,000	£4,366,000	£6,549,000	£21,830,000
Mink	£78,000	£24,000	£112,000	£214,000
Geese & Swans	£1,470,000	£11,000	£22,000	£1,503,000
Parakeets	£10,000	-	-	£10,000
Total	**£839,189,000**	**£71,110,000**	**£156,120,000**	**£1,066,419,000**

References

Allan JR, Kirby JS, Feare CJ (1995). The biology of Canada geese *Branta canadensis* in relation to the management of feral populations. Wildlife Biology 1: 129-143

Ainsworth GC (1969) History of Plant Pathology in Great Britain. Annual Review of Phytopathology, 7, 13-27.

Anon. (2009). Wild deer. POSTnote 325. http://www.parliament.uk/documents/ upload/postpn325.pdf

Areal FJ and Roy SS (2009) A management decision tool for mink (Mustela vison) control in the Western Isles. International Journal of Ecodynamics 40(1):16-31

Aston D, Carreck N, Davis I, Lovett T, Metcalf P (2009) Honey Bee Health Research Concepts , British Beekeepers' Association

Austin GE, Rehfisch MM, Allan JR, Holloway SJ (2007). Population size and differential population growth of introduced Greater Canada Geese (*Branta canadensis*) and re-established Greylag Geese (*Anser anser*) across habitats in Great Britain in the year 2000. Bird Study 54: 343-352

Bayer CropScience (2006) Expert Guide: Ryegrass Management in Cereals. Bayer CropScience Ltd

Boag B, Jones HD and Neilson R (1997) The spread of the New Zealand flatworm (*Artioposthia triangulata*) within Great Britain. European Journal of Soil Biology 33: 53-56

Bond, Davies and Turner (2007). The biology and non-chemical control of Common field-speedwell (Veronica persica Poiret.) – Review for Organic Weed Management project

British Association for Shooting & Conservation (2009). Canada Geese, a guide to legal control measures in the UK (Information Sheet)

Buckle A (2007). Rat control 1: Problems caused on farms, The Campaign for Responsible Rodenticide Use (CRRU), Farmers Weekly. http://www.fwi.co.uk/academy/article/106448/rat-control-2-problems-caused-on-farms.html

Cannon RJC, Baker RHA, Taylor MC, Moore JP (1999) A review of the status of the New Zealand flatworm in the UK. Annals of Applied Biology 135 (3): 597–614

Capinera JL (2001) Handbook of Vegetable Pests. Academic Press

Carlile WR (1995) Control of crop diseases. Cambridge University Press, Cambridge.

Clayton R, Storey M, Parket B, Ballingall M and Davies K (2008) Impact of reduced pesticide availability on control of potato cyst nematodes and weeds in potato crops. Potato Council

Conover MR (1991). Herbivory by Canada geese: diet selection and effect on lawns. Ecological Applications 1: 231-236

Cope DR, Vickery JA, Rowcliffe JM (2006). From conflict to coexistence: a case study of geese and agriculture in Scotland. In: Boere GC, Galbraith CA, Stroud DA (eds.). Water birds around the World. The Stationery Office, Edinburgh, UK. pp. 791

Dendy J, McKillop G, Fox S, Western G, Langton S (2003). The development of a model to assess the effects of rabbit grazing on grass. Annals of Applied Biology 142: 317-322

Dendy J, Mckillop G, Fox S, Western G, Langton S (2005). A field trial to assess the effects of rabbit grazing on spring barley. Annals of Applied Biology 145: 77-80

Dent D (2000) Insect Pest Management. CABI Publishing

Desprez-Loustau ML, Robin C, Buée M, Courtecuisee R, Garbaye J, Suffert F, Sache I and Rizzo DM (2007). The fungal dimension of biological invasions. Trends in Ecology & Evolution. 22, (9) 472-480.

Duck N, Evola S (1997) Use of Transgenes to Increase Host Plant Resistance to Insects: Opportunities and Challenges, in Advances in Insect Control: The Role of Transgenic Plants. Taylor & Francis Ltd.

Dunstone, N. (2000) Submission on Mink to the Hunting with Dogs Inquiry. http://www.huntinginquiry.gov.uk/evidence/mink-dunstone.htm

Ferguson G, Murphy G (2002). Glasshouse Crop Pest Management (Insects and Mites). In: Pimentel P (ed.). Encyclopaedia of Pest Management. Taylor & Francis Group, London

Fletcher M and Askew N (2007) Review of the Status, Ecology and Likely Future Spread of Parakeets in England. York: Central Science Laboratory.

Frank T (1998). Slug damage and numbers of the slug pests, *Arion lusitanicus* and *Deroceras reticulatum*, in oilseed rape grown beside sown wildflower strips. Agriculture, Ecosystems & Environment 67: 67-78

Garthwaite DG, Thomas MR (2005). Pesticide usage Survey: Hardy Nursery Stock in Great Britain

Garthwaite DG, Anderson HM, Thomas MR (2005a). Outdoor Bulbs and Flowers in Great Britain 2005. Pesticide Usage Survey 212

Garthwaite DG, Thomas MR, Anderson HM, Battersby A (2005b). Grassland & Fodder Crops in Great Britain 2005. Pesticide Usage Survey 210

Garthwaite DG, Thomas MR, Heywood E (2006). Soft Fruit in Great Britain 2006. Pesticide Usage Survey 214

Garthwaite DG, Thomas MR, Heywood E, Battersby A, Parrish G, Smith L (2007). Outdoor Vegetable Crops in Great Britain 2007. Pesticide Usage Survey 219

Garthwaite DG, Thomas MR, Parrish G, Smith L (2007). Protected Crops (Edible & Ornamental) in Great Britain 2007. Pesticide Usage Survey 220. http://www.agric.wa.gov.au/objtwr/imported_assets/content/pw/weed/major/wild%20oats.pdf

Garthwaite DG, Thomas MR, Parrish G, Smith L and Barker I (2008) Pesticide usage survey report 224- Arable Crops in Great Britain. Defra & Scottish Executive environment and rural affairs department.

Grünwald NJ and Flier WG (2005) The biology of Phytophthora infestans at its centre of origin. Annual Review of Phytopathology, 43,171–190.

Gurnell J and Hare EJ (2008) Rodents, Order Rodentia. In The Mammals of the British Isles: Handbook 4th Edition. Yalden, D.W. (Ed.) pp 55-199.

Haydock PPJ, and Evans K (1998) Management of potato cyst nematodes in the UK: an integrated approach: Outlook on Agriculture 27: 253-260 in Kerry B, Barker A and Evans K (2003) Investigation of potato cyst nematode control. Rothamsted Research, Harpenden, Herts.

Hendrikx P, Chauzat MP, Debin M, Neuman P, Fries I, Ritter W, Brown M, Mutinelli F, Le Conte Y, Gregorc A (2009) Bee Mortality and Bee Surveillance in Europe, Scientific Report submitted to EFSA

Hill M, Baker R, Broad G, Chandler PJ, Copp GH, Ellis J, Jones D, Hoyland C, Laing I, Longshaw M, Moore N, Parrott D, Pearman D, Preston C, Smith RM and Waters R (2005) Audit of non-native species in England. English Nature Research Reports, Number 662.

Jensen AG (1979) Proofing buildings against rats, mice and other pests. ADAS Technical Bulletin, Ministry of Agriculture, Fisheries and Food. London. 33 pp.

Jones DR and Baker RHA (2007) Introduction of non-native plant pathogens to Great Britain, 1970-2004. Plant Pathology, 56, 891-910.

Kirby JS, Owen M, Rowcliffe JM (1998). Geese and their interactions with agriculture and the environment. The Wildfowl & Wetlands Trust, UK

Knight B and Turner R (2009) Report on Economic, Financial and Market Studies to Demonstrate the Economic Value of Research Carried out by Rothamsted Research. Innovation Management

Lutman P, Storkey J, Martin H, Holland J (2009) Abundance of weeds in arable fields in southern England in 2007/08. Aspects of Applied Biology 91

Macdonald DW, Tattersall FH, Johnson PJ, Carbone C, Reynolds JC, Langbein J, Rushton SP, Shirley MDF (2000). Management and Control of Populations of Foxes, Deer, Hares and Mink in England and Wales, and the Impact of Hunting with Dogs. http://www.huntinginquiry.gov.uk/mainsections/research/macdonaldrep5and6.pdf

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M and Bazzaz FA (2000) Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10: 689–710

MacMillan D, Phillip S (2008). Consumptive and non-consumptive values of wild mammals. Britain Mammal Review 38: 189-204

MacMillan D, Hanley N, Daw M (2004) Costs and benefits of wild goose conservation in Scotland Biological Conservation 119 (4): 475-485

Manchester S and Bullock JM (2000) The impacts of non-native species on UK biodiversity and the effectiveness of control. Journal of Applied Ecology, 37, 845-864.

May M J, (2003) Economic consequences for UK farmers of growing GM herbicide tolerant sugar beet Annals of Applied Biology 142: 41-48

McKillop G, Dendy J, Fox S (1997). The costs of rabbit damage to crops. Abstract 48. First European Vertebrate Pest Management Conference

Moore NP, Robertson PA and Aegerter JN (2000) Feasibility Study into the Options for Management of Mink in the Western Isles, Report to Scottish Natural Heritage.

Myrfyn O (1990). The damage-conservation interface illustrated by geese. Ibis 132: 238-252

Nix J (2009) The John Nix Farm Management Pocketbook, 40th Edition, Imperial College, London

Oerke EC, Dehne HW Schonbeck F and Weber A (1994) Crop production and crop protection – estimated losses in major food and cash crops. Elsevier 808 pp

Parrott D and Watola G (2007) Variation in yield loss of oilseed rape due to grazing by mute swans *Cygnus olor*. Crop Protection 26: 1794-1800

Peters NCB, Froud-Williams RJ, Orson JH (1993). The rise of barren brome Bromus sterilis in UK cereal crops. Proceedings Brighton Crop Protection Conference – Weeds, Brighton. pp. 773-780

Rees EC, Kirby JS and Gilburn A (1997) Site selection by swans wintering in Britain and Ireland: the importance of habitat and geographic location. Ibis 139: 337-352

Richards CGJ (1989) The pest status of rodents in the United Kingdom. In: Putman RJ, ed., Mammals as pests. London: Chapman & Hall Ltd.

Rossman AY (2008) The impact of invasive fungi on agricultural ecosystems. Biological Invasions, 92, 1376-1386.

Rural Development Service Wildlife Management Team (2001). Rabbits. Defra Vertebrate Wildlife Management

Salisbury E (1962). The biology of garden weeds Part II Journal of the Royal Horticultural society 87: 458-470 & 497-508

Schroeder D, Mueller-Schaerer H, Stinson CAS (1993). A European weed survey in 10 major crop systems to identify targets for biological control. Weed Research 33: 449-458

Scott D, Palmer SCF (2000). Damage by Deer to Agriculture and Forestry: Report to Deer Commission for Scotland C01396

Signorile AL, Evans J (2007). Damage caused by the American grey squirrel (*Sciurus* carolinensis) to agricultural crops, poplar plantations and semi-natural woodland in Piedmont, Italy. Forestry 80: 89-98

Simpson (1991) Canada Geese Problems and Management Needs. pp 21-24. British Association for Shooting and Conservation

Smith GC, Prickett AJ, Cowan DP (2007). Costs and benefits of rabbit control options at the local level; Advances in vertebrate pest management. Proceedings of the 5th European Vertebrate Pest Management Conference, Budapest, Hungary, 5-8 September 2005. International Journal of Pest Management 53: 317-321

Speiser B, Glen D, Piggott D, Ester A, Davies K, Castillejo J, Coupland J (2001). Slug Damage and Control of Slugs in Horticultural Crops. Slugs Brochure

Tatchell GM (1989) An estimate of potential economic losses to some crops due to aphids in Britain. Crop Protection 8: 25-29

Wetlands International (2005). Guidelines on reducing crop damage, damage to fisheries, bird strikes and other forms of conflict between water birds and human activities AEWA Conservation Guidelines No. 8

White, P, Baker P, Newton Cross G, Smart J, Moberly R, McLaren G, Ansell R, Harris S (2000). Report on contract 5, Management of the population of foxes, deer, hares and mink and the impact of hunting with dogs; Report on Contract 6, Methods of controlling foxes, deer, hare and mink. Committee of Inquiry into Hunting with Dogs, Her Majesty's Government, London

White PCL, Smart JCR, Böhm M, Langbein J, Ward AI (2004). Economic Impacts of Wild Deer in the East of England. Woodland for Life. http://www.woodlandforlife.net/wfl-woodbank/DisplayArticle.asp?ID=2333

Wilkin DR (2003) An alternative approach to assessing pest problems in stored grain. pp 464-467. In Credland PF, Armitage DM, Bell CH, Cogan PM and Highley E (Eds) Proceedings of the 8th International Working conference on Stored Product Protection, York July 2002. CABI Publishing, Wallingford, UK

Wilson CJ (2003). A Preliminary Estimate of the Cost of Damage Caused by Deer to Agriculture in England

Wilson C, Britton A, Symes R (2009). An Assessment of Agricultural Damage Caused by Red Deer (*Cervus elaphus* L.) and Fallow Deer (*Dama dama* L.) in Southwest England. Wildlife Biology in Practice 2: 104-114

6 Forestry

6.1 Rabbit

Considerable damage is done to forests by rabbits, deer and insect pests. Rabbits are a particular issue with young trees where bark damage can result in tree death. However, browsing is the most common form of tree damage, especially on young trees up to approximately 50 cm tall. Control methods include the use of barriers, fencing and tree guards, clearing rabbits from fenced areas, reducing suitable habitats for rabbits to shelter in as well as killing them.

Rabbit fencing is a cost effective method of damage prevention for conifer planting and the Forestry Commission have estimated they spent £40,000 on fencing material in 2006/07 (S. Bailey, pers. comm.), which consists of approximately one third of the cost of fencing. Therefore, fencing can be estimated to cost £130,000 per year (adjusted for inflation to today's prices). In addition, annual costs for fence maintenance and other control measures, such as tree shelters, habitat work and replanting of damaged trees, should be included. This results in an estimated annual spend of £250,000 to £500,000 per year on rabbit control measures by the Forestry Commission. Further control measures will be undertaken by private woodland owners and adjoining landowners and it is estimated these control costs may be in the range of £5 million to £10 million per year (S. Bailey, pers. comm.). Therefore, based on the amount of woodland cover in each country[41], the estimated cost of rabbit control for forestry is £8 million annually, which can be attributed at £3.28 million in England £3.92 million in Scotland, and £800,000 in Wales.

There is limited data to indicate the reduction in value of timber due to rabbit damage. No data could be found to suggest what acreage of forests were damaged by rabbits, but given the spending on control measures, and assuming that they are not 100% effective, an estimated 5% of newly planted trees are assumed to be damaged by rabbit grazing in the first five years of growth. A further 1% of these trees are assumed to be damaged in the subsequent 10 years, as rabbits continue to cause damage to saplings for 10-20 years after planting (R. Trout, pers. comm.). The level of damage caused can reduce the timber value from the highest grade, used for furniture, to the lowest grade that is only suitable for firewood. Prices vary considerably for broadleaved and coniferous timber and a price of £45m^{-3} was assumed for high grade broadleaved timber, £6m^{-3} for the lowest grade

[41] http://www.forestry.gov.uk/pdf/area09.pdf/$FILE/area09.pdf

broadleaved timber, £10m^{-3} for high quality and £3m^{-3} for low quality coniferous timber (Nix 2009). Therefore, based on the assumption that the rabbits cause sufficient damage to reduce the timber quality and therefore the price from the highest to lowest grade, and on Forestry Commission statistics for the areas of new trees planted[42], damage costs can be estimated at £33,979,000 for Scotland, £21,072,000 for England and £6,966,000 for Wales, a total of £62,017,000.

Therefore, it is estimated that rabbit cost £70,017,000 annually to forestry (£37,899,000 Scotland, £24,352,000 England and £7,766,000 Wales) in both control and damage costs.

6.2 Deer

Deer, both native and non-native, affect the forestry industry, mainly through browsing damage. Fallow (*Dama dama*), sika (*Cervus nippon*) and muntjac (*Muntiacus reevesi*) deer are considered here. Chinese water deer are not, because they rarely use woodland. Non-native deer are estimated to make up approximately 29% of the deer population in Britain (A Ward, pers. comm.), with fallow and muntjac deer having the largest non-native populations.

Browsing damage is known to vary between deer species, tree species, the season, as well as the availability of alternative browse (White *et al*. 2004). Damage costs to conifers from browsing have been estimated as the reduction in volume at harvest using Corsican pine as a species example. Damage is estimated as ranging from £37 - £190 (an average of £131 today) per hectare annually (White *et al*. 2004), based on the net present value of the amount of timber lost (i.e. a loss of one year's growth or a loss of five years' growth). Ward *et al.* (2004) have estimated the cost of browsing damage as a reduction in the net present value of 1 ha of Sitka spruce to £426 when over 55% of trees where damaged, and Gill *et al.* (2000) have estimated the reduction in income from a hectare of Sitka spruce to vary between £147 and £1,436 (an average of £195 today when adjusted for inflation and discounted over 55 years) dependent on the amount of damage done and the crop rotation period. An average damage price per hectare of £163 was therefore used. Muntjac deer are not considered to cause browsing damage to conifers, hence the distribution of only sika and fallow deer were compared with the distribution of new coniferous planting in one year to provide an area of 9,400 ha in Scotland, 1,700 ha in England and 1,400 ha in Wales where fallow and sika may browse and cause damage to conifers. In addition, it is assumed that only 25% of new plantations are damaged by non-native deer in Scotland, 40% in England and 5% in Wales, based on the numbers of fallow and sika deer in each country, the lack of

[42] http://www.forestry.gov.uk/pdf/area09.pdf/$FILE/area09.pdf

conifer browsing damage caused by muntjac and Chinese water deer and the fact that many plantations will be fenced. Therefore, using the average cost damage figure above and the area of new coniferous planting[43] then cost estimates of £383,050 for Scotland, £110,840 for England, and £11,410 for Wales are obtained giving an annual total of £505,300 for damage to new coniferous planting.

Deer also cause browsing damage to new broadleaved plantings, but there is very little data estimating the cost of browsing to broadleaved species. Therefore the same cost of £163 ha^{-1} used for conifers is used here. A damage rate of 25% of newly planted broadleaved trees is assumed for Scotland due to the number of fallow and sika deer and 40% for England, based on the populations of fallow deer and muntjac (which do less damage). A rate of 5% is assumed for Wales due to the relatively low muntjac and fallow populations. Therefore, based on the area of new and replanting of broadleaved trees (3,700 ha Scotland, 3,600 ha England, 900 ha Wales), the cost of deer browsing damage can be estimated at £150,775 for Scotland, £234,720 for England, and £7,335 for Wales annually, giving a total of £392,830 annually for damage to broadleaved planting.

Bark stripping by deer also causes damage to forestry plantations at varying levels dependent on the deer species, the species of tree and the age of the trees (Gill *et al.* 2000). It leaves the tree open to infection by pathogens as well as causing uneven wood growth, both which can affect the price of timber once the trees are felled. The only non-native deer species known to bark strip are fallow and sika, with no evidence to suggest that either muntjac or Chinese water deer damage trees in this way. Trees are vulnerable to bark stripping for a number of years, and therefore the cumulative damage has been estimated to vary between 0.7% for Sitka spruce to 41.5% for lodgepole pine (Gill *et al.* 2000). Other species suffer more moderate damage levels of 26% in Corsican pine (White *et al.* 2004) and 11.4 % in Norway spruce (Gill *et al*. 2000). Yield loss therefore varies as well, and can range from a net present value of £231 ha^{-1} (£264 today) for Corsican pine felled at 55 years (White *et al.* 2004) or anything from £176 ha^{-1} to £309 ha^{-1} for Sitka spruce (Gill *et al.* 2000). An average of prices is used giving a cost per hectare of £225. Again there are few yield loss estimates for broadleaved species and therefore the same damage estimates are used. Based on the distribution of fallow and sika deer and the distribution of new plantations and assuming that 25% of plantations in Scotland suffer damage, 40% in England and 5% in Wales, then the cost of damage due to bark stripping by deer is estimated at £1,239,750 (Scotland £736,875, England £477,000 and Wales £25,875).

[43] http://www.forestry.gov.uk/pdf/area09.pdf/$FILE/area09.pdf

In addition to damage, measures to protect new plantings are also partly attributable to non-native deer species. A cost of protecting new plantations from muntjac deer is estimated at £759 (£873 today) per hectare and £1,344 (£1,547) per hectare for sika and fallow deer, in addition to the cost for protection of new trees against rabbit and other grazers (White *et al.* 2004). Therefore, based on the area of new trees planted and the populations and distribution of native and non-native deer within each country (66% non-native in England, 8% in Scotland and 68% in Wales (A Ward pers. comm.)), using a cost of £1,547 per hectare to protect against the larger deer species, and assuming that all new plantations are protected, then costs can be estimated at £1,621,256 for Scotland, £5,411,406 for England and £2,419,508 for Wales. This gives a total cost of £9,452,170 protecting newly planted trees against non-native deer damage.

The costs of culling deer are discussed above (see section 5.4.1) and £5,788,055 is estimated as a cost to forestry, £4,651,760 in England, £973,948 in Scotland and £162,347 in Wales.

Total costs of non-native deer to forestry are therefore estimated at £17,748,556 (Table 6.1).

Table 6.1. The annual costs of non-native deer to the British forestry sector.

	England	Scotland	Wales	GB
Browsing	£345,560	£533,825	£18,745	£898,130
Bark stripping	£477,000	£736,875	£25,875	£1,239,750
Prevention	£5,411,406	£1,621,256	£2,419,508	£9,452,170
Culling	£4,651,760	£973,948	£162,347	£5,788,055
Total	£10,885,726	£3,865,904	£2,626,475	£17,378,105

6.3 Edible Dormouse

Edible dormice (*Glis glis)* have a very limited distribution in Britain, with a current estimated population size of approximately 10,000 individuals centred in the northern Chilterns. They are known to damage trees by ring barking and the Forestry Commission has estimated the cost of damage at approximately £25,000 per year on land managed by them, in addition to £170,000 - £400,000 worth of damage on privately-owned woodland, based on the assumption that approximately 50% of trees are affected. In addition to this tree damage, Forest Research and Forest Enterprise have spent approximately £61,000 on research, advice and information about edible dormouse, giving an estimated total cost of edible dormouse to forestry of £250,000 per year (entirely contributable to England).

6.4 Grey Squirrel

Grey squirrels are widespread through England and Wales and have a more limited distribution in Scotland. Grey squirrels cause damage to the timber industry through bark stripping (Mayle *et al.* 2004), which can lead to either a decrease in the quality of timber, or death of the tree. Trees between 10 and 40 years old are particularly vulnerable, especially those species with thin bark. Younger trees are not strong enough to take the weight of a squirrel. There have been no systematic estimates of the value of timber damage done by squirrels, though damage to conifers was estimated at £224,000 per year in 2002, £271.662 today (Mayle 2002), a cost of £3.40 per hectare of vulnerable conifers. Kenwood and Dutton (1996 in Huxley 2003) estimated the cost of fairly severe damage in a beech plantation at £1,700/ha over the crop rotation of 85 years. This gives an annual cost per hectare for the 30 year period when the trees are particularly vulnerable of £57/ha. The Forestry Commission has estimated that the damage done by grey squirrels is around £10 million per year, with 80% of that to private estates (Anon. 2006). This estimate is based on work by Broome and Johnson (2000 in Huxley 2003) and is based on beech, sycamore and oak trees considered vulnerable to damage, assumes a total crop loss due to damage and is again a cost at the end of the rotation. Therefore, if this cost is considered over a 30 year period, for the estimated 43,000 ha of at risk trees, this gives an annual cost per hectare of £7.75 of damage caused by squirrel to these broadleaved tree species. As this figure is based on a total loss of crop, rather than some value being retained in the crop, a more realistic estimate may be lower than this and a figure of £5 per hectare is therefore used. The National Inventory of Woodland and Trees (Smith and Gilbert 2003) provides the area of trees planted and therefore using the area of broadleaved trees planted over a 30 year period (82,628 ha), then the cost of squirrel damage to broadleaved trees can be estimated at £413,140 per annum. Total yield loss is therefore estimated at £684,802.

The cost of control depends on the method used (i.e. poison in grey squirrel-only areas, trapping or shooting elsewhere), the trapping intensity, personnel etc. (Huxley 2003). Recent control efforts using traps and poison have been estimated to cost £9-30 to remove 5 animals per hectare (Brenda Mayle, Forestry Commission, pers. comm.). One of the British pest control companies specializing in grey squirrel control, www.greysquirrelcontrol.co.uk, sold £60,000 worth of traps in the past two years (pers. comm.) and their spokesman suggested that although it is difficult to get a good figure for the value of the industry, it must cost millions per year. Calls to other squirrel control businesses confirmed this suggestion. Respondents to the questionnaire who manage land indicated that their current annual control expenditures are approximately £2 per ha, presumably in mixed habitats. If it is assumed that a variety of control methods are used, an average price of £15 per hectare can be used. Control measures will be undertaken where the crop is at risk, i.e. those areas where the trees are aged between 10 and 40 years, and therefore using planting areas from the National Inventory of Wood and Trees (2003) a total area of 721,669 ha may be subject to squirrel control measures. However, it is unlikely that control measures are undertaken in the entire area, and therefore the area subject to control is reduced by 50% to 360,835 ha. Control costs for forestry were therefore estimated at £5,412,518 per annum.

Total costs for squirrel to forestry can therefore be estimated at £6,097,320 annually, and based on the area of at risk woodland and the squirrel population in each country, it is estimated that 65% of all costs are incurred in England, 20% in Scotland and 15% in Wales (£3,963,259 England, £1,219,464 Scotland, and £914,598 Wales).

6.5 Rhododendron

Rhododendron (*Rhododendron ponticum*) is a woody evergreen that was introduced in the late 1700s and was widely planted as game cover and a garden ornamental. Other rhododendron species (*R. catawbiense* and *R. maximum*) are thought to have hybridised with *R. ponticum* and may have introduced characteristics, e.g. increased cold tolerance, that increase the invasiveness of *R. ponticum* (Milne and Abbott 2000), although it appears that *R. ponticum* is considered to be the key invasive species in Britain. The species is present in 1225 10 x 10 km hectads in Britain. The dense evergreen shrubs cause shadow that hinders native species and exude toxic phenolic compounds that inhibit the growth of surrounding vegetation. It is also a vector of *Phytophthora* spp., pathogens that can cause diseases, among others sudden oak death.

An in-depth study in Argyll and Bute was carried out in 2004, where the infestation of rhododendron was assessed and a detailed breakdown of associated costs and their likely increases over time was developed (Edwards & Taylor 2008). This study provides a useful model for estimating the infestation of rhododendron in Britain. Argyll and Bute covers 69,090 ha of which 4,654 ha are invaded by rhododendron (6.74%).

Through an extensive targeted questionnaire, Dehnen-Schmutz *et al*. (2004) received responses relating to 52,000 ha of rhododendron infestation, of which only 1,275 ha was subject to control (2.5%). This control effort cost £530,003 in 2004 (now £609,881 or £478/ha). The Forestry Commission stated that their spending varied between £202 ha^{-1} and £344 ha^{-1}, an average of £285 ha^{-1} on rhododendron control (S. Bailey, pers. comm.), but this is only an 80% contribution to costs, hence making the actual control cost £356 ha^{-1}.

Based on the 6.74% invasion level this gives an estimated distribution of 826,998 ha in Great Britain. If 2.5% of this area is controlled at an average cost of £417 ha^{-1}, then the current control effort against rhododendron is estimated at £8,621,454 p.a.

Considering the distribution of rhododendron and the considerable efforts underway in high profile sites in Wales and Scotland, it would seem fair to distribute these costs evenly between the three countries. Therefore costs are estimated at £2,873,818 each for England, Wales and Scotland.

6.6 Insects

There are a limited number of non-native insect pests that cause serious damage to forests in Britain (Marc Kenis, pers. comm.). The main species are the great spruce bark beetle (*Dendroctonus micans*) and the green spruce aphid (*Elatobium abietinum*) in particular. The great spruce bark beetle was first found in Britain in 1982. Movement restrictions were used to control spread of the beetle for many years, but recently the *Dendroctonus micans* Protected Zone has been removed, in part because of the fall in timber prices, but also because of the effective use of a biological control agent. The predator beetle *Rhizophagus grandis* has proven very cost-effective with the release of approximately 100 individuals of *R. grandis* per infested site reducing the population size of *D. micans* by 80%-90% and economic loss to less than 1%, usually 0.25% (Snowdon 2004). Propagation and release of *R. grandis* amounted to approximately £25,000 per year in 2003. However, the range of the great spruce bark beetle has spread further in recent years, and therefore the annual cost of biological control can be estimated at £32,000, allowing for inflation. In addition, Snowdon (2004) estimated the costs, in terms of reduction in yield, of allowing the infestation to spread. Annual equivalent values at a 0.25% loss (considered the most likely rate when *R. grandis* is used for control) of timber value were estimated to range between £90,101 and £136,151. At a 'normal' spread rate of the great spruce bark beetle, loss of yield is therefore estimated to cost £130,840 per annum. Total costs of the beetle are therefore estimated at £162,840, the majority of which can be attributed to England and Wales (£75,000 each), as outbreaks are very limited in Scotland (£12,840).

The green spruce aphid is known to cause damage in particular when high-density outbreaks occur. There are no known control options and a timber crop may experience several attacks through its growth period that can result in a reduction of 2-4% of gross income on a discounted basis (Day 2007). Sitka and Norway spruce make up 55% of all conifers in Britain[44], and about 50% of forests in Scotland[45], giving an average of 53%. At an average spruce timber price of £42m^{-3}, and based on the area of conifers felled each year, the cost of the green spruce aphid at 3% loss of gross income, in terms of yield reduction can be estimated at £2,590,129 in Scotland, £536,978 in England and £442,217 in Wales, giving a total cost to the forestry industry from the green spruce aphid of £3,569,324.

