

# A cost-benefit analysis of controlling giant hogweed (*Heracleum mantegazzianum*) in Germany using a choice experiment approach

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## Abstract

Since first of January 2015, the EU-regulation 1143/2014 obligates all member states to conduct cost-benefit analyses in preparation of control programs for invasive alien species to minimize and mitigate their impacts. In addition, with ratification of the Rio Declaration and the amended Federal Nature Conservation Act, Germany is committed to control any further spread of invasive species. This is the first cost-benefit analysis estimating positive welfare effects and societal importance of *H. mantegazzianum* invasion control in Germany. The paper analyses possible control options limiting stands of giant hogweeds (*H. mantegazzianum*) based on survey data of  $n = 287$  German districts. We differentiate between several control options (e.g. root destruction, mechanical cutting or mowing, chemical treatment and grazing) depending on infested area size and protection status. The calculation of benefits is based on stated preference results (choice experiment;  $n = 282$ ). For the cost side, we calculate two different invasion scenarios (i) no re-infestation after successfully conducted control measures (optimistic) and (ii) re-infestation twice after conducting control measures occurring within ten years (pessimistic). Minimum costs of eradication measures including a time span of ten years and a social discount rate of 1% result in a total of 3,467,640 € for optimistic scenario and 6,254,932 € for pessimistic invasion scenario, where no success of the first eradication attempt is assumed. Benefits of invasion control in Germany result in a total of 238,063,641 € per year and overassessment-factor corrected in 59,515,910 € per year.

**Keywords**

Invasive species, giant hogweed, control measures, cost-benefit analysis, willingness to pay (WTP)

**Introduction**

Invasive species are considered to be a primary driver of biodiversity loss across the globe (UNEP 2015). Results of invasion experiments indicate that the loss of species may have profound effects on the integrity and functioning of ecosystems (see e.g. Mwangi et al. 2007, van Ruijven et al. 2003, Pfisterer et al. 2004). In addition, invasive species cause public health concerns (EEA 2012, EPPO 2009, Bundesamt für Naturschutz 2015). Currently, about 10 million € are spent annually in Germany for control measures of invasive plant species and about one million € only for health-treatment expenses (Bundesamt für Naturschutz 2015, Reinhardt et al. 2003). *H. mantegazzianum* is originally an endemic species of the sub-alpine zone in the Western Greater Caucasus. It was introduced to Central Europe as an ornamental plant in the 19<sup>th</sup> century (Pysek 1991, Starfinger and Kowarik 2003, Pergl et al. 2012). Beekeepers established giant hogweed as fodder plant (Westhus et al. 2006). Currently, *H. mantegazzianum* is spread all over Europe (Nehring et al. 2013a, Pergl et al. 2012, Kowarik 2010); and in Germany, *H. mantegazzianum* currently occupies 68 % of grid cells of the national floristic map (NetPhyD and BfN 2013). Field studies in Germany<sup>1</sup> revealed a high variability of cover-abundances; about one third of surveyed stands were dominant<sup>2</sup> with cover-abundances exceeding 50% (Thiele and Otte 2008). *H. mantegazzianum* occurs in a variety of different habitat types, such as roadsides, grasslands, riparian habitats and woodland margins (Thiele and Otte 2006). The highest invasion percentage (18.5%) was found for abandoned grasslands, field and grassland margins and tall-forb stands (Thiele and Otte 2008). Open stands generally prevailed over dominant ones and single stands with sizes between 100 and 1,000 m<sup>2</sup> occurred most frequently (145 of 233 stands) while stands larger than 1,000 m<sup>2</sup> were found as minority (32 of 233 stands; Thiele and Otte 2008).

*H. mantegazzianum* has impacts on biodiversity through competitive displacement of native plant species, particularly at abandoned sites (Thiele et al. 2010), although this seems not a serious threat to protected habitats or regional diversity (Bundesamt für Naturschutz 2015). More attention has to be drawn on the health risk to humans (Bundesamt für Naturschutz 2015, Maguire et al. 2008, Hipkin 1991, Camm et al. 1976, Drever and Hunter 1970). The species is dangerous to humans because it exudes a clear watery sap, containing several chemical agents (e.g. furocoumarins) which sensitise human skin and lead to severe blistering when exposed to sunlight (Drever

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<sup>1</sup> The quoted field studies were conducted in 2001 at 16 German sites at the Western Low Mountain Ranges (Thiele and Otte 2008).

<sup>2</sup> The observed limitations indicate only partly dominant stands in the future, namely those representing early habitat invasion and disturbances or land-use change (Thiele and Otte 2008).

and Hunter 1970, Hipkin 1991). Blisters can take up to twenty four hours to appear and the entire reaction can recur for many years (Maguire et al. 2008). In addition to the health hazard, occurrence of *H. mantegazzianum* can limit public accessibility of sites, trails and amenity areas (Tiley and Philp 1994). Besides, it bears the risk to cause ecological damages, e.g. erosion at riverbanks (Pyšek 1991).

With entering into force, the EU-regulation 1143/2014 obligates member states to develop concrete action plans (including timetables for action, description of the measures to be adopted, voluntary actions, codes of good practice) to limit (further) spread of invasive alien species into or within the European Union. After establishing a national list of invasive alien species of concern, member states have eighteen month for comprehensive cost-benefit analysis of pathways and spread and three years for the implementation of one single action plan (European Commission 2014). Appropriate monitoring needs to be planned to reduce density and abundance of invasive species and to keep its impact to an acceptable level (Emerton and Howard 2008, Genovesi and Shine 2003).

