Costs of meeting Aichi Targets for 2020: Target 9 – Invasive Alien Species

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1 Introduction

The Convention on Biological Diversity (CBD) has 193 signatory countries all of which are legally bound to abide by the legislation regarding biodiversity. Article 8(h) of the CBD states that "each Contracting Party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species". In October 2010 in Nagoya, Aichi Prefecture, Japan, the CBD met at the tenth Conference of Parties (COP). They adopted a revised Strategic Plan for Biodiversity for 2011-2020. Twenty Aichi Biodiversity Targets were set under strategic goals. Strategic Goal B aims to "*reduce the direct pressures on biodiversity and promote sustainable use*". Target 9 (which is listed under Goal B) deals specifically with invasive alien species:

"By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment."

Invasive alien species (IAS) are classed as one of the biggest threats to global biodiversity, along with habitat destruction and climate change (Vitsouek *et al.* 1997). Although biological invasions have been occurring for millennia, the rate of new introductions (either intentional or accidental) continues to increase and the numbers of documented IAS are increasing exponentially (McGeoch *et al.* 2010). Although increased research efforts have played a part in this, it is thought that globalization, and in particular, income growth and transport efficiency play a major role (Hulme 2009). With goods traded in greater volumes than ever before, between a wider network of countries and with quicker transit times, IAS are being accidentally introduced to the rest of the world.

As per the Convention of Biological Diversity (CBD) definition, an alien species is *"a species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce*". Accordingly, an IAS is "*an alien species whose introduction and/or spread threaten biological diversity*". The International Plant Protection Convention (IPCC) defines a pathway as *"any means that allows the entry or spread of a pest"*.

There are both negative and positive impacts associated with IAS (Bax *et al.* 2003). The negative impacts include impacts on the environment, impacts on human health and economic losses from marine activities, such as fisheries, aquaculture and tourism, leading to loss of income and wellbeing. Dealing with the problem incurs opportunity costs associated with the financial resources allocated to personnel, scientific and technical resources. Positive impacts include direct and indirect benefits from the use of the IAS, as well as employment in IAS research and management. The relative magnitudes of the advantages and disadvantages are likely to vary considerably between different IAS in their various contexts. Most economic studies on IAS have dealt with the damage costs caused by the invading species (e.g. Perrings 2002). The cost of IAS to ecosystem services can be vast. For example, in the 1980s, the introduction and subsequent population explosion of the comb jelly *Mnemiopsis leidyi* into the Black Sea caused dramatic reductions to the pelagic plankton communities which led to the collapse of several commercial fisheries (e.g. anchovy) which only recovered years later (Shiganova 1998). While estimates of the damage costs incurred by IAS or the benefits derived from their control are few, there have been even fewer analyses of the costs of research on and prevention and control of IAS, and these are likely to be influenced by a wide range of variables (Perrings *et al.* 2000).

The UK Department of Environment, Food and Rural Affairs (DEFRA), the United Nations Environmental Programme – World Conservation Monitoring Centre (UNEP – WCMC) and ICF GHK aim to develop a plausible range in which the total global cost of meeting the Aichi TargetsI is likely to fall. The overall study will include a broad analysis of type and scale of actions necessary for achieving the targets, and an initial aggregated assessment of resource requirements, and proposals on future actions required.

This study provides an estimate of the costs of meeting Target 9. Resources required will include costs relating to biodiversity action, administrative and transaction, as well as opportunity costs. Where feasible, additional expenditure required over current and planned expenditure will be calculated (highlighting the Financing Gap), as well as any potential savings. The analysis will identify total levels of expenditures or on-going expenditures required to meet the target as well as identifying the additional levels in relation to the current levels. The method (which is likely to involve both qualitative and quantitative analysis) will be detailed within, highlighting any assumptions made in the estimation process. All investment and expenditure needs will be in expressed in US$ at 2012 prices. Note that Target 9 also forms an essential input into meeting Target 12.

2 Types of IAS and pathways of invasion

Of the species that find their way to localities outside of their natural range, only about 1% are thought to establish in the host country and then become invasive (Williamson 1998). These species are generally those that find themselves in favourable habitats but without the forces such as predation, disease and competition, that keep their populations in check within their natural range. Invasive alien species thus represent all types of biota, but tend to be pioneer-type species that are tolerant of a wide range of conditions. Although invasive species also extend to disease and pathogens affecting humans, livestock, forestry and crops, in this study we have concentrated on plant, invertebrate and vertebrate invaders of freshwater, coastal and terrestrial habitats.

Introductions of IAS are facilitated by human activities such as trade and travel, which in turn are increased through economic growth and globalization. The propensity for introduced species to proliferate is also facilitated by human impacts on the environment, including climate change. Introductions can be intentional or accidental. The main means of introductions and spread of IAS are as follows:

- **Aquaculture and mariculture**, which can lead to the escape and establishment of IAS.
- **Agriculture and forestry** results in the introduction of many species which can become invasive and spread into other areas when not properly managed.

- **Transport systems** result in the unintentional transport of organisms. Ship ballast water, which is carried from one port and discharged in another area, is one of the most significant pathways for marine bio-invasions. Fouling on the hulls of ships and other boats is also a means of transport of organisms. Other such pathways include organisms transported with raw goods such as timber, or that end up on the vehicles themselves.
- **Tourists**, who number nearly a billion international arrivals annually and can transport species intentionally (e.g. as souvenirs) or unintentionally (e.g. in the soil on their shoes).
- The **trade of pets, aquarium species and ornamental plants** is responsible for legal and illegal movements of species across borders, resulting in introductions of escapees into new areas.

