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The purpose of this paper is to present calculations of total costs of 13 alien invasive species (AIS) in Sweden. All species are subject to control by Swedish public authorities, and estimates for most AIS include either damage cost or actual control cost. The results indicate a total annual cost between approximately 1620 and 5080 million SEK, which correspond to SEK 175 and SEK 565 per capita in Sweden. The estimates are well within the range of similar calculations for other countries, but differ with respect to the composition of costs of different AIS. Whereas costs for the agricultural and forestry sectors dominate in most other studies, the costs of AIS in Sweden are more equally divided among different categories. The results also indicate that the highest costs are attributable to unintentionally introduced AIS and that the most reliable cost estimates are related to human and animal health.

INTRODUCTION

Scientists have, during recent decades, reported a large number of alien invasive species (AIS) with considerable ecological impacts (1–3). Negative economic impacts of specific AIS, such as production losses resulting from alien pests in agriculture or degradation of power plants and water treatment plants caused by zebra mussels (*Dreissena polymorpha*) in the Great Lakes, have been documented in a number of studies since the 1960s (4–8). Such studies of the costs of a single AIS are indeed very useful when considering mitigation strategies for that particular species. However, for decision-making on strategies for national programs against AIS, information on potential nationwide costs of multiple AIS can be more relevant. In spite of the relatively early recognition of the considerable costs of AIS, there are few studies estimating costs at a nationwide scale for several AIS (3, 9–12). The purpose of this study is to extend on this literature on the costs of several AIS at the national scale by estimating the costs of AIS in a European country, Sweden.

Most of the economics research on alien species has focused on *ex ante* and *ex post* assessment of the costs of invasive species or on cost and benefit calculations of programs preventing, controlling, or eradicating damages from species invasions (4–8). These reviews reveal that most cost calculations are made for single species, such as the cost of comb jelly (*Mnemiopsis* sp.) in the Black Sea or black wattle tree (*Acacia mearnsii*) in South Africa (13, 14). To the best of our knowledge, there are only six different studies of nationwide estimates of several AIS with impacts on different ecosystems (3, 9–13). Three of them apply to the US (3, 9–12, 15) and one each applies to Germany (10), Canada (12), and Australia (15). One of the studies of the costs of AIS in the US applies the same method for national cost estimates in Australia, India, Brazil, the UK, and South Africa (3). Results from these studies point to annual costs of AIS ranging between SEK 20 and SEK 3100 per capita (1 Euro = 9.52 SEK, 19 July 2008) in different countries (3, 9–12).

Because of limited access to data on, in particular, the ecosystem impacts of AIS, all nationwide studies rely on simple methods for estimating costs; moreover, only a small fraction—a maximum of 1%—of the total number of recorded AIS are estimated (9, 10, 12, 15). Admittedly, this study faces similar problems in obtaining data, although the included 13 AIS correspond to a relatively larger fraction, 1.6%, of the total number of AIS in Sweden. Therefore, this study contains a discussion on the reliability of the results and a comparison of the costs of AIS in Sweden with similar estimates in other countries; we believe that the reliability discussion and cost comparison constitute contributions to the scarce literature on nationwide cost estimates of AIS. Another contribution of this paper is the calculation of nationwide estimates for an additional country, Sweden. Only two studies of the cost of AIS have been carried out in Sweden; these are applied to signal crayfish (*Pacifastacus leniusculus*) and the weed, yellow floating heart (*Nymphoides peltata*) (16, 17).

This paper is organized into three main sections. First, a brief presentation is made of the calculations of the costs of each invasive species. The next section provides a summary of all damage cost estimates and a discussion of the reliability of the results. The Swedish estimates of costs are compared with similar calculations for other countries in the third section. The paper ends with a concluding section.