However, life-cycle variation between stand types makes it difficult to infer simple management rules (Hüls et al. 2007). Small and open stands of *H. mantegazzianum* may eventually serve as initiators for further spread after land-use changes, whereas dense stands might be stable (Hüls et al. 2007). Westhus et al. (2006) suggest eradication of single plants or initial populations to prevent invasion of the whole area or district. Mowing or grazing are suitable for the management of grasslands and grassland-like fringe habitats (Nielsen et al. 2005, Buttenschøn and Nielsen 2007) to prevent growth and any further development stages. Since the threat of giant hogweed spread towards biodiversity and the health risk for humans are recognized in Germany, there are despite some attempts of local eradication not enough efforts for spatially inclusive and comprehensive management (Nehring et al. 2013b). Increasing habitat fragmentation and climate change will be forcing the spread of giant hogweed if no eradication action will be undertaken (Nehring et al. 2013b).

The aim of this paper is to identify costs of efficient eradication measures and their benefits to society and oppose them within a cost-benefit analysis at national level. The cost dimension covers a wide range of eradication measures with varying sizes depending on infestation share and site status in infested German districts (e.g. grazing for large area types). The benefit dimension is focused on the recreational value in terms of willingness to pay (WTP) for an environment being free of giant hogweed and its risks for humans.

### **Current control and management of *H. mantegazzianum***

Currently used control methods comprise a variety of manual or mechanical methods, grazing and chemical control (Nielsen et al. 2005). The probability of eradication success increases if control measures are conducted exhaustively and repeatedly within seven to ten years (Holzmann et al. 2014, Nicholas et al. 2005). The prevalence of *H. mantegazzianum* populations along steep embankments, in deep ravines and other

inaccessible places makes manual treatments difficult (Nielsen et al. 2005, Nicholas et al. 2005). The current *preventive* control options are:

- *Avoidance of vegetation gaps*, dense vegetation cover, respectively (Pergl et al. 2007) or presence of the same functional group as invader in the endangered plant community (Longo et al. 2013, Wang et al. 2013, Mwangi et al. 2007, Kahmen et al. 2005, Pokorny et al. 2005),
- *General increase of diversity* in endangered plant communities (Henry et al. 2009, Pfisterer et al. 2004, van Ruijven et al. 2003, Kennedy et al. 2002, Moore et al. 2001, Naeem et al. 2000),
- *Low grade of human disturbance* of the ‘natural’ ecosystem ‘degree of hemeroby’ (Mwangi et al. 2007, Machado 2004, Steinhardt et al. 1999, Jalas 1955).

Recent active control options according to the literature are:

- *Manual or mechanical control* such as pulling out the whole plant by hand (EPPO 2009), root cutting or umbel removal by hand (Pyšek et al. 2007a, Pyšek et al. 2007b, Nielsen et al. 2005), cutting the plant from above surface with scythe, mowing or milling machines (Westhus et al. 2006, Nielsen et al. 2005),
- *Grazing by sheep* whereas a time frame of at least 10 years was most effective (Westhus et al. 2006, Nielsen et al. 2005, Andersen and Calov 1996, Williamson and Forbes 1982) Grazing seems meaningful for control of large stands and areas inaccessible for machinery,
- *Chemical control* whereas glyphosate<sup>3</sup> was the most successful herbicide (Nielsen et al. 2007, Nicholas et al. 2005, EPPO 2009). To reduce damage to surrounding vegetation, applications are recommended as spot spraying early in the growing season. However, in the final calculation we suggested chemical treatment with hand-held equipment due to the lowest cost of the alternatives for medium and unprotected areas and its suitability for areas difficult to access.

Revegetation programs after giant hogweed eradication are required to restore the dense vegetation layer and prevent further re-infestations successfully (Noxious Weed Control Program 2015).

### **Basic assumptions for cost calculation of control measures**

Since there are only few data available for giant hogweed management in Germany, cost estimations are based on a nationwide survey of n = 287 German districts (Thie-

<sup>3</sup> Application of glyphosate beyond agricultural fields, in critical areas or their buffers as well as in areas used for forestry has to be permitted by the nature conservation agency in charge (Paragraph 13 and 17 of German Plant Protection Act).

**Table 1.** Suggested measures for control of *H. mantegazzianum* depending on area size and protection status.

Area size	Root destruction with shovel	Mechanical cutting with scythe	Mechanical cutting with flail mower	Chemical treatment with hand-held equipment	Chemical treatment with machines	Grazing
Unprotected areas						
Small (up to 100 m <sup>2</sup> )	X	-	-	X	-	-
Medium (>100–1000 m <sup>2</sup> )	-	X	-	X	-	X
Large (>1000 m <sup>2</sup> )	-	-	X	-	X	X
Protected areas (nature reserves)						
Small	X	-	-	-	-	-
Medium	-	X	-	-	-	-
Large	-	X	-	-	-	-

le and Otte 2008) and benefit estimations are based on a choice experiment survey of n = 282 German households. The data from the survey of Thiele and Otte (2008) contain also information on population density. In detail, the questionnaire included questions about the *maximum* spatial extent of single *H. mantegazzianum* stands in three proposed categories (up to 100 m<sup>2</sup>, >100–1,000 m<sup>2</sup>, >1,000 m<sup>2</sup>) for different habitat types (e.g. roadside or forest margin) and, about occurrences in nature reserves per district or city. Because no conclusion of the total frequency of single stands per district or city was possible, our calculations are based on the assumption of a *minimum* occurrence of the evaluated stands per district or city. This means, the available data indicate, if *at least* one small, medium or large area is infested and if at least one of these areas is protected. A range of possible control measures (manual, mechanical, chemical and grazing) is identified and shown in Table 1. The crosses (X's) indicate meaningful applications of infestation control measures. Suggested measures are root destruction with shovel (small areas), mechanical cutting with a scythe (medium areas) or flail mower (large areas). Regarding chemical control, hand-held equipment is suitable for small and medium areas, tractors with spraying machines for large areas. Chemical treatment includes the cost of restoration such as seeds, sowing and working hours. For nature reserves, where chemical control is prohibited by law, we suggest root destruction with shovel (small areas) and mechanical cutting with scythe (medium and large areas).