Table 6.2. Annual costs of non-native insects on forestry

	England	**Scotland**	**Wales**	**GB**
Great spruce bark beetle	£75,000	£12,840	£75,000	£162,840
Green spruce aphid	£536,978	£2,590,129	£442,217	£3,569,324
Total	**£611,978**	**£2,602,969**	**£517,217**	**£3,732,164**

Other insects have minimal costs at present or are still considered threats and are on the surveillance lists as they are not fully established in Britain yet. These include the Asian long horned beetle (*Anoplophora glabripennis),* oak processionary moth (*Thaumetopoea processionea*), the emerald ash borer (*Agrilus planipennis*) and the oak jewel beetle (*Agrilus pannonicus*). Costs of these insects, as they are not established in Great Britain, have been discussed in the quarantine and surveillance sector.

6.7 Plant Pathogens

6.7.1 Phytophthora spp.

As discussed in the agriculture sector there are many plant pathogens that affect trees, both native and non-native, and thus the forestry industry. Of particular concern at present is the spread of sudden oak death caused by *Phytophthora ramorum* as well as *P. kernoviae*. *Phytophthora ramorum* is a non-native fungus-like pathogen (oomycete) of trees, shrubs and other plants, which has caused the death of millions of trees in coastal regions of the USA. The pathogen was first detected in the UK in 2002 and has been found mainly on container-grown *Rhododendron*, *Viburnum* and *Camellia* plants in nurseries. Following the finding, emergency measures were introduced, including destruction of infected plants and import controls for certain hosts. Since this time a coordinated approach of control and eradication has been carried out, however the disease has spread and is present in the wild, primarily in southern and western Great Britain. It was also more recently confirmed, in 2009, in Japanese larch (*Larix kaempferi*) in south west England and subsequently in south Wales. *Phytophthora kernoviae*, a taxonomically distant relative of *P. ramorum*, was discovered in

[44] http://www.countrysideinfo.co.uk/woodland_manage/conifer2.htm
[45] http://www.forestpolicygroup.org/FPG%20Scotland's%20Forest%20Resource.pdf

the UK in Cornwall in 2003 during surveys for *P. ramorum*. This species is also pathogenic to certain tree and shrub species, including beech and rhododendron, and experts believe it is likely that it was introduced on imported rhododendron. In November 2003, the first case of an established tree affected by disease was confirmed (*Quercus falcate*) in Sussex.

In April 2009 a five-year programme was initiated against these pathogens in England and Wales, involving research and development, an awareness programme and clearance of host plants in high risk areas. These methods, combined with enhanced containment and eradication measures in infected gardens and nursery sites are hoped to reduce inoculum to epidemiologically insignificant levels. The cost of this programme is around £25,000,000, i.e. around £5,000,000 per year. This cost is assumed to be included in Fera plant health annual figures, as it is a Defra-funded programme. This cost includes research and applied quarantine measures as well as inspections of nurseries, woodlands and heath land in England and Wales. Therefore, this £25 million is not included as a cost here, rather it is included as part of the Fera plant health costs in the quarantine and surveillance chapter. In addition to this funding, the Forestry Commission England are funding their Plant Health Services £500,000 and FC Wales are funding FC Plant Health Services £100,000 for prophylactic Rhododendron clearance to combat *P. ramorum* and *P. kernoviae*. The funding from FC Wales and FC England is for work this year only and future funding has not yet been confirmed (Roddie Burgess, pers. comm.). Other costs of rhododendron clearance have been included in the forestry sector, due to it being an invasive non-native species itself. Similar measures are in place in Scotland and are being managed jointly by the Scottish Government Rural Environment Directorate, FC Scotland and the FC's Plant Health Service, although, given the lower levels of infection, these are being funded from existing departmental resources.

6.7.2 Red band needle blight

Red band needle blight, caused by the fungus *Dothistroma septosporum*, is considered to be of economic importance to conifers, in particular growth of Corsican pine (Brown and Webber 2008). It causes needle defoliation leading to yield loss and in some severe cases tree death. The disease mainly affects Corsican pine in Great Britain and therefore yield losses due to the presence of red band needle blight are calculated based on the area of Corsican pine in each country (Smith and Gilbert 2003). A total of 70% of stands are infected, although this varies between countries, with all stands (100%) infected in England, most in Wales (estimated at 90%) and a few in Scotland (estimated at 20%)[46]. Of these infected stands 44% had greater than 30% crown infection which equates to a 30% yield loss (based on work in New Zealand, Brown and Webber 2008). Therefore based on a yield class of 16, a crop rotation of 55 years and an average price of timber of £47m^{-3} and using a 3% discount rate, yield loss due to the presence of red band needle blight is estimated at approximately £756,000.

6.7.3 Total Costs of Plant Pathogens to Forestry

There are many other pathogens that affect forestry species and are known to cause sufficient damage to result in yield loss. While some of these are known to be native (Scleroderris canker, *Heterobasidion annosum* (K Tubby, Forest Research, pers. comm.)), the origin of other pathogens is unclear. As with agriculture, many pathogens have been found in Great Britain for a considerable time and it is not possible to identify their native range. Therefore, although the costs estimated for forestry above are likely to be an underestimate as they only account for a limited number of pathogens, no additional costs are assumed as there is a lack of information on which to estimate any other costs.

In addition to the diseases discussed above, trees become more susceptible to infection by plant pathogens when damaged, e.g. through bark stripping carried out by deer or squirrels. Some of these diseases may be non-native, but no additional cost is included here, as costs due to bark stripping are included in the forestry sector.

Table 6.3. Annual cost of non-native pathogens to forestry

	England	**Scotland**	**Wales**	**GB**
Phytophthora spp.	£500,000		£100,000	£600,000
Red band needle blight	£695,000	£8,000	£53,000	£756,000
Total	**£1,195,000**	**£8,000**	**£153,000**	**£1,356,000**

Most of the plant pathogen research costs that are carried out by Fera and Forest Research have been included in either the quarantine and surveillance sector, or the research sector and are not repeated here.

[46] http://www.forestresearch.gov.uk/forestry/INFD-7L6E57

6.8 Total Costs to Forestry

The costs of INNS to forestry are summarized below. In addition, a cost of £1,945,000 for the costs for quarantine and surveillance of forestry pests are included. Therefore, the total cost to forestry for all three countries is £109,515,000 (Table 6.3).

Table 6.4. Summary of the annual cost of INNS to British forestry.

	England	**Scotland**	**Wales**	**GB**
Rabbit	£24,352,000	£37,899,000	£7,766,000	£70,017,000
Deer	£10,886,000	£3,866,000	£2,626,000	£17,378,000
Edible Dormouse	£250,000	-	-	£250,000
Grey Squirrel	£3,963,000	£1,219,000	£915,000	£6,097,000
Rhododendron	£2,874,000	£2,874,000	£2,873,000	£8,621,000
Insects	£612,000	£2,603,000	£517,000	£3,732,000
Plant Pathogens	£1,195,000	£8,000	£153,000	£1,356,000
Quarantine and research	£1,648,000	£197,000	£100,000	£1,945,000
Total	**£45,780,000**	**£48,666,000**	**£14,950,000**	**£109,396,000**

References

Anon. (2006). Grey squirrels and England's woodlands: Policy and Action. Forestry Commission

Brown A and Webber J (2008) Red band needle blight of conifers in Britain. Forest Commission Research Note

Smith S and Gilbert J (2003) National Inventory of Woodland and Trees, Great Britain. Forestry Commission

Day K (2007). Improving resistance of spruce forests to the green spruce aphid. http://www.science.ulster.ac.uk/lnsrg/elatobium_abietinum.html

Dehnen-Schmutz K, Perrings C, Williamson M (2004). *Rhododendron ponticum* in the British Isles: an economic analysis. Journal of Environmental Management 70: 323-332

Edwards C, Taylor SL (2008). A survey and appraisal of *Rhododendron* invasion in Argyll and Bute. Forest Research report for Perth Conservancy, Forestry Commission Scotland

Gill R, Webber J and Peace A (2000) The Economic Implications of Deer Damage: A review of current evidence. Forest Research Agency, Deer Commission of Scotland

Huxley L (2003). The Grey Squirrel Review. Profile of an invasive alien species. Grey squirrel (*Sciurus carolinensis*). ESI Dorset.

Kenward RE, Dutton JCF (1996) 'Damage By Grey Squirrels II. The Value of Prediction' Quarterly Journal of Forestry 90: 211-218

Mayle B (2002) Grey Squirrel Control and Management in the UK - Lessons for Europe. 6th European Squirrel Workshop. Acqui Terme, Italy.

Mayle B, Pepper H and Ferryman M (2004) Controlling Grey Squirrel Damage to Woodlands, Forestry Commission Practice Note 4

Milne R, Abbott R (2000) Origin and evolution of invasive naturalized material of *Rhododendron ponticum L*. in the British Isles. Molecular Ecology 9: 541-556

Natural England (2007). Rabbits – Management Options for Preventing Damage. Technical Information Note TIN003, Natural England, UK

National Inventory of Wood and Trees (2003) Forestry Commission

Nix J (2009) The John Nix Farm Management Pocketbook, 40th Edition, Imperial College, London

Smith S and Gilbert J (2003) National Inventory of Woodland and Trees, Great Britain. Forestry Commission

Snowdon P (2004). Dendroctonus micans (Great spruce bark beetle) – Economic appraisal of control options. Forestry Commission

Ward AL, White PCL, Smith A and Critchley CH (2004) Modeling the cost of roe deer browsing damage to forestry. Forest Ecology and Management 191:301-310

White PCL, Smart JCR, Böhm M, Langbein J, Ward AI (2004). Economic Impacts of Wild Deer in the East of England. Woodland for Life. http://www.woodlandforlife.net/wfl-woodbank/DisplayArticle.asp?ID=2333

7 Quarantine and Surveillance

Quarantine and surveillance practices are carried out as a protective measure against the introduction of organisms that may be harmful to Great Britain and to prevent their spread, should they be introduced. Prevention of introduction and spread of non-native species has many benefits, tackling potentially invasive species before they are able to cause widespread damage (with associated expense) and become difficult to eradicate or control.

In Great Britain, quarantine procedures are undertaken by key agencies, including the Plant Health and Seeds Inspectorate (PHSI), the Horticultural Marketing Inspectorate (both falling under Defra) and the Forestry Commission (FC). These agencies carry out all inspection work for controlled plant health material, including species such as Asian longhorn beetle (*Anoplophora chinensis*), western corn rootworm (*Diabrotica virgifera virgifera*) and melon thrips (*Thrips palmi*). Quarantine measures are also taken to control legally introduced animal species or plant pests and diseases imported for research purposes, though costs associated with these are paid by the person introducing the organism to Great Britain and are therefore not included here.

When exclusion measures against quarantine species are unsuccessful and outbreaks occur in Great Britain, costs may be incurred by importers and affected landowners or growers, particularly in relation to costs of eradication of the INNS. Importers may also incur charges for inspection of regulated commodities.

7.1 Plant Health

The main quarantine measures related to plant health are those measures taken to keep those non-native species that may affect crops, trees and wild plants out of the country. These include import restrictions, inspections and treatments, surveys and publicity. In total Fera, through funding from Defra, spend £4,636,000 on exclusion measures, £6,633,000 on eradication and containment and a further £2,461,000 on trade measures and other activities, providing a total cost of £13,730,000 for England and Wales. This figure includes spending on controlling non-native pathogens that affect plant health. Also included in these totals are limited costs for indigenous species work. It is estimated that 90% of plant health work is related to non-native species and therefore the total cost is reduced to £12,357,000 (Steve Ashby, Fera. pers. comm.)

Plant health costs for Scotland include £6,251 for import inspections, £103,068 for general plant health inspection work, £775,144 for scientific support for quarantine organisms (quarantine, exclusion, surveillance and eradication) and £86,061 for policy management (J. Waddie, pers. comm.). This gives a total cost for plant health surveillance and quarantine work in Scotland of £970,524.

The Horticultural Marketing Inspectorate (HMI) carries out quarantine inspections of certain imported fresh fruits (specifically apples, pears, peaches, nectarines and citrus). These checks are carried out as part of inspections to ensure conformity with marketing standards and as such take no additional time and do not incur an additional cost. There are, however, costs for training HMI staff to identify quarantine pests and diseases. This training takes around 1 day every year, the average cost per hour for the inspector grade is £30 and HMI have 60 inspectors so the total cost per year for this training is £13,320 (Ian Hewett, pers. comm.). If a quarantine organism is detected, the local Fera Plant Health and Seeds inspector is contacted and takes responsibility for the situation.

In addition to these costs, landowners are required to pay for the costs of managing or eradicating outbreaks on their land. Information on this has been difficult to obtain, possibly due to the commercially sensitive nature of the information. However, a single outbreak of melon thrips (*Thrips palmi*) in 2004 cost one landowner £56,000 (£70,646 today) (MacLeod *et al*. 2004). This was considered to be a very large outbreak, with associated high costs. There were 59 outbreaks of agricultural and horticultural quarantine pests last year[47] of which 27 were *Bemisia tabaci*. Due to the limited amount of information available concerning the costs of dealing with outbreaks of controlled pests, it is assumed that each outbreak costs the same to deal with, with an estimated cost of £40,000 (reduced from the high cost of £70,500 for the melon thrips outbreak discussed above). Therefore, an annual cost of eliminating outbreaks of agricultural and horticultural pests can be estimated at £2,360,000. These outbreaks were all recorded in England, with no outbreaks recorded in Wales. No data were found concerning outbreaks in Scotland, so we assumed that 5% of the number of outbreaks in England occur in Scotland in any one year, and therefore, based on the same cost per outbreak, a total cost to control agricultural and horticultural pests in Scotland is estimated at £120,000.

The total costs for the quarantine and surveillance of plant pests are therefore estimated at £12,874,772 for England, £1,090,524 for Scotland and £1,855,548 for Wales, giving a total of £15,820,844.

[47] http://www.fera.defra.gov.uk/plants/plantHealth/pestsDiseases/interceptionCharts.cfm

7.2 Forestry

The Forestry Commission Plant Health Service runs a business unit that focuses on monitoring and surveillance of quarantine species and an inspection service. Costs for this unit amount to £695,000 per annum including work on inspection of imported wood, monitoring and surveillance of specific quarantine species, advice to importers and exporters on quarantine regulations. A further £250,000 is charged for inspections, which, although it is income to the Plant Health Service, it is also considered to be a cost to the economy as the inspections are paid for by those requiring them. The vast majority of wood is imported by ship to the major ports in England, hence the majority of inspections and surveying is carried out here. Some imports are made directly to Scotland and very few directly to Wales. Therefore estimated costs are £897,750 in England, £47,250 in Scotland, and a negligible amount in Wales.

Where outbreaks of quarantine species are detected, the FC Plant Health Service will be involved in survey and research work, but the cost of eradication falls entirely to the affected landowners (Roddie Burgess, pers. comm.). The annual cost of eradication of quarantine species varies due to differences in the number and persistence of outbreaks. For example, the estimated costs of attempted eradication of oak processionary moth (*Thaumetopoea processionea*) to landowners is £500,000 per year (Roddie Burgess, pers. comm.), including spending of approximately £50,000 by Kew Gardens annually (Anon. 2008) and another £50,000 by a golf course in the same area. These two organisations accounted for over half of the approximately 2400 nests found in the outbreak area. Therefore, assuming that there are 10 additional outbreaks of quarantine pests to control each year, and assuming an average cost per outbreak of £50,000, the annual cost of controlling quarantine forestry pests can be estimated at £1,000,000. An estimated £750,000 of this is attributable to England, £150,000 to Scotland and £100,000 to Wales.

This gives a total cost for forestry quarantine and surveillance of £1,945,000 per annum, £1,647,750 in England, £197,250 in Scotland and £100,000 in Wales.

7.3 Total Estimated Costs to Sector

Total costs are therefore estimated at £33,593,224 in total, with £28,509,000 in England, £3,204,549 in Scotland and £1,879,675 in Wales.

Table 7.1. Total annual quarantine and surveillance costs.

	England	Scotland	Wales	GB
Plant health	£12,875,000	£1,090,000	£1,856,000	£15,821,000
Forestry	£1,648,000	£197,000	£100,000	£1,945,000
Total	**£14,523,000**	**£1,287,000**	**£1,956,000**	**£17,766,000**

References

Anon. (2008). Invasive Non-Native Species. POSTnote Number 303, Parliamentary Office of Science and Technology.

Macleod A, Heada J and Gaunt A (2004) An assessment of the potential economic impact of *Thrips palmi* on horticulture in England and the significance of a successful eradication campaign. Crop protection 23: (7) 601

8 Aquaculture

The aquaculture industry in Great Britain is primarily concerned with finfish and shellfish farming for food, although part of the industry also supplies fisheries with coarse fish for angling. The industry was worth approximately £367 million to Scotland in 2008 (Scottish Government) with farmed salmon worth £336 million, rainbow trout £15 million and shellfish farming £8 million (Scottish government statistics[48]). In addition to salmon and rainbow trout, brown trout, sea trout, Arctic char and halibut are all farmed in Scotland. In England and Wales fish farming was estimated to be worth £23 million in 2006 (Defra), with salmon fishing worth £13 million and coarse fish production for restocking fisheries £10 million. In 2008, shellfish farming was worth £21.7 million (CEFAS 2009: pp. 47). Rainbow trout, brown trout, carp, salmon, turbot, barramundi and tilapia are also farmed. The shellfish industry farms mussels, Pacific and native oysters and King and Queen scallops.

8.1 Main costs to the sector

Investigations into the costs relating to INNS in the aquaculture sector have led to a general impression that INNS do not cause a specific issue to the industry. For example, we are unaware of costs incurred by the off-shore fisheries industry as a result of INNS. This is not necessarily because INNS do not affect the sector, but rather that the industry requires that all fish are kept pest free, whether the pest is a non-native species or not. However, species including slipper limpet (*Crepidula fornicata),* signal crayfish (*Pacifastacus leniusculus)* and wireweed (*Sargassum muticum)* have some effect on the industry, even if the impact is hard to quantify. The most common impacts of INNS on this sector are fouling, competition for resources, predation and vectoring of diseases.

A potential major impact is that of fouling (nets, cages, buoys, moorings, boat hulls etc), which can be a significant problem for approximately four months a year, and cause costs of approximately £13 million per annum (David Fraser, pers. comm.). However, various sources have indicated that INNS are generally not considered to be the main cause of these additional costs to the industry. A recent paper suggested that fouling is not a great enough issue for the mussel industry to spend time and money on (Leblanc *et al*. 2003). The main reason for the lack of focus on INNS is that there are also native fouling species and current management practices target fouling organisms in general, and do not consider whether the species that are being removed are native or non-native. The advice for boat

[48] http://www.scotland.gov.uk/Topics/marine/Fisheries/Fish-Shellfish

owners is, and has been for a number of years, to lift their boat out of the water and clean the hull on a regular basis (e.g. British Marine Federation, Green Blue book, BW guidance). However, as some of the species fouling a hull are non-native a cost estimate is made for hull cleaning, and anti-fouling measures.

The cost of hull cleaning through pressure washing is estimated as £25 m^{-1} vessel length (based on pricing information provided by Milford Haven Ship Repairers). Treatment with antifouling paint costs approximately five times as much, and is therefore estimated at £125 m^{-1}. The advice for boat owners is to clean the hull once per year, but treatment with antifouling paint is required less frequently, generally once every five years. There are 5834 fishing vessels[49] with an average length of 9.88m, and therefore the cost of annual cleaning is estimated at £1,440,998. In addition 20% of these boats will be treated with antifouling paint each year at a cost of £1,440,998, giving a total cost for control and treatment of hull fouling of £2,881,996.

Gollasch (2002) found that 57% of the species in samples (ballast, sediment and hulls) collected from shipping vessels arriving from outside the North Sea area were non-native to that area. No estimates could be found of the percentage of hull area covered by non-native fouling organisms, but is it possible that fishing vessels travel less to different marine ecological zones than international shipping vessels, and therefore have less exposure to non-native species and have a lower percentage of non-native organisms fouling their hulls. Therefore, assuming that only 25% of organisms fouling fishing vessels are non-native, the estimate for the cost of fouling to fishing vessels is reduced to £721,000.

Fouling can cause additional costs to the shellfish industry and it is estimated that the European shellfish industry experiences a loss of 5-10% (FAO) due to the cost of labour to clean fouled produce. The time and cost spent in cleaning shellfish can be 20% of the market price (GISP 2008). Therefore, based on the estimate of market value of the shellfish industry in Scotland (£7.6 million) and England and Wales (£14.1 million; CEFAS 2009) the annual cost of removing fouling species from shellfish could be more than £1.52 million in Scotland and £2.8 million in England and Wales. However, native species (e.g. tubeworms and barnacles) are also targeted and it is unknown what fraction of the fouling organisms are INNS and whether there has been a change in cleaning costs as a result of INNS. It is therefore difficult to estimate incurred costs due to INNS accurately. However, even if INNS only make up 20% of fouling species the cost incurred by the shellfish industry due to these species could be £864,000 (£304,000 in Scotland and £560,000 in England and Wales).

[49] http://www.marinemanagement.org.uk/fisheries/statistics/vessel_archive.htm

The slipper limpet can substantially reduce incomes in the shellfish industry by acting as a competitor for space and food. In Brittany, the scallop industry has lost an estimated 97% of the harvestable area (FitzGerald 2007). In Great Britain, slipper limpet occurs from Yorkshire to Pembrokeshire, with two recorded locations in Scotland with no recorded impact on commercially exploited shellfish. The population is localised, but populations occur in the Solent and Essex estuaries, Poole harbour, Lyme Bay, Truro Bay and Milford Haven. After a period of limited increases in population density, the population increase has been rapid in the past decade (Walker 2007). Currently, slipper limpet occurs in densities that are far higher than oysters and mussels together in Truro Bay (FitzGerald 2007). Where slipper limpet is present the efficiency of dredging for scallops is reduced, it takes longer to sort the catch, clean it and the quality of the catch is reduced. In Lyme Bay for instance, 10 kg of slipper limpet can be lifted for every 50 kg of scallops (Syvret and FitzGerald 2008). There do not appear to be any assessments of the costs of slipper limpet to GB, but even if additional costs and reduced catch cost the scallop industry 10%, an average of losses estimated by the FAO and GISP, then this cost could be £3,530,000 per annum (at an annual value of £35.3 million for UK scallop production (Seafish 2008)). In addition, recent increases in population density suggests that similar competition may occur to that found in France at present or in the near future and therefore costs are likely to increase.

The slipper limpet is also known to compete with oysters, in particular reducing the ability of young oysters to establish themselves. Oysters are also predated by the American oyster drill, which feeds on young oysters and is known commonly to cause 50% mortality in oyster spat (GISP, undated). There is a limited distribution in Britain, with records existing in only seven 10 km^2 squares along the south and south-eastern coast of England (NBN). Wireweed can also adversely affect the oyster industry (as well as fishing lines and nets) by smothering growth. Based on the amount of oysters produced and landed in England, Scotland and Wales[50] (CEFAS 2009 and using a value of £3,000 per tonne for native oysters and £2,500 per tonne for pacific oysters (pers. comm.)), the oyster industry can be valued at £10.4 million in England, £2.6 million in Wales and £1.3 million in Scotland. Therefore, assuming that the presence of both slipper limpet and the American oyster drill increase costs by 10% then the cost to the oyster industry is £1,430,000, (England £1,040,000, Wales £260,000 and Scotland £130,000).

The development of a Standard Operating Procedure for checking that shipments of mussel seeds are free of slipper limpet for the Menai Strait cost ca. £5,000 and each inspection costs approximately £2,000 (Andy Woolmer, pers. comm.). In 2009, the number of formal

[50] http://www.marinemanagement.org.uk/fisheries/statistics/annual.htm

inspections was 4 (James Wilson, pers. comm.). The total cost of implementing a code of good conduct in the Menai Strait was estimated at £20,000 (Gabrielle Wyn, pers. comm.). The four mussel companies fund a PhD project to examine the ecological requirements for slipper limpet establishment at an annual cost of £12,000 and authorisation to export mussels to the Netherlands costs approximately £5,000 per year (James Wilson, pers. comm.). Finally, the Environment and Heritage Service are very careful about mussel movements from the Menai Strait, which costs one of the mussel companies, Deepdock Ltd, in excess of £500,000 per year, as they cannot move mussels to their finishing grounds in Northern Ireland (James Wilson, pers. comm.). The total cost of slipper limpet on mussel production in the Menai Strait can thus be estimated at £550,000.

Other species, such as the Chinese mitten crab (*Eriocheir sinensis*) and topmouth gudgeon (*Pseudorasbora parva*), predate on native fish eggs or can damage nets (NNSS[51]). In addition, topmouth gudgeon carries a parasite that affects both salmon and trout breeding cycles, thus affecting coarse fish production in England. Current efforts to control topmouth gudgeon amount to £190,000 over 4 years, (£50,000 p.a., Britton *et al.* 2010). However, part of these costs can be attributed to either the biodiversity and conservation sector and the tourism and recreation sector, due to the effect of topmouth gudgeon on native fish species, and the effect on recreational coarse fishing.

8.2 Total Estimated Costs

Total estimated costs are £7,145,000 per annum (Table 8.1), although this is probably an underestimate due to the lack of distinction between native and non-native species in pest management.

Table 8.1. Annual costs of INNS to aquaculture

	England	Scotland	Wales	GB
Hull fouling	£361,000	£288,000	£72,000	£721,000
Fouling (shellfish)	£448,000	£304,000	£112,000	£864,000
Slipper limpet (oysters)	£1,040,000	£130,000	£260,000	£1,430,000
Slipper limpet (scallops)	£2,471,000	-	£1,059,000	£3,530,000
Slipper limpet (mussels)	-	-	£550,000	£550,000
Topmouth gudgeon	£50,000	-	-	£50,000
Total	**£4,370,000**	**£722,000**	**£2,053,000**	**£7,145,000**

[51] http://192.171.199.232//speciesFactsheet.do?speciesId=50176

References

Britton JR, Davies GD, Brazier M (2010). Towards the successful control of the invasive *Pseudoboras parva* in the UK. Biological Invasions 12: 125-131

CEFAS (2009) Shellfish News 28: Autumn/Winter 2009. http://www.cefas.co.uk/publications/shellfishnews/shellfishnews-28.pdf

Fitzgerald, A (2007). Port of Truro Oyster Management Group Slipper Limpet Utilisation and Management Final Report

Global Invasive Species Programme (2008). Marine biofouling: An assessment of risks and management initiatives. Compiled by Lynn Jackson on behalf of the Global Invasive Species Programme and the UNEP regional seas programme. 68 p.

Global Invasive Species Programme (undated). http://www.issg.org/database/species/ecology.asp?si=1383&fr=1&sts=&lang=EN

Gollasch S (2002). The Importance of Ship Hull Fouling as a Vector of Species Introductions into the North Sea. Biofouling 18 (2): pp 105-121

Leblanc AR, Landry T, Miron G (2003). Fouling organisms of the blue mussel *Mytilus edulis*: their effect on nutrient uptake and release. Journal of Shellfish Research 22: 633-638

SeaFish (2008). Responsible sourcing guide: scallops

Syvret M, FitzGerald A (2008). Slipper limpet mortality trials, seed mussel project. Report for Sea Fish Industry Authority. 47 pp. http://www.seafish.org/pdf.pl?file=seafish/Documents/B029_Slipper%20Limpet%20Mortality%20Trials.pdf

Walker P (2007). Oyster and Slipper Limpet Surveys 7 - 9 March 2006 & 13 – 15 February 2007. Shellfish Team Report 69 for the Port of Truro Oyster Fishery, CEFAS

9 Tourism and Recreation

In 2008, tourism spend by residents alone was estimated at £21 billion (UK Tourism Report 2009). Activities in this sector cover a broad spectrum, ranging from the traditional tourist activities of visiting towns, sites of historic interest, museums, etc., to recreational activities, such as walking, angling, beach holidays, camping, etc. Due to this wide range of activities, and therefore the wide range of environments that tourism and recreational activities take place in, a large number of species may affect the sector. However, as with other sectors, there are a few key species that create the largest costs. The costs of INNS to the biodiversity of tourist areas are not included in this sector, unless there is a direct link to the number of participants of the recreational or tourist activity due to reduced biodiversity.

9.1 Coastal tourism

Coastal tourism includes visits to the beach as well as any recreational activity in coastal water. Wireweed (*Sargassum muticum)* causes dense mats of buoyant fronds that not only become an eyesore, but also wash up on shore and rot, producing an offensive smell. The floating debris can cause problems to boats, swimmers and sail boarding etc., while the presence of a large rotting mass of vegetation on a beach will reduce visitor experience and hence numbers. In southern England and Wales, the fronds also foul propellers, fishing lines and nets and marina structures, causing problems for boat owners, anglers and marina owners alike. There is little information on the costs of marine non-natives' impacts and their control and/or clearance and this has been highlighted by the *Sargassum* Steering Group[52]. Currently there is limited control of wireweed within Great Britain, with an estimated 15 beach clearance events taking place in England per annum at an estimated cost of £15,000 in total. The GB non-native species Risk Assessment of wireweed does not highlight any major costs as yet[53].

As outlined in the case study, *Didemnum vexillum* (a carpet sea squirt), has the potential to add costs to coastal tourism through additional costs of cleaning leisure and recreation vessels and increased charges at marinas if they attempt to control the species. However, at present it is limited in its distribution to locations in Wales and the south coast of England. *D. vexillum* is a fouling organism that can cover boats' hulls, anchor chains, ropes and pier

[52] http://www.snh.org.uk/pdfs/species/SAF-wireweed/Sargassum%20group%20meeting%20-%20final%20minutes%20-%2026%20February%202009.pdf

[53] http://www.nonnativespecies.org/documents/RA_Sargassum_muticum_%28Wireweed%2911-09.pdf

supports in marinas. At present, however, there has been no increase in cost due to the presence of *D. vexillum* as the requirements for boat owners to clean their hulls once a year (see 8.6) has not changed. Therefore, currently no additional costs are attributable to the tourism sector due to *D. vexillum*.

9.2 Golf courses

Golf is a major recreational activity in Britain and involves the management of large areas of land that can be affected by non-native species. One respondent to our questionnaire, who carries out pest management for a golf course, indicated that golf courses spend between £6,000-£10,000 p.a. managing rabbits, Canada geese, moles (native) and mink, with rabbits making up more of the cost than the other species. The club in question was, however, in a wealthier part of the country with annual membership fees approaching £1,000. In addition, as many clubs may use local contractors who carry out some of the management for free in exchange for the rabbits they catch, it may be concluded that the actual spend per club is much lower. We assumed that the average cost is £4,000 p.a. per club. Based on personal communications with contractors we further assumed that each golf course spends the same amount on each species and that rabbit control contributes 50% of that cost, followed by moles (25%), Canada geese (20%) and mink (5%) and that estimates can be based on published figures for the number of golf courses in each country (Table 9.1). The total cost to golf courses in Great Britain is estimated at £7,926,000.