BRIEF DESCRIPTION OF COST CALCULATIONS

The choice of included species in this study is based on three main criteria: *i)* recognition of an AIS as reported in the database NOBANIS (North European and Baltic Network on Invasive Alien Species) (18); *ii)* relative ease of obtaining data; and *iii)* compatibility with other similar international studies. Although NOBANIS applies a definition of AIS that focuses mainly on threats to biological diversity, this study also considers alien species creating negative economic impacts with little or no documented impact on biodiversity. However, several alien species also have positive impacts, such as the introductions of pheasant (*Phasaianus colchicus*) and fallow deer (*Cervus dama*) for commercial purposes. It is therefore important to emphasize that the study is limited in scope by the calculations of only negative impacts of a certain number of alien species, and does not aim to estimate the total social cost of AIS in Sweden. Related to the definition of AIS is the timing of species introduction. Some invasive species in Sweden had already been introduced by the 16th century. In this study, we refrain from judging whether the time limits of our data sources are relevant; thus, based on the NOBANIS selections, and in line with many other research networks on alien species (19, 20), we consider both recent introductions and species transferred from their native ranges centuries ago.

The second criterion, access to data, requires a conceptual and operational definition of the costs of AIS. The cost of an uncontrolled AIS consists of the damage caused by the species, such as the costs of the health impacts of giant hogweed. However, these damage costs can be reduced by introducing control of the AIS as long as the marginal benefit from the control (i.e., avoided marginal damage costs) exceeds the marginal costs for control, such as labor costs for the removal of giant hogweed. The total cost of an AIS then consists of control and damage costs from the uncontrolled or remaining AIS when eradication has not been obtained. Ideally, data would exist on both control and damage costs. However, measurements of damage costs, in particular, pose a great challenge since this requires the quantification of all biological impacts and their associated measurement in monetary terms (21). Although there is a large literature on the valuation of nonmarketed environmental changes, its application to AIS is scarce (see Turner et al. [22] for a review of the valuation of nonmarketed environmental services). Therefore, similar to other studies of the national estimates of the costs of several AIS, estimates are obtained from judgments provided by national expertise, local authorities and organizations, and, to the greatest extent possible, from scientific publications. The third criterion, compatibility with other studies, is fulfilled mainly by the classification of the included species, but also by the inclusion of species such as rodents and the human immunodeficiency virus (HIV).

In total, 13 species were selected for this study which, following the literature, were classified into five different categories: aquatic alien species, biodiversity, health costs of alien species, forest, and others. This can be regarded as a relatively limited number of AIS when compared with double the number of AIS included in other studies, which range between 16 for Canada and 79 for the US, as reported in (12) and (9), respectively. However, when instead relating included species to the total number of known AIS, this study calculates the costs of 1.6% of all known AIS in Sweden, which is considerably larger coverage than that of similar studies in other countries, where the maximum coverage is 1% (9, 10, 12, 23). Unless otherwise stated, all data and calculations are found in (23).

Aquatic Alien Species

In total, four different aquatic AIS are included: signal crayfish; the bacteria *Aeromonas salmonicida*, which causes the fish disease furunculosis; yellow floating heart; and bay barnacle (*Balanus improvisus*). The signal crayfish was introduced in Sweden as a response to the decrease in harvests from the endemic noble crayfish (*Astacus astacus*), since it was regarded to be resistant to the crayfish plague (*Aphanomyces astaci*) (24). However, it was later recognized that the signal crayfish is a carrier of the plague, and therefore causes extinction of the noble crayfish when introduced into the same water. Damage costs for signal crayfish are therefore calculated as the difference in net profits between signal crayfish and the threatened endemic noble crayfish. The bacteria causing furunculosis, a serious fish disease affecting salmon, was first observed in Sweden in 1951, having been brought here accidentally from Denmark through aquaculture activities (19). Today, the number of observed outbreaks has decreased to about 1 y^{-1} and severe harm can be avoided by the use of antibiotics. The damage cost of furuncolosis therefore includes only fish health prevention costs, which mainly consist of the costs for the vaccination program.