3 The extent of the IAS problem

Invasive species pervade nearly every type of ecosystem and pose one of the biggest threats to biodiversity worldwide. They alter natural habitats, modify ecosystem processes such as hydrology, fire regimes and nutrient cycling, and they prey upon and/or compete with native species for resources such as space and food. These impacts lead to significant changes in ecosystems and result in the loss of diversity and populations. Invasive species are a significant factor in the plight of endangered birds, amphibians and mammals (McGeoch et al. 2010). Their impacts on ecosystem services can be felt at regional and national scales, such as the impacts of IAS on water supply in South Africa (Higgins et al. 1997, Turpie 2004). Some of the most prolific offenders have established virtually worldwide distributions outside of their native ranges. Invasive species lead to the homogenisation of biodiversity, reducing the diversity of crops and livestock and increasing their vulnerability (Luken & Thieret 1996). The effects on biodiversity over time are unpredictable.

Several organisations and networks collate country-level information on IAS at a regional or global scale (Table 1). However, most data sets suffer from some degree of data limitation (both in quality and global representation), and the Group on Earth Observations Biodiversity Observation Network (GEO BON) has been commissioned (in collaboration with several biodiversity organisations and experts) to assess the adequacy of current global observation systems in monitoring biodiversity, as a means of addressing the Aichi Biodiversity Targets set by the CBD to be achieved between 2011 and 2020. Currently, there are geographic and taxonomic gaps in IAS knowledge (Pfenninger & Schwenk 2007). In particular, temperate regions of the globe are data deficient, as well as the pelagic zones of the coast and open ocean.

In addition to the above, the University of California Santa Cruz (UCSC) in collaboration with Island Conservation are in the process of developing a database to keep track of trends in control or eradication programmes on islands. From a total of 700 global island eradications, only 50 or so contain data on costs of eradication. The focus is on single species mammal eradication programmes on islands which are mostly less than 200 km^2 (E. McCreless, UCSC, pers. comm.). The **Threatened Island Biodiversity (TIB)** database is the most comprehensive hub of information describing IUCN threatened species on islands at risk from invasive vertebrates, and to date has identified a total of 1347 islands have been identified for 1118 Critically Endangered (CR) or Endangered (EN) species (largest island is New Guinea). The TIB database provides key guidance by highlighting where eradications can be employed on a global scale to prevent extinctions. TIB partners include Island Conservation, the UCSC Coastal Conservation Action Laboratory, Birdlife International, and the IUCN Invasive Species Specialist Group.

Table 1. Detailed list of currently available observational datasets used to predict trends in IAS and their influence on the ecosystem and human responses. Modified from GEO BON 2011.

Observation dataset	Source	Year initiated	Update frequency	Geographical coverage
Pressure				
Extent of IAS	GISIN[1];	2004	Regular	Global
	SAHFOS[2]	1931	Regular	N. Atlantic & N. Sea
Trends in IAS	DAISIE[3]	1970	Regular	27 EU & 10 non-EU states
State				
Trends in IAS-driven species extinction	IUCN[5] Red List, RLI[6] dataset	1980	4-10 yearly	Global
Response				
IAS international policy	CIB[4]	1950	Annual	International
Ballast water treatment	IMO[7]	2012	In port	Global

[1] GISIN – Global Invasive Species Information Network; [2] SAHFOS – Sir Alister Hardy Foundation for Ocean Science; [3] DAISIE – Delivering Alien and Invasive Species Information for Europe; [4] CIB – Centre for Invasion Biology; [5] IUCN – International Union for Conservation of Nature; [6] RLI – Red List Index; [7] IMO – International Maritime Organisation

A list of the "**world's 100 worst invasive alien species"** has been compiled by the Global Invasive Species Database and La Fondation TOTAL d' Entreprise in collaboration with the IUCN's Invasive Species Specialist Group (ISSG). Due to the complexity of interactions between a species and its environment, certain assumptions were made in creating this list. Species were selected based on the severity of their impact on biodiversity and/or human activities, as well as "their illustration of important issues surrounding biological invasion." This latter criteria is somewhat biased as it by definition excludes those species which threaten biodiversity in data-poor countries. In addition, only one species from each genus was included in this list. Nevertheless it is interesting to note that there is a fairly good relationship between the number of these "worst 100 IAS" recorded per country and the total number of IAS recorded per country (Figure 1).

In addition, a few published studies have collated and analysed data on IAS at a global level (or for a large sample of countries). These include the recent study by McGeoch *et al.* (2010), who used a pressure-state-response framework to analyse progress in meeting the CBD's 2010 Biodiversity Targets relevant to IAS using a set of three indicators: i) The number of documented IAS per country (pressure); ii) the impact of IAS on Red List species (state); and iii) legislation regarding IAS (response). Ideally, such an analysis needs to be expanded to including the risk of further invasions (pressure), analysing the impacts on biodiversity, ecosystem services, and human health and wellbeing more generally (state), and responses need to be further analysed in terms of human-driven control and pathway management (GEO BON 2011).

