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Controlling *Rhododendron ponticum* in the British Isles: an economic analysis

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Abstract

What resources should be committed to the control of invasive species? This study is based on a survey of nature conservation and forestry authorities, wildlife trusts and private landowners which investigated the extent of the ecological and economic impacts of the invasive non-native plant *Rhododendron ponticum* in the British Isles. There are data on 52,000 ha of land affected by *R. ponticum*, more than 30,000 ha of it in nature reserves. For nearly all nature reserves, displacement of native species and habitat changes were both reported. In 2001, respondents controlled 1275 ha of *R. ponticum* at a cost of £670,924. To test the optimality of this, we apply a model of social expenditure. The external costs of *R. ponticum* control are estimated from the probability that it will spread to contiguous sites and the damage done on invaded sites. These are then used to calculate the socially optimal level of expenditure on *R. ponticum* control, and the funding gap it identified by comparing the result with current levels of expenditure. The results suggest that a socially optimal level of control effort requires a significant increase in social funding for *R. ponticum* control, although the size of the increase varies between landholders.

Keywords: Rhododendron ponticum; Invasive species; Control costs; External costs

1. Introduction

Increasing attention has been paid recently to the economic consequences of invasive species (US OTA, 1993; Perrings et al., 2000; Pimentel et al., 2000, 2002). The economic consequences of invasive species include damage costs, such as biodiversity loss or habitat change, plus the costs of control or eradication net of any possible benefits. Whereas damage costs are not directly calculable, the costs of control and eradication are. The costs of control are a measure of the effort committed to the eradication or reduction of an invasive species. Since individual landowners will increase control effort up to the point where marginal benefits and costs are equal, this can be seen as an indicator of the marginal private damage due to the invasive species. Depending on the species, the private benefits of control may not be a good measure of the social benefits. Benefits can be widely dispersed across the different stakeholders concerned, and aggregate costs can be difficult to estimate.

The spread of any invasive species depends on the control efforts of all those affected. The control costs faced by each person accordingly depend partly on conditions on the invaded site, and partly on conditions in neighbouring sites. Put another way, the private damage costs of harmful invasive species may be expected to be strictly less than the social damage costs.

In this paper, we are interested in the determinants of private expenditure on the control of a particular invasive species (*Rhododendron ponticum*), and in the options open to induce private landowners to undertake socially optimal level of control. To do this we investigate the extent of the problem of the invasive non-native plant *R. ponticum* in the British Isles, both from an ecological and economic perspective. We consider the species in its entire synanthropic area thus including a wide spectrum of different natural and socio-economic conditions. We use a survey of potentially affected groups to generate data on control costs, the reasons why people control *R. ponticum,* and what control options they consider. Surveys are a standard way of

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generating such data in the social sciences. They have also been used by biologists. Perrins et al. (1992), Kowarik and Schepker (1998) and Williamson (1998) have used questionnaire surveys before to get results on the perception of non-native species in general and their control in a certain areas. The taxonomy in the paper follows Stace (1997).

1.1. Rhododendron ponticum as invasive non-native plant in the British Isles

R. ponticum was introduced into Britain as an ornamental garden plant about 1763 (Curtis, 1803). Its native area is in the region of the Black Sea (Turkey, Georgia, Bulgaria) with disjunct occurrences in Lebanon, Spain and Portugal. The plants occurring in the British Isles today originate from Spain mostly (Milne and Abbott, 2000). First reports on its self-sowing abilities in Britain date back to the year 1849 (Hooker, 1849). Seeding may be one reason for its success as an ornamental plant in gardens and parks as well as for the use in extensive plantings for game cover, especially pheasants, in woodlands, particularly in the 19th Century (Elliott, 1996). Where conditions favoured establishment, it subsequently spread from these sites. *R. ponticum* was also used almost exclusively as the stock for grafted rhododendrons (Royal Horticulture Society, 1951), but it is so vigorous that it constantly sends up suckers which, if not removed, gradually take all the sap from the plant, eventually causing the grafted variety to die off (Cox, 1998). It is not known how far occurrences of *R. ponticum* go back to plantings of these grafted rootstocks. Today *R. ponticum* is widespread over the whole British Isles occurring in 2238 out of 3844 grid cells of $(10\,\text{km})^2$ (Preston et al., 2002).