Control costs are estimated for the other two aquatic invasive species, yellow floating heart and the bay barnacle. Yellow floating heart is an aquatic plant classified as a serious weed in Sweden (25). It was introduced as an ornamental plant in the late 19th century because of its attractive and colorful flower. As a weed, it causes problems by overgrowing water bodies and interfering with boat traffic as well as recreational activities, such as fishing, swimming, and canoeing. National estimates of the costs for mechanical control of the weed are based on a study of a lake in central Sweden (16). Control costs are also estimated for the bay barnacle, which is a crustacean growing on rocks, mussels, and algae from the water surface to a depth of 6 m. The bay barnacle is also a fouling organism; it grows on bridges and other constructions in maritime environments as well as on boats. Fouling on ships increases the frictional resistance when the vessel moves through water (26). This increased resistance can lead to increases in fuel consumption of up to 40% if no control measures against fouling are taken. Costs are calculated for the control of fouling on boats of two categories—private boats for recreational use and commercial ships—and on stationary constructions (23).

Biodiversity

Almost all AIS imply changes in biodiversity in the host region. The basis for classifying four terrestrial species—the Iberian slug (*Arion lusitanicus*), Japanese rose (*Rosa rugosa*), giant hogweed (*Heracleum mantegazzianum*), and mink (*Mustela vison*)—as causing mainly biodiversity changes is that such changes have been raised as the main concern for controlling these species in different municipalities.

The Iberian slug is considered to be one of the most aggressive and problematic invasive species in Sweden today (27). It was unintentionally introduced during the 1970s, most likely through imports of horticultural products (28). The slug has been a recurrent subject in Swedish media, often under the now commonly used nickname "killer slug" (21, 29). The main costs are likely to occur in cultivated areas, such as land used for agriculture, horticulture, public areas, and private gardens (28). However due to lack of data, the production loss in agriculture, horticulture, and public areas cannot be calculated. Costs are therefore calculated only for private gardeners, mainly based on a survey among private gardeners on their production losses from the Iberian slug (30).

The Japanese rose is a rose shrub originating from East Asia. As in other parts of Europe, the species was brought to Sweden as an ornamental plant during the 1920s (31) and is now common in the wild, often found in dense stands that can cover up to several hectares (32). The influence of the Japanese rose on surrounding flora and fauna is generally negative since it changes the natural habitats of the invaded areas. Its massive thickets cause shading effects and displace native species (33, 34). Costs of the species are estimated based on costs for implemented local measures in municipalities in southern Sweden.

Giant hogweed is a common name for a group of closely related species of the genus *Heracleum* that were introduced to Europe in the early 19th century (35). The main mechanism of introduction into Europe was as an ornamental curiosity, when seeds were planted in botanical gardens and on the grounds of important estates. Giant hogweed exudes a clear watery sap, which contains several photosensitizing furanocoumarins. In contact with the human skin and in combination with ultraviolet radiation, these compounds cause burning of the skin. Three types of control costs are estimated: costs for controlling giant hogweed along roads, railways, and in public areas such as parks. For all cost types, data are available at local scales and are scaled up to the national level based on the costs for a few municipalities and data on the spread of giant hogweed in Sweden.

The mink was introduced in the 1920s and 1930s from North America for fur farming. Both deliberate releases and escapes have made the mink successfully naturalized in the wild in Europe today. In Sweden, it is spread throughout the country, although no information on the number of individuals is available. The mink has a documented negative effect on native fauna by competition and predation (19). The most severe effect is caused by its preying on waterbirds, but fish and crayfish are also on the list of species being decimated by the mink (24). Local actions for controlling mink are taken all over Sweden, and control cost estimates are based on labor time for killing minks.

Health Costs

AIS with impacts on human and animal health constitute an important cause for early national and international control, such as foot-and-mouth disease. This study includes only mugwort (*Artemisia vulgaris*), ragweed (*Ambrosia aretmisiifolia*), and HIV.

Mugwort is the source of the third-most important pollen allergy in Northern Europe after the Fagales (mainly birch) and grass pollen (36). It was introduced to Scandinavia before 1700 (19). Mugwort is a perennial grass that propagates through seed dispersal; in Sweden, it appears in all kinds of agricultural environments, most commonly in pasture fields and in marginal lands. Ragweeds are the major cause of allergic rhinitis in North America and have entered Europe accidentally (36). Both mugwort and ragweed cause allergic rhinitis. Rhinitis is mostly not a serious illness, but it influences experienced well-being and quality of life as well as working capacity (37). National cost estimates of mugwort and ragweed are obtained by means of available data on costs per individual of allergic rhinitis, treatment costs and absence from work, and the number of allergic persons in Sweden (23).