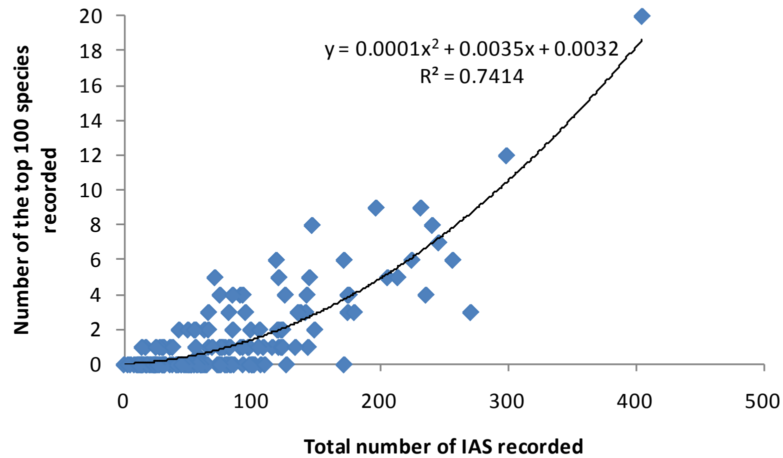

Figure 1. Relationship between the number of the 'top 100' IAS recorded and the total number of IAS recorded per country.

4 Type and scale of actions required to meet Target 9

Three main kinds of action are required to meet Target 9:

(i) research and prioritisation of IAS and pathways to be targeted;
(ii) control and eradication measures (including policy and legislation) to reduce existing IAS; and
(iii) measures (including policy and legislation) to prevent new introductions.

4.1 Research and prioritisation

Not every IAS is a priority, and in order for expenditure to be efficient, it is important to prioritise those efforts on the basis of potential damage by different types of invaders in different areas to biodiversity and society, as well as the costs and effectiveness of the potential actions that can be taken. This requires baseline and monitoring data on the extent and magnitude of invasions and research into the nature and invasion pathways of IAS, risk analysis, impact assessment, cost-benefit analysis, and research into the relative effectiveness of different actions.

4.2 Control and eradication

Four main strategies for dealing with established IAS are mitigation, containment, control and eradication (CBD 2009):

- **Mitigation** deals with attempting to minimise the damage caused by an IAS, e.g. by relocating an endangered species.
- **Containment** aims to restrict the spread of IAS and involves detecting and eradicating any new infestations outside of the containment area.
- **Control** aims to achieve a reduction in the density and abundance of IAS to below an acceptable threshold, such as a threshold that allows native species to recover and regain ground.
- **Eradication** is the elimination of the entire population of an IAS from a managed area, and although it requires high initial costs, in certain situations such as small islands, it has proven feasible and economically desirable compared with protracted control measures.

These measures are part of a gradient of interventions (Gherardi & Angiolini 2004). The relative impacts of these different measures is shown in Figure 2. In some cases, mitigation measures and/or adaptation can be more sensible (McNeely 2001). For priority species, control or eradication is desirable, as opposed to mitigation or containment. In addition to these measures, it is often necessary to include rehabilitation of damaged ecosystems or populations.

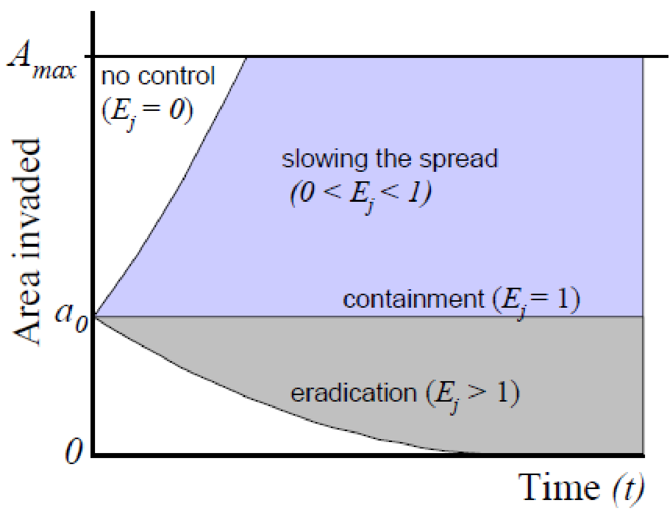

Figure 2. Impacts of different control measures on established IAPs (source: Wise *et al.* 2007).

The methods used are common across most types of IAS, and include mechanical removal, biological control, chemical treatment, habitat management and construction of barriers (based on Gherardi & Angiolini 2004). Eradication, involving the removal of every potentially reproducing individual from an area or reducing its population density below sustainable levels, is optimal in that it removes the need for further control and associated costs. However, this is generally only successful on small islands or similar situations where the problem is contained within a manageable area, such as in the early stages of an invasion.

4.3 Prevention of new introductions

Prevention has been shown to be a cost-effective means of dealing with IAS prior to introduction (Leung *et al.* 2002). Once high-risk species and pathways have been identified, measures need to be set in place to prevent the transport and establishment of species before they leave the source area (pre-border), or once they are arrive at the border.

In order to prevent intentional introductions, pathways need to be monitored and regulated (and strict authorisation, quarantine measures and standards have to be put in place). Examples of intentional introductions include the trading of goods (from foodstuffs to timber), the horticultural industry and the exotic pet trade. In these cases, the costs should be primarily borne by those who are responsible for the introduction and who will stand to benefit economically as a result (McNeely (2001)

Measures for preventing accidental introductions include monitoring of pathways (e.g. maritime ports, recreational boating marinas and airports) and vectors (e.g. ships or airplanes), quarantine and border control (biosecurity), treatment or vector control, raising public awareness and developing appropriate legislation to support enforcement.