Table 9.1. Annual cost of three vertebrate INNS to golf courses.

	England	**Wales**	**Scotland**	**GB**
Canada geese	£1,539,200	£140,000	£434,400	£2,113,600
Rabbits	£3,848,000	£350,000	£1,086,000	£5,284,000
Mink	£384,800	£35,000	£108,600	£528,400
Totals	£5,772,000	£525,000	£1,629,000	£7,926,000

Golf courses also have issues with other invasive species, such as Japanese knotweed, but it was not possible to establish the scale of the problem accurately, as many courses were reluctant to provide information on the problems they have with invasive species. Therefore based on the number of golf courses in Berkshire, we assumed that at least 10% of golf courses are affected. Using this figure and an estimated mean cost per year of £1,000, the figure for Great Britain is almost £500,000 p.a. (England £274,900, Wales £192,400 and Scotland £17,500).

Therefore a total estimated cost to golf courses of all INNS is £8,410,800 p.a. (England £6,046,900, Wales £717,400 and Scotland £1,646,500).

9.3 Inland Waterways

Waterways are crucial for tourism and recreation and they are estimated to provide over £500 million of public benefit annually, as well as over £1 billion in income to local economies[54]. Over 13 million people made over 380 million visits to the waterways in 2009. The various effects of INNS on recreational activities carried out using inland waterways range from direct effects, such as the presence of mats of floating weeds, such as floating pennywort, that may restrict navigation or prevent angling, to more indirect effects, such as riparian weeds that may hinder access to the water and loss of open surface water by continuous mats giving rise to aesthetic and safety issues. The rooted invasive aquatic species can also cause flood risks by restricting water flows and blocking weirs and sluices. Furthermore, a number of species, such as Japanese knotweed, Chinese mitten crab and zebra mussels, can cause damage to waterway infrastructure and may interfere with water control structures, potentially posing a further flood risk. In addition, many aquatic INNS are very mobile and may affect water quality and biological diversity, reducing the aesthetic value of the waterways causing a decline in their recreational value, potentially affecting local economies that are reliant on recreation and tourism.

9.3.1 Angling

A wide range of INNS, including fish, riparian weeds, crustaceans and aquatic plants can affect angling. Each of these taxa includes species that can have a serious impact on the willingness or ability of anglers to fish a stretch of water though the period over which these effects can be felt can vary significantly between taxa, as can the length of time required for any treatment programme. The angling industry makes a significant contribution to the UK economy. There are an estimated 2.9 million anglers in England and Wales and each angler spends an estimated £1483 per year on such items as travel, food and drink, bait, tackle and permits (£1,000 per year per angler in 1994: National Rivers Authority 1995), giving a total estimated value of angling to the economy of these two countries of approximately £4.3 billion. The angler spend in Scotland was estimated at £112.5 million in 2004. A further £164.6 million contribution to Scottish output from angling, and £77.1 million in household income due to angling as well as the 4,418 jobs in the sector, worth £125 million, can be

[54] BW annual report 2010 http://www.britishwaterways.co.uk/media/documents/Annual_Report_and_Accounts_2009-10.pdf

added to this spending figure (from Radford *et al.* 2004). This gives a total value of angling to Scotland of £479.2 million in 2004 or £548.5 million today. This gives a total estimated value of angling to Great Britain of £4.85 billion.

There are 42,123 km of rivers and 1,653 lakes in England and Wales of which 26,000 km of river and 30,000 km of still waters are fished (Lyons *et al.* 2002). Given the annual value of fishing in England and Wales of £4.3 billion, the value of angling on each kilometre of river is £76,786 p.a. The spending will vary throughout the year, and will be concentrated in the summer months. Therefore if it is assumed that two thirds of fishing is carried out in this period, then a kilometre of river/lake bank in a single summer month is worth £8,532.

The key weed species that need to be considered are the water weeds, water fern (*Azolla filiculoides)*, Australian swamp stonecrop (*Crassula helmsii)*, floating pennywort (*Hydrocotyle ranunculoides),* Canadian and Nuttall's pond weed (*Elodea canadensis* and *E. nuttallii*), curly waterweed *(Lagarosiphon major*) and parrots feather *(Myriophyllum aquaticum),* as well as the riparian species, Japanese knotweed *(Fallopia japonica),* Himalayan balsam (*Impatiens glandulifera*) and giant hogweed (*Heracleum mantegazzianum*). It is assumed that each of these ten main weed INNS that cause problems for anglers do so on around 10 km of river or lakeside for two summer months per year. Then based on a cost per kilometre of £8,532, each INNS would cost angling £170,636 for the 10 km stretch affected. This gives a total estimate of £1,365,084 per annum, which can be divided up using the proportion of river and canal length in each country to a cost in England of £1,177,452 and Wales, £187,632.

When the effect of crustaceans (e.g. Chinese mitten crab (*Eriocheir sinensis*), signal crayfish (*Pacifasticus leniusculus*), and the fish, topmouth gudgeon (*Pseudorasbora parva*) are considered, it is recognised that these can have an influence over a much longer stretch of fishable water, or often a whole catchment for a longer period than that of INNS weed species. The arrival of signal crayfish, which are known to predate heavily on fish ova, plant life and invertebrates, is often accompanied by a reduction in fish stocks and anglers ceasing to fish the affected stretches of river. In these cases it is therefore assumed that the range affected is 20 km and the impact is over a 2.5 month period giving additional figures of £1,103,862 for England and £175,905 for Wales. Whilst all species do not affect angling to the same degree, the impacts were assumed to average out across the ten plant species and three crustacean and vertebrate species.

Scotland does not have the same system as England and without a rod licence system, it is impossible to know how many anglers are active each year. However, accurate catch data are recorded and in 2009, on the Tweed alone, more than 12,000 salmon and grilse were caught alongside more than 4,000 sea trout which contributed to the total 85,859 salmon landed in Scotland as a whole. For comparison, the EA/CEFAS Annual Assessment of salmon stocks stated that the total rod catch for England and Wales was only 15,200.

In the absence of good information on the length of areas fished it is possible to extrapolate the figures estimated for England and Wales to Scotland based on land area. However, when the percentage value lost in England and Wales is then extrapolated to angling in Scotland, with its total value of £548.5 million, then the annual cost of both weed and crustacean INNS to angling is estimated at £239,423 for Scotland. This figure is clearly extremely low and does not adequately reflect the very high value placed on Scottish inland fishing including the very valuable salmon beats, which can cost £1,000 per rod per day in peak season and which are equally vulnerable to INNS.

It is possible to place a capital value on some stretches of river and even the value of a single fish. A typical 4-rod beat with an annual average catch of 100-150 salmon would cost an estimated £1,039,000 to purchase, including the value per fish of £7,500 (Rettie, 2010) Thus there is considerable capital value that is threatened by INNS in Scotland and these impacts can be felt over a much longer fishing season than in England and Wales.

According to a Government statement in 2008, the value of salmon fishing to Scotland is £120,000,000 p.a. (quoted by Association of Salmon Fisheries Board, 2010[55]) and there are on average 545,000 salmon fishing days each year. This gives a value of around £220 per day for salmon fishing. If the season is assumed to be 9 months long and the impact of all invasive species is felt over 25 km with a reduction from 5 to 4 anglers per km per day then the annual cost is £1,506,880. We also assumed that the capital value of the stretch has been reduced by at least 10% so with 25 beats (based on 2 km per beat) the loss in capital value is around £2,597,500. However, this reduction in capital value will not all be experienced in a single year, and in addition may return to previous levels if the INNS are cleared and removed, and therefore the loss of capital value is spread over 10 years giving an annual cost of £259,750. The impact of INNS of salmon fishing due to the reduction in number of anglers and the capital value of the beat is therefore £1,766,630. Due to the high value of many of its waterways, this cost of INNS to salmon fishing in Scotland was added to the main cost of £239,423 calculated above, which gives a total cost of £2,006,053.

[55] http://www.asfb.org.uk/asfb/asfb.asp

There are also the control costs being incurred as part of the INNS management on and beside rivers in Scotland, which include two SEPA funded INNS weed control projects over 5 years valued at over 800,000 and a 3-year RAFTS Biosecurity Planning Programme for weed control valued at more than £250,000 (C. Sinclair, pers. comm.). The additional control costs identified and of direct impact on fisheries and angling are therefore £243,333 p.a.

There may be further costs, for instance related to signal crayfish that have invaded at least 50 km of salmon river in Scotland so far (C. Sinclair pers. comm.). The actual impacts may vary from complete displacement of angling activity to little impact, but the perceived impacts can result in a significant devaluation through altered anglers' attitudes. In addition there are costs associated with the effect of signal crayfish on the food chain due to damage to aquatic plants that support the invertebrates that form part of both the signal crayfish and fish diets. These effects can have a negative impact both on fish growth rates and their population potential. However, no data could be found to quantify this effect in economic terms and therefore no additional cost is included here.

The total costs of INNS to angling is £4,894,237 of which Scotland incurs £2,249,386, England incurs £2,281,314 and Wales £363,537

9.3.2 Recreational boating

There are 380 million day visitors a year to canals and rivers and the canals and rivers are used by approximately 88,000 boats (AINA 2008). The IWAC report estimates direct boating expenditure for Britain of between £200 and £400 million and that the Broads boat-hire industry is worth around £146 million p.a. In total, estimated tourism spend on inland waterways is £1.8-2.2 billion and, as calculated in the species examples, this gives a per km value of £22,553. British Waterways spent £6.8 million on vegetation management in 2009[56] on the 2200 miles of canal and river navigation. A significant portion of this was used to target invasive species and we estimated that over £1.5m is spent on INNS per year. The canals are primarily used for recreation and we therefore estimate that 90% of this cost is attributable to tourism and recreation (80%, 10% and 10% of that 90% in England, Scotland and Wales respectively). This may be spent on the control of floating pennywort (*Hydrocotyle ranunculoides)*, which can make canals inaccessible, and weeds, such as giant hogweed (*Heracleum mantegazzianum*) or Himalayan balsam (*Impatiens glandulifera*).

[56] BW annual report 2010.

It is assumed that the majority of the costs associated with owning and maintaining a boat, i.e. the direct costs mentioned above, would remain largely unaffected by INNS. The costs of floating pennywort to recreational boat-based tourism have been considered in the species example and the only other species that could significantly affect recreational boating are *Elodea /Lagarosiphon spp*. Based on the distribution of these species in the country[57] and the length of waterways in each country, but in the absence of any firm data concerning how often they block waterways to a sufficient extent to impede boating, we assume that Canadian pond weed affects 20 km of waterways, and curly water weed affects only 10 km.. If it is assumed that these species only cause problems for boating for one month of the year before the weeds are cleared, and that two thirds of the season takes place over the 6 months of finer weather, then the value of one km of water in such a month is £30,071 per km. This gives a cost for Great Britain of £4,510,650, which, when combined with the costs associated with floating pennywort, gives a figure of £29,862,650 (Table 9.2).

Table 9.2. Calculation of cost of INNS to recreational boating.

	England	**Wales**	**Scotland**
Rivers and canals (km)	33,828	4,603	50,250
Distribution of waterways affected by both species	15	2	13
Value / km (£)	£22,553	£22,553	£22,553
Two thirds of value	£15,035	£15,035	£15,035
Value per summer km (two thirds in 6 months)	£30,071	£30,071	£30,071
Value of infected kms per summer month	£451,065	£60,142	£390,923
If blocked then effect on boating extends at least 5 times the length of infestation	£2,255,325	£300,710	£1,954,615
Floating Pennywort	£25,283,000	£69,000	-
Total	**£27,538,325**	**£369,710**	**£1,954,615**

In addition, there are the costs of fouling of access paths, slipways and pontoons by non-native bird species, such as Canada geese. The estimated costs for such cleanups are £750 p.a. for inland sailing clubs and £2,500 for inland marinas (J Johnston, pers. comm.). There are 450 inland sailing clubs and 102 inland marinas in England giving costs of £337,500 and £255,000 respectively. Scotland has 15 sailing clubs and two marinas giving costs of £11,250 and £5,000 respectively and Wales has 12 inland sailing clubs, but no inland marinas, with a cost of £9,000 per annum.

[57] http://data.nbn.org.uk/index_homepage/index.jsp

Thus, the total cost to recreational boating caused by the presence of INNS in Great Britain is £30,451,000 per annum (England £28,101,000, Scotland £1,971,000 and Wales £379,000).

9.3.3 Waterway management costs

In addition to the cost incurred by angling and recreational boating due to the presence of water weeds, general control measures are undertaken by agencies, such as internal drainage boards, British Waterways and the Environment Agency, as part of general river and canal management and flood prevention measures. Oreska and Aldridge (2010) calculated that control costs for seven freshwater invasive non-native plant species amounted to at least £18.9 million per year. However, this estimate included costs incurred by, for example, boat yards, the water industry and fisheries. The cost of managing floating pennywort in rivers and canals has been calculated at £1.93 million (species example), excluding the effect on angling and boating, etc., which was calculated separately. Given the findings of the GB non-native risk assessment for most of the aquatic plant species it is reasonable to assume that the other main freshwater weed species (Australian swamp stonecrop (*Crassula helmsii)*, water fern (*Azolla filiculoides)*, both pond weed (*Elodea canadensis* and *E. nuttallii*), parrot's feather (*Myriophyllum aquaticum),* curly water weed (*Lagarosiphon major*)) have a similar impact to floating pennywort. However the distribution of the species does vary[58], with Canadian pond weed having the most extensive distribution, and the other species having more widespread distributions that floating pennywort, though not as widespread as Canadian pond weed. Therefore based on the £1.93 million cost estimated for floating pennywort, we estimate that control costs for Australian swamp stonecrop, water fern, parrot's feather and curly water weed are £3 million each per annum, Nuttall's pond weed is estimated at £4 million and Canadian pond weed control costs £5 million per annum, giving a total cost of £21.86 million. This is slightly more than Oreska and Aldridge's figure (2010), but still seems a reasonable estimate of the cost of INNS on waterway management.

9.4 Giant hogweed

Although giant hogweed is primarily controlled due to its effect on human health, its presence in riparian habits means that certain areas become totally inaccessible, thereby limiting tourism and leisure activities. Therefore control costs of giant hogweed are included as a cost to tourism and recreation. Costs can be considerable. In Germany, the annual

[58] http://data.nbn.org.uk/index_homepage/index.jsp

costs incurred by infestation by giant hogweed are estimated at €12,313,000 (Reinhardt *et al.* 2003). There is a much larger giant hogweed problem in Germany than in Great Britain, however, and the estimated costs reflect that.

A number of councils control giant hogweed, as its prevalence along river valleys has particular impacts on public health and access for tourism or leisure activities. Giant hogweed is largely prevalent along rivers in the south and east of Scotland and major infestations along the Wye and Usk have been the subject of control efforts in Wales. In addition, coordinated eradication projects have been reported across England. For example, one giant hogweed programme by Wealden District Council, Tonbridge, Malling Borough Council and Maidstone Borough Council (Sussex, England) offered a coordinated approach and funding of just under £14,625 with additional support from the EA and others in 2006 with ongoing funds for the subsequent years. Similarly, an EU funded project in Caerphilly spent £7,000 on giant hogweed, whilst the Welsh Assembly Government Heads of the Valleys Project and local authority allocate a budget of £100,000 p.a., 5-10% of which is spent on giant hogweed (£10,000). Two district councils in Scotland spent a combined £13,000 to eradicate giant hogweed on the River Ayr, and a project by Stirling Council committed £15,000 annually to control giant hogweed with additional £15,000 for an eradication strategy. The Esmee Fairbairn Foundation granted £94,000 over three years to eradicate three species of non native weeds along the Wye with giant hogweed being one of them (estimated at £31,333), whilst the Tweed catchment invasive project specifically addressed the issue of giant hogweed over three years at a cost of £382,000 (£127,333 p.a.) (The Tweed Invasives Project 2006). Giant hogweed is known to affect angling, especially salmon fishing, by limiting access to rivers and river banks. Control efforts covered 3,080 square miles over 300 miles of riverbank. In addition, the Environment Agency spent and contributed roughly £112,500 p.a. on the control of giant hogweed in England and Wales in 2006, most of it in England (approximated at £75,000 England, £37,500 Wales).

There are 353 local authorities in England, 32 in Scotland and 22 in Wales[59]. Whilst it was not possible to determine what proportion of councils are concerned with giant hogweed or are actively controlling the plant, it was assumed that at least 10% of them spend the average of the amount quoted above (*circa* £10,360 p.a.). Thus the council spend across the country is estimated at £422,663 p.a. (England £365,686, Scotland £34,186 and Wales £22,790).

[59] Spending by National Park Authorities is included in the biodiversity and conservation chapter, as it was not possible to separate spending on giant hogweed from other INNS.

The non-council spend identified above equates to £271,166 per year (England £75,000, Scotland £127,333 and Wales £68,833). However, our research has suggested that other conservation and private groups also spend money on giant hogweed control, but it did not prove possible to capture all relevant costs, as many organisations do not keep spending records on a species level. Therefore, to adjust for this known underestimate, the non-council spending figures is doubled to £542,332 for Great Britain as a whole (England £150,000, Scotland £254,666 and Wales £137,666).

We assumed that council spending will be undertaken to counter threats to human health caused by giant hogweed whilst undertaking recreational activities, and the non-council spending will be driven by a mix of controlling the species due to the threat to recreation as well as general river bank maintenance and potentially some flood prevention work. However, it was not possible to attribute what portion of spending was undertaken for what reason, and therefore all spending is included here as a cost incurred by tourism and recreational activities.

Table 9.3. Annual cost of giant hogweed.

	England	Wales	Scotland	Total
Local authorities	£365,686	£22,791	£34,186	£422,663
Other	£150,000	£137,666	£254,666	£542,332
Total	**£515,686**	**£160,457**	**£288,852**	**£964,995**

9.5 Japanese knotweed

As discussed in the species example, substantial control measures are undertaken in riparian habitats to clear Japanese knotweed. This control cost is assumed to be primarily driven by the need for public access to river banks for recreational use, though some costs are associated with work carried out to prevent damage to water control structures and work to prevent structural damage to the banks of watercourses as well as some control solely for biodiversity purposes. However all the control costs for Japanese knotweed in riparian habitats are included here at a cost of £5,637,000 (England £3,444,000, Wales £469,000 and Scotland £1,724,000).

9.6 Hull fouling of recreational vessels, marinas, etc.

INNS are an issue for recreational vessels, as they are for commercial ones, but it is challenging to separate the costs incurred from native species. Hull fouling is included in general good maintenance by boat owners and boat owner should not incur additional costs due to the presence of INNS. Nonetheless, some of the species contributing to hull fouling will be INNS and therefore a portion of the cost of cleaning recreational vessels is included here. See aquaculture and transport sections for commercial vessels.

The cost of hull cleaning through pressure washing is estimated as £25 m^{-1} vessel length (based on pricing information provided by Milford Haven Ship Repairers). Treatment with antifouling paint costs approximately five times as much, and is therefore estimated at £125 m^{-1}. The advice for boat owners is to clean the hull once per year, and to treat hulls with antifouling paint approximately once every five years, although it is unlikely that all recreational vessel owners strictly follow this advice. There are around 88,267 boats on the inland waterways in Britain (AINA 2008) and a further 462,960 private and commercially owned marine vessels[60] (inflatables, kayaks, canoes, etc. were excluded from this estimate). Some of these marine vessels may be used for aquacultural activities rather than leisure and tourism and therefore the number is reduced to 450,000 as costs related to aquaculture are included in that chapter.

Gollasch (2002) found that 57% of the species in samples (ballast, sediment and hulls) collected from shipping vessels arriving from outside the North Sea area were non-native to that area. No estimates could be found of the percentage of hull fouling that was caused by non-native species. However, it is possible that leisure vessels, particularly those using inland waterways, have a lower exposure to INNS than international shipping vessels due to the reduced likelihood of a craft, e.g. a narrow boat, leaving Great Britain. Nonetheless these leisure vessels will still be exposed to INNS that are already present in British waters such as the zebra mussel and therefore it is assumed that 15% of species fouling leisure vessels are non-native. Therefore, based on the prices of cleaning and painting per metre discussed above, the number and length of leisure vessels in British waters, and assuming that 80% of boat owners carry out the hull cleaning on an annual basis as recommended we estimated for the cost of fouling at £21,367,735. Using the distribution of population between the three countries the costs are estimated to be England £18,441,535, Wales £1,073,135 and Scotland 1,853,735.

60 http://www.britishmarine.co.uk/what_we_do/statistics__market_research/current_projects/boat_production_and_boat_park.aspx

9.7 Shooting

A recent report claimed that the game shooting industry currently contributes £1.6 billion every year to the British economy (PACEC 2006). 15 million ha of land may be influenced by game management. The main species that are controlled as pests by the game shooting business include fox, mustelids (stoat, weasel, mink), corvids, rabbit, squirrel and rats (Spedding 2009, Canning undated). Mink in particular, can be a serious pest of game birds. In a 1996 survey of gamekeepers in Wales and the West Midlands, the 66 respondents ranked the mink as the third most serious predator of game, after foxes and feral cats (Packer and Birks, 1999). As with poultry rearing, penned pheasant and partridges have been killed after mink have gained access to the rearing enclosures with surplus killing frequently cited.

The PACEC report estimated pest control to protect game for shooting to involve 3,100 FTE's at an average salary of 12,000 p.a. (£13,013 today) costing £40,340,300 (PACEC 2006). In addition, £2 million was spent on subcontracting pest control. Therefore, pest control costs can be estimated at £42,340,300. This amount does not include species killed as part of a game shoot but does include money spent controlling the native pest species mentioned above. The most common pest species mentioned by Spedding (2009) and Canning (undated) include fox and corvids, and therefore it is estimated that 10% of total pest control expenditure is spent on controlling non-native species, reducing the £42,340,300 to £4,234,030.

However, this figure also includes Northern Ireland. Using the assessment of where people shoot presented in the PACEC report, it is possible to generate percentage activity in country and then use these to estimate the distribution of the cost of INNS (Table 9.5). This provides a better assessment of where the income is derived and therefore where the expenditure on pest management would be distributed, though land area is not considered here. This gives a total for Great Britain of £4,136,647.

Table 9.5. Breakdown of costs of INNS to shooting in the United Kingdom. Based on figures from the PACEC survey (2006).

	England	**Wales**	**Scotland**	**NI**
Respondents	1481	235	652	57
%	61.1%	9.7%	26.9%	2.4%
Estimated NNS cost	£2,586,992	£410,701	£1,138,954	£97,383

9.8 Total Estimated Costs to Sector

Costs to the sector are summarised in Table 9.6. The general effects of INNS that degrade a site and have an impact on the general leisure/tourist experience have not been assessed. While these effects could influence the decision by a tourist to visit or return to an area, insufficient information and data are available to allow an accurate estimation of the economic cost of INNS on tourist decision making and spending. Therefore, this estimation of the cost of INNS to tourism and recreation is likely to be an underestimation of the true economic costs.

Table 9.6. Total annual costs of INNS to British Tourism and Leisure Industry

	England	Wales	Scotland	GB
Coastal tourism	£15,000			£15,000
Golf	£6,047,000	£717,000	£1,647,000	£8,411,000
Angling (inland)	£2,281,000	£364,000	£2,249,000	£4,894,000
Recreational boating	£28,101,000	£379,000	£1,971,000	£30,451,000
Waterway management costs	£17,488,000	£2,186,000	£2,186,000	£21,860,000
Giant hogweed	£516,000	£160,000	£289,000	£965,000
Japanese knotweed	£3,444,000	£469,000	£1,724,000	£5,637,000
Hull fouling	£18,441,000	£1,073,000	£1,854,000	£21,368,000
Shooting	£2,587,000	£411,000	£1,139,000	£4,137,000
Total	**£78,920,000**	**£5,759,000**	**£13,059,000**	**£97,738,000**

References

AINA (2008) Numbers of Boats on the Inland Waterways, Report of the 2008 AINA survey

Canning P (undated) The UK Game Bird Industry – A short study. ADAS Lincoln for Defra

Gollasch S (2002). The Importance of Ship Hull Fouling as a Vector of Species Introductions into the North Sea. Biofouling 18 (2): pp 105-121

Lyons J, Hickley P, Gledhill S (2002). An evaluation of recreational fishing in England and Wales. In: T.J. Pitcher & C.E. Hollingworth (eds) Evaluating Recreational Fisheries. Oxford: Blackwell Science, pp. 144–155.

National Rivers Authority (1995). National Angling Survey 1994. NRA Fisheries Technical Report 5. 31 pp.

Oreska MPJ and Aldridge DC (2010) Estimating the financial costs of freshwater invasive species in Great Britain: a standardized approach to invasive species costing. Biological Invasions Online

PACEC (2006). The Economic and Environmental Impact of Sporting Shooting. A report prepared by PACEC on behalf of The British Association for Shooting and Conservation, Country Land and Business Association, and Countryside Alliance and in association with Game Conservancy Trust. 109 pp.

Radford, A., Riddington, G., Anderson, J. & Gibson, H. (2004). The Economic Impact of Game and Coarse Angling in Scotland. Research report prepared for Scottish Executive Environment and Rural Affairs Department. 70 pp.

Rettie, A (2010) Buying a Beat. *In* 2010 Annual Review. Association of Salmon Fishery Boards. Strutt & Parker for ASFB, Edinburgh, Scotland, 31pp

Spedding A (2009) Environmental impacts – management for lowland gamebirds. RuSource Rural Information Network Briefing 949

UK tourism report (2009). Tourism volumes and values in 2008. Published by VisitBritain, VisitScotland, Visit Wales, Northern Ireland Tourist Board. 48 pp.

10 Construction, Development and Infrastructure

There are a few key INNS that affect the development of new land and building construction but they can add considerable additional costs as well as increasing annual maintenance costs of properties. They include species such as Japanese knotweed (*Fallopia japonica*), grey squirrel (*Sciurus carolinensis*) and brown rat (*Rattus norvegicus).*

10.1 Construction and Development

The main species that causes additional costs to the construction industry is Japanese knotweed. As discussed in the species example (chapter 4), the estimated annual cost is £150,510,000 (£141,358,000 for England, £7,644,000 for Wales and £1,508,000 for Scotland). A further cost to infrastructure caused by the presence of Japanese knotweed is the devaluation of housing, at a cost of £1,116,000, costs to householders at £448,000 and the amount local authorities spend in maintaining property and land for which they are responsible, amounting to £432,000.

Invasive weeds such as Himalayan balsam, giant hogweed and rhododendron as well as non native animals such as crayfish, rabbit and deer can also cause significant delays to development/urban regeneration projects. Larger developers are increasingly obliged to carry out thorough ecological assessments and include management plans and site specific method statements for eradication and control of non-native species in their proposals. Specialist environmental consultancies/contractors often provide the necessary services and these can cost £750 - £1200 per site (ADAS[61]), although it is likely that costs will be much greater with larger infestations and protracted time dedicated to the whole process. Japanese knotweed and giant hogweed are likely to cause the most significant impacts on the construction industry and escalate costs and delays due to legislative requirements to dispose of controlled waste at licensed landfill (£55/tonne) and the supply of eradication plans to local councils. Developers can have legal outlays due to these two species, with adjoining owners taking civil action and seeking damages due to the spread of these plants onto their property or failures to comply with the Environmental Act. Quotes of individual cases have ranged from £10,000 to £100,000 for Japanese knotweed (Neil Strong, pers. comm.). These miscellaneous additional costs were dealt with for Japanese knotweed in the

[61] http://www.adas.co.uk/

species example discussed earlier in this report. Work on the Olympic sites has reportedly been delayed by giant hogweed which invaded vast areas of land on the Stratford/Leyton border. Other reports from private weed contractors suggest calls to remove and advise on giant hogweed that posed a risk to workers on construction sites are not uncommon. Complete removal with a guarantee that it will not return cost £20,000 for an area described as not much bigger than a small town garden (Poison garden[62] website) and remediating a small contamination could cost over £130,000 (Muskateers Group[63]). Whilst estimates can be made for the high profile species Japanese knotweed, incidences of giant hogweed and other INNS on development sites can only be guessed at based on anecdotal references. Assuming an infestation rate of 0.1% in development/urban remediation sites for giant hogweed and an average cost of survey, treatment, waste disposal of £3,500 (estimate based on quoted rates for standard treatment and disposal measures) then based on number of planning applications made (see Japanese knotweed example), the cost to England is £1,316,836, to Wales is £66,679 and to Scotland £13,135.

10.2 Infrastructure

The ongoing maintenance of buildings is affected by INNS, in particular by the brown rat, house mouse and grey squirrel. Rats and mice are renowned for chewing through electrical and data cables and the pest control industry in the USA claims 26% of all electrical cable breaks and around 18% of all phone cable breaks are caused by rats. Brown rats will gnaw through any material softer than the enamel on their teeth, including most building woods, aluminium sheeting, soft mortar, poor quality concrete and asphalt and are estimated to cost between £61.9 million and £209 million per year in damage to society in England and Wales (Battersby 2004).

Nearly 75% of all pest control treatments carried out are due to brown rats. Around 60% of local authorities charge for a course of in-house or contracted treatment for rats and these can range in price to in excess of £100 per treatment depending on the location and size of the infestation. For house mice, 80% of local authorities charge and treatment can cost up to £70. According to the National Pest Technicians Association annual UK survey, there were a total of 378,000 professional, council-organised rat treatments carried out in 2007/8 and 144,000 house mouse treatments. If we take an average charge out rate of £50 per treatment for rats and £46 per treatment for mice (Bristol Council, pers. comm.), this provides an estimated expenditure of £18,900,000 for rats and £6,624,000 for mice in the

[62] http://www.thepoisongarden.co.uk/atoz/heracleum_mantegazzianum.htm

[63] http://www.musketeers-group.com/

UK. These figures are likely to be an underestimate, however, since they do not take into account the independent expenditure of occupiers/land owners, using commercially available pest control products or calling in alternative pest control companies. In addition, they do not capture all costs incurred by councils. The costs of control in sewers are included in the utility chapter.