Workload, frequency and effectiveness of treatments are shown in Table 2 (based on Nielsen et al. 2005). It must be considered that chemical control has several restrictions. Grazing is a 'continuous treatment' and includes the workload for fencing and maintenance. Grazing is supposed for medium and large areas, where suitable conditions for livestock farming are given with regard to soil and climatic conditions.

**Table 2.** Estimated workload and effectiveness of different control methods.

Control methods	Workload	Number of treatments per year	Effectiveness
Root cutting	Estimated time for control: 100 plants/hour	One	high
Mechanical control by scythe	Estimated time for control: 500 plants/hour	Three	low
Mechanical cutting by flail mower	0.5 ha/1,000 plants/hour	Three	low
Chemical control by hand held equipment	Estimated time effort: 100 plants/hour	Two	high
Chemical control by machinery	Estimated time effort: 0.5 ha/1,000 plants/hour	Two	high
Grazing	Fencing: 4-wire electric pasture fencing Maintenance: yearly inspection of the fence, other inspections	'Continuous' treatment	high if conducted regularly

Source: Nielsen et al. (2005) for information on control methods, workload and number of treatments; own estimations on effectiveness of control methods.

## Methods

### Cost-benefit analysis

Costs and benefits arise because invasive species interfere with the functioning of natural or human-modified ecosystems which yields flows of economically valuable goods and (ecosystem) services (Emerton and Howard 2008). Cost-benefit analysis (CBA) aims to quantify the value of all positive and negative consequences of a project or measure to all members of society in monetary terms. Usually, benefits and costs accrue over extended periods (years). From today's point of view all resources available in the future are less valuable than those available today. Therefore, in CBA future benefits (costs) are discounted relative to present benefits (costs) to obtain their present values. A benefit (cost) that occurs in year  $t$  is converted to its present value by dividing it by  $(1+d)^t$  where  $d$  is the social discount rate.

So if a project has a duration of  $n$  years with yearly benefits ( $B_t$ ) and costs ( $C_t$ ), the present value of the benefits ( $PV(B)$ ) is

$$PV(B) = \sum_{i=0}^n B_i / (1+d)^i$$

and the present value of the costs ( $PV(C)$ ) is

$$PV(C) = \sum_{i=0}^n C_i / (1+d)^i$$

If the present value of the benefits exceeds the present value of the costs, the project is valued positively because it leads to a more efficient allocation of society's resources (Boardman et al. 2011). The purpose of this CBA application is to compare different control measures in order to select the most efficient eradication strategy. As they can crucially influence CBA outcome, we also vary social discount rates between 1%

and 3% (Florio and Sirtori 2013, Drupp et al. 2015). Within sensitivity analysis, we consider potential overestimation of empirically investigated benefits (scenario 1). In the second part of sensitivity analysis, we assume a worst case scenario (scenario 2), in which every German district is infested. Benefits of control measures are based on results of a choice experiment (n = 282 respondents) investigated as WTP per person and year (for further details see chapter *Calculation of benefits*). WTP can be regarded as indicator showing if respondents are in favor or disfavor for a change from the status quo situation when comparing different alternatives (see Suppl. material 2). WTP results are particularly important where no market proxies or prices are available, as this is usually the case for public goods. In order to meet potential criticism on WTP results in terms of possible overassessment, we suggest several approaches to calibrate our WTP results. In the sensitivity analysis, we recalculate WTP results based on Arrow et al. (1993) proposing a calibration factor of 0.5. It seems impossible to develop a unique calibration factor but we can at least compare our WTP results with other empirical studies which is done in the discussion part of this paper.

Bräuer and Suhr (2005) evaluated 43 empirical studies comparing hypothetical and real WTP for various environmental conservation programs. The term ‘hypothetical WTP’ describes the fact that WTP is ‘just’ stated as answer in a survey situation, whereas the term ‘real WTP’ means the truly payment of the amount stated by respondents. The authors suggest calculating ‘switching values’ which equal WTP necessary for benefit-cost relations  $>1$ . WTP divided by ‘switching values’ identify the maximum allowed overestimation (Bräuer 2002:264). The maximum allowed overestimation in the study of Bräuer results in a factor of 9.38 and the switching value is 0.08 € (recreation tax as average one-time payment), meaning that if respondents were only willing to pay 8 cent per day during their vacation or stated WTP was overestimated by a factor of 9, the benefits of the described program would still exceed the costs.