In order to prevent IAS from entering the country, the Risk Assessment process requires the development of 'white', 'black' and 'grey' lists (McNeely 2001). The placing of a species on one of these lists, demonstrates the level of threat it represents. The 'white' list contains species which are considered safe, although some monitoring is required (as the behavior of a species in a new environment cannot always be predicted). The 'black' list contains species which are likely to become invasive (often based on their invasiveness in other countries) and introduction of these is strictly prohibited. 'Grey' lists contain species which have unknown consequences most often due to a lack of biological data or resources. In all cases, the precautionary principle should be applied wherever possible (Fairbrother & Bennet 1999).

The CBD developed a set of interim guiding principles for the prevention and mitigation of impacts of alien species. These have been modified by McNeely (2001) to include the following strategic responses:

1. Build capacity to address invasive alien species problems;
2. Build research capacity;
3. Develop economic policies and tools for addressing problems of invasive alien species ;
4. Strengthen national, regional and international legal and institutional frameworks to address invasive alien species;
5. Institute a system of environmental impact and risk assessment for invasive alien species;
6. Build public awareness of the problem of invasive alien species;
7. Promote sharing of information about invasive alien species;

8. Build responses to invasive alien species into other relevant sectors;
9. Build invasive alien species issues into global change programmes; and
10. Promote international cooperation to deal with problems of invasive alien species.

Several countries have now developed 'rapid response' measures for those scenarios where prevention measures are not effective and the invasive species is only identified once introduced or established (McEnnulty *et al.* 2001, NISC 2003, NEANS 2006, Locke & Hanson 2009). Most rapid response systems ultimately aim for complete eradication, that is, the removal of all reproductive potential from the population and there are several successful cases of this (Locke & Hanson 2009).

In order to be effective, both pre- and post-invasion measures must be reflected and enforced through the adoption of appropriate national and international policies. However, in order to tackle this, countries require expertise in IAS ecology and management, a sufficient degree of development and long-term financial support for projects (GEO BON 2011). The number of agreements and the number of countries party to these have been increasing exponentially since 1951 (McGeoch *et al.* 2010). Just over half of all countries signatory to the CBD have national legislation which covers IAS, and there are ten international agreements (currently in force) which specifically address the control/eradication and prevention of IAS.

5 Methods for estimating costs

This study was based on existing information in the published and unpublished literature sourced from internet searches, correspondence and interviews with key informants and organisations. As the time for the entire study to draft report was limited to four weeks, the amount of effort that could be put into this task was limited, and the search could not be exhaustive.

Available data on IAS, IAS costs and a range of country statistics were collected from websites, published papers and unpublished reports and were collated first as notes then summarised into a spreadsheet database. Data were separated into (a) research and prioritisation, (b) impacts and control of IAS on mainland areas, (c) impacts and eradication costs of IAS on small islands and (d) prevention measures. Data on (a) and (d) were comparatively sparse.

Data on impacts and control of IAS on mainland areas were collated by country. These data comprised either estimates of impacts or estimates of control expenditures, or in some cases, both given separately or both given as a combined value. Only in once case (New Zealand) was it difficult to separate expenditure on prevention from control. For each country, information on damage and control costs were recorded for each IAS, then these were summarised into fourteen groups of IAS. Estimates of different types of costs pertaining to single or multiple groups of IAS were obtained for a total of 33 different countries on all five continents. One study allowed us to produce estimates for a particular group of IAS for all African countries on the basis of area of different biomes, bringing our total number of countries for which we had at least partial estimates to 55. We were only able to compile a sufficiently "complete" set of estimates (in which it was felt that most or all IAS groups were covered) from existing information for eleven countries, most of which were developed countries.

A major limitation in the above data was that, in most cases, information on control costs reflected actual expenditure rather than the estimated expenditure required to meet targets such as the Aichi 9 target. In South Africa, estimates of both were available for the most costly group of IAS, and the required expenditure was estimated to be roughly ten times the actual expenditure over the past 15 years. Thus to get around this, as well as the shortage of data on control costs generally, we made use of damage cost data to produce estimates of the required expenditure on control. Damage costs were used to estimate control expenditures required based on cost-benefit ratios that have been estimated for a variety of control programmes (Table 2). Thus even where control costs data were available (e.g. Pimental *et al.* 2005), we adjusted estimates of control costs where large damage costs were reported and control costs were zero or substantially less than our estimates based on damage costs. Where studies only reported current control costs, these were not adjusted, and may be underestimates of the actual expenditure required to meet the Aichi 9 target.

Table 2. Cost-benefit ratios reported for the control or eradication of a range of IAS.

Species	B-C ratio	Source
Water hyacinth	5:1 – 67:1	Wise *et al*. 2007
Water hyacinth	13.6:1	OTA 1993
Red water fern	1,130:1	Emerton & Howard 2008
Purple loosestrife	26.5:1	OTA 1993
Parthenium weed	0.2:1 – 5.4:1	Wise *et al*. 2007
Triffid weed	1.7:1 – 3.1:1	Wise *et al*. 2007
Melaleuca	11.4:1	OTA 1993
Sea lamprey	30:1	OTA 1993
Larger grain borer	3.6:1 - 15.6:1	Wise *et al*. 2007
Alfalfa blotch leafminer	8.5:1	OTA 1993
Mediterranean fruitfly	19.6:1	OTA 1993

Another limitation was that many studies reported control costs at a site level or limited spatial scale, such as at a provincial level. Where possible, information in these studies was used to provide an estimate scaled up to the national level, based on information that could be found on the full extent of the problem. If this could not be done then the data were omitted from the study.