Naturalisation has taken place in natural and near natural vegetation like acid oak woods, heaths and bogs. *R. ponticum* causes ecological modifications such as changes in the species composition, light reduction, prevention of regeneration of native shrubs and trees, thus endangering native species (e.g. Cross, 1975; Fuller and Boorman, 1977; Shaw, 1984; Thomson et al., 1993; Compton et al., 2002). However, forestry plantations, both conifer and broadleaf, are also invaded causing problems for forest management (Brown, 1953; Robinson, 1980; Tabbush and Williamson, 1987; Edwards et al., 2000). Consequently, the first experiments on best eradication techniques took place in 1949. They were carried out by the Forestry Commission (Brown, 1953; Miller, 1954) later followed by control measures in nature reserves and on private estates (Jones, 1974; Gritten, 1987; Becker, 1988; Searle, 1999; Singleton and Rawlins, 1999).

Today *R. ponticum* is probably the major alien environmental weed in the British Isles (Williamson, 2002).

1.2. The economic problem

The economic problem investigated is the following. Since each landowner incurs direct costs from the presence of *R. ponticum* they will control the species up to the point where the private marginal benefits of control (the private marginal damage avoided) is equal to the private marginal costs of control. But control of *R. ponticum* in any one site also reduces the probability that it will spread in other sites. So the social marginal benefit of control (the social damage avoided) includes the damage avoided on contiguous sites. Since landowners in general have no incentive to increase control effort up to the point where their private control costs equal the social damage avoided, if landowners are left to choose the level of control they exercise, there will be too little control from the perspective of society.

To see the problem consider the following simple model. Let output on the ith of n contiguous sites, Q^i, depend on a vector of m inputs, $\mathbf{X}^i$, and on the extent of *R. ponticum* on that site, R^i. Further, let the extent of *R. ponticum* on the ith site depend on the level of control undertaken in all sites, $\sum_{j=1}^{n} E^j$.

That is

$$Q^i = Q^i\left(x_1^i \ldots x_m^i, R^i\left[\sum_{j=1}^{n} E^j\right]\right) \tag{1}$$

We can identify two problems: a private problem and a social problem.

The private decision problem takes the form:

$$\mathrm{Max}_{X^i,E^i}\,\Pi^i = pQ^i - c(\mathbf{X}^i, E^i) \tag{2}$$

subject to Eq. (1), where

Π^i	profit on the ith site
p	the price of output
c^i	$c(\mathbf{X}^i, E^i)$, costs on the ith site.

The first order necessary conditions for the solution of this problem include the following:

$$\begin{aligned} &pQ^i_{X^i} - c^i_{X^i} = 0 \\ &pQ^i_{R^i}R^i_{E^i} - c^i_{E^i} = 0 \end{aligned} \tag{3}$$

implying that private landowners will equate the private marginal benefits and costs of their control effort. The social decision problem takes the form

$$\mathrm{Max}_S\,\Pi = \sum_{i}^{n}\left[pQ^i - c(\mathbf{X}^i, E^i(S))\right] \tag{4}$$

subject to Eq. (1) and the way in which private effort depends on the policy instruments, S. The first order necessary condition for the solution of this problem includes the following:

$$pQ^i_{R^i}R^i_{E^i}E^i_S + \sum_{j\neq i}^{n} pQ^j_{R^j}R^j_{E^i}E^i_S - c^i_{E^i}E^i_S = 0, \quad \forall_i \tag{5}$$

In which $\sum_{j\neq i}^{n} pQ_{R^j}^{j} R_{E^i}^{j}$ is the impact of control on the ith site on the value of output on all other contiguous sites. In the private decision problem the decision-maker has no incentive to take into account the effects of their actions on others. Solution of the social decision problem requires that they do. In the absence of intervention, there will be too little control. The implication of this is that it would be socially desirable to induce people, through choice of the policy instruments, S, to undertake the socially optimal level of control.

We have two problems to solve. The first is the estimation of the marginal external damage costs of *R. ponticum* in any one site—i.e. the value of the term $\sum_{j\neq i}^{n} pQ_{R^j}^{j} R_{E^i}^{j}$. The second is the specification and estimation of a control effort function in order to calculate the optimal value of S. We take the general form of such a control effort function to be $E^i = E^i(\mathbf{Z}^i, S)$ where $\mathbf{Z}$ is a vector of control inputs.

In other words we wish to calculate (a) how far current control efforts may fall short of the socially optimal control effort, and (b) what policy, S, would induce the socially optimal level of control.

2. Impact and control costs of *R. ponticum*

2.1. Description of the survey

Data were obtained by designing and administering a questionnaire to landowners and land managers. The questionnaire elicited information on three main topics: (a) general information about *R. ponticum* and its presence on sites, (b) the control regime, and (c) the costs (see Appendix A). Addressees were asked to give estimates if they did not know the exact numbers requested. The questions about the control regime and control costs relate to 2001. Figures for 2000 were also accepted if control work was not possible in 2001 due to the Foot and Mouth Disease (FMD) outbreak in the UK in that year. In some areas FMD prevented movement and work in the countryside for more than half the year. Recipients were asked also to report the non-occurrence of *R. ponticum* in their area of responsibility.