## **Calculation of benefits**

For some public goods, such as recreation in uninfested landscapes, there are simply no market proxies for preferences. Many analysts have concluded that in this case, there is no alternative to *asking* a sample of people directly about their preferences (Boardman et al. 2011, Bateman et al. 2002, Hanemann 1994). Questionnaires to elicit such preferences have to be prepared carefully, e.g. the formulation of valuation scenario, including sampling, and data analysis. In some countries, economically relevant benefits from eradication of invasives on direct production may arise (e.g. benefits from commercial crops and livestock), as well as secondary effects on other sectors and times in terms of markets and nutrition (Emerton and Howard 2008). This seems not to be the case for Germany in an economically relevant dimension (Bundesamt für Naturschutz 2015). In our calculations, we focus only on *one* benefit of eradication control: the recreational value in terms of WTP for an environment being free of giant hogweed and its risks for humans (for further benefits see Pergl et al. 2007, Nielsen et al. 2005,

**Table 3.** Overview of main steps undertaken in the CBA application.

Steps in CBA	Eradication of <i>H. mantegazzianum</i> in Germany
Definition of purpose	Compare different control measures for <i>H. mantegazzianum</i> ; select the most effective strategy for eradication
Definition of perspective	Perspective of benefits: direct use value for population from uninfested landscapes in terms of recreation value; perspective of costs: costs for implementation of eradication measures
Identification of scope and scale	National level based on regional data of districts; costs: based on survey data of n = 287 districts and own calculations; benefits: survey data of n = 282 German households and own calculations
Assumptions for time frame	Costs were calculated over a time period of 10 years; benefits were calculated as one single payment as result of a choice experiment survey for change of the status quo situation ('willingness to pay' for defined eradication measure per household and year)
Assumptions for discount rate	We assume 1-3% discounting (material costs) per year, 1% increase of labor costs and 1% inflation rate per year; additionally we added an excess burden of taxation at the rate of 15%
Definition of baseline scenario	No official intervention (due to unknown/uncertain data); (uncertain) national cost estimations of average 10 million per year (Reinhardt et al. 2003) in discussion section
List and select control options	Root destruction, mechanical cutting, chemical treatment and grazing (for further details see Table 1 and 2)
Select appropriate scenarios	We calculate optimistic and pessimistic scenarios for small, medium, large, non-protected and protected areas. In the pessimistic scenario, we assume twice re-infestation within ten years; in the optimistic scenario, we assume no re-infestation after successfully conducted control measures. Chemical eradication includes costs of renaturation. Because we do not consider all measures to be successful at once, we calculate 30% additional costs for monitoring (ten years) and 50% additional costs for after-treatment (each measure).
Estimate direct costs and benefits	Cost of labor and cost of materials (see Table 5), net present values for suggested control options within the two scenarios (see Table 6); benefits: willingness to pay of 9 Euro for measure per year and person, received from n = 282 German households
Estimate indirect costs and benefits	Due to lacking reliable data base, no precise cost of indirect effects or side effects have been calculated. However, we address this issue. Indirect benefits are the avoided indirect cost of the baseline scenario (which we do not include here).
Compare benefits and costs	B/C ratio was determined by comparing the costs incurred by eradication control with the benefits resulting from eradication as direct use value. The resulting ratio expresses the efficiency of the policy scenario.
Perform sensitivity analysis	We calculate switching values and overestimation factors to address the reliability of WTP results (compare Bräuer and Suhr 2005).

Source: Summary of main CBA steps inspired by Kehlenbeck et al. (2012), Boardman et al. (2011) and Pearce et al. (2006).

Pfisterer et al. 2004, Williamson and Forbes 1982). The calculation of benefits is based upon an empirical face-to-face survey using results of a choice experiment (stated preference method see e.g. Adamowicz et al. 1998, Bateman et al. 2002). The main survey was preceded by qualitative preliminary studies (face-to-face; n = 16), pre-test interviews (as mail survey and face-to-face; n = 57) and pilot study (face-to-face; n = 106). Our qualitative pre-study showed that respondents were aware of non-native plants,



**Table 4.** Attributes and levels presented to respondents in the main survey.

Attribute	Measure	Level of change (Coding in parenthesis if not directly given; *: <i>Status Quo</i> )		
Climate change	Afforestation	Sequestration/emission equivalents of 540 persons* (540)	Sequestration/emission equivalent of 630 persons (630)	Sequestration/emission equivalent of 720 persons (720)
Invasive plants	Removal of invasive plants	Only if harmful and in particular cases (1)*	Large scale removal if harmful or not (2)	
Insect pests and storms	Planting site-adapted trees	Low resistance and resilience (1)	Medium resistance and resilience (2)*	High resistance and resilience (3)
General ecosystem resilience	Changes in the diversity of mycorrhizal fungi	Low resistance and resilience (1)	Medium resistance and resilience (2)*	High resistance and resilience (3)
Price	Income change per year/person	0 €, 5 €, 10 €, 20 €, 35 €, 50 €, 60 €, 80 € (=coding)		

particularly the giant hogweed was mentioned in several independent interviews (open question format). Thus, we decided to use *H. mantegazzianum* as an indicator for invasive plants. To prepare respondents to the choice experiment task, there was a section in the questionnaire, where some details of the attributes and levels were explained. In the explanation we focused on the risks of giant hogweed to humans in order to justify different types of potential eradication measures. The proposed eradication measures of the attribute ‘Invasive plants’ are shown in Table 4.

An exemplary choice set used in the main survey is shown in Suppl. material 2. Choice cards included a picture of the *H. mantegazzianum*. Within the choice experiment, the following two options were offered to respondents:

- Option 1: removal of invasive plants in particular cases for which negative effects are known, or
- Option 2: large-scale removal of invasive plants even when unclear if they have negative effects or not.