The 2004 English House Condition Survey stated that 2.02% of the sampled homes were infested with mice and 3.28% with rats. Assuming infestation levels to be the same in 2008, the number of mouse infested homes in England is 445,074 (2.02% of 22,033,400) and the number of rat infested homes is 722,695. Meyer *et al*. (1995) found that a quarter of all rat infested properties were not subject to any control. Assuming this statement holds true for mice and rats in 2008, then 75% of mouse infested homes, i.e. 333,806 are treated and 542,022 homes are treated for rats. Taking an average treatment cost of £50 for rats and £46 for mice (as above), treatment of house mice in England costs £15,355,076 p.a. whilst treatment of rats costs £27,101,082 p.a. Since house condition surveys were unavailable for Scotland or Wales, infestation levels from the English house surveys were used to extrapolate rat and mouse costs in these countries based on number of households and dwellings data and a 75% control level. By this rationale, the cost of treatment of mice in Wales is £896,126 and £1,581,657 for rats. In Scotland rat control costs £2,867,450 and mouse control £1,624,628.

Table 10.1. Annual cost of rat and mouse control in homes.

	No. of mouse infested homes	Cost of mice/year	No. of rat infested homes	Cost of rats/year
England	445,075	£15,355,076	722,696	£27,101,082
Scotland	47,091	£1,624,628	76,465	£2,867,450
Wales	25,975	£896,126	42,178	£1,581,657
Total	**518,141**	**£17,875,830**	**841,338**	**£31,550,189**

Non domestic, surface infestation control of rats by local authorities in England and Wales is estimated to cost between £156,000-415,000 per annum (Battersby 2004) and it is considered appropriate to include this cost here as brown rats are known to impact on a large variety of habitats. Therefore, an average annual cost of £328,528 for England and Wales in today's terms has been included split according to land area. Scottish environment statistics from 1998 estimated that the percentage of the British rat population occurring in Scotland impacting on the environment is 13% therefore applying this percentage to the surface infestation costs gives an annual expenditure of £42,709 in Scotland.

In addition to the brown rat, the edible dormouse (*Glis glis*) is known to damage houses and impact on utilities and as it is listed on Schedule 6 of the Wildlife and Countryside Act 1981, trapping must be licensed. Forest Research collected infrastructure repair costs, which included 'nuisance', water pipe and electrical cable cutting, food and airing cupboard/storage/insulation spoiling and health issues associated with animals dying in water tanks or contaminating food. Costs also include occasional refusal of repeated insurance claims for damage caused by edible dormice. One couple in Tring placed an insurance claim of £2,000 for damages. Chiltern District Council quote a fee of £70 for up to five collections per cage over a six week period whilst a one-off charge to deal with any number of *Glis glis* in a home varies across councils from £82-130. Pest controllers in Bedfordshire reportedly received up to seven calls a day (Mail online, 2006[2]). Records indicate that approximately 1,000 animals were removed from about 400 properties in one year. No authority was able to provide an average number of visits per year but using the highest call out fee of £130 per council per pest controller to account for repeat call outs and reinfestations, then annual control costs from pest controllers and councils can be estimated at £52,000. With wiring and plumbing repair typically costing £150 (estimated from about half the properties) and taking into account insurance claims (one off cost quoted), the total associated property damage is estimated at £62,000 per year. The total cost of the damage caused by edible dormouse in England is therefore estimated at £ 114,000. Edible dormice do not occur in Scotland and Wales and no cost is included here.

Grey squirrels can do serious damage inside lofts. Many local councils have pest control services that either undertake squirrel control in properties (paid or for free) themselves, subsidize control by contractors, or direct people towards companies that can remove squirrels. Accurate figures for either the number of reports of damage or the money spent on squirrel control in buildings are difficult to obtain, though several councils were contacted in this regard. The London Borough of Richmond upon Thames (population 180,000) has received seven written inquiries or complaints about squirrels in the past three years. Kettering council (Northamptonshire, population 82,000) receives around 15 calls per year for squirrels, each one of which is dealt with within three visits at a cost of £56 per hour plus materials. Bath and North-East Somerset council (population 180,000) receive an estimated 60-80 enquiries about grey squirrels per year. It is assumed that the average number of inquiries in the three councils that responded to this request for information (2.03 inquiries per 10,000 inhabitants per year) is typical for England and Wales, while only a quarter of that number is assumed in Scotland, due to the lower number of grey squirrels. If each of the those inquiries is dealt with by eradicating the squirrels in three visits at a cost of £56 per visit, then the annual control cost can be estimated at £1,754,514, £44,067 and £115,974 for England, Scotland and Wales respectively, giving a total of £1,914,555.

Apart from control, costs will be incurred as a result of the damage done by squirrels in properties. The vast majority of household insurance policies have a clause excluding damage by vermin, and incidents have been reported of homeowners facing bills in the thousands and as high as ten thousand pounds (The Mail online, 2006[64], The Guardian, May 2006[65]) as a result of squirrel damage to furniture, ornaments and even due to fire outbreaks. Albeit rare, repeated damage to homes and power outages in homes as a result of squirrels chewing cables is known to occur. If it is assumed that squirrels cost an average of £150 of damage to each house (a conservative estimate for DIY replacement of loft insulation, commonly affected) and that three times as many people who contact their council with enquiries about grey squirrels suffer damage (i.e. 6 out of every 10,000 inhabitants - see case study estimates), the damage done to houses can be estimated at £5,128,274 (England £4,699,593, Scotland £118,036 and Wales £310,645). Based on grey squirrels density and distribution data, only a quarter of the Scottish population is assumed to be affected by grey squirrel damage. The total cost of grey squirrel control and damage is estimated at £7,042,829.

Both rose ringed parakeets (Psittacula *krameri*) and monk parakeets (*Myiopsitta monachus*) are known to damage buildings or structures (such as masts), especially in the London area where the populations are concentrated. Specific damage to a listed building was estimated at £60,000 (Anon, 2009), but it is recognised that there are one-off costs so an estimated annual cost of £10,000 is included.

Signal crayfish (*Pacifastacus leniusculus)* are known to burrow into river and canal banks and cause erosion damage to the infrastructure of canals, as well as river banks. While this may cause an increased flood risk, this damage to river and canal banks could also lead to banks collapsing, therefore requiring restoration work, involving revetments and other man-made support structures. These structural costs are included here and as discussed in the species example, are estimated at £200,000 per annum, although this will be very variable dependent on the number of projects undertaken. Chinese mitten crab are known to have the same effect on river and canal banks as signal crayfish, and in addition zebra mussels

[64] http://www.dailymail.co.uk/news/article-400958/163-10-000-rampage-squirrel-fell-chimney.html

[65] http://www.guardian.co.uk/money/2006/may/14/homeinsurance.insurance

can foul lock gates and mechanisms. Therefore, British Waterways undertake INNS control work at a cost of £1 million each year (British Waterways 2008) to prevent damage to the infrastructure of the canals. Only a small proportion of this spending will be associated with the canal infrastructure, rather than keeping canals clear of water weeds for example, and therefore 15% of this cost is attributed to INNS control for infrastructure, estimated at £150,000 p.a.

Buddleia (*Buddleia davidii*) causes serious damage to built structures as its tiny wind-blown seeds can germinate in decaying mortar between brick courses and the subsequent plant can displace the bricks (Booy *et al*. 2008). Infrastructure maintenance companies have started to take a more proactive approach, as the problems that buddleia causes have been recognised and the cost of remedial measures realised. Large regenerative development plans in cities, such as the London fields lido, reportedly involved clearance of lorry loads of buddleia bushes by 180 volunteers over a period of 4 days (2006). Medway Council's repair and maintenance fund for 2004/5 outlines costs of survey, buddleia removal and repairs for Rochester Castle and City Wall and Upnor Castle totalling £51,950 (£55,766 today, averaging at £18,500 per building). Listed and historical buildings are particularly vulnerable and often require their walls to be repointed and consolidated through local council funds and heritage trusts. The total number of listed buildings at risk (i.e. known by Heritage Trusts to be at risk of or vulnerable to neglect and decay) for England reportedly stands at 1631, 2882 in Wales and 2284 in Scotland. According to the most recent English house condition survey, 7.7 million houses (public and private sector) were considered unfit with 1,579,000 of these failing on the repair criterion. In Scotland and Wales the latest surveys report 1,810,000 and 98,000 houses qualifying as unfit due to disrepair. Since very little information is available on the actual costs to councils of buddleia removal, one can only make rough estimations based on the potential vulnerability of derelict houses and listed buildings to the impacts of the plant. A residential property tribunal services report details a £375 bill for buddleia removal. Taking a conservative figure that of the properties, under disrepair in England, Wales and Scotland only one in 1,000 have a buddleia issue which is treated at a cost of £100, then the cost to England is £157,900, and to Wales is £9,800 and £181,000 for Scotland giving a total of £348,700 for Great Britain. This figure was more than matched by councils and those organisations responsible for landmark properties when considering the Medway Council costs, which we have assumed to be representative of all councils. Estimating conservatively that 5 in every 1000 vulnerable heritage building has buddleia and an average survey, removal, repair cost of £18,000 then the total spend in England is

£146,790, Wales is £259,380 and Scotland is £205,560. The total cost of buddleia to England is £304,690, Wales is £269,180, Scotland is £386,560 giving a total of £960,430 for Great Britain.

In the US, between $200 - $300 million of damage is done to property each year by termites. It is still difficult for termites to establish themselves in the UK as the climate is not ideal and though the damage that they cause can sometimes be catastrophic, it takes several years to attain these population levels. One example where levels did reach catastrophic levels was in Devon, where a colony was found infesting a bungalow leaving it uninhabitable and government funding of £190,000 was announced to eradicate the colony and to monitor the surrounding area (Verkerk *et al.* 2001). This one-off cost is included for termite control in England.

There are two main types of cockroaches prevalent in the UK, the Oriental cockroach (*Blatta orientalis*) and the German cockroach (*Blattella germanica*). An infestation of cockroaches can number in the thousands though they are not normally associated with damage to buildings or vegetation. However, it has been known for their corrosive body fluids to cause short circuits and fires in electrical systems. The main impact of cockroaches relates to human health and food contamination and this is considered in a later section.

10.3 Total Estimated Costs to Sector

The total estimated cost of INNS to the construction and development sector, as well as to infrastructure in Great Britain is £225,940,000 (Table 10.2).

Table 10.2. Estimated annual costs of INNS to the Construction, Development and Infrastructure sectors

	England	Scotland	Wales	GB
Japanese knotweed - construction	£141,358,000	£1,508,000	£7,644,000	£150,510,000
Japanese knotweed – housing devaluation	£963,000	£97,000	£56,000	£1,116,000
Japanese knotweed - households	£383,000	£42,000	£23,000	£448,000
Japanese knotweed – local authority management	£270,000	£96,000	£66,000	£432,000
Other plants - construction	£1,317,000	£13,000	£67,000	£1,397,000
Brown rat-control	£27,101,000	£2,867,000	£1,582,000	£31,550,000
Brown rat –surface control	£300,000	£43,000	£28,000	£371,000
House mouse-control	£15,355,000	£1,625,000	£896,000	£17,876,000
Edible dormouse	£114,000	_	_	£114,000
Grey squirrel - damage	£4,699,000	£118,000	£311,000	£5,128,000
Grey squirrel - control	£1,755,000	£44,000	£116,000	£1,915,000
Parakeets	£10,000	_	_	£10,000
River/ Canal bank/lock infrastructure repairs	£300,000	£30,000	£20,000	£350,000
Buddleia - disrepair control	£158,000	£181,000	£10,000	£349,000
Buddleia- listed buildings	£147,000	£206,000	£259,000	£612,000
Termites	£190,000			£190,000
Total	**£194,420,000**	**£6,870,000**	**£11,078,000**	**£212,368,000**

References

Anon. (2009). Article in "This is Croydon today". http://www.metro.co.uk/news/362878-parakeets-destroying-precious-windmill

Battersby JE (2004). Public health policy – can there be an economic imperative? An examination of one such issue. *Journal* of Environmental Health Research 3: 19-28

Booy O, Wade M, White V (2008). Invasive species management for infrastructure managers and the construction industry. Construction Industry Research and Information Association (CIRIA) Publication C679. 240 pp.

British Waterways (2008). Press release 14/08/2008. http://www.britishwaterways.co.uk/newsroom/all-press-releases/display/id/2221

Meyer AN, Shankster A, Langton SD, Jukes G (1995) National Commensal Rodent Survey 1993. Environmental Health 103, (6) 127-135.

Verkerk R and Bravery AF (2001) The UK termite eradication programme: Justification and implementation. Sociobiology 37, 351-360.

11 Transport

Transport is one of the main methods through which INNS spread from country to country and within a country and the transport sector itself experiences costs due to the presence of INNS. In the shipping industry, a major cost relates to ballast water, while for both the road and rail networks terrestrial weeds such as Japanese knotweed (*Fallopia japonica*), buddleia (*Buddleia davidii*) and giant hogweed (*Heracleum mantegazzianum)* cause problems. Non-native trees can also cause problems on these networks through excessive leaf drop whilst some rodents, mammals and birds can have major impacts through collisions and damage to infrastructure. Bird strikes cost the aviation industry a significant amount per annum, both through the cost of strikes and through the prevention measures undertaken to reduce the number of bird strikes.

11.1 Road Network

Japanese knotweed is a major INNS of concern to those who manage the road network. The (national) Highways Agency has stated that they spend significant amounts on Japanese knotweed each year. Local highways agencies also control Japanese knotweed along the minor road network. The total cost of Japanese knotweed to the whole road network in Great Britain is estimated at £5,096,000 (see species calculations).

There are other species of concern to the national Highways Agency, including rabbit and giant hogweed. The Highways Agency stated that they spend a total of £228,500 on control of all weed INNS (questionnaire response). As discussed in the species example for Japanese knotweed, 2/3^{rds} of the Highways Agency spending was assumed to be on Japanese knotweed control and therefore the remaining third is spent on all remaining non-native weed control. This gives a cost per kilometre of £2.27 and therefore it is estimated that the Highways Agency spends a total of £113,953 per annum on control of weeds other than Japanese knotweed in England. Similarly, using the Department for Transport statistics for minor roads in the three countries (Anon 2009), the spend can be estimated at £602,545 (for England's 265,700 km of minor roads), £67,017 (for Wales' 29,552 km of minor roads) and £111,039 (for the 48,964 km of minor roads in Scotland). The total expenditure on minor roads on weed INNS for Great Britain is estimated to be £780,601.

The Highways Agency spend a total of £615,000 on rabbits across the whole network of trunk roads and motorways in England as a consequence of direct control using specialist contractors, vegetation management (e.g. removal of harbouring shrubs), litigation charges and vegetation protection (i.e. cost of installing and removing plastic shelter for trees, etc.) (D. Griffiths, pers. comm.). This would equate to roughly £17 per km using the national figures for the road network in England. We can extrapolate figures for Wales and Scotland to £75,074 and £186,212, respectively. The total cost of rabbits on the main British road network is £876,286. This does not include for the cost of rabbits on minor roads.

In addition to spending on the control of INNS by the Highways Agency, another significant cost is that caused by collision with non-native deer species (Dr Jochen Langbein, pers. comm.). Vehicle damage caused by deer is estimated at £17 million per annum of which 80% happens in England, 19% in Scotland and less than 1% in Wales[66]. Therefore, the costs caused by all deer can be estimated as £13.6 million in England, £3.23 million in Scotland, and £170,000 in Wales. In England 40% of deer-vehicle collisions (DVCs) are caused by fallow, 25% by muntjac and less than 3% by sika and Chinese water deer. Therefore, costs in England due to non-native deer are reduced to £9,249,000. In Scotland, fallow and sika deer have much smaller populations compared to the native deer and only about 6% of DVCs are attributable to non-native deer at a cost of £193,800. Information for Wales is limited, but based on population distribution figures from the British Deer Society, approximately half the costs of collision may be attributable to non-native deer and therefore a cost of £85,000 is estimated.

In addition to this vehicle damage cost, some of the culling of deer is likely to be due to attempts to reduce deer numbers to reduce vehicle collisions. Therefore 6% of the total cost of culling, as discussed in section 5.4.1, is estimated to be undertaken to prevent vehicle collisions, giving a cost of £593,841 in England, £124,338 in Scotland and £20,725 in Wales, a total of £738,904.

Thus, the total costs of INNS to the road network are estimated to be £17,133,438, of which £1,372,474 in Scotland, £15,075,732 in England and £685,232 in Wales.

11.2 Railway Network

Non-native trees, such as sycamore (*Acer pseudoplatanus)*, horse chestnut (*Aesculus hippocastanum)* and sweet chestnut (*Castanea sativa*) can cause significant problems to management of the railway network in the south of England. Other plant species, such as Japanese knotweed, giant hogweed, Himalayan balsam and buddleia, often require specific

[66] http://www.highways.gov.uk/knowledge/documents/DeerAware_FAQs.pdf

management across the network. Network Rail spends approximately £25 million on non-native vegetation management annually, however it should be recognised that this is not targeted specifically at the non-native species and is purely as a result of the routine vegetation management necessary to operate the railway infrastructure. Using the distribution of railway as an approximation for the split of expenditure, roughly 66% of this spend is in England (£16.6 million), 17% in Wales (£4.2 million), and 17% (£4.2 million) in Scotland (Neil Strong, pers. comm.).

Non-native trees falling on power lines can cause train delays several times a year, at a cost of £400 per minute at peak times[67]. Increased leaf senescence caused by the horse chestnut leaf miner (*Cameraria ohridella*) may cause problems if there are large concentrations of chestnut adjacent to busy sections of the railway and the requirement to treat species such as the oak processionary moth (*Thaumetopoea processionea*) have cost up to £10,000 in one location. In 2003, Network Rail estimated that tree leaves falling on the rails each autumn caused 3,000 minutes of delays[68]. Recent reports indicate that these costs have been reduced year on year. In 2000, the environmental consultancy ADAS highlighted six species of trees, half of which are non-native (ash, poplar, sycamore, sweet/horse chestnut and lime) that cause the most trouble[69] and are the ones targeted for specific removal on the rails. If we assume that leaves now cost Network Rail 2000 delay minutes annually and that half the delay minutes are attributed to non-natives, through leaf fall or tree fall, and that the cost is £400/minute then a further £400,000 is added. Using the same proportions as above, this cost is divided as £264,000 in England, and £68,000 in both Scotland and Wales.

The brown rat (*Rattus norvegicus*) does not pose a major problem to the railway network, although isolated incidents have generated substantial reactive costs and delay costs. Battersby (2004) reviewed the issues of rats on the railways and confirmed that damaged cables and subsequent impact on signalling were the main causes of concern, including power failures caused by gnawed cables. Based on information supplied by Railtrack, Battersby (2004) proposed that potential costs to the railways and its passengers as a result of damage could be between £1.6 and £5.7 million when one takes into account potential penalties, delays to passengers and treatment costs. Using the middle of Battersby’s range £3.65 million (£4.2 million today) these costs are split between England and Wales, according to the proportions of spending by Network Rail on management of other non-

[67] http://www.rfs.org.uk/leaves-line
[68] http://news.bbc.co.uk/1/hi/uk/8314114.stm
[69] http://www.thisislondon.co.uk/news/article-949700-the-villain-leaves-that-stop-trains.do

native species, giving an estimated spending of £3,340,000 in England and £860,000 in Wales. Scotland is assumed to have the same spending as Wales (as above) with an estimated cost of £860,000, giving a total cost of rats of £5,060,000.

Total costs of INNS to the railway network are therefore £30,460,000 of which £20,204,000 in England, £5,128,000 in Scotland and £5,128,000 in Wales.

11.3 Aviation

The most significant cost to the aviation industry from INNS is the cost of bird strikes to aircraft. The species known to cause the majority of bird strikes are gulls (several species) and wood pigeons. However the species causing 60% of strikes are unknown[70]. The only non-native species specifically mentioned was pheasant (*Phasianus colchicus*), causing 10 strikes in 2009.

The majority of bird strikes have no effect on the flight[71] and presumably cause no damage due to the small size of the bird. However, Canada geese (*Branta canadensis*) are known to have the potential to cause significant economic damage if they hit an aircraft and cause it to crash. No major incidents have been reported in the UK at present, although Baxter and Robinson (2007) report that Canada geese were hit by aircraft 11 times in the UK between 1994 and 2004, an average of one hit per year. An analysis of damage following a strike with Canada geese revealed 40% of events caused damage to aircraft (CAA 2001) with actual losses approximately £28,000-£100,000 per annum, averaging at £64,000 (Fera, pers. comm.). In addition, a bird the size of a pheasant is also likely to cause some damage, though less than Canada geese, due to their solitary rather than flock nature. Therefore, a damage estimate of approximately half that of Canada geese is estimated (£30,000 per bird) and for the 10 pheasant strikes experienced in 2009 a further £300,000 is estimated. Bird strikes are reported to cost the Royal Air Force around £8 million in repairs to aircraft annually, though not all due to INNS. Based on the data from the Civil Aviation Authority (CAA 2001) that suggest that very few non-native species are involved in bird strikes it is assumed only £500,000 of this is attributable to non-native birds including Canada geese and pheasants. The total costs due to damage were estimated at £864,000 annually.

The increase in the numbers of rose-ringed parakeets (*Psittacula krameri*) around London has also presented a bird strike problem to aircraft. In 2005, 54 bird strikes were reported at

[70] http://www.caa.co.uk/docs/375/srg_asd_ukbirdstrikestopspecies_2009.pdf
[71] http://www.caa.co.uk/docs/375/srg_asd_ukbirdstrikes_2008various.pdf

Heathrow Airport, one of which involved rose-ringed parakeets. In 2006, 44 bird strikes were reported of which two involved rose-ringed parakeets. All these bird strikes involved more than one bird. However, given the size of these birds, as compared to Canada geese, it is likely they do comparatively little damage to aircraft. Therefore a cost of £5,000 is estimated per parakeet strike and based on an average of three to four bird strikes per year (Fera, pers. comm.) then the annual cost of rose-ringed parakeet bird strikes can be estimated at £17,500.

The London airports spend £250,000 per year on habitat management and a further £125,000 on general control to prevent bird strikes on aircraft (BAA, pers. comm. to Fera) and a Fera spokesman suggested that airports across the UK were spending millions in bird management to avoid collisions[72]. Advice notes published by the Airport Operators Association[73] concerning safeguarding airports against birds make no mention of any non-native species, but concentrate primarily on gulls, starlings and pigeons. Although non-native species are likely to contribute to the need for habitat management in and around airports, it appears that very little of the management costs can be specifically attributed to INNS. Therefore of the £375,000 spent by London airports annually 10% is attributed to non-native birds. National transport data for airport passenger traffic indicates that the London airports represent about 65% of all air traffic (CAA, 2008) and therefore using the costs for London airports, and airport passenger numbers, the total cost of habitat management in all major airports in Great Britain is estimated at £52,321 for England, £112 in Wales and £5,726 in Scotland, a total of £58,159.

As discussed by the Airport Operators Association advice notes, planning applications within 13 km of an airport or aerodrome need to consider the effects of the development on bird movements including roosting and feeding patterns. It is possible that some planning applications are delayed or refused due to a lack of consideration of these issues, but data concerning the number of applications near airports, and whether bird management was an issue in the consideration of the application is not available. Therefore the estimated costs of non-native birds to aviation may be underestimated.

A total cost to the aviation industry of INNS was estimated at £939,659 per annum, with the majority of this cost being in England (£613,821), £245,726 in Scotland and £80,112 in Wales.

[72] http://www.guardian.co.uk/environment/2009/jan/25/canada-geese-airport-cull
[73] http://www.aoa.org.uk/publications/safeguarding.asp

This cost would increase dramatically if an aircraft were brought down by a bird strike by Canada geese, and there may be additional one-off costs, such as that reported by the Civil Aviation Authority (CAA, 2008) where it was stated that one airport authority in Canada reached a $5.3 million pre-trial settlement with one airline after an airliner was struck in 1995 by at least one Canada goose at their airport.

11.4 Shipping

The costs of INNS to the shipping industry are due primarily to the cost of ballast water management. There are also costs associated with hull fouling, and increased costs associated with running ports and harbours where INNS are present. The costs of INNS on inland waterways have not been included in this sector, apart from where a river is used by commercial shipping, such as the River Thames up to the Port of London. Other costs associated with boat movement on inland waterways have been attributed to tourism and recreational activities. Costs associated with the fishing industry are included in the aquaculture sector.

A number of INNS are known to have an impact on ships through fouling, such as leathery sea squirt (*Styela clava*), Australian barnacle (*Elminius modestus*) and other algae, molluscs and tunicates. Most commercial ships undertake hull-cleaning measures and use anti-fouling paint, whether the species are native or non-native, as fuel consumption is lowest when the hull is clean. There is limited data concerning the percentage of native and non-native species found on ships' hulls, but Gollasch's (2002) study of fouling on international shipping traffic found INNS in 57% of all sampled ships' hulls in Germany. No data on the abundance of INNS on ship's hulls are available and we have assumed that 50% of the fouling organisms on ocean-going ships are non native and thus we have attributed half of the cost of hull cleaning and painting to INNS.

The cost of hull cleaning and painting varies considerably depending on the size of the vessel, the amount of cleaning that needs to be done, and the type and number of coats of anti-fouling paint required (Milford Haven Ship Repairers, pers. comm.). Ferries are required by law to dry dock every year, while tankers are required to have an intermediate clean every three years and a major clean every five years. A tanker will cost over £100,000 to blast clean and paint (Milford Haven Ship Repairers, pers. comm.). Although there were 131,000 ship arrivals to UK ports in 2008, there were only 2,103 vessels owned by UK companies[74] (over 100 gross tonnage), and as the cost of hull cleaning and painting will be paid for by the owner, only the cost of treating 2,103 ships is considered. Of the UK owned 2,103 vessels, 193 were roll-on roll-off or passenger ferries, and the remainder were container ships or specialist carriers, such as liquid tankers. If container ships are fully cleaned once every five years, 20% (382) are likely to be cleaned each year, in addition to the 193 ferries that must be cleaned annually. A cost of £100,000 is assumed on the basis that all tankers will need to have blast treatment and painting every five years, and that although ferries may not need such extensive treatment, the lower cost per ferry is compensated for by the cost of intermediate treatments (every three years) for tankers. Therefore a cost of £57,500,000 is estimated for the total cost of hull treatment each year. However, as discussed above, only 50% of this is assumed to be attributable to the presence of INNS and therefore the cost is reduced to £28,750,000.

An audit of "alien species" in the River Thames found a large population of zebra mussel present in a short stretch of the river near Richmond[75]. This has caused a number of accidents on the Thames due to excessive fouling of propellers and rudders. Oreska (2009) estimated the annual costs of mussel management based on boat cleaning, occurrence records and numbers of boats at around £4 million. Given the notable increases in zebra mussel in southern, central and eastern England (Aldridge *et al*. 2004), their significant extent in commercially used rivers in these areas and the potential for expensive accidents, this figure is likely to be appropriate for the whole of England. Port authorities can be expected to incur some costs, but based on the feedback received from the questionnaire, these are insignificant.

11.5 Ballast Water Management

All costs associated with ballast water management can be attributed to INNS, as ballast water exchange treatments are specifically designed to prevent the spread of INNS across the world's oceans. The Ballast Water Convention stipulates discharge standards that will come into force between 2009 and 2016, depending on the type and size of vessel (Fisheries Research Services, 2006). In the interim, ships will be required to exchange ballast water over 200 nautical miles from land in water over 200 m deep. However, much shipping from Great Britain involves short coastal journeys from continental Europe that do not fulfil either the depth or distance criteria. Therefore, many vessels are currently not required to fulfil either standard outlined in the Convention. Current costs to Great Britain

[74] http://www.dft.gov.uk/adobepdf/162469/221412/221658/223721/4082361/maritimestatistics2008.pdf
[75] http://www.thisislondon.co.uk/standard/article-23431277-alien-mussels-invade-thames.do

shipping are therefore limited to ballast water exchange on voyages beyond Europe and to costs associated with retro-fitting ballast water treatment systems on vessels, although this appears to be in the early stages and so no costs have been estimated during the current year.

The Orkney Island council prohibits vessels from discharging ballast in Scapa Flow and estimated that they lose over £500,000 per annum in reduced profit as vessels chose to use other ports that have more liberal ballast water requirements (A. Simpson, pers. comm.). This cannot be attributed as a net cost to the Scottish economy, however, as the business will presumably have moved to other Scottish ports.

Vessels built before 2009 are required to carry out ballast water exchange as described above until 2014 or 2016, depending on the size of the vessel, after which they will all be required to treat ballast water. Vessels built from 2009 onwards are required to have a ballast water treatment system, the cost of which will be included in the construction of the vessel. The equipment costs an average of \$380,000 (£239,324) for a 200m^3/hr plant and \$875,000 (£550,375) for a 2000m^3/hr plant (Lloyd's Register 2007). 3445 new sea going merchant ships were built in 2009 (Fairplay, Lloyds Register, pers. comm.) but none of these ships were built in Great Britain. In addition, the majority of companies ordering these vessels are large international companies with worldwide operations, and so no additional costs can be attributed specifically to the British economy from construction incorporating ballast water treatment plants (Fairplay, Lloyds Register, pers. comm.).

The total cost of INNS to the shipping industry is therefore estimated at £32,750,000 with £2,875,000 Scotland, £27,000,000 England and £2,875,000 Wales. The split between the countries is based on the assumption that four fifths of the losses are incurred by England with the remainder shared equally between Scotland and Wales.

11.6 Total Estimated Costs to Sector

Table 11.1. Total annual costs of INNS to transport

	England	**Wales**	**Scotland**	**GB**
Roads	£15,076,000	£685,000	£1,372,000	£17,133,000
Railway	£20,204,000	£5,128,000	£5,128,000	£30,460,000
Aviation	£614,000	£80,000	£246,000	£940,000
Shipping	£27,000,000	£2,875,000	£2,875,000	£32,750,000
Total	**£62,894,000**	**£8,768,000**	**£9,621,000**	**£81,283,000**

References

Aldridge DC, Elliott P, Moggridge GD (2004). The recent and rapid spread of the zebra mussel (*Dreissena polymorpha*) in Great Britain. Biological Conservation 119: 253-261

Battersby JE (2004). Public health policy – can there be an economic imperative? An examination of one such issue. Journal of Environmental Health Research 3: 19-28

Baxter AT, Robinson AP (2007). Monitoring and influencing feral Canada goose (*Branta canadensis*) behaviour to reduce birdstrike risks to aircraft; Advances in vertebrate pest management. Proceedings of the 5th European Vertebrate Pest Management Conference, Budapest, Hungary, 5-8 September 2005. International Journal of Pest Management 53: pp. 341-346

CAA (2001). Large flocking birds – an international conflict between conservation and air safety. Civil Aviation Authority Safety Regulation Group. http://www.caa.co.uk/docs/1437/srg_acp_00018-01-030303.pdf

CAA (2008). UK airport statistics. www.caa.co.uk

Fisheries Research Services (2006). Aquatic Organisms in Ships' Ballast Water. http://www.marlab.ac.uk/Uploads/Documents/AE06BallastWater.pdf

Gollasch S (2002). The Importance of Ship Hull Fouling as a Vector of Species Introductions into the North Sea. Biofouling 18 (2): pp 105-121

Lloyds Register (2007). Ballast water treatment technology: Current status. 35 pp.