In order to cover all areas where *R. ponticum* causes problems four target groups were identified. For problems in nature conservation these were the managers of nature reserves and national parks. These include both public authorities (group 1) and non-governmental organisations (group 2). The two groups manage the majority of nature reserves in the UK. In forestry, Forest Enterprise, the executive agency of the governmental Forestry Commission, is responsible for the management of 8,00,000 hectares of woodland (1/3 of the woodland in Britain). The Forest Service in Northern Ireland and Coillte, a state owned company managing 70% of woodlands in the Republic of Ireland, represent group 3. Private owners of large estates and forests form group 4. Questionnaires were sent to groups 1–3 across the country. Private owners were asked in the magazines of the Country Land and Business Association and of the Scottish Landowner Federation to request a questionnaire if they have *R. ponticum* on their estate. Additionally, any information available, e.g. from respondents of the questionnaire, was used to contact private estates known to have *R. ponticum*. In contrast to the other three groups, preselection excluded nil answers in group 4. Since private landowners without *R. ponticum* had no incentive to take part in the survey, we decided to use the remaining three groups to obtain information on the absence of *R. ponticum*.

In total, 301 questionnaires were sent out, 173 of them from February to June 2002. From November to December 2002, the group of public authorities was extended to local governments (County Councils) with 128 additional questionnaires. Table 1 shows the number of recipients and respondents for all four groups. As some of the recipients circulated the questionnaire further, the total number of recipients is unknown and the number of respondents may be higher than the number of recipients (e.g. in public nature conservation authorities).

2.2. General information on sites with R. ponticum presence

In total, the respondents gave information on some 52,000 ha affected by *R. ponticum* in 248 different sites.

Table 1
Number of questionnaires sent out and total number of responses

Recipient	Total	Public authorities		Charities	Forestry	Private landowners
		Nature conservation	Local government			
Recipients	301	38	128	71	33	31
Respondents	187	46	33	65	27	16
Completed questionnaires	105	23	10	46	12	14
R. ponticum: yes						
Questionnaire: no	41	8	8	9	14	2
R. ponticum: no	41	15	15	10	1	0

The responses are divided according to the type of answer received: completed questionnaires, respondents saying they have *R. ponticum* on the sites they are responsible for but did not fill in the questionnaire (‘*R. ponticum*: yes, questionnaire: no’) and respondents without any *R. ponticum* (‘*R. ponticum*: no’).

Table 2
Areas (ha) covered by *R. ponticum* today, 10 years ago, new growth and removed in the last 10 years, and controlled in the reference year 2001 (2000)

Area (ha)	Covered today*	10 years ago	New growth in the last 10 years	Removed in the last 10 years	Controlled in 2001 (2000)
Public authorities	4252.66	4661.27	24.50	505.28	146.72
Charities	359.93	655.18	43.03	315.20	103.01
Forestry	47485.70	22975.50	3935.50	2586.00	1003.10
Private landowners	771.72	211.79	53.30	96.47	21.70
Total	52870.01	28503.74	4056.33	3502.95	1274.53

*Including additional areas of 12120 ha and 606 ha, respectively, mentioned by respondents in forestry and private landowners, for which they were not able to provide more detailed information in the questionnaire.

This figure includes 12,726 ha affected in forestry for which no further information was provided. As only some of the respondents provided information on the total number of reserves/sites or areas for which they are responsible, this information was (so far as possible) obtained from other sources like websites from wildlife trusts. This produced an estimate of 2678 sites implying that about 9% of all sites are affected by *R. ponticum*.

The most affected group is forestry (Table 2). Consequently, the most affected habitat type is woodland (89% of total area). A more detailed characterisation of the type of woodland was given only by a few of the respondents. They mentioned oak woods, broadleaf woods, native pine woodlands and conifer plantations. However, 26,698 ha (75%) of the affected woodland are registered in the Ancient Woodland Inventory, i.e. land that has had continuous woodland cover since at least 1600 AD (Kirby et al., 1998). Ancient woodland, even if it is covered by conifer plantation today, may still contain ancient woodland species and is regarded as important for the regeneration of native woodlands (Pryor et al. 2002). Many respondents did not assign the area affected to a single habitat type and 869 ha (2.2% of total area) are therefore described as a mixture of woodland, heath and moorland. Heath as a single habitat type (117 ha) is described mostly as lowland heath, but respondents mentioned also dune heath and heather moor. Other small scale habitat types are bogs, mires, riverbanks, grassland and salt marsh.

Most of the respondents gave information on the area covered by *R. ponticum* today, but not all of them were able to answer the questions relating to the change in cover over the last 10 years.