While most attention has been paid to estimating the costs incurred by IAS and the costs of their control or eradication, very little has been written on the costs of preventative measures, or on the research, risk assessment and prioritization measures that have to be undertaken to inform strategies for dealing with IAS.

The cost estimate for eradication for small islands, included islands from the TIB database where IUCN CR or EN birds, mammals, amphibians, reptiles were confirmed as breeding or probably breeding in the last 20 years, where the presence of rodents was confirmed, suspected or unknown, which had fewer than 1000 people, and which were smaller than 40,000 ha for rodent and predator projects, and smaller than 55,000 ha for ungulate projects. This was considered achievable by 2020.

The estimates per IAS group, as well as the overall cost estimates for research and prioritisation, impacts and control of IAS on mainland areas, and prevention measures were analysed in terms of various national-level statistics and indicators. Impacts and eradication costs of IAS on small islands were analysed in relation to island size and extrapolated based on known infestations on islands (Brad Keit, *in litt*.). In the absence of any robust relationship, geometric mean of the costs per unit area of each group was used to produce estimates of missing values. A separate analysis was performed in parallel for the costs of eradication of IAS from small islands, by Island Conservation.

All costs were first converted to 2012 values using CPI index values published by the World Bank, then converted to US dollars. In general, our study aimed to produce order-of-magnitude estimates and does not pretend to be accurate. There was too little information on the breakdown of costs into government versus private to produce a general estimate of this breakdown. For the same reason, estimates of the breakdown of the costs into labour, materials etc, could not be attempted.

6 Costs of research and prioritisation

Considerable progress has already been made in terms of baseline information at a global level. However, the current observation networks described in Table 2.1 require expansion so that they have greater global coverage. GEO BON (2011) estimated that in order to meet Target 9, €110,000 per annum would be required to construct the additional observation databases.

In the 1990s the Office of Technology Assessment (OTA) of the United States of America undertook a study to determine the economic and environmental impacts of all IAS in the country. Several years later, a 400-page report was published with details of the results. The estimated costs of completing this study were approximately US$1.125 million (Wittenberg & Cock 2001).

Williams *et al.* (2010) estimated that the research on IAS (in which the IAS is the main focus of the study) comprises GBP 16,846,000 p.a. in general funded research £541,000 in published research, giving a total of £17,387,000. In the United States, approximately $250 million is spent annually on research on IAS (NISC 2012). In South Africa, the costs of researching biological control of seven invasive alien weed species from 1932 – 2000 was estimated to be ZAR41.1 million (2000 prices). Of this research budget, 42% was spent on one species (Lantana; van Wilgen *et al.* 2004).

The UNEP-WCMC 2010 BIP IAS Indicator project, which was run through the Global Invasive Species Programme, received US$0.149 million in funds over 2009 and 2010. This project aimed to determine how successful the CBD parties had been in meeting the 2010 Biodiversity Target.

7 Costs of control on mainland areas

No-one has attempted to produce a comprehensive estimate the costs of IAS at a global scale, either in terms of their impacts or the costs of prevention and control. Based on their work in the United States, Pimentel *et al.* (2002, in Williams *et al.* 2010) suggest that the total loss to the world economy could be in the order of 5% of annual production. Based on estimates put forward by a group of experts, the GEF-6 Needs Assessment suggested that the global costs required for dealing with IAS for the period 2014-2018, might be in the order of $67.5 – 103.2 million.

A handful of studies have been carried out at a national or multi-national scale on the costs incurred by multiple IAS. In 1993, the Office of Technology Assessment (OTA) of the **United States** Congress compiled the first national estimate of costs associated with IAS, with 79 species causing an estimated US$97 billion in damages from 1906-1991 (approximately $1.1 billion per annum). Pimental *et al.* (2000) calculated costs of IAS on the **United States, United Kingdom, South Africa, Brazil, India and Australia** (a total of 120,000 IAS in the six nations) which amounted to US$314 billion annually. The annual costs for the six countries to control the problem were estimated to be $30 billion. The estimate for damage costs incurred to the **United States** alone, originally published by Pimental *et al.* (2001), were updated to US$120 billion per year (Pimental *et al.* 2005). This estimate was calculated by considering impacts resulting from the following groups: plants, mammals (rats and other), birds, reptiles, fishes, arthropods, 12rioriti, livestock diseases and human diseases. This includes combined damage and control costs (direct costs), however, it does not adequately reflect the value of losses of biodiversity and ecosystem services, as some of the values associated with these are challenging to express in monetary terms.