Oreska MPJ (2009). Assessing the economic aspects of aquatic invasive species in Great Britain. Master's thesis, Cambridge UK

12 Utilities

The utility sector is critical to the way people live in Britain today. The supply of electricity, gas, clean water, and the provision of telecommunications, both phone and internet, are all considered to be essential. INNS have a limited effect on this sector, but they still do cause additional costs to the industry in terms of damage to infrastructure and additional control and clearance costs. Both the water and electricity generation industries are discussed below. No costs to the telecommunications industry due to the presence of INNS were discovered during the course of the research.

12.1 Water Industry

One of the main INNS affecting this industry is the zebra mussel (*Dreissena polymorpha)*, one of the most invasive freshwater pests in the world. The annual cost of zebra mussels to industry in North America is estimated to be *circa* $5 billion (Aldridge *et al*. 2004) and the costs in Great Britain are rapidly increasing. Although the creatures are smaller than 2 cm, they cling together to form large populations, which can block water pipes and outlet pipes from power stations. Thousands of tonnes have already been found in London's water pipes, constricting the flow and forcing Thames Water engineers to clear clogged pipes (Observer, October 2006), whilst many other water suppliers use specialist contractors to remove zebra mussel from their condensers each year.

There are 25 main water and sewerage companies supplying England and Wales and one in Scotland (covering 8 million ha). In England, the largest company by population served is Thames Water, which covers an area of 1.2 million ha. Bristol Water, covering an area of 1,500 ha, reported costs of £21,750 per annum for management of invasive species including weeds (<1 %), mink, signal crayfish and zebra mussels. Northumbrian Water spent £44,775 annually on the management of INNS, and Anglian Water, covering 2.7 million ha, spent on average £75,000 per annum on controlling zebra mussel. Oreska and Aldridge (2010) have calculated that the cost of zebra mussel alone to the water industry is £551,400 per year. There are approximately 361,402 km of water mains in Scotland, England and Wales. Using an average cost per km from the three water companies above (£2.61), the water industry spends approximately £943,259 per year on controlling INNS.

These costs, however, do not include any one-off costs from zebra mussels that may be caused by biofouling. Water intake structures for municipal, industrial and hydroelectric plants are highly vulnerable to fouling if they draw intake water from an infested water body.

In Northern Ireland, zebra mussels have blocked water intake pipes at Killyhevlin water works in Enniskillen and modifications were needed at a cost of over £100,000 (Maguire and Sykes 2004). Anglian Water has included mussel traps in the design of one system at a capital cost of £70,000 (Barrie Holden pers. comm.). Capital spend required for a new zebra mussel control system will be approximately £500,000, and such a control system should last 20 years (questionnaire, P. Bulmer, Bristol Water). Given the period that such a control system lasts, it is likely in any given year that only one such capital project is undertaken by the water industry as a whole, to combat the effects of zebra mussels, and therefore only £500,000 is added to the annual costs of control.

A further expense to the water industry, this time the sewage network, rather than the mains network, is the presence of brown rat (*Rattus norvegicus*). The expenditure on sewer baiting for the control of rats was assessed using the proportion of Thames Water's baiting costs (21.25% of sewers baited), which in 1989 cost £36.88 per km of sewer baited (£42.43 today; Battersby 2004). If all major sewerage companies bait the same proportion of the national sewerage network (359,763 km), then the cost for Great Britain is approximately £3,243,758 (England £2,641,406, Scotland £448,682 and Wales £153,670.

This gives an annual cost to water companies of approximately £4,687,017 for Great Britain (England £3,816,658, Scotland £648,316 and Wales £222,044)

12.2 Power Companies

Virtually all power stations will have INNS problems to deal with from aquatic species like curly water weed (*Lagarosiphon major*), Chinese mitten crab (*Eriocheir sinensis*) and zebra mussel (*Dreissena polymorpha*) that block water intakes, riparian plants, nesting birds, and brown rats which chew electrical cables. Historically, mussels had to be cleared by hand from condenser culverts on a regular basis. Many coastal power stations control fouling by chlorination, whilst in freshwater, where one of the most damaging fouling organisms is the zebra mussel, a variety of approaches are used including heat treatment and the use of intake screens. It has been shown that the single largest return on investment for power plants maintenance expenditure is in condenser cleaning (Conco Systems newsletter, 2008[76]). Because nuclear power plants use large quantities of water they tend to have the highest associated costs per plant, followed by industrial plants, fossil fuel power plants, and drinking water facilities. Private companies, such as Tube Tech International, use an advanced form of darting technique in the 8,000 tubes of the turbine condenser and reported numerous visits to individual power stations. These routine operations are likely to be costly.

[76] http://www.concosystems.com/Files/Downloads/Conco_FALL_Newsletter_08.pdf

It was not possible, however, to gain any detailed information on these costs from this industry so it is necessary to make an estimate for the 2,615 plants producing in excess of 1 MW in the UK (Digest of UK Energy Statistics, 2005[77]). Some stations will spend hundreds of thousands of pounds whilst others spend a lot less. Assuming that each station incurs an average of £2,000 worth of costs per year, then the annual cost to the power industry is £5,230,000. If this is apportioned by population then the costs to England are £4,497,800, to Scotland, £470,700 and to Wales, £261,500.

As discussed in the transport sector, one off costs to the railway industry due to non native tree fall on electricity pylons can prove costly with one incident costing £200,000 in delays and this is included here for England.

12.3 Total Estimated Costs to Sector

The total costs to the sector are estimated at £10,117,000, of which England £8,515,000, Scotland £1,119,000 and Wales £483,000.

Table 12.1. Annual costs of INNS to the utility industries.

	England	**Scotland**	**Wales**	**GB**
Water companies	£3,817,000	£648,000	£222,000	£4,687,000
Power stations	£4,498,000	£471,000	£261,000	£5,230,000
Railway power lines	£200,000	-	-	£200,000
Total	**£8,515,000**	**£1,119,000**	**£483,000**	**£10,117,000**

References

Aldridge D, Elliott P, Moggridge G (2004). The recent and rapid spread of the zebra mussel (*Dreissena polymorpha*) in Great Britain. Biological Conservation 119: 253-261

Battersby JE (2004). Public health policy – can there be an economic imperative? An examination of one such issue. Journal of Environmental Health Research 3: 19-28

Maguire MC and Sykes LM (2004). The Zebra Mussel Management Strategy for Northern Ireland 2004-2010. Report Queen's University Belfast. 57pp.

Oreska PJ and Aldridge DC (2010) Estimating the financial costs of freshwater invasive species in Great Britain: a standardized approach to invasive species costing. Biological Invasions: on-line July 2010

[77] http://www.berr.gov.uk/files/file10737.pdf

13 Research

Research into INNS is important, as it enables a better understanding of the problem species and the prevention and mitigation measures available. This should result in a reduction in associated spend in the long run. Research enables evidence-based policy to be developed at both a local and national level. Research and policy are linked in this section as they can both be considered to be direct methods to pre-empt future invasive species problems, and may curb the effects of INNS already present in the country.

Funding for science and policy research comes from many organisations, at a local, national and international level. Many of the projects on problematic INNS in Great Britain are funded by a coalition of many donors, thereby creating a risk of double counting the total costs involved in science and policy research. Therefore, the format for this section is organisation-orientated, and the amount of money spent by each organisation, as found in the grey literature, on internet sites and through interviews with scientists, was averaged out over the period 1999-2009, resulting in an average annual spend by each large organisation in Great Britain (Table 13.1). Projects that started in 2009 and continued for several years were included, but project funding with a later start date was not included. Where no details were forthcoming, an estimate was made based on the proportion of an annual budget that was allocated to a project or theme.

13.1 Defra

The main governmental agencies carry most of the costs relating to research. Defra has funded at least 24 INNS projects since 1999, a majority of which were applied research. Within these, many were focused on particularly problematic species, such as rabbit, ruddy duck and Japanese knotweed. Some of these projects have been carried out by organisations such as Fera, and where known, projects funded by Defra, even where carried out by other bodies, are included here. The average annual spend is around £4.5 million, which includes the bee project allocation of £1.3 million, or a total of £3.2 million if the spending on bee research and policy is excluded. A Defra response to the questionnaire indicated a spend of £707,304 on INNS research in 2009. The discrepancy is most likely to be due to annual fluctuations, but could also be due to some policy work being included here in addition to the research work.

Table 13.1. Defra funding

Subject Summary	**Value**	**Period**	**p.a.**
Apple pests	£531,379	1999-2003	£106,000
Assessing the risk of INNS to the environment	£60,000	2004-2005	£30,000
Beekeeping	£1,300,000	Annual	£1,300,000
Bemisia tabaci	£142,164	1999-2003	£28,400
Bemisia tabaci and other whitefly species	£61,527	2001-04	£12,300
Bemisia tabaci on poinsettia cuttings	£29,443	2005-06	£15,000
Climate change risks and impacts of INN fish	£870,000	2007-2012	£145,000
Decision support for invasive aquatic macrophytes	£84,000	2009-2010	£42,000
Defra policy, delivery, publicity work (excluding projects identified separately)	£1,727,000	Annual	£1,727,000
Didemnum vexillum survey work	£30,000	1 year	£30,000
Economic Costs of INNS	£35,000	1 year	£35,000
Future threats to arable weed management	£34,682	2009	£34,682
Indicator of INNS abundance	£30,000	2008-2009	£15,000
INNS detection, reporting and decision making	£460,000	2009-2012	£115,000
Japanese knotweed biocontrol	£500,000	2003-2015	£41,666
Ludwigia	£10,000	Annual	£10,000
Monk parakeets control feasibility study	£38,000	Annual	£38,000
Mute swan control research	£430,000	1998-2008	£43,000
Non-native arthropods	£207,000	1998-2001	£70,000
Non-native species information portal	£500,000	3 ½ years	£142,000
Non-native species public attitude survey	£80,000	Annual	£80,000
Non-native species secretariat policy and delivery	£240,000	Annual	£240,000
Non-native risk analysis mechanism	£85,000	Annual	£85,000
Rabbit	£1,876,000	1999-2004	£375,200
Rose-ringed parakeets	£167,000	2009-2010	£167,000
Ruddy duck control research	£1,350,000	6 years	£225,000
Ruddy duck research and policy (including LIFE funding)	£3,700,000	5 years	£740,000
Storage pests	£532,390	1998-2002	£106,000
Thrips palmi	£147,630	2000-2003	£36,750
Thrips palmi	£226,007	2005-2009	£45,200

Subject Summary	Value	Period	p.a.
Tortricid pests	£426,122	2002-2006	£85,200
Water Framework Directive weed biocontrol research and publicity	£525,000	2010	£525,000
Weeds in cereals and other arable crops	£787,000	1997-2001	£157,400
Whitefly transmitted viruses	£155,000	2004-07	£38,750
Wild prey & NNS	£145,000	2004-2006	£48,000
Subtotal			**£6,934,548**

13.2 Fera

Fera has spent £3 million pounds over the last ten years on research into plant health management. This is in addition to projects undertaken by Fera that have been funded by Defra and are included above.

Table 13.2. Fera Funding

Subject Summary	Value	Period	p.a.
Plant health management (new project)	£3,000,000	10 years	£300,000
Subtotal			**£300,000**

13.3 The Environment Agency

The Environment Agency (EA) spends a considerable amount of time and money dealing with invasive species, including £1.5 million p.a. on INNS projects, of which an estimated one third is research. In addition, the EA incurs total policy costs of £3 million per year and contributes to various applied research projects, including the Japanese knotweed biological control project.

Table 13.3. Environment Agency Funding

Subject Summary	Value	Period	p.a.
Japanese knotweed biocontrol project	£100,000	5 years	£20,000
Project and staff costs vs INNS (estimate one third is research)	£1,500,000	Annual	£500,000
Total policy costs	£3,000,000	Annual	£3,000,000
Subtotal			**£3,520,000**

13.4 Forestry Commission/Forest Research

The Forestry Commission and Forest Research spend up to £1,945,000 annually on non-native species, either those that are quarantine species or established invasive non-native species. The research often has a Great Britain-wide focus and research costs cannot be broken down on a country-by-country basis. Further details are given in the quarantine and surveillance sector in this report.

Table 13.4. Forestry Commission Funding

Subject Summary	Value	Period	p.a.
All forest plant health	£1,945,000	Annual	£1,945,000
Subtotal			**£1,945,000**

13.5 Scottish Government

Plant Health Scotland spends on average £200,000 annually on plant health scientific advice to policy makers, which can be classified as research. The Scottish Government funded a project carrying out a detailed assessment of the efficiency of in-transit ballast exchange in the North Sea and Irish Sea on planktonic organisms in ship's ballast tanks (1999-2003, £325,000), as well as being co-funders of this report. In addition they have funded many other projects including work on Himalayan balsam, squirrel pox and bluebells.

Table 13.5. Scottish Government Funding

Subject Summary	Value	Period	p.a.
Biosecurity River Basin Planning	£50,000	3 years	£16,667
Crayfish project	£90,000	1 year	£90,000
Economics of INNS	£22,000	1 year	£22,000
Efficiency of in-transit ballast exchange	£325,000	1999-2003	£65,000
Epidemiology of *Phytophthora ramorum* and *P. kernoviae*	£403,407	2009-1012	£134,469
Himalayan balsam biocontrol	£30,000	3 years	£10,000
Plant Health Scotland -Plant health scientific advice to policy	£200,000	Annual	£200,000
Risk Assessment trial and peer review	£48,468	2006	£48,468
Squirrel pox transmission	£281,893	2007-2011	£70,473
Variation within bluebell and hybrid population	£44,000	2006-07	£44,000
Subtotal			**£701,077**

13.6 Scottish Natural Heritage

Scottish Natural Heritage has contributed to scientific research through detailed monitoring work to develop a model of mink control for the whole of the Western Isles. Considerable funding has been provided for various mink project, including ones that aimed to demonstrate best practice for other countries where the American mink is present. It also carried out an extensive information campaign for the local community and for the general public, to inform them of the activities being undertaken, the methods being used and the reasons why it was considered necessary (2000, £1.35 million). SNH have contributed approximately £1.675 million between 1999 and 2003 through these two projects, giving an average annual spend of £335,000[78][79]. In the last year a total of £520,454 has been spent by SNH on mink projects. In addition almost £209,000 has been spent on grey and red squirrel work, and over £36,000 on signal crayfish work.

Table 13.6. SNH Funding

Subject Summary	**Value**	**Period**	**p.a.**
Brown rats impact on Manx shearwater	£6,054	Annual	£6,054
Brown rats monitoring on Rum	£21,763	Annual	£21,763
Didemnum vexillum survey	£7,469	1 year	£7,469
Grey squirrel opinion poll	£16,368	1 year	£16,368
Introduced crayfish PhD	£16,014	Annual	£16,014
Invasive Species Management Guide	£8,043	1 year	£8,043
Invasive Species Mapping	£3,000	Annual	£3,000
Mink	£54,995	Annual	£54,995
Mink and water vole	£90,052	Annual	£90,052
Mink eradication in Western Isles	£359,107	Annual	£359,107
Mink PhD	£16,300	Annual	£16,300
New Zealand pigmyweed	£24,689	Annual	£24,689
North American signal crayfish	£20,364	Annual	£20,364
Red squirrel (plus grey)	£183,067	Annual	£183,067
Rhododendron ponticum	£15,000	Annual	£15,000
Squirrelpox virus surveillance	£9,552	Annual	£9,552
Uist Wader Project	£179,042	Annual	£179,042
Wireweed	£16,598	Annual	£16,598
Subtotal			**£1,047,477**

[78] http://globallast.imo.org/R&DDirectory8thEd.pdf

[79] http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.createPage&format=p&s_ref=LIFE00

13.7 Welsh Assembly Government

The Welsh Assembly Government makes various contributions to INNS issues with an estimated value of £100,000 p.a. The funded research includes the Japanese knotweed biological control project, slipper limpet monitoring, biodiversity audits and deer management.

Table 13.7. Welsh Assembly Government Funding

Subject summary	**Value**	**Period**	**p.a.**
Economics of INNS	£7,000	1 year	£7,000
Japanese knotweed	£250,000	5 years	£50,000
Other (estimate)	£50,000	1 year	£50,000
Subtotal			**£107,000**

13.8 Countryside Council for Wales

The Countryside Council for Wales (CCW) funds smaller projects, such as those in collaboration with Marine Life Information Network (MarLIN) to determine the potential risk of certain non-native species being introduced to North Wales with mussel seeds dredged from wild seedbeds. They allocate up to £100,000 for certain projects, one due to start in 2010. CCW also funds PhD students, two of them in the last 4 years, and is working primarily on mink and slipper limpet research with the People's Trust for Endangered Species.

Table 13.8. CCW Funding

Subject summary	**Value**	**Period**	**p.a.**
Ghost slug (*Selenochlamys* spp.)	£1,000	2008	£1,000
Neovison vison	£30,000	2008-2010	£10,000
Risk with mussel seed dredged from wild seed beds	£12,000	1 year	£12,000
Sargassum muticum	£6,000	4 years	£1,500
Slipper limpet	£16,000	4 years	£4,000
Subtotal			**£28,500**

13.9 National Research Councils

The national research councils fund various INNS-related research projects. Funding is normally provided through studentships, fellowships and research grants (accorded to universities). NERC funded 14 INNS projects starting between 1999 and 2009. The great majority of NERC INNS projects considered here are pure and applied scientific research, with only one project containing an element of policy research. A recently announced £10 million bee project will be administered through BBSRC of which it is anticipated that one third will be categorised as research and that the project runs over five years, adding £666,000 to the research cost.

Table 13.9. National Research Councils Funding

Subject summary	**Value**	**Period**	**p.a.**
Chemical communication between invading and native lobsters	£25,674	2003-2004	£12,500
Climate warming effects on aquatic food webs.	£143,997	2005-2008	£36,000
Diversity role in alien invasion of marine algal communities	£69,345	2003-2004	£35,000
Do mycorrhizal fungi control plant invasion potential	£187,536	2004-2005	£93,500
Expansion of grey squirrel populations	£182,682	2009-2013	£36,400
INN fish potential for invasion via estuarine saline-bridges	£185,215	2004-2007	£46,250
Invasive species as vectors of amphibian disease	£242,720	2008-2012	£48,400
Modelling ecological and environmental processes for INNS	£85,924	2001-2004	£21,500
Non-native fish establishment and predictions	£71,486	2009-2013	£14,200
Overcoming the compensatory response of an alien predator	£17,267	2007-2009	£6,000
Parasitism in biological invasions of freshwaters	£30,145	1999-2003	£6,000
Predicting population responses to life cycle perturbations	£51,707	2006-2007	£25,500
The effect of rats on island biodiversity	£25,785	2008-2012	£5,200
NERC subtotal			**£386,450**
Clogging of water treatment and power stations	£238,110	2004	£238,110
EPSRC subtotal			**£238,110**
New bee project funded by many (one third on IAS)	£10,000,000	2009-2015	£666,667
Research Council subtotal			**£1,291,227**

13.10 European Funding

The UK has benefited from eight EU-funded Life programmes between 1992 and 2002, including the ruddy duck programme included above. Six of the programmes focussed on invasive non-native plants and had a combined value of €3.324 million (£2.061 million) over

10 years (Scalera and Zaghi 1998). This equates to just over £200,000 p.a. on invasive non-native plant projects. A search of the Europa website (www.europa.eu) revealed no projects awarded to the UK between 2006-2010.

13.11 Other Funding Sources

The Esmee Fairbairn Foundation funded seven INNS-related research projects between 2004 and 2009, at a cost of just under £700,000, therefore a little over £246,000 per year (assuming a three year project cycle). The projects focused on research to target specific species, such as giant hogweed and Japanese knotweed.

13.10. Other Funding

Subject summary	**Value**	**Period**	**p.a.**
Controlling marine INNS by targeting vectors of dispersal	£20,000	3 years	£6,667
Counter the spread of INNS in England and Wales	£121,000	3 years	£40,333
Damaging marine alien species in UK waters (to SAMS)	£145,000	3 years	£48,333
Giant hogweed and Japanese knotweed	£70,000	3 years	£23,333
Hebridean mink contribution	£100,000	5 years	£20,000
Hull fouling	£126,000	3 years	£42,000
Japanese knotweed, Himalayan balsam and giant hogweed	£94,000	3 years	£31,333
River fisheries trusts support for biosecurity	£103,000	3 years	£34,333
Subtotal			**£246,332**

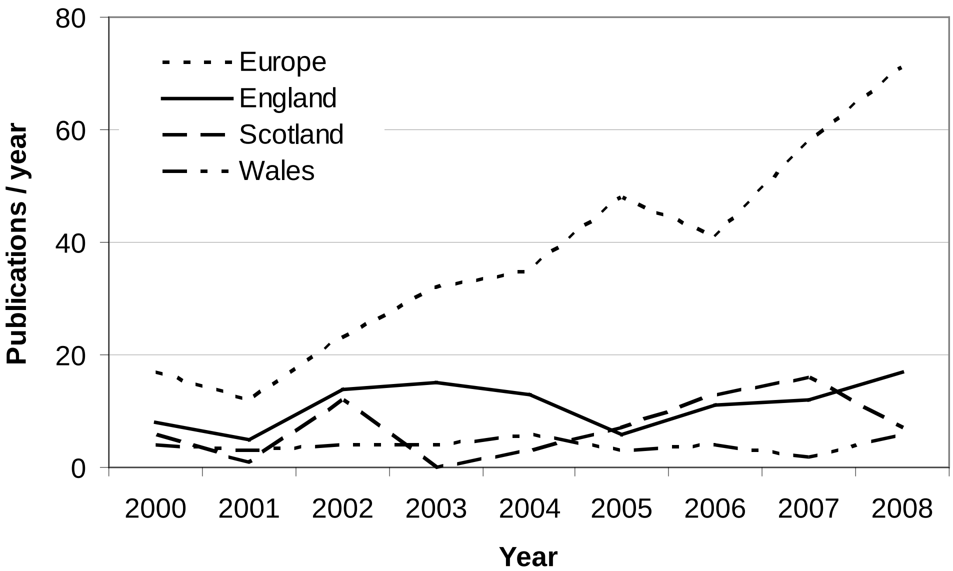
British Waterways (2008) estimate that dealing with problem INNS costs the organisation £1 million each year. An estimated 25% of this is used by its ecologists, in conjunction with other organisations, to monitor the impact of invasive species on native wildlife habitats and advise and assess the success of control activities, giving an annual research spend of £250,000. They are also co-funders of the Japanese knotweed biological control project.

The above funds for INNS-related research do not include the many smaller pieces of funding provided by councils such as Comhairle na Eilean Siar council (£100,000 to mink project), or support funds such as the Highlands and Islands Enterprise (£75,000 on mink), or private companies such as Network Rail (£100,000 to Japanese knotweed), or the many charitable societies with grant mechanisms for research. The Environmental Funders Network (Cracknell and Godwin 2007) estimated that research of approximately £6 million was funded in 2004-05 with a wide variety of recipients from Flora and Fauna International, RSPB, BTCV and the RHS. This £6 million has not been included in the total due to the lack of details of which projects related to INNS and a risk of double counting the grants already detailed. Total private funding can therefore be estimated at £771,000 as detailed above.

13.12 Published research

Much of the research in Great Britain is carried out by universities or research institutes. The ultimate output of academic research are scientific publications. The number of publications about INNS published by authors with affiliations to British institutions or by authors that studied INNS in Great Britain were assessed using the CABDirect (www.cabdirect.org) database, which holds over 8 million abstracts. The combined annual number of British publications on INNS has not changed and has remained stable at around 22 papers per year (Fig. 13.1). By contrast, the annual number of European INNS-related publications has increased linearly during the researched period from about 15 per year in 2000-2001 to over 70 in 2008.

Figure 13.1. The number of annual INNS-related publications in the past years by country.[a]



[a] Data were obtained through searches in the CABDirect database (www.cabdirect.org), looking for "invasive species", "alien species", "invader" or "introduced species" in all fields.

The production of a paper involves considerable effort, not just in the writing of the paper, but also in the generation of the data required. It is difficult to set a standard figure for the production of a piece of published scientific work, as one paper could represent 5 years' work by a team of 20 or 6 months work by one person. However, it was assumed, based on the authors' experience, that any paper published in a peer-reviewed journal would have involved at least £20,000 worth of data generation together with the writing and submission.

Moreover, revision of the paper would take at least 10 staff days (£2,500). In addition, each publication and linked project will be associated with at least 1.5 conference attendances at a cost of £2,100. So it was concluded that each year £541,200 worth of research is published each year. Although some double counting may occur as a result of our calculation of the cost of writing scientific papers, as some of these costs are paid from the research grants included above, this will be considerably less than the amount of research carried out on INNS that is not published in scientific journals or not on the CABDirect database.

13.13 Summary

The details given above capture only a part of the total funding, as it covers only a handful of sponsors, and do not capture the many projects for which invasive species are not the main target of research, but a smaller integral part of the study. While not all spending is current, we assumed that the funding that has come to an end, but is still being counted, counterbalances current funding that has not been detailed below.

Total research spending on INNS in Britain therefore comprises of general funded research (£16,846,000 p.a.), together with £541,000 in published research generation, giving a total of £17,387,000.

Table 13.11 Total Research Funding

Funder	**Annual Estimated Amount**
Defra	£6,935,000
Fera	£300,000
Environment Agency	£3,520,000
Forestry Commission / Forest Research	£1,945,000
Scottish Government	£701,000
Scottish Natural Heritage	£1,047,000
Welsh Assembly Government	£107,000
Countryside Council for Wales	£29,000
National Research Councils	£1,291,000
European Funding	£200,000
Other, including private funding	£771,000
Total	**£16,846,000**

References

British Waterways (2008). Press release (14/08/2008). http://www.britishwaterways.co.uk/newsroom/all-press-releases/display/id/2221

Cracknell J and Godwin H (2007) Where the Green Grants Went: Patterns of UK Funding for Environmental and Conservation Work: The Environmental Funders Network

Scalera R, Zaghi D (1998). Alien species and nature conservation in the EU: The role of the Life Programme. European Commission. http://ec.europa.eu/environment/life/publications/lifepublications/lifefocus/documents/alienspecies_en.pdf

14 Biodiversity and Conservation

Biodiversity is hugely important for life on earth and for the economy, but it is nearly impossible to put a monetary value on it. In a controversial paper, Costanza *et al.* (1997) estimated the value of the World's ecosystems at $33 trillion and regardless of criticism of this value, it is obvious that well-functioning ecosystems are valuable to a country's economy because of the services they provide. Species diversity is a key element of ecosystem functioning and a change in species composition, or relationships among species, almost always leads to changes in the behaviour and performance of individual species (e.g. Montoya *et al*. 2006; Dunne and Williams 2009). The invasiveness of INNS in the absence of their specialist natural enemies (sensu Enemy Release Hypothesis; Keane and Crawley 2002) is a good example, but there are numerous other examples. The effects of INNS can be manifold, as stated in the introduction. INNS can cause changes in ecosystems that result in disappearance of species, for example through increased competition for space or nutrients, or changes in ecosystem functioning as a result of chemical exclusion of their neighbours' symbiotic organisms (e.g. Mack *et al*. 2000; Majerus *et al.* 2006; Stinson *et al*. 2006). However, the impacts of INNS on ecosystems are often not well understood, which appears to be reflected by the resources invested in research. Most of the research done on INNS is of some benefit to biodiversity and therefore all those costs (£11,290,000) are included in this section.

14.1 Direct costs

Although the costs of INNS to most sectors have some link to biodiversity, the main direct costs that are captured in this sector are those where the reason for the cost being incurred is to protect native biodiversity. Control costs, where the stimulus and purpose of the control is some reason other than protection of native biodiversity, are not included in this sector, even though the control measures may also protect native biodiversity as well. This includes much of the spending by the Environment Agency as well as spending by local councils etc. Examples, described in other sectors, include the following:

- Rhododendron control
- Rabbit control to prevent crop damage
- Deer control to prevent forest and crop damage
- Control of water weeds to prevent flooding, and maintain river access for tourism and recreational activities
- Slipper limpet control to protect commercial shellfish production

- Wireweed control to ensure beaches are still available for use for recreational activities
- Control of non-native geese and swans to protect crops, prevent damage to golf courses, reduce fouling in parks and marinas and reduce the risk of bird – air strikes
- Control of giant hogweed to prevent injuries to recreational users and reduce the risk of flooding
- Control of riparian Japanese knotweed to increase access for recreational users
- Control of Japanese knotweed along transport corridors
- Control of parakeet populations to protect orchard crops and buildings
- Control of edible dormouse to protect forests and buildings

The main control costs that can be entirely attributed to biodiversity are those related to control of INNS for conservation purposes in protected areas and landscapes. Conservation is aimed at retaining native species or ecosystem functions in order to limit damage. This can be done, for example, by localised eradications or limiting of the spread of INNS. Costs will include the time and money spent by conservation organisations, non-governmental organisations and local authorities on the removal of INNS from the natural environment. Many conservation programmes are ongoing for a number of species that are threatened by INNS, some examples of which are given below:

- In Wales, northern England and Scotland efforts are made to limit the distribution and spread of **grey squirrels** (*Sciurus carolinensis*) to protect the native red squirrels (*S. vulgaris*). The Forestry Commission spent £115,000 in 2005-2006 and currently spends £135,000 per year on fertility control research, red squirrel protection and tree crop protection (http://www.forestry.gov.uk/forestry/infd-6l4fdh). On Anglesey, the current annual expenditure is £110,000. The Northumberland Wildlife Trust has created 3-mile exclusion zones around 16 red squirrel populations for a period of three years spending a total of £1.1 million from the Heritage Lottery Fund and other sources to limit spread of grey squirrels in northern England and Scotland. The annual cost of grey squirrel control as part of the red squirrel protection therefore is estimated at £611,600 (estimated division: £140,800 in Wales, and £235,400 each in England and Scotland).