Costs of the alien virus HIV affecting humans are calculated in the same way as for ragweed and mugwort, where data on both the number of people subjected to different treatments and associated treatment cost per individual are available. In addition, the estimates include government expenses for preventive measures (e.g., information and education campaigns) against HIV.

Forest

Following (12), Dutch elm disease is classified as affecting the forest sector, for which control costs are calculated. Dutch elm disease is caused by the fungal species *Ophiostoma* (*Ceratocystis*) *ulmi* and the more aggressive *Ophiostoma* (*Ceratocystis*) *novo-ulmi* (38). *O. ulmi* is native to East Asia; at the beginning of the 20th century, it arrived in Europe, where it was first isolated in the Netherlands (10). The more aggressive *O. novo-ulmi* reached Sweden in 1979 (38). The costs are calculated as control costs, which includes the cost of felling infected trees in order to avoid the spread of the infection. This cost consists, in turn, of the cost for felling and of the lost value from the tree. An annualized value of the latter is calculated by means of studies estimating values of Dutch elm trees and on the assumption that an uninfected tree would live for a maximum of 500 y. Estimates of the spread of infected trees are based on information from a county in southern Sweden.

Other

The European (black or tree) rat (*Rattus rattus*), which came to Sweden as early as the 16th century, and the house mouse (*Mus musculus*) are both among the most aggressive AIS in the world today (20). In Sweden, the European rat is nowadays rare, while the house mouse and the Norwegian (Asiatic or brown) rat (*Rattus norvegicus*) are more common. The latter two species were introduced from East Asia during the 1750s as blind passengers of ships (19). They live almost exclusively near humans and cause essential damages and production losses to society by feeding on crops and foodstuffs, gnawing on electric wires and sewage pipelines, and acting as vectors of several diseases. However, in spite of the well-known damages from these rodents, there are no data on the occurrences of alien rats and mice and associated damages in Sweden. Furthermore, there is no assessment of damage and control cost of the species in Sweden. We have therefore used Danish cost estimates of controlling rats and mice, which is based on control cost per capita (23).

TOTAL COSTS OF 13 AIS IN SWEDEN

Cost estimates of all 13 species presented in the previous section are summarized in Table 1 with respect to the type of cost and minimum and maximum estimates.

The total cost estimates range between 1618 and 5077 million SEK y^{-1}. The HIV cost is the highest single cost for the low estimate, and the Dutch elm disease cost accounts for the largest share of the high-cost estimate. The latter also explains why the costs of terrestrial AIS account for almost two-thirds of the total costs of the high estimate but for only approximately one-third of the low estimate.

In order to assess the reliability of the cost estimates, they are grouped into four categories depending on the availability of data on costs and on biological impacts at national versus local scales (see Table 2).

It is interesting to note that the relatively more reliable estimates are all connected to health impacts of AIS on animals or humans. A simple measure of precision in cost estimates in each group, $V = \text{range mean}^{-1}$, shows that the dispersion in estimates can be almost 20 times larger for costs related to biodiversity changes and Dutch elm disease than for those related to impacts on human or animal health.

Another way of classifying costs is to distinguish between intentionally and unintentionally introduced species. The first category, which includes giant hogweed, Japanese rose, yellow floating heart, signal crayfish, and mink, accounts for approximately one-quarter of the lower total cost estimate and for 16% of the higher cost. Unintentionally introduced AIS—furunculosis, Iberian slug, rat, house mouse, mugwort, ragweed, Dutch elm disease, bay barnacle, crayfish plague, mink, and HIV—account for larger shares of both lower and higher total cost estimates, 75 and 84%, respectively.

SWEDISH COSTS IN AN INTERNATIONAL PERSPECTIVE

When comparing the costs presented in Table 1 with similar estimates carried out for other countries, three types of observations can be made. The first is related to the magnitude of total estimates, the second to the composition of species costs, and the third to estimates of a single species. Starting with the first observation, it is noticed that the calculated costs for Sweden are relatively low as measured by the percentage of gross domestic product (GDP) but are in the middle range when reported in cost per capita (see Table 3).