Of the 248 sites mentioned 186 are nature reserves, among them 39 National Nature Reserves (NNRs). These are nature reserves with the highest protection status in the UK. Table 3 shows the areas affected by *R. ponticum* in nature reserves of different protection status. According to the respondents the main ecological impact of *R. ponticum* on the sites concerned was displacement of native species (193 sites), followed by habitat change (153). On 26 sites hydrological impacts were reported. This information was related to the area of *R. ponticum* at a site and the designated nature conservation status of the same site. The results (Table 3) show the ecological impact of *R. ponticum* measured in hectares of nature reserve areas. There is no difference in the perception of the ecological impact between nature reserves of different conservation status and sites without designated status. For nearly all sites, respondents reported displacement of native species and habitat changes as consequences of *R. ponticum* invasion. A comparison of reported hydrological impacts is not possible as no evidence was given on the hydrological characteristics of the sites in general.

Respondents for the three impacts mentioned above had to tick a box per site only. They were also asked to name species that had become extinct locally due to the invasion of *R. ponticum*. This question was answered for 17 sites and the following species were named: *Hyacinthoides non-scripta* (3 sites), *Eriophorum vaginatum* (1 site), *Drosera rotundifolia* (1 site) and heather (species not specified: *Calluna vulgaris* (probably) or *Erica spp* (possibly)., 5 sites), *Quercus spp*. (6 sites), *Betula spp*. (6 sites), and *Pinus sylvestris* (2 sites).

Other impacts mentioned by the respondents for single sites included visual effects, overshading of watercourses,

Table 3
Ecological impact of *R. ponticum* on sites without nature conservation status and in nature reserves

	No status	AONB	LNR, NP	SSSI	Part SSSI	NNR	Total
R. ponticum area	970.5	157.1	3567.4	23062.6	2025.3	2122.2	31905.0
Area affected by displacement of native species	944.0	141.1	3551.4	23010.4	2007.3	2110.0	31764.1
Area affected by habitat change	911.7	140.1	3526.1	17932.3	2021.2	2090.9	26622.2
Area affected by hydrological effects	16.0	0.0	3408.3	9057.7	0.0	66.8	12548.8

AONB: Area of Outstanding Natural Beauty; LNR: Local Nature Reserve; NP: National Park; SSSI: Site of Special Scientific Interest, a category that also includes SAC (Special Area of Conservation), SPA (Special Protection Area) and RAMSAR sites. Part SSSI: only a non-reported percentage of the site has the status of a SSSI. NNR: National Nature Reserve, the highest protection status in the UK. All figures are given in hectares (ha).

impeding of access, security ('hiding place for muggers'), damage of fencing, loss of grazing and poisoning of livestock.

2.3. Control of *R. ponticum*

In the reference year, 69 respondents of the questionnaire controlled 1275 ha of Rhododendron (see Table 2). The average area controlled was 18 ha, but the median is at 2.5 ha, indicating that the majority of respondents controlled smaller areas. These results are influenced strongly by the answers of one of the nine respondents from forestry where from the 1003 ha controlled by this group, 850 ha were in the Cowal and Trossach Forest District in Scotland alone. In this Forest District a partly EU funded project took place in the reference year.

On 121 sites the aim of control measures was the total eradication, on 59 sites part eradication and on 68 sites containment. These aims were reached adequately on 133 sites, whereas for 57 sites the respondents came to the conclusion that the control measures undertaken were not sufficient to reach their aim.

R. ponticum control was mainly carried out by manual methods combined with herbicides (47 respondents). Nearly half of the respondents (22) also used mechanical methods. The most common disposal method was burning (52); just 15 respondents did not do anything with the removed plants.

Thirty seven respondents controlled with the help of volunteers. Most volunteers were working for environmental charities, but some public authorities like the Killarney and Snowdonia National Parks also used volunteers for clearance works. In total, more than 36,000 volunteer hours were spent working on control measures.

The total control costs in the reference year were £530,003. That is an average of £416 per hectare. Again, the project taking place in the Cowal and Trossach Forest District has a strong impact on the average values. The reference year was the last year of a five year project in this Forest District. In parts of the district control measures included follow-up spraying of regrown Rhododendron and monitoring for regrowth and new seedlings. This explains the relatively low costs of £148 per hectare, the third lowest value of all respondents. Details on control costs per hectare given in the literature (Burton and Carpenter, 1999; Searle, 1999; Cross, 2002; Wong et al., 2002) or specified by the Forestry Commission for grant applications are very variable depending on the control methods used, the density and age of the Rhododendron stand and the accessibility of the sites. They vary widely from £150 for chemical control of re-grown Rhododendron up to £10,000 as the maximum, which is assumed to be reached only in exceptional circumstances like at steep cliff sites accessible for hand cutting and by rope only. With our results, a detailed analysis and comparison of the control costs per hectare is not possible because the questionnaire did not contain questions about the age structure of *R. ponticum* stands or site conditions. In four cases control costs per hectare were estimated to be more than £10,000 per hectare (£60,000/ha for one respondent). In general, we assume that respondents were more likely to be wrong in their estimates of the areas rather than in the costs they had paid. Costs per hectare were not calculated by the respondents themselves and may be biased by false area estimates. Therefore, in the further analysis of the data (see the control effort model below) these four exceptional observations were excluded.