- There is a strong causal link between introduction and spread of **mink** (*Neovison vison*) and decline in water vole (*Arvicola amphibius*) population and bird-nesting success can be reduced by half due to mink. Control activities are taking place throughout England, Wales and Scotland, in particular in the Western Isles. Control measures, mainly trapping, appear to be concentrated in areas managed by wildlife trusts and conservation bodies, as conservation of the water vole is one of the main motivations for control activities. Further trapping activities are carried out by game keepers, lock keepers, water bailiffs, angling clubs, fisheries managers and farmers. The cost of trapping mink has been estimated at £431 - £517 per mink (2006), £467-£561 today (Macdonald and Baker 2006) in situations where mink populations are being controlled, not eradicated. The cost per mink would be considerably higher where an eradication effort was being undertaken due to the very high cost of removing the last few individuals from an area. Data about the number trapped per year are scarce and inaccurate (Macdonald *et al.* 2000). One control project removed 260 mink from southwest England between 2003 and 2006 (MacDonald and Baker 2006) with similar projects taking place in other English counties, Wales and Scotland. Thompson (2006) showed that the deployment of 220 traps along a river in Norfolk (381.74 ha, of which 42% water bodies and 12% water-fringed vegetation) resulted in the removal of 262 mink over three years. Each control project therefore appears to remove approximately 85 mink each year, and we assumed that there are eighteen such control projects running each year (ten in England, and five in Scotland and three in Wales). Therefore, using an average cost per mink of £514, the costs were estimated at £436,900 in England, £218,450 in Scotland and £131,070 in Wales, giving an annual cost for Great Britain of £786,420 on control measures alone. The Environment Agency contributes over £160,000 a year for mink control to the water vole Biodiversity Action Plan (RIA Strategy), but it is anticipated that much of this money is used by wildlife trusts for mink trapping so is not included as an additional cost.

- **Mink** are also known to predate on ground-nesting birds that are particularly vulnerable to attack and declines of between 48% and 58% have been recorded in arctic tern colonies in Scotland due to the presence of mink (MacDonald *et al.* 2000). However, there is an absence of data to demonstrate the annual economic cost of mink on seabird nesting colonies, in terms of reduced tourism revenue, or a loss of an existence value of the nesting colonies, for example. Therefore, it is not possible to include an estimate of the annual economic cost of mink predation on seabirds.

- Considerable research work, including eradication studies have been carried out on **mink**. Scottish Natural Heritage spends approximately £350,000 annually for the conservation of ground nesting sea birds through the eradication of mink from the Western Isles. This cost includes labour and a very small amount of research into the eradication (David Mclennan, pers. comm.). Further work has modelled the benefits of mink control for seabird nesting colonies (Ratcliffe *et al.* 2008), demonstrating that mink control allows nesting colonies to recover. An on-going research project into the eradication of mink from the Western Isles cost £1.65 million in the first phase, with the current phase, extending the work to Lewis and Harris, costing £2.5 million. This work is being carried out over a number of years and therefore the annual cost amounts to £160,000. The Hebridean Mink research is supported £20,000 p.a. by the Esmee Fairbairn Foundation. In addition, £30,000 was spent on research projects in Wales (Wales INNS Group). Costs, detailed in the research chapter amount to £550,454 p.a., but are not included in the totals here.

- The **brown rat** (*Rattus norvegicus*) can have devastating ecological impacts on islands where there were previously no natural predators for certain species, particularly seabirds. In Scotland, on the Isle of Canna, rats predate seabirds. They are now controlled by baiting and quarantine procedures have been set up. A rat-proof waste management strategy was installed, long-term rat surveillance was introduced and a contingency plan was formulated to come into action in the event of a rat being accidentally introduced. The cost was £689,184 (including labour) over 3 years (Anon. 2008). The total annual cost therefore is approximately £230,000. The National Trust has spent £64,136 on rat control on Lundy Island, (pers. comm.).

- Since 2006, five populations of **topmouth gudgeon** (*Pseudoboras parva*) in England have been successfully eradicated, at a cost of £190,000 (Britton *et al*. 2010). This cost includes the use of piscicides in the eradication effort and the conservation and restoration of the native fish species in the ponds (Matt Brazier, pers. comm.). The species is currently only controlled in England at an average annual cost of £50,000 (Britton *et al*. 2010).

- In Europe, the **ruddy duck** (*Oxyura jamaicensis*) is a threat to the endangered white-headed duck as a result of hybridization and loss of genetic integrity in the native species. The white-headed duck breeds in Spain and, although the ruddy duck does not interbreed with native British duck species, the UK is often the source of the ruddy ducks that hybridize with the white headed duck (Lever, 2005). An international effort is thus required across all the countries in which the ruddy duck is present to limit its impact on the white-headed duck populations (Green & Hughes 1996). Since 1991, various parties in the UK have funded eradication efforts, with a current annual cost of approximately £395,000.

- **Rhododendron** (*Rhododendron ponticum*) is a perennial shrub that overshadows native vegetation and is a vector for various *Phytophthora* spp. It is actively managed around Great Britain by land managers, conservation groups and the forestry industry, at a total annual cost of £8.6 million (see forestry sector costs). This cost reflects current spending levels to control rhododendron, and does not include the previous higher amounts spent on control to reduce the spread of the species (Mike McCabe pers. comm.).

- **Himalayan balsam** (*Impatiens glandulifera*) is a fast-growing annual plant that predominantly occurs in dense stands in riparian habitats, where it can overshadow native flora. An estimated £1 million per year is spent on control, mainly carried out by Wildlife Trusts and volunteers (Rob Tanner, pers. comm.).

- All current costs of **carpet sea squirt** (*Didemnum vexillum*) control are assumed to ultimately be for conservation, as the main motivation for the control measures appears to be to protect native ecosystems (£100,000; case study).

- A considerable portion **signal crayfish** control costs are taken as biodiversity costs as much of the control work is undertaken to protect native crayfish, although some measures are undertaken to conserve angling stocks. Control and white-clawed crayfish conservation work amounts to £1,502,000 per annum (species calculation).

There are other non-native species that are controlled by conservation organisations for conservation or biodiversity purposes, such as cotoneaster (particularly an issue for CCW), hottentot fig, three cornered leek, piri piri burr and Australian swamp stonecrop (*Crassula helmsii*). Although many of these conservation organisations were contacted directly, as well as being included in the follow up interviews to the questionnaire, it was particularly difficult to obtain clear data on spending on INNS. Organisations such as the wildlife trusts and the RSPB reported that while they knew they spent money on the control of INNS, this information was not recorded in any way. The RSPB in particular were keen to contribute to this work, but eventually reported back that they were unable to provide any data on spending on INNS, because they did not hold information on the costs of work carried out on INNS separately from the costs of their conservation work in general and were unable to attribute a proportion of spending to INNS. In addition, where costs were provided they were often for an individual area, included non-INNS related costs and were incomplete. e.g. Spelthorne Borough Council provide costs of £7225 for *C. helmsii* clearance from a single pond, but stated that they had not managed to include the cost of volunteer time, transporting the cleared *C. helmsii* to the green tip or the tipping fees (C Bendickson, pers. comm.). Some costs also varied so considerably that there was no reliable method to extrapolate the costs. E.g. The National Trust controls *C. helmsii* at a minimum of three sites, but the control cost varied between £3,750 to clear 2,000 m^2, £5,150 for 100 m^2 and £1,450 per 100 m^2 at three sites. The variation is due to access, terrain, equipment or method used, etc. (Simon Ford, pers. comm.).

However, an estimation of INNS costs can be made based on total spending by these national organisations. For example, the National Trust spent approximately £32 million on conservation and advisory services, as well as publicity and education in 2008-2009[80]. If it is assumed that at least 10% of this money is spent on activities relating to INNS, then annual spending can be estimated at £3,214,000. This amount equates with the estimate provided by the National Trust (S. Ford pers. comm.) of annual spending on INNS of approximately £3,500,000 on the control of INNS together with awareness raising, staff time, increased flooding and siltation etc. The National Trust for Scotland spent £7,952,000 on conservation, repairs and improvements in 2009[81], and assuming some of this work was INNS control and management and that approximately 10% of the amount went on INNS work, then a spend of £795,200 can be approximated.

National parks received nearly £73 million of government funding in 2008-2009[82], in addition to other funding sources, such as the European Union, as well as their own income. This money is used for a large variety of activities, but on average three of the parks spent 8% of their money on conserving the natural environment. If this average is used across all the national parks then spending on conserving the natural environment can be estimated at £5,830,557, of which an estimated 10% is spent on INNS (as above) giving a cost of £583,000.

Natural England programme spend on INNS has been estimated at approximately £223,000 for the current financial year (Richard Saunders pers. comm.), with a further approximately £66,000 spent on delivery work, funded by Defra last year. This was considered to be a reflection of the budget available for the work rather than the true costs of INNS, and was thought to be an underestimation of the true costs of INNS. The Countryside Council for Wales do not have a specific funding line for INNS work, with money being spent in national nature reserves, and through management agreements and grants (Mike McCabe pers.

[80] http://www.nationaltrust.org.uk/annualreport09/
[81] http://www.nts.org.uk/About/
[82] http://www.nationalparks.gov.uk/learningabout/wholooksafternationalparks/costsandspending.htm

comm.). CCW spend an estimated £120,000 per year on the management of INNS in the nature reserves, including control and restoration work, awareness raising and increased maintenance costs. Scottish Natural Heritage were unable to provide specific details of their spending on INNS in nature reserve management and therefore a figure of £200,000 has been assumed, the average of spending by Natural England and CCW.

Some species cause quantifiable costs to biodiversity or conservation, which are not incurred as a result of control. For example, all six species of deer have a detrimental impact on conservation woodland, especially where deer densities are high (Quine *et al.* 2004). Browsing and grazing by deer can significantly alter the structure and development of natural forests (White *et al.* 2004), and coppiced broadleaved woodlands are particularly susceptible to deer damage, especially that caused by fallow and muntjac (Langbein 1997). The cost of deer to conservation interests within the east of England was estimated at £265,775 annually, £305,831 today (White *et al.* 2004). Therefore, based on the deer populations in each country and the percentage of these populations that are non-native (see agriculture sector) and the assumption that the damage caused per non-native deer in the east of England is similar to the cost per deer caused by the non-native deer populations across the rest of the country, then deer damage to conservation interests is estimated at £1,458,173 for England, £106,774 for Scotland and £239,408 for Wales.

In summary, the total annual direct costs of INNS to biodiversity are estimated to be at least £38,039,000 (£20,652,000 conservation, £17,387,000 research). The costs recorded here are a snapshot of current annual costs, and do not reflect the fact that for some species extensive control measures, with associated high costs, may have been carried out a few years ago and so current control costs have been reduced by this action. The costs also do not reflect the level of spending that is required to effectively control these species, with several organisations commenting that they would do more work to combat INNS if there was more money available. Many INNS are controlled as part of general site management agreements, such as for a nature reserve, with several different organisations contributing funding towards the work. This makes it difficult to identify costs directly associated with INNS work and leads to a risk of double counting funding from multiple sources. However, given that the current estimate is likely to underestimate the total spent on INNS management and control within this sector due to difficultly in separating out INNS costs, the risk of double counting will not greatly distort the estimate for biodiversity and conservation work. In addition, many of the activities undertaken to control INNS that protect native biodiversity are not undertaken primarily for conservation measures but for land management or the management of tourism or recreational activities, and have therefore been included in those sectors even though the measures do also protect native species.

Table 14.1. Annual biodiversity costs by country

	England	Scotland	Wales	GB
Individual species	£6,681,000	£4,208,000	£4,276,000	£15,165,000
NE/SNH/CCW	£289,000	£200,000	£120,000	£609,000
National Trusts	£2,310,000	£795,000	£1,190,000	£4,295,000
National Parks	£370,000	£90,000	£123,000	£583,000
Total	**£9,650,000**	**£5,293,000**	**£5,709,000**	**£20,652,000**

14.2 Indirect costs

Although the costs and manpower involved in control of INNS can often be substantial, the cost of widespread impacts of INNS on biodiversity is likely to be many times higher because many impacts are indirect, non-market costs. The economic impact of the displacement of a species, or a change to ecosystem functioning is very difficult to value and some changes to ecosystems may go unnoticed, especially if an established non-native species is not considered a nuisance yet. The impact of INNS on biodiversity, like the cost of control, increases with the time a species has been present in the country as shown in the case studies.

An indirect effect of INNS can be a perceived devaluation of the natural environment when INNS are present. The resources spent on control of these INNS are driven by people's fear of losing an attractive or rare species. Hence, the resources that are invested in the eradication of INNS from natural habitats in Great Britain and in the protection of a few, high profile endangered species, such as the red squirrel, illustrate some of the appreciation of native flora and fauna and the willingness to protect them. However, very little data are available that attributes a monetary value on the existence of the native flora and fauna separately from the control costs to protect them. One example that was available was that of the impact of the American mink on water vole.

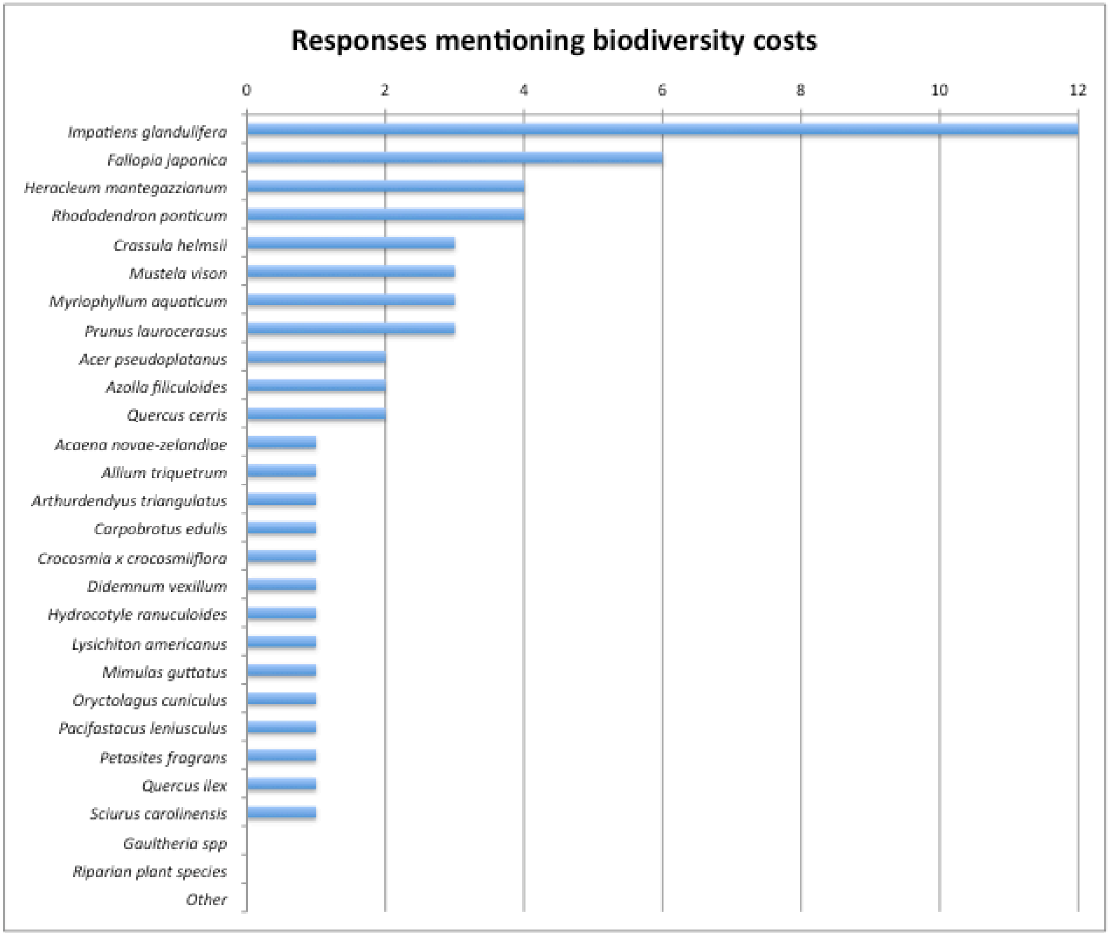
There is a strong causal link between the introduction and spread of mink and the decline in water vole population in Britain. The entire population of water vole would crash if mink control measures failed, regardless of other conservation or land management effort (Jonathan Reynolds, Game and Wildlife Conservation Trust, pers. comm.). The value of water vole was estimated using a contingent valuation telephone survey giving a willingness to pay value of £7.44 in 1996, £10.46 today (White *et al.* 1997). Therefore, with a total population loss of 1,946,000 water voles between 1990 and 1998, a cost of £2,544,395 can be attributed to mink. Although the water vole population has been stable in recent years, the reduction in population of water vole is still a cost to the economy, as people are not able to gain enjoyment from the water vole that no longer exist. This is included as an annual cost in the same manner as the lost production experienced by crofters in the Western Isles is included as an annual cost. In the Western Isles the presence of mink prevents crofters from keeping poultry, and here the presence of mink prevents the water vole population from re-establishing itself, and is therefore considered to be an annual cost. This cost may reduce if the water vole population increases in the future and the value that people place on a water vole reduces as they become more common. It is, however, a current annual cost.

Table 14.3. Cost of biodiversity loss due to mink.

	Pop. 1990	**Pop. 1998**	**Pop. decrease**	**Cost at £10.46 per vole**
England	1,479,795	227,760	156,504	£1,637,036
Scotland	740,488	113,971	78,315	£819,171
Wales	79,718	12,270	8,431	£88,188
GB	2,300,000	354,000	243,250	£2,544,395

The responses to the questionnaire from people who indicated that they work in the biodiversity and conservation sector indicated that 26 INNS species caused a quantifiable reduction in biodiversity (Fig. 14.1). Himalayan balsam was mentioned 12 times, but the majority of species were mentioned only once or twice. The respondents were asked to indicate the biodiversity costs of the species they mentioned in nine classes, ranging from £1 to “more than £500,000”. However, many respondents indicated that the value of reduction in biodiversity was almost impossible to estimate, and therefore the response they had given was a guess, or they were not prepared to provide an estimate at all. Of the responses provided, it is clear that the estimates of lost biodiversity value vary considerably, confirming the difficulties in estimating the value of lost biodiversity. However, all these respondents were controlling INNS for the primary purpose of protecting native biodiversity, so even though they could not put a monetary value on the biodiversity lost due to the INNS, they knew that the native biodiversity has a value that was worth protecting.

Figure 14.1. The number of times that INNS were identified as causing a reduction in biodiversity. Other includes responses where no species were identified.



The indirect costs to biodiversity are undoubtedly very high, but due to the lack of information on which to base an estimate, no attempt to put a value on indirect costs of INNS to biodiversity specifically has been made. This is due to a paucity of studies that have investigated the cost of reduced biodiversity in terms of its intrinsic value, or the ecosystem services provided. In the descriptions of the costs of INNS to various sectors described in this report, it has become clear that the loss of species as a result of INNS can or could be very expensive to the economy and if an ecosystem services approach were applied to the impact and cost of every INNS, then it is likely that the costs attributable to this sector would be much higher than that recorded here.

Table 14.4 Biodiversity costs by country

	England	Scotland	Wales	GB
Direct Costs	£9,650,000	£5,293,000	£5,709,000	£20,652,000
Research				£17,387,000
Quantifiable indirect costs	£1,526,000	£509,000	£509,000	£2,544,000
Total	**£11,176,000**	**£5,802,000**	**£6,218,000**	**£40,583,000**

References

Anon. (2008) Technical final report for Life project LIFE05 NAT/UK/000141. http://www.ntsseabirds.org.uk/File/Microsoft Word - LIFE Final Report 2.pdf

Britton JR, Davies GD, Brazier M (2010). Towards the successful eradication of the invasive *Pseudoboras parva* in the UK. Biological Invasions 12: 125-131

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hanun B, Limburg K, Naeem S, O'Neill R, Paruelo J, Raskin R, Sutton P, Van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387: 253-260

Dunne JA, Williams, RJ (2009). Cascading extinctions and community collapse in model food webs. Phil. Trans. R. Soc. B 364: 1711-1723

Green AJ, Hughes B (1996) Action plan for the white-headed duck *Oxyura leucocephala*. In: Hereida B, Rose L, Painter M. Globally threatened birds. Council of Europe Publishing, Strasbourg. Pp. 119-146

Keane RM and Crawley MJ (2002) Exotic plant invasions and the enemy release hypothesis. Trends in Ecology and Evolution 17: 164-170

Langbein J (1997) The ranging behaviour, habitat use and impact of deer on oak woods and heather moors of Exmoor and the Quantock Hills. PhD thesis, University of Southampton

MacDonald D, Baker S (2006). The State of Britain's Mammals, The Wildlife Conservation Research Unit, People's Trust for Endangered Species/Mammals Trust UK

Macdonald DW, Tattersall FH, Johnson PJ, Carbone C, Reynolds JC, Langbein J, Rushton SP, Shirley MDF (2000). Management and Control of Populations of Foxes, Deer, Hares and Mink in England and Wales, and the Impact of Hunting with Dogs. http://www.huntinginquiry.gov.uk/mainsections/research/macdonaldrep5and6.pdf

Mack R N, Simberloff D, Lonsdale WM, Evans H, Clout M, Bazzaz FA (2000) Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10: 689-710

Majerus M, Strawson V, Roy H (2006) The potential impacts of the arrival of the harlequin ladybird, *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae). Britain Ecological Entomology 31: 207-215

Montoya JM, Pimm, SM, Solé RV (2006). Ecological networks and their fragility. Nature 442: 259-264

Quine C, Humphrey J, Watts K (2004) Biodiversity in the UK's forests – Recent policy developments and future research challenges. In: Andersson F, Birot Y, Päivinen R (eds.) Towards the sustainable use of Europe's forests – Forest ecosystem and landscape research: scientific challenges and opportunities. EFI Proceedings 49. pp. 239-248

Ratcliffe N, Craik C, Helyar A, Roy S and Scott M (2008) Modelling the benefits of mink management options for terns in west Scotland. Ibis 150 (s1): 141-121

Stinson KA, Campbell SA, Powell JR, Wolfe E, Callaway RM, Thelen GC, Hallett SG, Prati D, Klironomos JN (2006) Invasive plant suppresses the growth of native tree seedlings by disrupting belowground mutualisms. PLOS Biology 4: 727-731

Thompson H (2006). The use of floating rafts to detect and trap American mink Mustela vison for the conservation of water voles Arvicola terrestris along the River Wensum, Norfolk, England. Conservation Evidence 3: 114-116

White PCL, Gregory KW, Lindley PJ, Richards G (1997). Economic values of threatened mammals in Britain: A case study of the otter Lutra lutra and the water vole Arvicola terrestris. Biological Conservation 82: 345

White PCL, Smart JCR, Böhm M, Langbein J, Ward AI (2004). Economic impacts of wild deer in the East of England. Report to the Forestry Commission and English Nature. www.woodlandforlife.net/wfl-woodbank/Display Article.asp?ID=2333

15 Human Health Issues

15.1 Cockroaches

Amongst the many insects considered nuisance species by Roy *et al.* (2009), cockroaches (*Blatta orientalis* and *Blatella germanica*) are probably the most likely to be associated with human health issues. They can carry pathogenic bacteria onto food and cause food poisoning events. A survey by the Chartered Institute of Environmental Health in the Cossall Estate in London, which consists of 421 apartments contained in eight three-storey blocks with a history of cockroach infestation, found that 15.7% of the apartments were infested. An estimated 59% of English hospitals were reported to have cockroach infestations according to official figures reported in Environmental Health News in 2008 (Majekodunmi *et al.* 2002).

15.1.1 Control costs and fines

Control is normally through pesticide treatments and the average cost of treatment by councils is £56 (averaged from four councils' responses) for domestic properties and £82 for commercial ones (the charge out rate was either per hour or per treatment but a per treatment cost is taken here).

Although cockroaches may be found in any type of building, those dwellings that are considered to be in disrepair or unfit as housing are more likely to experience cockroach infestations than those buildings that are well maintained. Cockroaches live in crevices and cracks such as loose fittings, wallpaper and architraves and buildings such as tower blocks are especially vulnerable to infestation as cockroaches can easily move throughout the building[83]. According to the 2007 England House Condition Report there are 9,313,000 dwellings in "deprived districts". The equivalent for Scotland is the 1,810,000 properties in "disrepair" and in the 1998 Welsh house condition survey 1,157,300 properties are considered "unfit" If we assume only 5% of these are infested and treated compared with the 15.7% reported above for a extreme situation then at a treatment cost of £56 the total for the countries is as follows:

[83] http://www.lhc.org.uk/members/pubs/factsht/44fact.htm

Table 15.1. Cost of cockroach treatments in residential dwellings

	England	Scotland	Wales	GB
No. of susceptible properties	9,313,000	1,157,300	1,810,000	
No. of infested properties at 5% infestation rate	465,650	57,865	90,500	
Cost (£) per treatment	£56	£56	£56	
Total Cost	**£26,076,400**	**£3,240,440**	**£5,068,000**	**£34,384,840**

In addition to the above dwellings, cockroaches are also found in shops and restaurants where the warm, moist conditions are favourable to cockroach growth. These premises are inspected by local authority environmental health departments and local authorities, and failed hygiene standards due to cockroaches commonly lead to legal fees in the thousands if not tens of thousands of pounds per establishment. Over £12 million is spent per year on food safety issues by local authorities in London alone, which represents nearly 16% of all environmental health staff time in Greater London. There are around 600,000 food premises in the UK (Post, 2003) and the implications of an infestation are severe with heavy fines and closure notices. Food premises are more likely to suffer infestations than human dwellings so an estimate of 1% of all properties is assumed. Using the £82 commercial cost for 6,000 premises gives an annual cost of £492,000 for control costs alone. There would also be a number of days of lost business for those unable to undertake control measures immediately together with the fines, which frequently are more than £10,000. We suggest that 10% of the estimated 6,000 infested premises would incur additional costs of £5,000 through lost business and fines giving a further £3 million. The total cost to the commercial sector from the presence of cockroaches was estimated at £3,492,000 for the UK, allocated according to population to give England £3,013,786, Wales £175,378 and Scotland 302,836.

15.1.2 Food poisoning

The costs of an estimated 2.4 million food poisoning cases related to the consumption of food in England and Wales were £750 million, using 1993/4 pricing (Post, 2003), £884 million today. There are no figures available for the percentage of food poisoning cases caused by cockroaches, but the fact that they can transmit many of the bacteria associated with such infections and can be present at almost every stage of the food chain process mean it would seem justified to attribute at least 1% of cases to the infections that cockroaches spread. This gives a minimum cost of £8.84 million in England and Wales. Using population ratios for the three countries then costs can be estimated at England £8,353,871, Wales £486,128 and Scotland £839,426, giving a total cost of £9,679,425.

Table 15.2. Total annual cost of cockroaches

	England	Scotland	Wales	GB
Domestic Properties	£26,076,400	£3,240,440	£5,068,000	£34,384,840
Commercial Properties	£3,013,786	£302,836	£175,378	£3,492,000
Food Poisoning	£8,353,871	£839,426	£486,128	£9,679,425
Total	**£37,444,057**	**£4,382,702**	**£5,729,506**	**£47,556,265**

15.2 Rat-transmitted Diseases

Rats have been associated with various disease causing pathogens as discussed by Gratz (1999). However, of those that are known to occur and cause problems in Great Britain, Weil's disease is probably the most significant. Other diseases include cryptosporiosis (Quy *et al.* 1999), Q fever (Webster *et al.* 1995), salmonellosis (Davies & Ray 1995) and toxoplasmosis (Webster 1994). The incidence of these diseases being vectored by rats to humans is limited and therefore no separate costs are included here.

Although leptospirosis is vectored by a range of animals, virtually all the Weil's disease cases in Great Britain are due to Norway rat, *Rattus norvegicus* (R. Quy pers. comm.). Neither the NHS nor the Department of Health keep records. However, the NHS website states that there are on average 40 cases of leptospirosis p.a., of which approximately 5-10% are Weil's disease, i.e. a maximum of four cases annually. The disease requires a blood test, followed by an antibiotic treatment and normally involves two weeks of fever-like symptoms. Whilst the estimates above include the health care costs and lost time it is necessary to make some estimates for those diseases where such estimates have not already been made. Beale *et al.* (2004) were able to use figures generated by Netten (2002) and combine them with a survey of all clinical activity, aggregated by patient, over one year in an English semi-rural general practice, to produce average costs per clinical activity per patient. These give the cost of a GP consultation as being £6.11 in today's prices. However, this only covers the cost to the practice and a more widely quoted figure generated by a survey for Doctor Patient Partnerships in 2005 is £18 (£20.03 in today's prices). The majority of the cost will be the 40 days (10 working days per case, 4 cases per year, see above) of work lost as well as the costs of the treatment. Therefore, we estimate the cost of Weil's disease to be around £10,000.

15.3 Lyme Disease

The microbial Lyme disease is vectored by the sheep tick (*Ixodes ricinus*) in Great Britain which is hosted by many species, including sheep, cattle, fox, hedgehog and deer. Although other mammal species can act as hosts, virtually all human infection is due to deer (A. Ward, pers. comm.). The NHS website states that the Health Protection Agency estimates that there are approximately 1,000 – 2,000 cases p.a. If we assume there are 1,500 cases of Lyme disease per year, and that 29% (see section 5.1) were facilitated by non-native deer, we can attribute 435 cases to the presence of non-native deer. There is a general expectance that 2-4 weeks of antibiotics can cure the disease but this is only if it is diagnosed quickly (Phillips *et al.* 2005). Thus, each case would involve a minimum of two visits to the GP (2 x £20, using the same rates as discussed above) and a 2 week course of antibiotics (£5), which would cost £19,575 annually. In addition, at least a week would be lost from work by the patient (5 days x £250 x 435), which would cost the country £543,750 in lost labour. Thus the total cost of Lyme disease caused by non-native deer hosting the sheep tick is £563,325. A few cases may go on to cause arthritic symptoms or worse but there is no information of how many and what the costs could be so these are excluded from this assessment.