Respondents were asked to state their choice regarding the preferred option. Including the ‘price’ (mandatory tax payment) of the hypothetical measure each choice option indicates benefits of respondents obtained by the choices. The ‘price’ for implementation of the proposed measures ranged from 0 to 80 Euro per programmed year. For the Status Quo situation, the cost was always zero. Statistically significant attribute coefficients allow for the calculation of WTP for attribute level changes. In the econometric analysis, WTP can not only be identified for a program or scenario but also for single attributes (details in Suppl. material 2). Average WTP of respondents for control measures is calculated as follows. For attributes linear in parameters, the marginal WTP equals the negative ratio of the respective attribute coefficient  $c_z$  and the coefficient of the monetary attribute  $c_y$ :

$$WTP = -\frac{c_z}{c_y}$$

WTP values refer to *one*-level change in the attributes. For respondents protesting the choice experiment, '0' WTP is assumed in order to avoid a bias in favor of higher WTP than stated in the sample. Benefits are opposed as single payment to the costs of a ten year eradication program limiting stands of *H. mantegazzianum*. In the following analysis WTP results for the single attribute 'Invasive plants' are multiplied with the number of households per infested district accounting for nationwide control measures.

### Calculation of costs

For the cost side, we calculate two different invasion scenarios for each area size, type and measure: (i) no re-infestation after successfully conducted control measures (optimistic) and (ii) re-infestation twice after conducting control measures within ten years (pessimistic). Both scenarios include the suggested number of treatments per year (up to three treatments) and measure such as displayed in Table 2. For the cost-benefit analysis, we chose the measures with lowest costs for each area type (protected or not) and size. We calculate with yearly discount rates of 1%, 2% and 3% (Florio and Sirtori 2013, Drupp et al. 2015) and a yearly inflation rate of 1% (e.g. national bonds with expiry date of 2026, corresponding to a 10 year program starting this year, comprising a value of 0,96%, Deutsche Bundesbank 2016). Additionally, 1% increase in labor costs per year is assumed. Both scenarios include 50% additional costs for after-treatment and 30% additional costs for monitoring (30% of labor costs) for each year.

In the following, the procedure of cost calculation is briefly described (see Table 5): As hourly rate of labor costs, 33 € are calculated for all measures. For root destruction measures of *H. mantegazzianum*, additional job training of 5 hours for instruction are considered. One worker is suggested for every small area (up to 100 m<sup>2</sup>; average 50 m<sup>2</sup>), ten workers for every medium area (>100–1,000 m<sup>2</sup>; average 550 m<sup>2</sup>), and five workers for every large area using machines (>1,000 m<sup>2</sup>; average 5,500 m<sup>2</sup>). We considered establishment costs for protective clothing, shovel, scythe and flail mower. Running costs include monitoring (30% of labor costs) and two additional treatments, plus repair costs for machines (e.g. flail mower). Costs for chemical control include two treatments per area, protective clothing (safety glasses, (mouth-) mask, cap, coat and trousers, shoes and gloves), herbicide sprayer for small and medium areas and tractor with spraying machine for large areas, diesel and machine oil, technical inspection and machine check, glyphosate concentrate, restoration (seed mixture, e.g. 70% grass, 30% herbs, 4,000 seeds or 20 g per m<sup>2</sup>; planting costs, two cuttings per year), plough and seeder. Besides working hours for the described measures, we add five hours for job training for each area. Establishment costs for chemical control include protective clothing, shovel, scythe, machines (tractor with spraying machine, plough and seeder), herbicide sprayer, glyphosate and seeds for restoration. Running costs for chemical control are for diesel and machine oil, tech-

**Table 5.** Basic assumptions for labor and material cost calculations of giant hogweed eradication measures.

Description of measure	Cost of labor	Cost of materials
Root destruction and mechanical cutting	33 € per hour; additional job training of 5 hours, one treatment and one after-treatment	Protective clothing, shovel, scythe, flail mower, repair cost
Chemical treatment	33 € per hour; additional job training of 5 hours, two treatments, restoration (plough and seeder, planting costs and two cuttings per year)	Protective clothing, machines, herbicide sprayer, diesel and machine oil, technical inspection agency and machine check, machine repair, glyphosate
Grazing	33 € per hour; maintenance of fencing, periodic inspection, daily inspection of animals, moving of animals between fenced area, scrub removal, branch pruning, building of stiles, supplementary cutting outside the fencing with 1,000 hours per year and administration with 15 hours per site and year	Fencing, purchase of animals, shelter, water supply, additional fodder, veterinary inspection and treatment

Source: Based on suggestions from Nielsen et al. (2005) and adjusted to the concrete case of eradication in the infested German districts.

nical inspection and machine check. For calculations of technical agricultural cost (e.g. agricultural machines), we used KTBL software (2015). Grazing is suggested for medium (>100–1,000 m<sup>2</sup>) and large (>1,000 m<sup>2</sup>) infested areas. Considering sheep having to get used to *H. mantegazzianum*, we included an additional 5 % of total costs for initiation of the measure. We consider establishment costs as those associated with the purchase of animals, fencing in a lifespan of 10 years and shelter. Running costs include maintenance of fencing, periodic inspection, and moving of animals between fenced areas as well as supplementary cutting of *H. mantegazzianum* outside the fenced area, in total, 1,000 hours (33 € per hour) workload per year. Additionally, we calculate 15 hours in administrative costs per area and year for planning, organisation and coordination of the grazing measures. Furthermore, additional fodder for the winter time as well as veterinary inspection with treatment in the case of diseases and water supply are considered. Thirty percent of total costs are suggested for yearly monitoring. Costs of labor are calculated with three people for medium areas (average 550 m<sup>2</sup>; by maximum 1,000 m<sup>2</sup>) and 5 people for large areas (average 5,500 m<sup>2</sup>; by maximum 10,000 m<sup>2</sup>). Assuming that the costs are financed by the public authority, we include an excess burden of taxation at the rate of 15% (see Boardman et al. 2011). The excess burden or efficiency cost of taxation recognizes that transfers between consumers, producers and the government are not costless to implement (Boardman et al. 2011). Finally, cost-effectiveness of eradication strategies depend on the length of the period over which they are implemented and observed.