Once *R. ponticum* is eradicated, there may be costs for the restoration of habitats, e.g. the planting of native plants. The costs for this specified by eight respondents total £126,585. Furthermore, *R. ponticum* could cause costs not related to its control. Six respondents mentioned additional costs of £14,336 e.g. for surveying of the sites concerned or scraping of leaf litter. Adding these sums to the control costs, the total costs caused by *R. ponticum* in the reference year are £670,924.

Most control funds did not come from external sources. Respondents estimated that 36% of their total costs were met from external sources (Table 4). Private landowners and environmental charities were best able to cover their expenses by external funding (62 and 56%, respectively), whereas public authorities and forestry cover less of their costs by external funding (30 and 25%, respectively).

Respondents were asked if they want to control Rhododendron in future, and if yes, what their financial needs for that would be per year over the next five years. The answers of 56 respondents add up to £17 million per year. Related to the total area managed by the same respondents that would be £2800 per hectare over the whole five years. This seems to be a reasonable sum compared with the figures given in the literature or by the Forestry Commission. Respondents reporting financial needs above £10,000 per hectare were excluded from the analysis. The remaining answers of 41 respondents add up to £4.5 million per year over the next five years at an average annual cost of £847/ha. This might be an underestimate but it should be noted that some of the respondents might not want to control *R. ponticum* completely on their land.

Two respondents did not want to control Rhododendron in their area at all. This is partly because there are

Table 4
External funding sources for *R. ponticum* control in 2001

Funding source:	£
Forestry grants	93215
EU	64500
Public authorities	42920
Landfill tax	24000
Heritage lottery fund	8200
Other	10500
Total	243335

also benefits offered by *R. ponticum* in terms of aesthetic appeal, recreational amenity and tourism during the flowering time in May/June. *R. ponticum* is an attraction for tourists especially in regions where it covers large areas of open land. Addressees were asked if there were more visitors on their land during that time, and if they had any revenues from increased entrance fees. Seventeen respondents reported more visitors at the sites, but none was able to quantify the numbers or additional revenue. Six respondents specified returns for the sale of charcoal, chippings and leaves totalling £885 in the reference year.

2.4. The external costs of *R. ponticum* control

To identify the best policy response to the problem of *R. ponticum* we need first to estimate the external costs of *R. ponticum* control. To do this using the data provided by the survey requires us to make some rather strong assumptions about the marginal propensity of *R. ponticum* to spread from one site to another. Specifically, we assume that the marginal propensity to spread is equal to the average propensity to spread and that this is appropriately measured by the proportion of sites recording neighbouring sites as the initial source of *R. ponticum*.

There are a number of difficulties with this approach, but it does allow us to distinguish between sites where *R. ponticum* was intentionally introduced (either as an ornamental plant in its own right, or as rootstock for other cultivars) and sites to which it spread. The survey provided data on the origin of *R. ponticum* in a total of 197 sites. It was originally planted in 117 sites, and was recorded as having invaded from elsewhere in 102 sites. Note that in 22 sites *R. ponticum* is due both to original plantings and to invasion from neighbouring sites. The source of infestation was unknown at 42 sites, and 1987 sites reported no *R. ponticum* at all.

To obtain a probability of spreading we need a true dimension. The first occurrence (whether planting or invasion) was only recorded for 84 sites and in many cases was a rough approximation. The results are summarised in Table 5 for the 67 sites where respondents also gave information on the source of infestation. This subsample implies a cumulative probability that a site will be invaded rising from 20% in the 19th century, to 38% by 1950 and 89% by 2000. This compares with 47% for the full sample (102 of 219 sites were we have the information).

Table 5
Reputed date of planting/first arrival of *R. ponticum* at 67 sites

	Planted	Not planted
Before 1900	8	2
1900–1950	30	18
After 1950	1	8

The cumulative probability of invasion into new sites indicates that *R. ponticum* control in any one site reduces the probability of invasion in neighbouring sites by 47%. That is, the term

$$\sum_{j\neq i} pQ^j_{R^j}R^j_{E^i} = -0.47p\sum_{j\neq i} Q^j_{R^i}$$

This is a very rough proxy for the true value of the *R. ponticum* externality, but it provides a plausible test for the optimality of the current social commitment to *R. ponticum* control.