As shown in Table 3, there is a large variation in total costs among countries. This is explained by differences in the choice of alien species, cost estimation methods, availability of data, and human preferences in the countries. Nevertheless, the numbers presented in Table 3 give an order of magnitude with respect to the possible total costs of aliens and show that these can correspond to approximately 12% of GDP.

With regard to the second observation, it can be noticed from Table 3 that the main part of the costs of AIS occurs in the agricultural sector in all countries except for Canada, Germany, and Sweden. A main difficulty arises from quantifying impacts of an invasive weed on agricultural production. In (3) it is assumed that these impacts are proportional to the total number of weeds, while (10) argues that native weeds would increase if the AIS weed were not present. Therefore, very conservative estimates of damage costs in agriculture are made for Germany and Sweden. These two countries also share the feature of relatively large costs of AIS in aquatic systems. For

Table 1. Summary of estimated annual costs of 13 AIS in Sweden, in millions of SEK * in 2006 prices.

Species	Type of estimates	Low estimate	High estimate
Aquatic AIS:			
Bay barnacle (*Balanus improvises*)	Control cost, private boats	122	331
	Control cost, commercial vessels	33	47
	Control cost, power plants	10	38
	Total bay barnacle	165	416
Aeromonas salmonicidae	Damage cost, cost of vaccination	2	2
Yellow floating heart (*Nymphoides peltata*)	Control costs	28	73
Signal crayfish (*Pacifastacus leniusculus*) and crayfish plague (*Aphanomyces astaci*)	Private harvest/production loss	336	552
	Commercial production loss	27	44
	Information and research	2	2
	Total signal crayfish	365	598
Total aquatic species		560	1089
Biodiversity:			
Japanese rose, Kamchatka rose (*Rosa rugosa*)	Control cost	1	15
Iberian slug (*Arion lusitanicus*)	Control cost	45	450
Giant hogweed (*Heracleum mantegazzianum*)	Control cost	17	73
Mink (*Mustela vison*)	Control cost	17	77
Total biodiversity		80	615
Health costs			
Mugwort (*Artemisia vulgaris* var. *Vulgaris*)	Damage cost, health impact	18	116
Ragweed (*Ambrosia artemisiifolia*) (potentially invasive)	Damage cost, health impact	1	36
HIV	Damage cost, health impact	400	465
	Control cost, prevention	151	151
	Total HIV	551	616
Total health costs		570	768
Forests:			
Dutch elm disease (*Ophiostoma novo-ulmi*)	Control costs	20	54
	Lost value of urban tree	63	1999
Total forest costs:		83	2053
Other			
Rat (*Rattus norvegicus*) and house mouse (*Mus musculus*)	Control costs for municipalities	116	134
	Damage cost in private sector sewage system	209	418
Total others:		325	552
Sum		1618	5077

* 1 Euro = 9.52 SEK (19 July 2008)

Source: Gren, Isacs, and Carlsson (23)

Table 2. Classification of the costs of different AIS estimates according to the availability of data on costs and impacts at the national or local scale.

Control/damage cost data availability	Spread and impact data availability * — National	Spread and impact data availability * — Local
National	Furunculosis, signal crayfish and plague, mugwort, ragweed, HIV (937-1368 million SEK; V = 0.09)	Rat and mouse (326–552 million SEK; V = 0.52)
Local	Yellow floating heart, bay barnacle, mink (210–566 million SEK; V = 0.92)	Japanese rose, Iberian slug, giant hogweed, Dutch elm disease (146-2591 million SEK; V = 1.78)

* V is defined as the range in estimates divided by the mean.

Table 3. Total annual costs of AIS and allocation among categories for different countries.