15.4 Giant Hogweed

Giant hogweed causes significant damage to susceptible people through the effects of its phytophototoxic sap. Unfortunately, the Department of Health does not record incidences of health effects caused by exposure to giant hogweed, and has no estimate of costs associated with treatment. The NHS data does not distinguish between burns caused by different plants, so it has not been possible to separate out those caused by giant hogweed. Treatment for most cases seems limited (keeping covered up from the sun, using sun cream, etc.) and very few cases discussed appear to lead to costly treatments, even though the effects can remain for a long time. Due to the apparent low cost of any treatment that does occur, and the lack of data on the number of incidences, no figures are presented for this species.

15.5 Total Costs

The total human health cost to the British economy due to INNS is estimated at £48,130,000 (Table 15.3).

Table 15.3. Annual costs of INNS vectored diseases to human health

	England	Scotland	Wales	GB
Cockroaches	£37,444,000	£4,383,000	£5,730,000	£47,557,000
Weil's Disease	£5,000	£3,000	£2,000	£10,000
Lyme Disease	£395,000	£84,000	£84,000	£563,000
Total	**£37,844,000**	**£4,470,000**	**£5,816,000**	**£48,130,000**

References

Beale N, Hollinghurst S, Taylor G, Gwynne M, Peart C and Straker-Cook D (2005) The costs of care in general practice: patients compared by the council tax valuation band of their home address. Family Practice 22: 317–322

Davies RH, Wray C (1995) Mice as carriers of *Salmonella enterotidis* on persistently infected poultry units. The Veterinary Record 30 p337-340

Majekodunmi A, Howard MD, and Shah V (2002) The perceived importance of cockroach (*Blatta orientalis* (L.) and *Blattella germanica* (L.)) infestation to social housing residents. Journal of Environmental Health Research 5 (1) 29-36

Parliamentary Office of Science and Technology (2003) Food Poisoning. Postnote 193

Phillips SE, Harris NS, Horowitz R, Johnson L Stricker RB (2005) Lyme disease: scratching the surface. The Lancet 366 (9499): 1771

Netten A, Curtis L (2002) Unit Costs of Health & Social Care, Personal Social Services Research Unit, University of Kent, Canterbury

Roy HE, Beckmann BC, Comont RF, Hails RS, Harrington R, Medlock J, Purse B, Shortall CR, (2009) An investigation into the potential for new and existing species of insect with the potential to cause statutory nuisance to occur in the UK as a result of current and predicted climate change. Centre for Ecology and Hydrology. Defra 109pp

Quy RJ, Cowan DP, Haynes PJ, Sturdee AP, Chalmers RM, Bodley-Tickell AT, Bull SA (1999) The Norway rat as a reservoir host of *Cryptosporidium parvum*. Journal of Wildlife Diseases 35(4) pp.660-70

Webster JP (1994) Prevalence and transmission of *Toxoplasma gondii* in wild brown rats, *Rattus norvegicus*. Parasitology 108 (4):407-11

Webster JP, Lloyd G, Macdonald DW (1995) Q fever (*Coxiella burnetii*) reservoir in wild brown rat (*Rattus norvegicus*) populations in the UK. Parasitology 110, pp31-35

16 Case Studies

The main purpose of this work was to estimate the current economic cost of INNS to the British economy. However, in order to help decision-making about the future management of INNS, five case studies are given below to illustrate how the cost of eradicating INNS varies depending on the length of time that a species has been established in the country. A comparison has been made between species that have not become established yet (Asian long-horned beetle), that have become established recently and may, without intervention, become widespread in the foreseeable future (carpet sea squirt, water primrose) and species that are widely established and currently cause costs (grey squirrel). In addition, coypu was chosen as an example of an established species that has been successfully eradicated. Cost estimates have been provided, either for prevention, or costs for eradication at an early stage of invasiveness for those species that are a threat or are newly established. In addition, for all the case studies an estimated cost of eradication if the species became widely established has been included. The implications of these different cost estimates are discussed.

16.1 Asian long-horned beetle (*Anoplophora glabripennis*)

The Asian long-horned Beetle (ALB) originates from Japan, Korea and China. They are wood-boring beetles, with the females chewing a hole into the bark of the tree and then laying a single egg into the hole. Larval development can last between 10 to 22 months, depending on climatic conditions and the time of year that the egg was laid. The larvae bore into the tree, creating tunnels that can affect the vascular functioning of the tree. This disruption in vascular flow weakens the tree and can lead to tree death. There are several symptoms of infested trees, including holes on branches and the trunk, sap emerging from the holes, sawdust (or frass) on branches and at the base of the tree. However, most of these symptoms occur at least 1.5 m above ground level and upwards towards the crown. This makes initial symptoms harder to spot. The beetle infests a variety of hardwood trees, such as ash, maple, chestnut, birch and willow and once established the beetle is very hard to control.

It is a quarantine pest for Europe and was found in various parts of North America (New York, Chicago, New Jersey, Ontario) in 1996. Since then, quarantine zones have been set up around infested areas to contain the beetle, but they have been discovered in warehouses in the USA and Canada (http://www.uvm.edu/albeetle/) as well as Europe. ALB has been found regularly in North America in imported wood and in wooden packaging, but there had only been five outbreaks until 2008 (Smith and Wu 2008).

16.1.1 Early Eradication Costs

An outbreak on four trees in northern Italy, with only one adult beetle, caused the four infested trees to be cut down and destroyed along with uninfested trees of susceptible species (genera *Acer*, *Betula*, *Salix* and *Populus)* within a 500 m radius of the infestation. A total of 309 trees were destroyed. In addition to these clearance measures, the area was replanted with trees from non-susceptible species together with six sentinel trees. This area is thoroughly inspected periodically and will continue to be inspected until no sign of ALB has been detected for four years (Herard *et al.* 2009). The cost of removal of the 309 trees is estimated at £10,000 and the cost of 309 replacement and 6 sentinel trees, at £30 each, plus ten days labour for planting them at £250 a day. Surveillance was carried out six times per year for a period of 2 days, for 4 years i.e. 48 days. At an estimated cost of £250 per day surveillance costs therefore amount to £12,000. Despite efforts to contact those involved, details about the financial cost of the Italian outbreak could not be obtained. Hence, this figure does not include the cost of compensation for landowners, and the cost of removal and replanting are approximate estimates. Despite those limitations, the estimated cost for this very small outbreak is **£33,950**, indicating how even limited infestations can have large associated costs.

16.1.2 Widespread Eradication Costs

Fera has reported that environmental conditions in most of England and Wales as well as warmer coastal regions in Scotland would allow the establishment and breeding of this beetle. According to American research, the beetles are very resistant to cold temperatures, being able to tolerate -25.8 °C (Roden *et al.* 2008). It is therefore anticipated that the Asian long-horned beetle could potentially become established throughout Great Britain, with an associated increase in damage that would be very widespread and costly if initial outbreaks are not sufficiently contained.

Current control costs within the USA provide an indication of likely costs. Eradication attempts rely on the removal and destruction of infested trees and ‘high risk’ trees within a certain radius. Transport of woody material out of this area is banned and prophylactic treatment of at risk trees with systemic insecticides is carried out. An encapsulated contact insecticide is also used against adult beetles. Estimated costs provided by the US

Government Accountability Office associated with invasive populations of ALB include costs of eradication and costs resulting from the loss of tree cover. The Animal and Plant Health Inspection Service (APHIS) estimated the costs of eradication from 1998 to 2006 at $249 million (2006) (£18.7 million per annum), including the costs for survey and detection, tree removal, public outreach, and preventive treatment of landscape trees (Smith *et al.* 2009). A 1996 infestation in New York State cost more than $4 million (USDA 1998[84]), and by December 2007 over 400,000 trees had been removed and over 97,000 trees treated in an attempt to eradicate this beetle.

If the beetle did become established in Great Britain, eradication would pose huge challenges, partly due to its biological nature and the difficulties in identifying infested trees when most of the signs of infestation are found above 1.5 m from the ground towards the crown of the tree. However, it is assumed that all hardwood forests could become infested, as well as trees found in gardens, parks and hedgerows. It is likely that similar methods would be used to eradicate the species as are currently used to control it in the USA and Italy.

There are 1,191,000 ha of hardwood forest in Great Britain. If it is assumed that for one infested tree, all trees within a radius of 500 m are to be felled, this corresponds to an area of 78.5 ha. The quantity of timber, hence the value of the crop, varies among tree species, but it is assumed for this calculation that the hardwood yield per ha is an average of the yield for oak, birch and beech (155 m^3 ha^{-1}) and the current average timber value is £28.5 m^{-3}. Felling 78.5 ha of forest to contain a single infestation with ALB would consequently cost about £346,774, or £4,417.5 per ha worth of lost timber crop. It is assumed for this calculation that the market value of timber is such that it includes, felling, management, replanting and profit. Using these assumptions and assuming that 25% of the hardwood forests are infested, the cost of a widespread infestation could cost England £843,743,107, Scotland £331,312,739 and Wales £141,360,102. Therefore if ALB became established in Britain it could cost an **£1,316,415,948** to eradicate the species (if it was actually possible). This figure does not include the cost of eradication from other habitats, such as parks and gardens or hedgerows, so the cost of eradication could be even higher.

Each year, about 0.15 million m^3 of sawn hardwood is produced in the UK, approximately 0.43% of the annual US hardwood production. The cost of the beetle to the US hardwood industry, if uncontrolled, has been estimated as $138 billion (Meyer 1998). Therefore, if ALB

[84] www.aphis.usda.gov/oa/alb/

became established in the UK, it could cost an estimated £434.69 million today to the forestry industry alone, based on the assumption that the cost of ALB is similar per unit of wood produced in Britain and USA. The calculated estimate is higher but it is assumed that the species would be eradicated by felling all infested trees and the trees surrounding them, which is costlier than accounting for the loss of crop only.

16.2 Carpet Sea Squirt (*Didemnum vexillum*)

The carpet sea squirt is a marine colonial ascidian that is thought to be native to the north-western Pacific Ocean (Japan). It reproduces rapidly, spreads easily and is highly invasive. It threatens fishing and aquaculture as well as other coastal activities and marine habitats. *D. vexillum* is found at depths up to 65 m and forms colonies that can encrust rocky sea beds preventing fish from feeding. They can overgrow native organisms, such as mussel and scallop beds. Colonies are also found on any hard surface, including docks, mooring lines, ships' hulls, pilings etc (USGS 2009). As a fouling organism, it is known to be present in various countries and continents, e.g. USA, Canada, the Netherlands, France, Ireland, New Zealand, and to do great damage to oyster beds, leading to substantial losses in income.

16.2.1 Current Eradication Costs

D. vexillum was recently found in Great Britain for the first time. Infestations have been found in Holyhead, Lymington, the Dart Estuary, Gosport, Cowes and the Firth of Clyde. The outbreak in Holyhead was investigated by the Countryside Council for Wales (CCW), who provided £100,000 until the end of March 2010 to an ongoing eradication trial in 10% of Holyhead Marina. Monitoring of marinas in the region as well as Special Areas of Conservation (SACs) with an estimated area of c. 500,000 ha is also being undertaken. The trial eradication from harbour structures appears to be successful, although the long-term success will have to be confirmed through monitoring in coming years. The cost of the current eradication and monitoring effort can be broken down into material costs (£21,000), project management (£23,000), divers for eradicating and monitoring (£20,000) and one week's worth of surveying costs a total of £13,000 (boat, personnel, etc.). Holyhead marina has 300 mooring berths, giving a cost of eradication per berth of £333. Extensive populations were found in both Gosport and Dart, in particular the Darthaven marina, and eradication is anticipated to require treatment of the majority of berths within the marinas, as well as some additional pontoons beyond the marinas (J. Bishop, pers. comm.). The three affected marinas in Gosport and one in the Dart have a total of 1689 berths[85,86,87,88], in

[85] http://www.royalclarencemarina.org/

addition to other affected adjacent pontoons (6 long and 5 ordinary pontoons in the Dart). A single colony of *D. vexillum* was identified in Plymouth and it was found at four locations in Cowes. If it is assumed that the cost of eradication of these five colonies is equivalent to the cost of eradication at a single berth, then using a cost of £333 per berth, it would initially cost an estimated £564,102 to eradicate *D. vexillum.* This does not include the cost of eradication from adjacent pontoons in Gosport and the Dart where *D. vexillum* was found, and therefore, assuming as pontoons are considerably longer than berths, that it costs five times as much to clear a pontoon, and that a total of 15 pontoons will need to be cleared then an additional £24,975 is added, providing an initial eradication costs of £589,077. Based on the experiences of trying to eradicate the sea squirt in Holyhead marina, it is anticipated that full eradication will take two years (Dr R Holt, pers. comm.), and therefore this estimate is doubled to £1,178,154.

In addition, monitoring activities will be needed over the next few years to ensure eradication has been successful and CCW have requested a further £200,000 for additional monitoring activities in Holyhead. (Dr R Holt, pers. comm.). This is double the amount spent on eradication in Holyhead and therefore a further £1,178,154 is added to the eradication costs. In total it is estimated that eradication of the current population of *D. vexillum* in British waters will cost **£2,356,308**.

16.2.2 Widespread Eradication Costs

D. vexillum distribution does not appear to be limited by cold tolerance or substrate (Valentine *et al*. 2007) though at temperatures below 15 ^{o}C the species may not be able to breed (NNSS Risk Assessment, undated). The species is however limited by salinity, and growth is reduced in areas of low salinity (Bullard and Whitlatch 2009). Although the cost of cleaning vessels in these marinas should probably not be linked to this particular species, as boat hulls should be cleaned once a year anyway, the cleaning of anchor chains and ropes, pontoons and harbour structures can be linked to *D. vexillum*. An estimated 160 marinas and 55 commercial harbours are estimated to have suitable water conditions to allow *D. vexillum* to colonise (J Bishop pers. comm.). The exact number of berths of these susceptible marinas and harbours is not known, but the 221 marinas in Great Britain have approximately 44,136 berths (K Boss, British Marine Federation, pers. comm.), an average of 200 berths per marina. If a cleaning cost of £333 per berth is used again, then for the 32,000 berths in

[86] http://www.deanreddyhoff.co.uk/haslar/
[87] http://www.premiermarinas.com/pages/gosport_marina
[88] http://www.darthaven.co.uk/

the susceptible marinas, an eradication cost for one year is estimated at £10,656,000. The size of the harbours and the number of berths is unknown, but assuming that each one has twice the length of moorings and pontoons of a marina then the cost of eradication from one harbour can be estimated at £133,200, £7,326,000 for the 55 harbours. The total cost of one year's eradication strategy is therefore estimated at 17,982,000, but again assuming a two year eradication strategy would be required, and that monitoring would be undertaken for a further two years then the cost of eradication from marinas can be estimated at £71,928,000.

An additional potential cost factor is attributable to the growth of *D. vexillum* on a wide variety of substrates, including (mobile) animals and the seabed. It is very difficult to estimate if and what area of seabed may become invaded, but although it's growth is limited by salinity it is not greatly limited by depth, having been found on the sea floor up to a depth of 65 m, so effectively, its range could extend all around Great Britain up to a water depth of 65 m. If *D. vexillum* does become widespread, eradication costs would include all of the above control measures, but in addition it would be necessary to clear growth from coastal waters beyond the harbours and marinas.

Trials in New Zealand have shown that eradication through manual removal and suffocation using plastic sheeting is expensive but can be very effective. Pannell and Coutts (2007) reported that the cost of cleaning the seabed was approximately NZ$3.21 (~£1.12) m^{-2}. If it is assumed that 0.1% of British territorial waters (Exclusive Economic Zone of 764,071 km^2) were infested by *D. vexillum,* then at a cost of £1.12 per m^2, it would cost £855,680,000 to clear the sea bed. This is assuming that uninfected areas will also be surveyed, but it is probably an underestimate because the need for diving under potentially difficult sea conditions will increase the price. A total potential eradication cost for the coastline and harbours/marinas is therefore **£927,608,000**. However if the infestation reaches this level it is unlikely eradication will be a serious option either economically or ecologically.

16.3 Water Primrose (*Ludwigia* spp.)

Ludwigia species (synonym *Jussiaea* spp.) form a group of aquatic weeds native to South America. They grow rapidly and extensively and can double their biomass in 15-20 days in slow moving water. The stems and leaves of *Ludwigia* spp. float on the water surface and form dense mats that can quickly block waterways and interfere with navigation, fishing etc. These vegetative mats shade deeper water plants, reducing their photosynthetic rate and therefore their growth. The lower photosynthetic rate also reduces the amount of dissolved oxygen in the water, which is not replaced because the surface is covered by *Ludwigia* spp., rather than submerged growth (Anon 2009). *Ludwigia* spp. can easily become invasive outside their native range, especially as the main means of dispersal are seed spread and through stem fragmentation and viable seed production. Even a small piece of stem remaining in a water body can lead to new growth of the plant.

Ludwigia spp. are sold as garden plants in Great Britain and elsewhere, although their sale has been banned in France since 2007, due to the invasive nature of the species. The species have recently become established in England, and a Defra funded project has recorded the current distribution of *Ludwigia* spp. At the time of writing, 13 locations of *L. grandiflora* have been recorded in England and one in Wales (Dr Jonathan Newman, pers. comm.). None of the *L. grandiflora* sites are currently larger than one acre. The surveys of *Ludwigia* occurrence in the UK indicate that *L. peploides* currently does not occur in Great Britain, but there are some doubts about the identification and research is being conducted to clarify the species level identifications.

16.3.1 Current Eradication Costs

The Defra project has tested two chemical methods to control the species: either a spray of glyphosate or a spray of a mixture of a non-oil soya sticking agent and glyphosate. The latter mixture resulted in near-complete removal of the plants. However the spraying treatments needed to be repeated to kill plants that were establishing from seed, even though seed set was prevented in the trials (Dr Jonathan Newman, pers. comm.). This research and work in southern France, has led to the conclusion that prevention or early intervention are the most effective option to control the species (Agence Méditerraneen de l'Environnement, 2002). However, repeated intervention is necessary to keep the plants under control, firstly by mechanical clearance, followed by repeated hand removal (2-3 times per year over 2-3 years). Current costs, including the research to establish the extent of current outbreaks and eradicate them, amount to £10,000 (the cost of Defra funded project PH0422 (Defra 2007)), but Dr Newman estimates that he has spent £14,000 on research to date (pers. comm.). Oreska (2009) estimated that the current control cost is £10,263 pa. In summer 2009, *Ludwigia* was found at Breamore Marsh SSSI and funding to spray this area twice in autumn 2009 has been secured. The annual cost for this site is £1,881.40 (Catherine Chatters, pers. comm.). There are currently 13 sites in England and Wales. If it is assumed that the control costs are similar for all sites, then the estimated current annual control cost for *Ludwigia* spp. is £24,457. This is about double that estimated by Oreska, but that figure was based on 6-7 populations (Oreska 2009, Table 3.6a) and therefore this figure is largely in accordance with that estimate.

Above is only the cost of the initial removal. In addition there is a need for regular follow-up treatment where re-growth has to be manually removed every three weeks (Bianca Veraart, Antwerp Province, pers. comm.). This can effectively eradicate the species, though there may be areas that are difficult to reach in which small plant parts remain and the infestation re-establishes itself. Intensive surveying for at least two years is necessary to ensure any new outbreaks are rapidly cleared. Assuming that the control is similar to that of *Hydrocotyle*, then the ratio between initial removal and follow-up control from Kelly (2006), who described the removal of *Hydrocotyle* from 1 km of ditch in the Gillingham Marshes, can be used. The cost of the initial removal was approximately half of the follow-up costs (Dan Hoare, pers. comm.). The cost of follow-up treatment at Breamore Marsh is also estimated at twice that of the initial treatment (Catherine Chatters, pers. comm.). Therefore, the cost of follow up treatments is estimated at £48,914 and the total cost of eradicating the current outbreaks of *Ludwigia spp.* can be estimated at **£73,371**.

16.3.2 Widespread Eradication Costs

The cost of *Ludwigia* spp will increase if the species spreads, as is exemplified by the situation in continental Europe and the US. *Ludwigia* species are a widely distributed pest in France (*L. grandiflora* and *L. peploides*) and California (*L. hexapetala*). In southern France (Languedoc-Roussillon) and California, various control methods have been tested with mixed results. The most effective methods rely on a combination of herbicides and labour-intensive manual removal of plants (Trocme and Pipet 2005). Manual/mechanical removal has been successful in reducing the abundance of plants the following year, but only if the size of the *Ludwigia* patch was smaller than $20m^2$. In both countries, positive results were achieved during the first 1-2 years after the initial single clearance, but the re-growth occurred at pre-treatment levels, indicating that continuous control is necessary (Agence Mediterranée de l'Environnement 2002, CAL-IPC News 2009). In the Pays de la Loire, $269{,}000m^2$ (26.9 ha) of waterways were cleared of *Ludwigia* in 2003 and 2004, costing €350,000 (€11.8 per ha, £8.07 per ha) (Dubos 2005). The French Department of Maine and Loire spent €100,000 per year (£68,367 per year) on the control of *Ludwigia* species (Genillon 2005). In California, the cost of removal from two wetlands varied between US$14.67 and US$39.95 per km^2 (£8.06 - £21.94) in 2005 (McNabb and Meisler 2006) demonstrating that the cost of control is very variable, depending on habitat (i.e. accessibility, abundance, etc.).

Ludwigia spp. are likely to spread in the UK if the current populations are not eradicated and continued sale is not banned, therefore increasing the associated costs. The use of herbicide on a vast area would be very damaging for the environment and it may be that that future control would be mechanical, as in other countries where the species is currently causing problems (Mike Sutton-Croft, pers. comm.). Assuming that mechanical removal will be used, that about 10% of all 68,310 km of waterways (rivers and canals) in England and Wales will be invaded and that the cost of removal per km is similar to other species and countries (e.g. £1800-2000/km for *Hydrocotyle* spp., Jonathan Newman, pers. comm.), this would amount to £13,662,000 per year. There are 24,404 km of rivers in Scotland[89] and 220 km of canals (British Waterways Scotland website). Therefore, using the same cost of clearance per kilometre, but assuming only 5% of rivers are affected, then the cost of removal of *Ludwigia* from Scottish waterways would be approximately £2,462,400 per year. The lochs of Scotland have a combined surface area of 1527.9 km^2, England 322.5 km^2 and Wales 73.9 km^2 (FAO). Assuming that 0.1% of the surface of the lakes close to tourist destinations and on main transport corridors becomes invaded and that the cost of management is similar to that in other countries (€129,727.5/km^2 ~ £103,782/km^2), the annual costs for eradicating *Ludwigia* from lakes in England, Scotland and Wales would be £33,470, £1,585,685 and £7,670 per year, respectively. The total area of wetlands in England is 9,322 km^2 (Marina Flamank, EA, pers. comm.). No similar figure could be obtained for Wales, so it was assumed that the area of wetlands in Wales is 20% of that in England, and that 5% of the wetland area could become infested with *Ludwigia* (466 and 93 km^2 in England and Wales, respectively). Again, no figure for the wetland area in Scotland could be obtained, but it was assumed that the area where *Ludwigia* would become established in Scotland if widespread would be 10% of the wetland area in England (47 km^2). Based, as above, on the assumption that the cost of management would be similar to that in other countries, the cost of eradicating *Ludwigia* from wetlands would be £48,372,790, £9,674,558 and £4,837,279 in England, Wales and Scotland. This gives a total annual cost for the three countries of £80,635,852.

As discussed above, removal of *Ludwigia* on a single occasion is unlikely to result in eradication of the species. Eradication would require repeated treatments and would cost double the amount needed for the original treatment. Hence, repeated removal of widely occurring *Ludwigia* could cost £161,271,704. The total cost of *Ludwigia* eradication if it became widespread in Great Britain is estimated to be **£241,907,556**. However, as Bianca

89 http://www.sepa.org.uk/science_and_research/classification_schemes/river_classifications_scheme.aspx

Veraart indicated, though the above treatment will lead to reductions in the abundance of *Ludwigia*, it is unlikely to lead to complete eradication (pers. comm.). One may expect that complete eradication of *Ludwigia* would require a continuous effort over a longer period of time and the cost of complete eradication would consequently be higher. The figure presented above should therefore be seen as a conservative estimate of the eradication cost.

16.4 Grey squirrel (*Sciurus carolinensis*)

The grey squirrel is a terrestrial mammal, native to North America that was introduced to England in the late 19th and early 20th century. Since then it has spread rapidly across most of Great Britain and the current distribution covers most of England and Wales and southern Scotland, but not the Scottish Highlands. While no accurate population estimates exist, various sources have suggested that the current population is between 2 and 3.3 million. The animals live in areas of deciduous and mixed forests, parks and gardens and feed on fruits, nuts, tree shoots, flowers and cereals. The habitat requirements are similar to those of the native red squirrel (*S. vulgaris*), but the grey squirrels are more adaptable.

Grey squirrels have a wide range of impacts, from a reduction in wood production and chewing cables in homes to a reduction in biodiversity (Huxley 2003). Squirrels are also increasingly doing damage to properties when they build dreys in lofts (www.greysquirrelcontrol.co.uk, pers. comm.), tear up insulation, chew timber and wires and stored goods. They are also a source of noise and pollution. However, the current control costs are difficult to estimate, and no record is currently kept of the numbers culled each year or the impact the culling has on population dynamics (Dr Shuttleworth pers. comm.).

A long-term solution to control damage would be total eradication of grey squirrels in Britain and therefore an attempt is made to estimate the associated costs, even if practically it may not be possible. In Italy, an attempt was made to eradicate grey squirrels in a relatively early stage of the invasion, but after legal charges brought by animal rights groups, the eradication trial was halted and after the court case, it was deemed too late for eradication (Bertolino and Genovesi 2003). Based on the Italian experience and the failure of previous attempts to eradicate grey squirrels from Great Britain), it may no longer be possible to eradicate grey squirrels from Britain (http://www.greysquirrelcontrol.co.uk/facts.html.

16.4.1 Early Stage Eradication

In Anglesey, grey squirrels have been eradicated as part of an effort to conserve red squirrels. The eradication of an initial grey squirrel population of approximately 3500 individuals cost **£440,000** over four years and the red squirrel population has increased fivefold since the eradication programme (Dr Shuttleworth pers. comm., http://www.redsquirrels.info/greytiderelease.htm). However, the eradication is not complete and Anglesey appears to behave like a peninsula rather than an island, as squirrels re-invade from the mainland over the two bridges and perhaps by swimming across the Strait of Menai (Shuttleworth, pers. comm.). Dr Shuttleworth stated that complete eradication of grey squirrels from an area is difficult to achieve, with the final remaining adults needing to be shot as they no longer enter traps. This increases the cost of the eradication effort. Although it is not a perfect example, the costs are used as an illustration of early stage eradication in this report.

16.4.2 Late Stage Eradication

Anglesey has a surface area of 71,400 ha, Wales 2,076,100 ha, Scotland 7,877,200 ha, England 13,039,500 ha, and Great Britain 22,992,800. On Anglesey, there was an estimated population of 3500 individuals living in 71,400 ha of mixed landscape, which would equate to approximately 1,127,098 individuals in Great Britain, if the density were similar throughout. The current population estimate is approximately double or triple this number (for a smaller area because only about 25% of Scotland is affected), so for this calculation it is assumed that a minimum of three times the trapping intensity may be necessary. That would amount to £1,200,000 for Anglesey, or £18.5 per ha, and £425,366,800 over four years for all of Great Britain. However, as noted, the cost depends on methods used and border areas may be more expensive, accounted for here by using the complete area of Scotland in the calculation. In addition, a considerable period of time is necessary to trap the last individuals at the end of the eradication effort, as indicated by the coypu eradication in East Anglia (Bertolino and Viterbi 2010). Therefore, the trapping period has been doubled to eight years, providing a total cost of **£850,733,600**. This is probably a conservative estimate, because of the difficulty in eradicating large, interconnected populations and the necessity of control measures taking place on private land for which permission for access is required.

16.5 Coypu (*Myocastor coypus*)

The coypu is a large, semi-aquatic rodent native to South America. They are generally found near rivers, streams, lakes, etc., especially in marshy habitat. They burrow into riverbanks as well as dykes, irrigation facilities, etc., causing instability and damage. Their presence, outside their native range, can also lead to the destruction of marshes and reed swamp through overgrazing especially of rhizomes and young shoots of marsh plants (Bertolino 2005). This can lead to habitat loss for insects, birds and fish.

Coypu were originally introduced into Britain for fur farming, but as fur farming became less profitable, and maintenance at the farms reduced, coypu escaped. A population became established in East Anglia and was estimated to have reached approximately 200,000 individuals by the early 1960's. Another population was known to have escaped near Slough, but these animals disappeared without any control measures being undertaken (Baker 2005) and it appears that the main established population was limited to East Anglia, covering an area of 28,500 km^2. Other isolated sightings were recorded in other parts of England northwards to Scotland (www.nbn.org.uk).

16.5.1 Eradication Costs

An initial attempt to eradicate coypu from Great Britain was made between 1962 and 1965, costing £70,500, (£959,050 today) (Norris 1967). Over 40,000 animals were killed, and it is estimated that 80%-90% of coypu were killed by the 1962/63 winter (Baker 2005), the coldest winter in Britain for over 200 years. However, a lack of understanding of the population response to trapping meant that mild winters in the 1970s allowed a population explosion to occur. This led to a second eradication effort from 1981 to 1989 when the species was successfully eradicated, through the employment of 24 trappers for eight years at a cost of £2.5 million, equivalent to **£4.7 million** today (Gosling 1989).

16.5.2 Estimated Widespread Eradication Costs

It is possible that coypu may not have been eradicated from Great Britain and therefore it is useful to consider the situation in continental Europe, where the species is considered a pest due to its feeding on crops, such as sugar beets and maize, and for its burrowing activity that damages and weakens riverbanks and dykes. Work carried out by Panzacchi *et al.* (2007) on the situation in Italy demonstrated that, despite control activities involving the removal of 220,688 coypus and costing €2,614,408 (current equivalent £2,011,097), damage to the riverbanks exceeded €10 million (£7,659,371) and the impact on agriculture reached €935,138 (£719,335) between 1995 and 2000, giving an annual cost of £1,731,634 today. The cost of flooding was not included, as it was not possible to differentiate between costs incurred due to lack of management and those incurred by coypu damage to collapsed dykes. These control measures have not limited the spread of, or the damage done by coypu, and the population size, that can be approximated by the number of trapped animals (Gosling *et al.* 1988, Panzacchi *et al.* 2007), continued to rise throughout the trapping period. Bertolino and Piero (2005) also examined the current costs of coypu to Italy, estimating the total annual cost between 1995 and 2000. Their data indicated increased costs each year with an annual cost of €3,773,786 in 2000 (£3,045,916 today). This estimate included compensation for crop damage, the cost of control and the cost of damage to river banks, although again they excluded any increased flooding costs. This cost covered a range of 68,599 km^2.