Without discriminating between landowners, the survey reveals (Table 4) that 36% of control costs were met from external sources—whether forestry grants, EU, to national public authorities or the national lottery.

Assuming damage costs to be site independent such that $a = pQ^i_{R^i} = pQ^h_{R^h}$ for all $i, h \in \{1, 2 \ldots n\}$, the first order necessary conditions for a social optimum require that social optimal control costs, $c^{i^*}_{E^i}$, satisfy

$$c^{i^*}_{E^i} = aR^i_{Ei} - (n-1)a0.47$$

and hence that

$$c^{i^*}_{E^i} = c^i_{Ei} + (n-1)a0.47$$

i.e. that the social benefits of *R. ponticum* control optima include both the damage avoided on the *i*th site and the marginal external benefits of control, the damage avoided on *n* contiguous sites

It follows that, if $R^i_{E^i} = -1$ (a unit of control on the *i*th site reduces *R. ponticum* on that site by the same amount), the ratio of marginal social control costs to marginal private control costs is $c^{i^*}_{E^i}/c_{E^i} = 1 + (n-1)0.47$.

From the survey we know that 64% of control costs are currently not funded from external public sources implying that $c^{i^*}_{E^i}/c_{E^i} = 1.57$.

This ratio of social to private control costs would satisfy the conditions for a social optimum if $n = 2.2$. Put another way, the current average subsidy is socially efficient under the various assumptions of the paper if the number of contiguous sites affected by control in site *i* were 2.2.

If we can obtain data on the mean number of contiguous sites, we can estimate the socially optimal ratio $c^{i^*}_{E^i}/c_{E^i}$. A sample of respondents was surveyed yielding an average of contiguous sites of $n = 5.6$, implying that $c^{i^*}_{E^i}/c_{E^i} = 3.16$. From that we can calculate the optimal social control costs $c^* = £1,350,628$, which is £679,704 more than the actual funding. Table 6 specifies the results for the different groups of the survey. Due to the small number of sites in some of the groups we used the average of *n* for all groups to calculate the funding gaps for the groups. The only figure on the number of contiguous properties available for comparison

Table 6
The external costs of *R. ponticum* control in 2001 in total and for the 4 groups

	All	Public	Charities	Private	Forestry
Total costs	670 924	228 098	134 813	60 133	247 880
External	243 335	67 860	76 045	37 430	62 000
Internal	427 589	160 238	58 768	22 703	185 880
n^*	2.2	1.9	3.8	4.5	1.7
n	5.6	7.7	3.5	7.6	4.6
Number of sites	32	9	10	5	8
Std. Deviation	8.7	16.0	1.7	5.2	3.3
c^*	1 350 628	506 145	185 630	71 712	587 141
Difference to actual spending	679 705	278 047	50 817	11 579	339 261

Total costs (£)-external funded and internal; n^* =number of contiguous sites affected by control effects in anyone site with the current level of funding; n = average number of contiguous sites and standard deviation for a sample of sites (number of sites); c^* =optimal social control costs, i.e. the costs of a control level sufficient to prevent damage in contiguous sites calculated using the average of n for the whole sample.

is the number of 6.5 (Keeling et al., 2001) derived from data of all farms in the United Kingdom by tessellation about each farm location, using the area of each farm as a weighting. If we used this figure for n it would imply a ratio of $c^{i^*}_{E^i}/c_{E^i} = 3.59$ and a funding gap of £861,982 for our dataset.

While the socially optimal level of control effort will generally be site specific, this first order approximation of the difference between actual and socially optimal levels of control effort indicates that landowners in each group should be committing more to *R. ponticum* control than they currently do. However, we note that the funding gap varies significantly between groups.

3. Model of the control effort

The next step is to identify the best mechanism for achieving the optimal level of control. To do this we specify a control effort function. This relates control effort to (a) the scale of the current problem, (b) the private control costs, (c) external funding of control inputs, (d) external labour support (volunteer labour). The area controlled in the reference year is taken to represent the control effort. We assume a Cobb-Douglas control effort function, implying an estimated function of the form:

$$E = (\mathrm{AR}p^{\beta_1}\mathrm{Cost}^{\beta_2}\mathrm{Vol}^{\beta_3}\mathrm{Fund}^{\beta_4}\mathrm{Rain}^{\beta_5}\mathrm{ChCtrl}^{\beta_6})$$

Where:

E	Control effort, i.e. controlled area in 2001 (ha)
ARp	total area of *R. ponticum* (ha)
Cost	control costs per hectare (£)
Vol	volunteer labour (hours per hectare area controlled)
Fund	external funding per hectare (£)
Rain	average annual rainfall per hectare (mm)
ChCtrl	use of herbicides in the control process, a dummy variable.