In **Canada**, economic losses to fisheries, agriculture and forestry production as a result of ten IAS were estimated using available literature on indirect and direct costs (including costs of control, reduced yield, reduced land value, trade bans on exported goods, compensation paid to farmers, health care costs, and reduced tourism and tourism-related revenues. Where this data was unavailable for certain regions, but the distribution of the species was known, an extrapolation was completed to estimate national costs. The value of the resource or industry was also considered in the calculations. Characterised costs amounted to CDN$187 million per annum. In addition to this, due to a lack of comprehensive, nationwide data, a simple empirical model was constructed to estimate the effects of sixteen IAS on annual production, excluding non-market values. The estimated losses in fisheries, agriculture and forestry production as a result of IAS were estimated to be CDN$ 13.3 – 34.5 billion (Colautti *et al.* 2006).

Williams *et al.* (2010) conducted a comprehensive analysis of the economic cost of IAS on **Great Britain** based on a detailed questionnaire sent to key organisations as well as existing published, unpublished and internet-based data. They estimated a total annual direct economic cost of £1,291 million, £245 million and £125 million to England, Scotland and Wales respectively, with an overall total direct cost of approximately £1.7 billion. Their estimates explicitly include some estimates on control costs.

Other national scale studies include studies on China, Germany and Sweden. The 283 invasive alien species in **China** were estimated to incur direct costs totalling $2397.39 million (2000 value). The total economic impact, including indirect losses, was estimated to be $14.45 billion (2000 value), some five times the direct loss, and 1.9% of GDP (Xu *et al.* 2006). Their study aggregated impacts at an industry level rather than at an IAS level (or IAS group) making their estimates difficult to compare with others. Nevertheless they noted that while the costs to China were only a ninth of those in the United States, they were a similar proportion of GDP. Gren *et al.* (2009) estimated the total costs (impacts and control) of 13 different IAS in **Sweden** to be between 1620 and 5081 millions of SEK, commenting that the most reliable estimates related to human and animal health impacts, with the costs of impacts on biodiversity being least reliable. Rheinhardt *et al.* (2009) estimated the costs of controlling a variety of types of Ias in **Germany** to be in the order of €109-263 million (2009).

Most other studies have been more limited in scope (types of IAS or economic sectors considered) or geographic scale (subnational or project-level studies). For example, Leavold *et al.* (2007a,b) estimated the costs of two species of IAS in multiple African countries. The majority of studies describe the impacts of a particular species in a particular area (e.g. de Groot *et al.* 2003).

In addition to studies on the impacts of IAS, numerous studies, mostly in the grey literature, describe management of particular species in particular areas, and discuss the costs of management, with a view to achieving efficiency in control methods. There have also been a number of studies incorporating estimates of both impacts and control costs to inform cost-benefit analyses of particular control programmes, as well as retrospective analyses to inform future strategy (e.g. Wise *et al.* 2007, van Wilgen *et al.* 2012).

The estimates collated in this study yielded partial estimates of control costs for 55 countries, but only 12 countries had estimates that were considered reasonably complete (Table 2). There is enormous variation in these estimates, as could be expected given the variety of ways in which they have been derived. Very little pattern could be found in the total estimates for these countries. Total cost was not related to country size, GDP or other country statistics relating to trade. The best relationship that we could find was with the number of alien species per country ($y=119.73e^{0.0082x}$, $R^2=0.42$, n=12).

Table 3. Estimated annual costs required for controlling IAS in 12 countries (US$ millions)

Country Name	Australia	Brazil	Canada	China	Germany	India	Namibia	New Zealand	South Africa	Sweden	United Kingdom	United States
Aquatic weeds								5.1	1.8	7.3	57.4	100.0
Woody invasive plants	1.2		0.2		67.5		89.4	3.0	215.4		1.7	49.5
Agricultural weeds	3 605.0	1 700.0	1 196.8		203.3	3 872.0		16.2	1 190.0	7.2	182.0	8 000.0
Large mammals	14.9										5.5	80.5
Small mammals	76.4				44.0			7.1		70.6	84.2	3 667.0
Birds	20.0								0.5		120.9	190.0
Reptiles and amphibians	0.6				0.7							11.0
Freshwater animals	2.1		748.2						1.0	6.4	48.1	950.0
Ants & termites												400.0
Crop & livestock pests	94.0	850.0	1 123.2		114.1	1 680.0		53.0	100.0	35.9	96.0	1 390.0
Forest pests			1 604.7					18.2			0.6	221.0
Marine algae												
Marine invertebrates			103.5					1.2		42.4	1.3	24.9
TOTAL	**4 329.0**	**2 550.0**	**4 776.5**	**257.2**	**429.6**	**5 552.0**	**89.4**	**103.7**	**572.7**	**169.9**	**597.6**	**15 083.9**

Based on the data collated from a number of studies, the average control costs per unit area could also be estimated for each type of IAS at a national scale. Costs were highest for woody invasive plants, agricultural weeds and agricultural insect pests (Table 2). These were also the groups for which most data were available, probably as a result of the high stakes and costs involved as well as the extensiveness of these problems.

Based on the relationship between cost and numbers of IAS per country, the total annual cost required for the control of IAS on mainland areas could be estimated to be in the order of $54,258 million. If the mean cost per IAS group is used to estimate overall costs, then a very estimate of $54 415 million is derived.

Table 4. Minimum, maximum and mean control costs for each type of IAS, per km^2 at a national scale.