	US*	Australia*†	South Africa*	India*	Brazil*	UK*	Canada‡	Germany§	Sweden Low	Sweden High
Total cost										
Total, thousand million SEK	785	50	25	759	307	63	97	1.7	1.6	5.1
Share of GDP in %	0.9	1.0	1.4	12.4	4.5	0.4	0.9	0.01	0.06	0.2
SEK per capita	2680	420	595	752	1812	131	3201	16	174	565
Allocation of costs:										
Agriculture	62	58	92	100	94	83	40	15		
Forestry	4						57	16	5	41
Aquatic species	6		3				3	29	34	22
Health impacts	5	1	5		6	7		28	36	15
Biodiversity impacts	15	41				10			5	12
Other‖	8							12	20	10
Total	100	100	100	100	100	100	100	100	100	100

* Pimentel et al. (3). † Because of the larger coverage of invasive species, the estimates in Pimentel et al. (3) are used instead of the country-specific calculations in McLeod (15). ‡ Colautti et al. (12). § Reinhardt et al. (10). ‖ Other includes, for example, municipality costs for maintenance of traffic routes and parks. GDP = gross domestic product.

Table 4. Comparison of cost estimates of single AIS for different countries, in SEK per capita y^{-1}.

AIS	USA*	Australia*	South Africa*	India*	Brazil*	UK*	Canada†	Germany‡	Sweden
Rats	424	66	420	165	170	56			23–46
HIV	155	30	18		90	14			61–68
Ragweed								0.4	0.1–4
Giant hogweed								0.2	1.9–8
Dutch elm disease							121	0.6	9.1–219
Mink								0.5	1.9–8.5

* Pimental et al. (3). † Dolautti et al. (12). ‡ McLeod (15).

Canada, the most severe AIS in forest is the Scleroderris canker, which accounts for 65% of the losses in the forest sector.

Turning to the third observation—that is, cost estimates of a single AIS—it can be noticed that the Swedish estimates are in the lower range for rats and HIV, and are relatively large for ragweed, giant hogweed, and mink (see Table 4).

The difference in the magnitude of costs for AIS is partly explained by differences in the choices of methods and underlying assumptions for cost calculations. For example, the costs of rats are estimated by means of damage cost per rat and the number of rats per capita in the US, Australia, South Africa, India, Brazil, and the UK, whereas control cost estimates are made for Sweden. Cost estimates of a single species can differ, not only because of differences in methods applied, but also because of actual differences in the impacts of AIS depending on the host region. In order to distinguish among the causes of differences in cost estimates of species among countries, a meta-analysis of several studies estimating the costs of a particular AIS could be an interesting future research topic.

CONCLUDING COMMENTS

The total estimated costs of 13 AIS in Sweden vary between approximately 1620 and 5080 million SEK y^{-1}, which corresponds to approximately SEK 175 or SEK 565 per capita y^{-1}. Based on this result, could we say that invasive species represent a potentially serious environmental problem in Sweden? One way of answering this question is to compare the cost estimates with the costs of managing other environmental issues, such as the prioritized targets for reductions in emissions of carbon dioxide and decreases in damage from the eutrophication of the Baltic Sea. According to (39), the costs of a Swedish program against carbon dioxide emissions vary between SEK 240 and SEK 903 per capita y^{-1}, depending on assumptions regarding the future development of equilibrium prices of carbon dioxide emissions permits on the European market. The annual cost of the Swedish Baltic Sea program during the period 1995 to 2000 amounted to approximately SEK 135 per capita (40). The calculated costs of the included 13 AIS thus seem to be in the same order of magnitude as the costs for the Swedish prioritized environmental programs against climate change and eutrophication in the Baltic Sea.

However, as emphasized in this paper, the calculations rest on several simplifying assumptions, in particular with respect to quantifying the biological impacts of AIS. Only partial estimates have therefore been possible to carry out for all included species; this implies an underestimation of the true costs. Considering the rapid development of methods for valuation of nonmarket goods, such as changes in biodiversity, during recent decades in environmental economics and the expected increase in the spread of alien species due to climate change, the estimation of the costs of AIS is likely to be an important future interdisciplinary research field. Furthermore, due to the relatively recent and scant application of economics on AIS, there is a need for evaluating and comparing the cost effectiveness and feasibility of alternative national and international policies for combating the spread and establishment of the AIS that are perceived to be costly for society (23).

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