As professional labour is included in the control cost term, volunteer labour is not, but may have influence on the control effort. Therefore, it is included in the model as a variable.

Taking logs of both sides, the estimated function can now be written in the form

$$\log E = \alpha + \beta_1 \log \mathrm{AR}p + \beta_2 \log \mathrm{Cost} + \beta_3 \log \mathrm{Vol} + \beta_4 \log \mathrm{Fund} + \beta_5 \log \mathrm{Rain} + \beta_6 \log \mathrm{ChCtrl}$$

Table 7 shows that the model (for a sample size of 62) explains 56% of the control effort. The values of the coefficients indicate that control effort is positively and significantly affected by the area of Rhododendrons, precipitation, use of chemical methods and external funding. Control costs have the biggest negative impact on the control effort as, surprisingly, does volunteer activity. The latter apparently reflects the fact that volunteers cannot use cost-effective tools like chainsaws, machinery or herbicides without violating safety regulations.

The model was also tested with additional parameters like lowest temperatures, sensitivity against the different groups and nature conservation status of the controlled sites.

Table 7
Coefficients and *p*-values of the regression analysis of the control effort model

Variable	Coefficient	*p*-Value
(Constant)	−2.895	0.075
Log AR*p*	0.153	0.001
Log ChCtrl	0.037	0.019
Log Cost	−0.584	<0.001
Log Fund	0.031	0.003
Log Rain	1.657	0.001
Log Vol	−0.028	0.009

n = 62, adjusted $R^2 = 0.561$. Variables: ARp = total area of *R. ponticum* (ha); Chctrl = chemical control, dummy variable; Cost = control costs per hectare (£); Fund = funding per hectare (£); Rain = average annual rainfall (mm); Vol = volunteer activity (hours per hectare area controlled).

However, none of these parameters had a significant influence on the control effort in our dataset.

4. Discussion

R. ponticum has negative effects on nature conservation and forestry in the British Isles—a fact which respondents to the survey are highly aware of. *R. ponticum* imposes high costs on all groups, and many commit significant resources to control and restore land invaded by *R. ponticum*. Nevertheless, in an analysis designed to test the level of control effort relative to the social optimum, we find that this level of effort falls significantly short of what is needed. To be socially optimal, aggregate social expenditure on *R. ponticum* control should be increased by more than 100%, but the funding gap differs between groups. Recall that the funding gap is the difference between current and socially optimal external funding. The funding gap in public sector and forestry implies that external funding should be increased by 122% and 137% respectively. On the other hand private landowners and charities—the main beneficiaries of external funding at the moment—should receive 38 and 19% more external funding respectively. These figures are based on the current funding situation and they may be biased by the fact that public authorities and predominantly state owned forestry are unable to use external funding to the same extent as private landowners and charities. However, compared with the size of the areas controlled in 2001 and the areas reported to have *R. ponticum,* the calculated funding gaps correlate with the size of the area in the different groups roughly.

We have also been able to identify—if only in a preliminary way-the effectiveness of alternative ways of achieving an increase in control effort. Specifically, we find that the most effective and reliable method for this will be a subsidy on control costs. From our estimates of the control effort elasticities, we calculate that 1% subsidy would induce a 3.8% increase in control effort. The social cost of this would be £5300. In order to achieve the same result through external funding, funding would have to be increased by 3.6% at an aggregate social cost of £19,080.

Volunteers are widely used in Britain and Ireland for nature conservation, and so-called "Rhody bashing" is one of the main activities of volunteers. Our results suggest that the use of volunteers is not an effective way to increase control. The attempt to attract more people to volunteer work therefore does not appear to be a good solution, although volunteers may well be appropriate in specific cases. Under the present funding situation they seem to be the only option, especially for some charities. Groundwork, a volunteer organisation in Ireland, has organised almost 4000 volunteer weeks of Rhododendron clearance. Approximately 40% of the infested Killarney oak woods have been cleared and are being maintained clear by Groundwork volunteers (Barron, 2000).

Regarding the economic effects, our results are confined mainly to the costs of control and restoration. Damage caused by *R. ponticum* in terms of changes in biodiversity has not been valued, but may be high considering the ecological effects described by the respondents. In forestry, the losses in timber production should be calculated to see if there are benefits for timber production if *R. ponticum* is removed in a forest. It is likely that there are also benefits from *R. ponticum* for recreation and in horticulture. Including this entire spectrum of external costs and benefits would almost certainly increase the socially optimal level of control. So our results should be taken to indicate a lower bound.