Type of IAS	n	Min	Max	Geometric mean
Aquatic weeds	9	0.1	237.2	37.8
Woody invasive plants	37	0.2	2641.4	137.5
Agricultural weeds	20	1.4	979.9	51.2
Large mammals	3	1.9	22.6	7.3
Small mammals	9	1.7	347.9	18.0
Birds	4	0.4	499.8	6.2
Reptiles and amphibians	4	0.2	2.5	0.9
Freshwater animals	7	0.3	198.8	10.1
Ants & termites	1	43.7	43.7	43.7
Crop & livestock insect and snail pests	13	1.5	565.5	49.2
Forest insect pests	5	2.4	176.5	21.1
Marine algae	1	32.8	32.8	32.8
Marine invertebrates	6	0.2	13.4	3.6

8 Costs of eradication on small islands[1]

Islands represent both a unique conservation need and opportunity. Islands represent less than 5% of the earth's land area yet harbor 80% of known species extinctions since 1600 and 40% of today's IUCN Critically Endangered species (IUCN 2011, Ricketts *et al.* 2005). Invasive alien vertebrates (IAV) are implicated in the majority of insular extinctions and remain a key risk to today's threatened species. (Alcover *et al.* 1998, Atkinson 1989, Blackburn *et al.* 2004, Clavero and Garcia Berthou 2005). Eradication of IAV from islands has proven an effective conservation tool, resulting in remarkable recoveries of endangered species and threatened island ecosystems (Aguirre-Muñoz *et al.* 2008, Campbell and Donlan 2005, Howald *et al.* 2007, Nogales *et al.* 2004, Veitch and Clout 2002). Over 1,100 successful IAV eradications have been implemented on islands worldwide, with

[1] This section is based on work in progress by Brad Keitt and Nick Holmes of Island Conservation.

practitioners are undertaking removals from increasingly larger, more remote, and more technically challenging islands each year (Howald *et al.* 2010, Keitt *et al.* 2011, Phillips 2010).

The Invasive Vertebrate Eradication Costing Model was developed using known costs associated with planning and implementing 37 successful vertebrate eradications on islands ranging from 6 hectares to over 400,000 hectares (Isabela Island, Galapagos goat eradication). These projects were grouped as rodent projects of less than 50 hectares (includes rabbits and mustelids), rodent projects of greater than 50 hectares (includes rabbits and mustelids), ungulate projects and predator projects. Rodent projects of less than 50 hectares were assigned a flat cost assuming the implementation would involve a bait station or hand broadcast of rodenticide. For rodent projects above 50 hectares it was assumed the project would involve helicopter broadcast of rodenticide.

Costs were separated into five different categories: implementation, planning, non-target mitigation, additional costs associated with human inhabited islands, and isolation. We divided the costs into these categories so that we could assess costs of these aspects of the projects separately, but also because not all project report the full costs of implementing a project. By separating out the implementation costs we were able to more accurately reflect actual implementation costs and maximize the sample size. Thus, the model estimates implementation cost for each eradication project. Additional costs are estimated as a percent of the implementation costs. Planning costs were estimated to be 50% of the implementation cost of a rodent project and 10% for ungulate and predator projects. The increased cost for rodent projects reflects the increased up-front work needed to plan for success on rodent projects. Ungulate and predator projects allow for adaptive management during implementation and thus do not require as much up front planning. Planning costs were added to all islands. Non-target mitigation costs were assumed to be 15% of the project implementation costs for rodent projects and 5% for ungulate and predator projects. The higher cost for rodent projects reflects that the currently available tool for rodent eradications, use of rodenticide, has a higher potential for non-target impacts and mitigating them tends to be more costly than for other types of projects. Non target mitigation costs were added to all islands.

To address the costs associated with implementing vertebrate eradications on islands with human populations, 100% of implementation costs for rodent projects and 10% of implementation costs for ungulate and predator projects were added. The high cost for rodent projects reflects the increased effort associated with engaging island residents and addressing their concerns related to the use of a rodenticide on their island. Human costs were added only to islands with known human populations.

Isolation costs (distance of island to nearest port) are known to be a factor in budgeting invasive vertebrate eradication projects. However, isolation has not been determined in the Threatened Biodiversity Database, and existing information on costs suggests that isolation might only add about 5% to costs. Thus these costs were not included in the model.

Using the parameters described above, 496 islands were identified, representing breeding habitat for 210 species. This represents 38% of islands holding CR or EN species, and would provide protection for 19% of insular CR and EN species. These islands occurred within 68 ISO Country codes (including countries and external territories such as French Polynesia). The total cost of removing invasive alien vertebrates from these islands was estimated to be **approximately $1 389 million**, which if spread over the period from now to 2020 would require an outlay of *at least* $174 million per annum (assuming delays will incur additional costs). A breakdown of the costs for the top 20 countries is shown in Table 2. If the eradication expenditure is taken as an up front cost, it is assumed that future expenses will be limited to far less costly monitoring and preventative actions.