## Results

### Benefits from control measures

The choice experiment was conducted as a household survey using face-to-face interviews in central Germany. Of the successfully contacted 302 households, 282 respondents completed the choice task (6.6% protest answers). An average interview took 35 minutes. Respondents preferred on average the first control option offered in the choice experiment, the ‘removal of invasive plants in particular cases for which negative effects are known’. Interviewees were willing to pay 9 € ( $p < 0.05$ ) as annual contribution when compared to the more abrasive eradication program. For the 20 respondents (6.6% of interview respondents) protesting the choice experiment, ‘0’ WTP was assumed. Accepting a minimum advantage of invasion control for the German population living in infested districts, in terms of recreation in an environment free of giant hogweed plants, benefits amount to 238,063,641 € per year, average 829,490 € per district. To avoid overestimation, we calculated direct use values as only one single payment *per household*, despite WTP was investigated as annual payment *per person*. The control of *H. mantegazzianum*, offered in two options, was identified as significant predictor of choice within the econometric model ( $p < 0.05$ ;  $\text{Chi}^2 < 0.001$ ;  $R^2$  - values 0.19–0.22<sup>4</sup>). For more details on the conducted choice experiment and further results see Rajmis et al. (2009).

### Costs of control measures

Table 6 shows the costs in terms of net present values for a ten year eradication program with varying discount rates (1%, 2% and 3%) for each proposed measure. Costs of control measures result in a total of 3.3 million € for the optimistic invasion scenario and 5.8 million € for the pessimistic invasion scenario<sup>5</sup> at a discount rate of 3%. Calculating a discount rate of 2% costs result in a total of 3.4 million € for the optimistic invasion scenario and 6 million € for the pessimistic invasion scenario. The 1% discount rate leads to a total cost of 3.5 million € for the optimistic invasion scenario and 6.3 million € for the pessimistic invasion scenario. The costs for the single area types are as follows: for an optimistic scenario in non-protected areas, the lowest cost identified for small areas are root destruction with shovel and result in min. 810 € (max. 855 €), for medium areas the lowest cost resulted in chemical treatment with hand-held equipment including; which amount to min. 5,180 € (max. 5,385 €) and for large areas mechanical cutting with flail mower resulting in min. 44,631 € (max. 45,406 €). For a pessimistic scenario in non-protected and small areas lowest costs were also identified for root destruction with shovel resulting in min. 1,511 €

<sup>4</sup> In the calculated model we received  $R^2$  - values between 0.06–0.07 which corresponds to  $R^2$  - values of 0.19–0.22 of linear models (see for details Hensher et al. 2005:338).

<sup>5</sup> Costs are calculated for available data of  $n=287$  districts (see Thiele and Otte 2008).

**Table 6.** Costs (net present values) for suggested control measures of infested areas for a time-period of ten years.

Area size	Scenario	Root destruction with shovel			Mechanical cutting with scythe			Mechanical cutting with flail mower			Chemical treatment with hand-held equipment			Chemical treatment with machines			Grazing		
		1%	2%	3%	1%	2%	3%	1%	2%	3%	1%	2%	3%	1%	2%	3%	1%	2%	3%
S <sup>b</sup>	Opt. <sup>c</sup>	855	831	810e	-	-	-	-	-	-	3,023	2,938	2,860	-	-	-	-	-	-
	Pess. <sup>d</sup>	1,628	1,567	1,511	-	-	-	-	-	-	5,636	5,426	5,230	-	-	-	-	-	-
M	Opt.	-	-	-	7,727	7,569	7,424	-	-	-	5,385	5,279	5,180	-	-	-	-	-	-
	Pess.	-	-	-	16,834	16,240	15,685	-	-	-	11,832	11,416	11,028	-	-	-	12,670	12,483	12,310
L	Opt.	-	-	-	-	-	-	45,406	45,003	44,631	-	-	-	129,552	129,462	129,379	-	-	-
	Pess.	-	-	-	-	-	-	119,988	116,011	112,295	-	-	-	385,014	372,692	361,161	52,850	50,981	49,251
Unprotected areas																			
Protected areas (nature reserves)																			
S	Opt.	855	831	810	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pess.	1,628	1,567	1,511	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M	Opt.	-	-	-	7,727	7,569	7,424	-	-	-	-	-	-	-	-	-	-	-	-
	Pess.	-	-	-	16,834	16,240	15,685	-	-	-	-	-	-	-	-	-	-	-	-
L	Opt.	-	-	-	24,071	23,362	22,707	-	-	-	-	-	-	-	-	-	-	-	-
	Pess.	-	-	-	43,310	41,677	40,157	-	-	-	-	-	-	-	-	-	-	-	-

a Discount rate

b S = small areas, M = medium areas, L = large areas

c optimistic scenario: no re-infestation after successfully conducted control measures

d pessimistic scenario: twice re-infestation within ten years

e cheapest option for each area size in bold

(max. 1,628 €), for medium areas chemical treatment with hand-held equipment including restoration at a min. price of 11,028 € (max. 11,832 €), for large areas the lowest cost were reached by grazing with a min. of 49,251 € (max. 52,850 €). For an optimistic scenario in small protected areas, lowest costs are also reached by root destruction with shovel and amount to min. 810 € (max. 855 €), for medium areas the lowest cost result for mechanical cutting with scythe amounting to min. 7,424 € (max. 7,727 €). For large areas mechanical cutting with scythe is suggested which amounts to min. cost of 22,707 € (max. 24,071 €). For the pessimistic scenario in protected and small areas the lowest cost result in root destruction with shovel and amount to min. costs of 1,511 € (max. 1,628 €) for medium areas mechanical cutting with scythe resulting in min. cost of 15,658 € (max. 16,834 €), and for large areas (mechanical cutting with scythe as well) in min. cost of 40,157 € (max. 43,310 €). Some details of scenario calculations are shown in the supplementary material (Suppl. material 1).