Both Panzacchi *et al.* (2007) and Bertolino and Piero (2005) compared current coypu costs in Italy with the cost of the eradication from East Anglia and concluded that a large investment in an eradication campaign would reduce costs in the long term as compared with continuous control, but the success of the campaign would depend on careful planning based on the ecology of the targeted area and regular evaluation of the success of the control measures. Bertolino and Ingegno (2009) have modelled the predicted range of coypu in Italy and confirmed that it is found predominately in areas of flat land below 300 m above sea level (a.s.l.). Its presence is also strongly correlated to the presence of running water, including drainage ditches, but is not found in woodland, cropped areas (apart from rice) or urban areas. Given these habitat requirements, and the spread of the species in Italy to discontiguous areas (Bertolino and Piero 2005), it is possible that coypu could have spread to all wetland areas below 300m a.s.l. in Great Britain, as well as riverine habitats. Therefore it is assumed, based on the height of land in the country, and the prevalence of rivers, streams and wetland areas, that coypu may have spread to four times the area they occupied in East Anglia (28,500 km^2; Baker 2005), giving a range of 114,000 km^2. If it is also assumed that the eradication costs of £4.7 million (today's prices) for East Anglia are still valid, then eradication costs for four times that area are estimated at **£18.8 million**.

16.6 Discussion

These case studies illustrate how costs caused by INNS increase depending on the stage of invasion that the species has reached (see Table 16.1). In situations where the species is in an early stage of invasion, the costs of eradication are relatively low. This is illustrated by the Asian long-horned beetle, water primrose and carpet sea squirt. The costs of keeping a species out of Great Britain, or ensuring that any outbreaks are immediately eradicated are very low in comparison to the costs incurred in other countries where the species are fully established. The costs incurred in Great Britain for these species are mainly due to prevention and quarantine measures and localized eradications.

Table 16.1. Cost of intervention controls by species.

Species		**Control Stage**	**Cost**
Asian long-horned beetle	*Anoplophora glabripennis*	Early stage eradication	£34,000
		Late stage eradication	£1,316,416,000
Carpet sea squirt	*Didemnum vexillum*	Early stage eradication	£2,356,000
		Late stage eradication	£927,608,000
Water primrose	*Ludwigia* spp.	Early stage eradication	£73,000
		Late stage eradication	£241,908,000
Grey squirrel	*Sciurus carolinensis*	Early stage eradication	£440,000
		Late stage eradication	£850,734,000
Coypu	*Myocastor coypus*	Mid stage eradication	£4,700,000
		Late stage eradication	£18,800,000

However, when species become established and consolidate their presence in the country, the eradication costs increase considerably. All the case studies illustrate that the cost of late stage eradication vastly exceed eradication at an early stage of invasiveness. For example, the cost of eradicating water primrose at its present stage of invasiveness is less than 0.03% of its potential eradication costs if the species is allowed to become fully established.

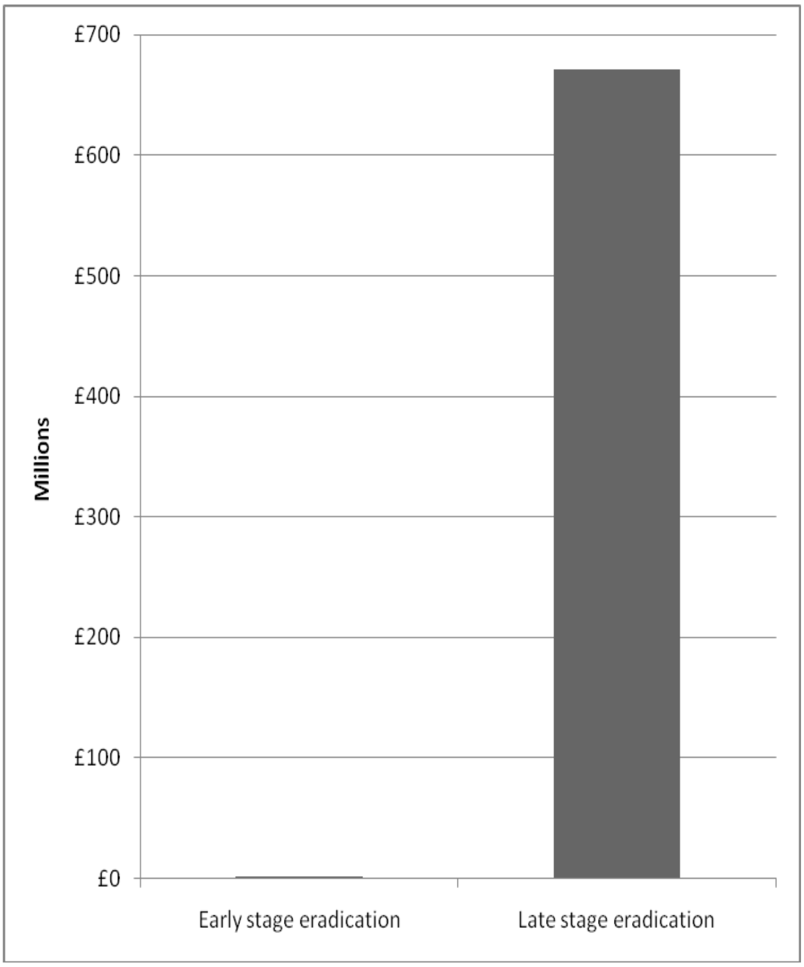


Figure 16.1. Average estimated eradication costs, depending on stage of invasiveness. Prevention costs are on an annual basis, other costs are total.

Generally speaking, the costs increase exponentially if species are allowed to spread (Fig. 16.1). These case studies therefore show that early eradication is more cost-effective than long-term control or eradication of well-established INNS. They also demonstrate that even eradication of some well-established INNS could be more cost-effective that long-term control of the species as annual costs can quickly exceed eradication costs over a few years. These conclusions are in agreement with findings based on the other species and the general consensus on the best methods to deal with biological invasions (Wittenberg and Cock 2001). They are also supported by the fact that most attempts to eradicate well-established INNS have failed (Pimentel *et al.* 2001), emphasising that eradication at an early stage of invasion is the most cost-effective method of controlling an INNS.

References

Anon. (2002). Pour contrôler la prolifération des jussies (*Ludwigia* spp.) dans les zones humides méditerranéennes - guide technique. Technical report, Agence Méditerraneen de l'Environnement

Anon. (2006). Grey squirrels and England's woodlands: Policy and action Forestry Commission

Anon. (2007). Development of eradication strategies for *Ludwigia* species. Technical report, Defra PH0422

Anon. (2009). Water Primrose, or Floating Primrose Willow, Peconic Estuary Program

Baker S (2006). The eradication of coypus (*Myocastor coypus*) from Britain: the elements required for a successful campaign. In: Assessment and Control of Biological Invasion Risks. Shoukadoh Book Sellers, Kyoto, Japan and IUCN, Gland, Switzerland. pp. 142–147

Bertolino S (2005). *Myocastor coypus* (mammal). Global Invasive Species Database

Bertolino S, Genovesi P (2003). Spread and attempted eradication of grey squirrel (*Sciurus carolinensis*) in Italy, and consequences for the red squirrel (*Sciurus vulgaris*) in Eurasia. Biological Conservation 109: 351-358

Bertolino S, Ingegno B (2009) Modelling the distribution of an introduced species: The coypu *Myocastor coypus* (Mammalia, Rodentia) in Piedmont region, NW Italy. Italian Journal of Zoology 76 (3):340 - 346

Bertolino S, Piero G (2005). Aquatic alien mammals introduced into Italy: their impact and possibility of control. Biological Invasions in Inland Waters. Florence 5-7 May

Bertolino S, Viterbi R (2010). Long-term cost-effectiveness of coypu (*Myocastor coypus*) control in Piedmont (Italy) Biological Invasions (*in press*)

Bullard SF and Whitlatch RB (2009) *In situ* growth of the colonial ascidian *Didemnum vexillum* under different environmental conditions. Aquatic Invasions 4: 275-278

Culliney TW (2005). Benefits of classical biological control for managing invasive plants. Critical Reviews in Plant Sciences 24: 131–150

Dubos J-P (2005). Lutte contre les végétaux aquatiques envahissants - action du conseil général de loire atlantique. In: Coreve (ed.). Colloque sur la gestion des plantes exotiques envahissantes en cours d'eau et zones humides. pp. 36–38

Genillon A (2005). Présentation de l'expérience du département de maine et loire en matière de lutte contre les plantes aquatiques envahissantes. In: Coreve (ed.). Colloque sur la gestion des plantes exotiques envahissantes en cours d'eau et zones humides. pp. 39–41

Gosling LM (1989). Extinction to order. New Scientist 4 March 1989: 44–51

Gosling LM, Baker SJ, Clarke CN (1988). An attempt to remove coypus (*Myocastor coypus*) from a wetland habitat in East Anglia. Journal of Applied Ecology 25: 49–62

Herard F, Maspero M, Ramualde N, Jucker C, Coomobo M, Ciampitti M, Cavagna B (2009). *Anoplophora glabripennis* - Eradication programme in Italy (April 2009). EPPO. http://www.eppo.org/QUARANTINE/anoplophora_glabripennis/ANOLGL_IT.htm

Holmes T, Aukema J, Von Holl B, Liebhold A, Sills E (2009). Economic Impacts of invasive species in forests. Annals of the New York Academy of Sciences 1162: 18-38

Huxley L (2003). The grey squirrel review. ESI Dorset

Kelly A (2006). Removal of invasive floating pennywort *Hydrocotyle ranunculoides* from Gillingham Marshes, Suffolk, England. Conservation Evidence 3: 52-53

Macmillan D, Phillip S (2008). Consumptive and non-consumptive values of wild mammals. Britain Mammal Review 38: 189-204

Meyer DA (1998). Asian longhorned beetle. Hardwood Research Bulletin 500. http://www.invasive.org/publications/98025.pdf

McNabb TJ, Meisler J (2006). Two years of *Ludwigia* control in the laguna de Santa Rosa process and progress. In CAL-IPC Symposium, Rohnert Park, CA

Non-Native Species Secretariat Risk Assessment (undated) *Didemnum vexillum*

Norris JD (1967). A campaign against feral coypus (*Myocastor coypus*) in Great Britain. Journal of Applied Ecology 4: 191–199

Oreska MPJ (2009). Assessing the economic aspects of aquatic invasive species in Great Britain. Master's thesis, Cambridge University

Pannell A, Coutts ADM (2007). Treatment methods used to manage *Didemnum vexillum* in New Zealand. Technical report, Biosecurity New Zealand

Panzacchi M, Bertolino S, Cocchi R, Genovesi P (2007). Population control of coypu *Myocastor coypus* in Italy compared to eradication in UK: a cost-benefit analysis. Wildlife Biology 13: 159–171

Pimentel D, McNair S, Janecka J, Wightman J, Simmonds C, O'Connell C, Wong E, Russel L, Zern J, Aquino A, Tsomondo T (2001). Economic and environmental threats of alien plant, animal, and microbe invasions. Agriculture, Ecosystems and Environment 84: 1–20

Roden DB, Haack RA, Keena MA, McKenny DW, Beall FD, Roden PM (2008). Potential northern distribution of Asian longhorned beetle in North America. 2008 USDA Forum on Invasive Species

Smith MT, Wu J (2008). Asian longhorned beetle: renewed threat to north-eastern USA and implications worldwide. International Pest Control 50: 311-316

Smith TM, Turgeon JJ, De Groot P, Gasman B (2009). Asian longhorned beetle *Anoplophora glabripennis* (Motschulsky): Lessons learned and opportunities to improve the process of eradication and management. American Entomologist 55: 21-25

Trocme M, Pipet N (2005). Maitrise de la colonisation et al prolifération des jussies dans le Marais Poitevin. In: Coreve (ed.). Colloque sur la gestion des plantes exotiques envahissantes en cours d'eau et zones humides. pp. 24–28

United States Geological Service (2009). Marine Nuisance Species. Woods Hole Science Center

Valentine PC, Carman MR, Blackwood DS, Heffron EJ (2007). Ecological observations on the ecological ascidian *Didemnum* sp. in a New England tide pool habitat. Journal of Experimental Marine Biology and Ecology 342: 109–121

Wittenberg R, Cock MJW (2001). Invasive alien species: A toolkit of best prevention and management practices. CAB International, Wallingford

Xu H, Ding H, Li M, Qiang S, Guo J, Han Z, Huang Z, Su H, He S, Wu H, Wan F (2006). The distribution and economic losses of alien species invasion to China. Biological Invasions 8: 1495–1500

17 Discussion

The total annual cost of INNS to the British economy, as estimated in this report, is £1,678,434,000. Table 17.1 presents the costs by sector and country and reveals that the costs to the sectors are widespread and often significant. In most cases, the only costs that could be quantified are the direct market costs, such as the money spent on control measures or the reduction in productivity due to the presence of an INNS. Indirect costs constitute less than 1% of our total estimate and exclusion of the indirect costs from the estimate for better comparison with other studies reduces the estimate of the total cost to £1,674,774,000.

Table 17.1 Estimated total costs of INNS to Great Britain by sector and country.

All Costs	England	Scotland	Wales	GB
Agriculture	£839,189,000	£156,120,000	£71,110,000	£1,066,419,000
Forestry	£45,780,000	£48,666,000	£14,950,000	£109,396,000
Quarantine and Surveillance	£14,523,000	£1,287,000	£1,956,000	£17,766,000
Aquaculture	£4,370,000	£722,000	£2,053,000	£7,145,000
Tourism and Recreation	£78,920,000	£13,059,000	£5,759,000	£97,738,000
Construction, Development, Infrastructure	£194,420,000	£6,870,000	£11,078,000	£212,368,000
Transport	£62,894,000	£9,621,000	£8,768,000	£81,283,000
Utilities	£8,515,000	£1,119,000	£483,000	£10,117,000
Research				£17,387,000
Biodiversity and Conservation	£11,176,000	£5,802,000	£6,218,000	£40,583,000[a]
Human Health	£37,844,000	£4,470,000	£5,816,000	£48,130,000
Subtotal	**£1,297,631,000**	**£247,736,000**	**£128,191,000**	**£1,708,332,000[a]**
Double count	£6,170,000	£3,268,000	£3,073,000	£29,898,000[b]
Total costs	**£1,291,461,000**	**£244,468,000**	**£125,118,000**	**£1,678,434,000**

[a] The total cost for biodiversity does not equal the country totals, due to the inclusion of research costs, which are not divided by country. Similarly, the GB total does not equal the country totals.

[B] The double counting, removed to obtain the overall total cost estimate, relates to the £1,945,000 cost of quarantine and surveillance for forestry species that is included in the quarantine, forestry, and research sectors. The £8,621,000 cost of rhododendron control is included in both the forestry and biodiversity sectors. Finally, the entire cost of research is included in the biodiversity and conservation sector, as all research carried out on INNS will be of benefit to biodiversity and conservation either directly or indirectly.

INNS have by far the largest effect on the agriculture and horticulture sector, amounting to just under two thirds of the total estimated cost (Table 17.1). These costs arise from a wide variety of species, from plant pathogens, insect pests and weeds to some of the most common mammalian species in Great Britain, such as rabbit. A further cost that can be considered to affect agriculture is the amount spent on quarantine and surveillance. While approximately £1.9 million of a total of approximately £18 million is spent on forestry quarantine, the remaining £16 million is spent on quarantine and surveillance measures for plant health, primarily agriculture. This emphasises the impact of INNS on the agricultural industry in Britain. The cost to construction, development and infrastructure is also considerable, but the costs in this sector arise from very few species, with Japanese knotweed being by far the most costly species, followed by the brown rat.

The majority of the costs are incurred by England, with far lower costs to Scotland and Wales. Based on the respective land areas, England has higher and Scotland lower costs than expected, and Wales roughly what one would expect if the costs were equally distributed over Great Britain. This is due to a number of factors. England has proportionally more agricultural land than Scotland and Wales and as this is the sector with the highest costs, a larger proportion of the costs are incurred in England. England also has more international transport links than the other two countries and is therefore more likely to be the entry point for any invasion. Consequently, more non-native species have become established in England and some species that are widespread in England only have a limited distribution in Scotland and Wales (e.g. grey squirrel).

Of those costs that could be directly attributed to a species or group of species, plants as a group inflict the highest costs to the economy, with mammals and plant pathogens also causing considerable costs across the sectors (Table 17.2). This is likely to be due to the large number of non-native plants in the country, compared to the number of non-native species in other taxa. Spending on INNS management in general, for example by conservation organisations on general land management where a portion of the cost relates to INNS, was not included in this summary table.

On an individual species level, rabbits and Japanese knotweed cause the highest cost (Table 17.3), reflecting their widespread distribution throughout the country, as well as their impact on a number of different sectors.

Table 17.2. The annual costs of species groups to the British economy.

Group	**Cost**
Plants	£483,030,000
Plant pathogens	£403,063,000
Mammals	£402,483,000
Insects	£254,695,000
Birds	£6,284,000
Total	**£1,563,127,000**

Table 17.3. The annual cost of individual species or species groups to the British economy.

Species	**Cost**
Rabbit	£263,173,000
Japanese knotweed	£165,609,000
Common field-speedwell/ wild oat	£100,000,000
Rat	£62,162,000
Potato cyst nematodes	£50,000,000
Non-native deer	£34,907,000
Varroa mite	£27,119,000
Floating pennywort	£25,467,000
House Mouse	£17,876,000
Grey squirrel	£14,067,000
Rhododendron	£8,621,000
Slipper limpet	£5,514,000
Mink	£4,797,000
Geese/swans	£3,617,000
Green spruce aphid	£3,569,000
Signal crayfish	£2,689,000
Giant hogweed	£2,362,000
Himalayan balsam	£1,000,000
Buddleia	£961,000
Edible dormouse	£364,000
Great spruce bark beetle	£163,000
Carpet sea squirt	£107,000
Parakeets	£38,000
Total	**£794,182,000**

The difference in the estimated costs of species and species groups (Tables 17.2 and 17.3) reflects that the calculations for the cost of INNS to agriculture and due to plant pathogens are based on the treatment of all unwanted species in agricultural systems, and the portion of these species that are estimated to be non-native, and not on the treatment of individual species. Consequently, it can be seen that roughly one third of the total cost estimate is based on the more detailed calculations of the impact of individual species.

The results from this study demonstrate that the highest level of interest from stakeholders, both on a sector and a species level, is not necessarily in areas where INNS cause the most costs. The majority of respondents to the questionnaire worked in the biodiversity and conservation sector, even though costs were much higher in other sectors. Follow-up interviews with respondents from the biodiversity and conservation sector confirmed that, although people in this sector are mostly aware of the ecological impact, they were unable to put a monetary value on the damage or changes due to INNS. Oreska and Aldridge (2010) reported similar difficulties associated with the valuation of impact of INNS to ecosystems by stakeholders. This does not mean, however, that the costs of INNS are inconsiderable in this sector. Indeed, the true costs are likely to be higher than indicated in this report and the low cost estimate is due to the difficulties in placing a monetary value on the effects of INNS on the environment and ecosystems. This research has also revealed that the cost of control or perceived impact of INNS as a separate group is limited in various sectors, because all undesirable species are treated in the same manner, whether the species is native or non-native to Great Britain (e.g. insect pests in agriculture or hull-fouling). However, it was clear from interviews with people in those sectors that the lack of specific treatment is not due to a lack of awareness of the problems caused by INNS. For example, strict regulations exist in the shipping industry to prevent the introduction and spread of non-native species. Furthermore, there is considerable spending on quarantine and surveillance, again indicating awareness of the problems caused by INNS, as both quarantine and surveillance measures help to prevent the introduction, establishment and spread of new non-native species.

17.1 Confidence level of the estimates.

The assessment of the true costs of INNS is difficult in the absence of empirical evidence (Huxley 2003). This report contains one of the most detailed assessments of the economic cost of INNS on a country's economy, partially as a result of investigations into sector costs. The methods used were dissimilar to previous studies of the same kind, and this study may add to the variability of methods used for the assessment of INNS costs to the economy (Born *et al*. 2004). However, the combination that we used, of research of the grey and scientific literature, coupled with a questionnaire and follow-up interviews, has proved to be hugely valuable for gaining an insight of the market costs for a variety of sectors, species and stakeholders. Consequently, the direct cost estimate is based on a wide range of sources and different information for the many species examined. Most of the estimates are based on data obtained from literature, and where possible, the figures are based on information obtained from those involved, i.e. land managers, councils, scientists and other specialists. In other words, the estimates are based on real data and when compared with other studies, these estimates appear to be well-founded. On a number of occasions, data from other countries have been used in our estimates, or comparisons have been made with data from other countries to help verify the accuracy of these estimates. While the transfer of data from other situations adds variation to the estimates due to ecological and methodological differences in data collection (Hanley *et al.* 2006), this was still more accurate than using values obtained through educated guesses or assumptions.

The level of confidence in our estimates for market costs is very dependent on the species and sectors. For example, there is a high level of confidence in the cost estimate for the aquaculture sector, because those people who were contacted confirmed each other's assessments that INNS are not a distinct issue currently. Nevertheless, they were aware of the presence of INNS and the potential problems they could cause. By contrast, despite considerable efforts to obtain figures, information availability was limited in various cases because of its commercially sensitive nature, for example in the utilities and pest control industries, and consequently, a number of calculations had to depend on assumptions about incurred costs. In addition, many costs were difficult to estimate since, for example, the population size of the species causing the effect was unknown, or because the control effort is not monitored consistently across the country (e.g. grey squirrel and mink). In this work, where solid evidence was not available, assumptions based on the biology and ecology of the species involved were used to extrapolate costs. These assumptions were checked with experts in the field, corrected where necessary, or remained as assumptions when no expert was able to provide a better estimate to use. When assumptions did have to be used, the figures that were used were intentionally conservative and it has been explicitly stated that they were assumptions. In the anonymous peer review process the calculations and assumptions were challenged, corrected or accepted. This has added greatly to the confidence in the estimates.

Previous studies have estimated the impact of alien plants, vertebrates, arthropods, plant pathogens and freshwater organisms in the UK. The estimate of arthropod pest damage presented here (approximately £255 million) is considerably lower than the UK figures presented by Pimentel (2002), in which he estimated that mites alone caused $960 million (£591.65 million) of crop damage and the cost of forest insects was $2 million (£1.23 million). In total, Pimentel estimated that insects and plant pathogens do $5 billion (£3.08 billion) of damage to crops and forests every year, whereas we have estimated that insects and plant pathogens cost just over £658 million per year. However, due to the fact that the estimates in this study were extrapolated from known costs, we are confident that the figure presented here is a fairly accurate assessment of the costs.

Oreska (2009) estimated the current cost of aquatic INNS on Great Britain using a modelling approach. His estimate, £19 million spent annually on control, was based on eight plant species. Although these estimates are not based on the same species, the estimates for the species that the two studies have in common are in general agreement. For example, we estimated a current cost of *Ludwigia* spp. of £24,000 p.a. and Oreska's estimate was £10,263. Williamson (2002) estimated the economic impact of alien plants on the British Isles at £200-300 million. This is lower than our estimate of approximately £493 million for Great Britain alone. The economic impact of vertebrates was estimated at over £239 million by White and Harris (2002), with about 20% of that spent on control. Our estimate is £402 million. It is difficult to identify the cause for these differences, but it is possible that the considerable effort that went into our data collection using a wide variety of sources has resulted in the retrieval of more costs.

Non-market costs are notoriously difficult to estimate in any study (Perrings *et al.* 2000), although they compose probably the largest part of the economic impact of INNS (Colautti *et al.* 2006). This study captured some non-market costs, such as the estimated costs to the native water vole due to mink, but a key issue is that no estimates have been made for the majority of non-market costs, due to the lack of available data on which to base any calculations. In most cases, little or no research has been carried out to quantify these consequential effects. It was not the scope of this project to carry out additional research to quantify the costs of the ecosystem effects of INNS. Instead, we focused on capturing the costs of ecosystem effects that had already been quantified. The analysis of how the inclusion of non-market costs has affected the total estimate in previous studies of the impact of INNS to various countries' economies is shown in Box 1 in the introduction. Studies that included non-market costs had estimates that were on average 57 times higher than studies that did not. This indicates that, as expected (Colautti *et al.* 2006), market costs represent only a small portion of the total cost of INNS. The estimate provided in this report consists almost entirely of market costs and the actual, total cost of INNS to the British economy is likely to be much higher, possibly as much as £96 billion per year. No attempt was made to verify how realistic this is, as this would involve the valuation of non-market costs which was not possible in this study. However, it does provide an indication of what the true costs of INNS to the British economy could be.

17.2 Increasing costs

The impacts of INNS increase over the course of an invasion. As a newly introduced species becomes established and spreads, its impact, and therefore the associated costs, will increase. Although this may appear self-evident, there is little evidence that supports this statement and the scale of the cost increase is unknown. The case studies have suggested that the cost of eradication increases as the invasion progresses (chapter 16). In all the scenarios presented, the costs of eradication when the distribution of the species was limited were considerably less than if the species was widespread through the country. It can be assumed that the cost of control is related to the abundance of the INNS, so if the occurrence of a species increases exponentially, as can be expected based on random population spread (Skellam 1951) and as illustrated by Japanese knotweed (Shaw *et al*. 2009), so may the cost. However, the cost increase may also be affected by the level of attention paid to the species: a more aggressive species, or a species that is perceived as damaging, may attract more attention and thus cause more direct costs.

The analysis of the evolution of the costs as an invasion progresses demonstrates the likelihood of increasing costs to the economy as more species enter Great Britain. New, aggressive INNS are known to have recently entered the country, e.g. carpet sea squirt, and if these species are not controlled or eradicated and become established throughout the country, then it is probable that the direct costs of INNS to the British economy of approximately £1.7 billion will increase. Comparisons with the situation in other countries demonstrate the importance of early and sustained control methods. For example, eradication of coypu from Great Britain in the 1980s cost a considerable amount at the time (Gosling 1989), but the costs that Italy is now experiencing due to the continued presence of the species far outweigh the costs of eradication (Bertolino and Genovesi 2003). In addition, the cost of water primrose control in France and Belgium demonstrates how costs could easily increase here if that species is not controlled and kept to the current early stage of invasion.

Of course, many species may behave in unexpected ways as they enter a new country, due to differences in environmental and climatic conditions and reduced predation. A lack of knowledge about many of these species and the impact they may have, could also contribute to increasing costs. A thorough understanding of the biology and ecology of potentially invasive species could, while increasing current research funding, mitigate costs in the long term, as species with a high potential impact could be recognised and controlled at an early stage or eradicated. In that context, it is striking that the number of scientific publications about INNS from Great Britain has remained constant for almost a decade, while the number of European publications has more than tripled (Fig. 13.1). At the start of the century, a substantial portion of the European INNS-related publications came from Great Britain but that portion has decreased steadily since then.

17.3. Conclusion

The overall conclusion from this study is that the costs of INNS to the British economy are considerable and widespread. These costs are likely to rise as more species arrive each year and species that are already present become invasive. Hence, we recommend that measures continue to be taken to prevent the introduction and establishment of new non-native species to Great Britain. Effective control becomes increasingly difficult when the scale of an invasion increases along with its impacts. It is therefore equally important to eradicate species that are currently having an impact as soon as possible, to limit the further spread of locally or regionally established INNS, whilst not ignoring the need to reduce the impact of widespread INNS which have the highest costs. Although the cost of these control measures may appear high, it is money well spent, as without them the future costs of INNS to the British economy will be much higher.

References

Bertolino S, Genovesi P (2003). Spread and attempted eradication of grey squirrel (*Sciurus carolinensis*) in Italy, and consequences for the red squirrel (*Sciurus vulgaris*) in Eurasia. Biological Conservation 109: 351-358

Born W, Rauschmayer F, Bräuer I (2004). Economic evaluation of biological invasions - a survey. UFZ, Halle Germany

Colautti R, Bailey S, van Overdijk C, Amundsen K, MacIsaac H (2006). Characterised and projected costs of non-indigenous species in Canada. Biological Invasions 8: 45-59

Gosling LM (1989). Extinction to order. New Scientist 4 March 1989: 44–51

Hanley N, Wright R, Alvarez-Farizo B (2006). Estimating the economic value of improvements in river ecology using choice experiments: an application to the water framework directive. Journal of Environmental Management 78: 183-193

Huxley L (2003). The Grey Squirrel Review. Profile of an invasive alien species. Grey squirrel (*Sciurus carolinensis).* ESI Dorset.

Oreska MPJ (2009). Assessing the economic aspects of aquatic invasive species in Great Britain. Master's thesis, Cambridge University

Oreska MPJ and Aldridge DC (2010) Estimating the financial costs of freshwater invasive species in Great Britain: a standardized approach to invasive species costing. Biological Invasions, in press. doi: 10.1007/s10530-010-9807-7

Perrings C, Williamson M, Dalmazzone S (2000). The economics of biological invasions. Edward Elgar Publishing

Pimentel D (2002). Non-native invasive species of arthropods and plant pathogens in the British Isles. In: Pimentel D (ed.). Biological invasions. CRC Press, pp. 151-158

Shaw RH, Bryner S, Tanner R (2009). The life history and host range of the Japanese knotweed psyllid, *Aphalara itadori* Shinji: Potentially the first classical biological weed control agent for the European Union. Biological Control 49: 105-113

Skellam JG (1951) Random dispersal in theoretical populations. Biometrika 38: 196-218

White P, Harris S (2002). Economic and environmental costs of alien vertebrate species in Britain. In: Pimentel D (ed.). Biological invasions. CRC Press, pp. 113-150

Williamson M (2002). Alien plants in the British Isles. In: Pimentel D (ed.). Biological invasions. CRC Press. pp. 91-112

Annexes

Accompanying this report are two electronic annexes. **Annex 1** is a copy of the questionnaire. The order of the pages as they appeared to those who responded to it was dependent on the answers given, but it was possible to access all pages. **Annex 2** contains the database assembled during the literature research. The first sheet contains information about INNS that are present in Great Britain and the second sheet contains information about current quarantine pests and species perceived as a threat to Great Britain, but that are not established at present.

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