The historic reasons for planting are certainly no longer valid today. The private landowners whose ancestors planted *R. ponticum* on their estates for amenity reasons a century ago try to get rid of it now. In game keeping, shrub cover in woodlands is regarded as a suitable habitat for pheasants if it is between 30 cm and 2 m tall. *R. ponticum* becomes unattractive for this soon, or requires expensive management. Although *R. ponticum* is still available from some nurseries in Britain it is not a species recommended for planting. Nor has it been fashionable since the middle of the last century (Elliott, 1996; Cox, 1998).

R. ponticum is an example of a deliberately introduced invasive species whose spread was accelerated by human behaviour. It was introduced to most of the sites mentioned in this study as an ornamental shrub. Today, the planting of *R. ponticum* in woodland for game cover is no longer recommended because it can become invasive (Robertson, 1992). Other non-native plants like *Cotoneaster* spp., *Symphoricarpos albus* and *Prunus laurocerasus* are recommended in its place (Robertson, 1992). The evergreen shrub *P. laurocerasus* was mentioned by respondents of the questionnaire as causing similar problems as *R. ponticum* in some areas of Wales and Southwestern England. *P. laurocerasus* showed the highest relative increase between the 1930–69 and 1987–99 survey of plant distributions in the British Isles (Preston et al., 2002).

Our data do not allow us to estimate the total impact of *R. ponticum* in the British Isles, and hence our results may be biased. The response rate from managers of wildlife reserves, including responses from the most affected areas like North Wales, Southwestern England and the West Coast of Ireland, indicate that the impacts on nature reserves are well represented. However, the relative small number of responses from private landowners and the relative high number of respondents from forestry who did not fill in the questionnaire but reported problems in their woodlands, suggest that the extent of the problem may be under-reported by these two groups. Nevertheless, we consider that the approach adopted provides a useful way of testing the optimality of invasive species control generally, and *R. ponticum* control in particular.

5. Conclusion

The continued spread of *R. ponticum* imposes high costs in terms of habitat loss, production losses in forestry and agriculture in the British Isles. Taking these costs into account we find that current control levels are below the socially optimal level. This implies that there should be a significant increase in funding for *R. ponticum* control by central or local government, although the size of the increase varies between landscapes. We also find that a subsidy on the control costs would be more effective than an increase in direct grants.

This finding is qualified by the fact that we are still unable to offer a complete analysis of the costs and benefits of control. Missing data include estimates of the value of the loss of biodiversity in affected habitats, the potential loss of timber production, and the positive recreational benefits offered during flowering time. We would not expect inclusion of these data to affect our general conclusion that there is underfunding of *R. ponticum* control. However, they would affect the size of subsidies required to bring control up to the socially optimal level.

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Appendix

A.1. Questionnaire

1.	General information about sites with *R. ponticum* presence
1.1	Sites with *R. ponticum*, name of the estate/forest/reserve, location, size
1.2	Statuses of the sites: respondents had to tick the appropriate boxes in a list of different statuses of nature reserves
1.3	Description of *R. ponticum* occurrences: size of the area covered today, 10 years ago, removed in the last 10 years, area of natural spread in the last 10 years, was it planted, did it spread from neighbouring sites, when did it first arrive/was it planted, invaded habitat type
1.4	Impact: Displacement of native species, changes of habitat, hydrological effects, other impacts, local extinction of species as a result of the invasion
1.5	Visitors: more visitors to the reserves during flowering time of *R. ponticum* (additional number if known)
2	Control
2.1	Aims of control: total eradication, eradication in parts of the site, preventing further spread (containment), other aims; measures undertaken sufficient to reach these aims, controlled area in the reference year
2.2	Control in the reference year: methods (manual, mechanical, chemical, other), disposal method (burning at the site, chipping and deposit outside, deposit at the site, remove and deposit, other)
3	Economics of control (all questions related to the reference year)
3.1	Labour: number of man hours (professional/volunteers)
3.2	Control costs: labour costs, equipment and equipment operating costs, herbicide costs, other
3.3	Additional costs: costs not directly related to control, specify
3.4	Restoration: costs for restoring of habitats following control
3.5	Funding: funding organisation, programme, amount
3.6	Financial needs: if the funds were available would you choose to remove *R. ponticum*, how much would you need per year over the next five years
3.7	Revenues from entrance fees during flowering time, sale of wood, chippings, seedlings, other
4	Impact on woodland management
4.1	Impact on forest operations (harvest, new plantings, maintenance) and timber growth, other and costs (tick box: positive, negative, no effect)
4.2	Economic impact in the reference year: change in timber production and in woodland management costs per hectare (tick box: benefit, no change, loss (£0–100, 100–300, > 300), no estimation possible)

There were different versions for the target groups (e.g. no questions related to woodland management in the questionnaire for nature reserve managers).

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