### **Benefit-cost relation of control measures and sensitivity analysis**

We chose the measures with lowest costs for each area type (protected or not) and size (small, medium and large) for the final calculation. The lowest cost measures are root destruction with shovel in small areas (optimistic and pessimistic scenario), chemical treatment with hand-held equipment in medium areas (optimistic and pessimistic scenario), mechanical cutting with flail mower in large areas (optimistic scenario), and grazing for large areas in the pessimistic scenario. Root destruction with shovel and mechanical cutting with scythe are due to legal constraints the only options for protected areas. The benefit-cost relation of German districts for control measures of *H. mantegazzianum* lies between 69:1 (discount rate of 1%) and 72:1 (discount rate of 3%) for optimistic scenario and 38:1 (discount rate of 1%) and 41:1 (discount rate of 3%) for pessimistic scenario calculations for each area size. Results indicate that every euro of calculated costs can be opposed to averagely 55 € of benefits (discount rates between 1% and 3%). To give consideration to the earlier mentioned concerns of potential overestimations, we calculate the maximum allowed overestimation (Bräuer 2002, Bräuer and Suhr 2005).

Switching values range between 0,02 and 0,03 € (average 2,5 cent) in Scenario 1 and between 0,24 and 0,30 € (average 26 cent) in Scenario 2. This is the amount necessary to result in a benefit-cost relation >1. Calculating the net-benefit of measure implementation (WTP/switching value), a factor of 448 results for optimistic and 299 for pessimistic scenario calculations. This means, if our empirically investigated results would be overestimated by factors between 299 (pessimistic scenario) and 448 (optimistic scenario), ‘necessary’ real WTP would be still the amount of the switching values (0.03 € and 0.02 €), hence high enough to keep the benefit-cost relation positive.

Since the utilized source of data (Thiele and Otte 2008) may not represent the current state of invasion status in Germany, we also provide a sensitivity analysis in terms of infestation assumptions (Scenario 2). We assume that every German district is

**Table 7.** Scenario 1. Benefit-cost relation of infested German districts (N= 287) based on data from Thiele and Otte (2008) and overestimation factor of WTP results.

Results	Optimistic scenario			Pessimistic scenario		
	1%	2%	3%	1%	2%	3%
Discount rate (DR)						
Average benefit-cost relation of German districts	68.65	70.27	71.83	38.06	39.5	40.96
Switching value (in €)	0.02			0.03		
Maximum allowed overestimation (WTP/switching value)	448			299		

**Table 8.** Scenario 2. Benefit-cost relation of worst case scenario: every German district (N= 440) infested and overestimation factor of WTP results.

Results	Pessimistic scenario		
	1%	2%	3%
Discount rate (DR)			
Average benefit-cost relation of German districts	3.9	4.0	4.2
Switching value (in €)	0.30	0.25	0.24
Maximum allowed overestimation (WTP/switching value)	29.9	35.8	37.3

infested with at least one small, one medium and one large area and calculate the pessimistic infestation scenario without chemical treatment (due to possible infested nature reserves or other sensitive landscape areas), control cost amount to 57 and 61 million euro for ten years of treatment. As this is a worst case scenario, we assume the most expensive cost for each measure and area size here. This cost estimate is well within the range of similar calculations for other countries (Reinhardt et al. 2003, Sampson 1994, van Wilgen et al. 2004). The cost estimates of Gren et al. (2009) are somewhat higher than our results (see below). Opposed to the benefits of our survey with one single payment per German household in the infested districts, this results in a benefit cost-relation of 4:1. The maximum allowed overestimation ranges between 30 and 37 and is thus lower as in scenario 1 (between 38 and 72). This result seems reasoned due to average benefit-cost relation in scenario 2 is ten times lower (e.g. 4 versus 40 using DR of 2%) comparing pessimistic scenario calculations. Switching values range between 0,24 and 0,30 €, meaning that even if WTP would have been overestimated 37 times, we would still have a benefit-cost relation >1. As mentioned earlier, the NOAA Panel suggests calibrating empirical WTP results by a factor of 0.5 (Arrow et al. 1993). If we recalculate scenario 1 with halved WTP, the allowed overestimation is 50% reduced and results in a factor of 150 considering pessimistic assumptions and a factor of 225 for optimistic assumptions. For scenario 2, the allowed overestimation with halved WTP has still a factor of 17, meaning that even if WTP would have been stated 17 times higher then conceived by respondents, we would still have a benefit-cost relation >1.

## Discussion

Our cost-benefit-analysis clearly shows that control measures limiting *H. mantagezianum* in infested German districts are efficient from an economic point of view. The most promising measures from the control perspective are root cutting and chemical treatment by hand-held equipment or machinery, although chemical control includes two treatments and revegetation. Root cutting is an important control measure for protected areas. These findings are in line with experiences from Latvia (Olukalns 2007) and United Kingdom (Sampson 1994; see below). If the suggested measures are implemented successfully including after-treatment, the probability of re-infestation is low and the measures may have a very positive benefit-cost ratio in the long term as well. Reducing monitoring frequency increases yearly costs up to 162% (Breukers et al. 2008). *Net present values* of control measures range between 810 € for root destruction with shovel (DR of 3%) and 385 thousand € (DR of 1%) for chemical treatment with machines for a time period of ten years depending on area size and type of treatment or 4 and 8 cent per capita in Germany for all necessary control measures. The cost have to be recognized as lower limit of minimum necessary eradication cost. The identified benefits of our survey are approximately 9 Euro per capita in Germany, resulting in a benefit cost-relation of 225:1 (lowest cost within 1% DR) and 113:1 (highest cost within 3% DR). If we consider just one person per German household willing to pay, the benefit-cost relation lies between 113:1 and 56:1. By the way, this is again equivalent to a 50% reduction of our WTP results, which is suggested by the NOAA-panel as factor of calibration (Arrow et al. 1993). Especially the cost estimates are somewhat lower in comparison to the calculations for other countries. The benefit cost-results are in the dimension of van Wilgen et al. (2004).

Unfortunately, there are very few studies about costs and benefits of invasion control.

In the following, available *cost estimations* on invasion control scenarios are presented and – if possible – compared to the findings of our cost-benefit analysis. The only economic assessment of giant hogweed eradication cost especially for Germany can be found in Reinhardt et al. (2003). The authors estimate annual control cost of giant hogweed in Germany amounting to average 12 million euro, including 1 million euro for medical treatment of injured humans, 1.2 million euro for measures in nature reserves, 2.1 million for measures in road management, 2.4 million for measures in municipal management and 5.6 million euro for district management measures (no further differentiation of costs). If we assume a minimum infestation of each area size and type in the surveyed districts ( $n = 287$ ) and add the (uncertain) current cost of about 12 million spent in Germany for yearly giant hogweed eradication (Reinhardt et al. 2003) for a ten year eradication program in our analysis and compare the benefits for only one year to the cost results, the benefit-cost relation ist still 2:1. The resulting values still demonstrate an environmental improvement and welfare improvement for the society even if we look at more costly invasion scenarios.

Gren et al. (2009) estimated the total costs of 13 invasive species in Sweden. All species are subject to control by Swedish public authorities, and estimates for most



invasive species include either damage cost or actual control cost. The results indicate a total annual cost between approximately 153 million € and 479 million €, which correspond to 17 euro and 53 € per capita in Sweden. The total annual cost for giant hogweed control range from 38 thousand € to 47 thousand € (0.004 to 0.005 € per capita in Sweden). In our study, annual control cost per measure type and size range between 81 € and 39 thousand € (up to 0.0005 € per capita in Germany), which is in the lower limit of Gren et al. (2009).

Sampson (1994) estimated control cost of giant hogweed in UK for 150 infested sites identified by a postal survey conducted in 1990. The three main adopted control strategies were: cutting plus glyphosate, cutting alone or glyphosate alone. Overall expenditure of control costs for 1989 range between approximately 148 € and 42.630 € (historical exchange values from 2000; 1989 not available). These results are in the same dimension of our calculations for control measures of  $n = 396$  infested sites ranging between 810 € and 385 thousand €, that is 1 € to 284 € per site in UK versus 2 € to 972 € per site in Germany.

In the study of van Wilgen et al. (2004), costs and benefits from biological control of six invasive alien weed species (e.g. red sesbania and jointed cactus) in South Africa are compared. Red sesbania replaces indigenous riverine and wetland species, especially the seeds are poisonous and lethal to mammals, birds and reptiles. The jointed cactus competes with indigenous species as well. Dense infestations reduce the grazing potential (up to 90%) and hence the value of the agricultural land. The authors calculate benefits as economic losses in water use, biodiversity, and preservation of the value of agricultural land. Benefit-cost ratios range from 8:1 for the red sesbania (*Sesbania punicea*) to 709:1 for the jointed cactus (*Opuntia aurantiaca* Lindley). The sensitivity analysis shows that the returns on investment in biological control generally remain positive with some variations between species (van Wilgen et al. 2004). In our study, we did neither include benefits as economic losses from values of agricultural land nor biodiversity deducting that our benefit estimates are rather underestimated than overestimated.

## Conclusions

The studies mentioned above result in positive benefit-cost outcomes indicating that invasion control is sensefull from an economic point of view: the control activities are economically efficient and they have in large part positive effects on biodiversity, water use, human and animal health. This might be a more convincing argument for policymakers than nature conservation as good achievement. Since the EU regulation 1143/2014 entered into force, member states are anyway obligated to conduct cost-benefit analysis to identify cost efficient control measures. However, we quantified just *one* benefit of giant hogweed control in terms of direct use value for recreation; there might be much more benefits which we did not include. The true benefits of giant hogweed control to society might be much higher. Compared to the studies in this

discussion section, we conclude that our results might reveal only the lower limit of control costs. Based on our findings and the review literature, we suggest for future control programs:

- to support research on prevention methods in different ecosystems e.g. biodiversity conservation at landscape level as invasion insurance
- incorporate non-market values such as loss in aesthetic values, recreation or other ecosystem services as benefit of control programs;
- to plan control measures at an adequate spatial scale taking into account potential re-infestations.

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## **Supplementary material 1**

### **Details of scenario cost calculations**

Authors: Sandra Rajmis, Jan Thiele, Rainer Marggraf

Data type: Adobe PDF file

Explanation note: In Suppl. material 1 we present some cost calculation details of different infested area types and sizes.

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## **Supplementary material 2**

### **Exemplary choice set and details of scenario benefit calculations**

Authors: Sandra Rajmis, Jan Thiele, Rainer Marggraf

Data type: Adobe PDF file

Explanation note: In Suppl. material 2 we present an exemplary choice set used in the choice experiment and some details of econometric analysis.

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