Table 5. A breakdown of total cost, number of species, number of islands and total area treated for the top 20 countries with the highest number of threatened species is in table 1

ISO Code	Number of threatened species	Number of Islands	Total area of islands (km^2)	Estimated cost (US$)
ID	15	24	1907.97	135 436 513
PH	14	17	575.10	76 774 094
MX	13	12	692.68	56 921 556
NZ	12	9	1214.70	85 156 020
AU	11	17	1192.66	116 814 140
PF	11	19	512.72	83 969 466
JP	10	29	148.09	38 051 999
SC	10	5	25.14	6 868 476
BS	9	22	486.09	54 897 338
US	9	18	948.24	79 325 896
MP	8	9	176.85	27 265 486
IN	6	15	997.33	90 178 675
SH	6	2	180.51	22 101 733
CL	5	5	163.64	25 378 388
PR	5	2	58.21	7 055 892
EC	4	3	185.32	27 194 795
ES	4	32	39.05	15 921 347
FJ	4	16	291.44	41 808 496
MG	4	13	62.07	12 514 177
TF	4	3	73.15	12 209 101

9 Costs of prevention/invasion pathway management

9.1 Government expenditure on biosecurity

The governments of Great Britain, Australia, New Zealand and the United States have completed nationwide studies addressing the biosecurity costs incurred in dealing with IAS and have published their biosecurity budgets. Other countries, such as South Africa, have budgeted for some biosecurity measures, with most of the current emphasis being on protection of agriculture, forestry and fisheries.

In **Great Britain** (includes England, Scotland, Wales in this analysis) the government spends some GBP17.766 million per annum (equivalent to US$30 million in 2012) on quarantine & surveillance (Williams *et al.* 2010). These costs are covered primarily by the Department of Forestry and Rural Affairs (DEFRA) (GBP15.821 million) but also the Forestry Commission (GBP1.945 million). These agencies focus on animal and plant pests. The costs associated with organisms imported for research purposes are excluded from this, as these are incurred privately, by the person or organization responsible.

The government of **Australia** has invested more than AU$1.6 billion since 2009 towards a reliable biosecurity system (Department of Agriculture, Forestry and Fisheries, 2012). This allows for continued protection of human health and biodiversity, while minimizing trade restrictions on exports. In particular, the budget for the period 2012-2013 amounted to AU$542.2 million. This included AU$379.9 million over seven years to construct a new quarantine facility for high risk imports, AU$124.5 million towards biosecurity operation at airports and mail centres nationwide and the supporting personnel and AU$19.8 million over three years to support information and communication technology systems. This annual budget is equivalent to some US$95 million.

In **New Zealand**, the Ministry of Primary Industries is responsible for biosecurity, for which a budget of NZ$136.505 million (US$ 108 million) was allocated for 2012-2013. This included the following components: Border Biosecurity Monitoring and Clearance (i.e. managing the biosecurity risk associated with international trade and travel); Border Biosecurity Systems Development and Maintenance (the development and maintenance of standards and systems that manage biosecurity risk associated with imports and exports); Implementation and development of Biosecurity Policy Advice and Domestic Biosecurity Surveillance (NZ MPI 2012).

In the **United States**, the National Invasive Species Council summarized the funding made available from several government departments (including the Department of the Interior, Department of Agriculture, Department of Commerce, Department of State Department of Defense, Department of Homeland Security, Department of Transportation and the U.S. Agency for International Development) for the Fiscal year of 2012, a total of US$338 million on IAS prevention measures, of which US$95 million was for education and public awareness and US$62 million was for leadership and international co-operation.

In **South Africa**, the South African National Biodiversity Institute (SANBI) runs government funded programmes into IAS prevention (including surveillance, the development of a DNA Bar-coding system to identify and verify the presence of IAS and an advocacy and awareness programme). The annual budget for prevention in 2012-2013 was estimated at ZAR17.4 million (US$2 million).

There were too few data to find any statistical trends in the national-level expenditure on biosecurity. One could expect the required expenditure on biosecurity to be a function of the numbers of points of entry, the volumes or values of freight or the numbers of passengers passing though these points. The value of imports is closely correlated to the value of GDP, and in fact the above figures correspond more closely to GDP than other statistics, mainly due to the high expenditure by the US. However as a percentage of GDP, expenditure by the US and UK are relatively modest (0.001-2% of GDP) compared with that of Australia (0.007%) and particularly New Zealand (0.076%). South Africa's expenditure is much lower than the others and current expenditure by most other developing countries is likely to be even lower as a % of GDP. While the % of GDP spent on biosecurity could be expected to be related to proportion of GDP spent on imports, this is not the case in this small sample. While expenditure in our small sample was somewhat related to import expenditure (an indicator of level of potential new introductions; $y = 0.0001x + 30.565$, $R^2 = 0.7557$), it turned out to be more strongly related to the number of the worst 100 invaders recorded in the country (an indicator of past invasions; $y = 6.2179x – 12.246$, $R^2 = 0.9395$) and the total number of IAS recorded ($y = 0.0017x^2 – 0.5066x + 55.499$, $R^2 = 0.9356$). Using import expenditure as a basis for estimation, biosecurity expenditures would need to be in the order of $8,500 million annually. Using existing number of IAS as an assumed correlate of future threat, then the estimate is $7,677 million – slightly more conservative, but in a similar order of magnitude.

9.2 Private sector costs

Prevention costs are transferred to the private sector by means of legislation concerning imports and safety precautions that have to be taken in transportation, and these costs can be substantial. In **New Zealand**, defensive expenditure by the private sector (including primary sector spending and annual household expenditure) was estimated to be in the order of US$475.6 million (2012 value; Nimmo-Bell 2009), which is more than four time government expenditure.

In **Great Britain**, commercial shipping vessels have various legal requirements they must comply with regarding maintenance of the hull. Ferries are required to dry dock annually for a hull inspection and clean while tankers dry dock every three to five years. These cleans are required for safety reasons and also to rid the vessels of biofouling, a known vector for marine IAS (Eno 1996, Gollasch 2002, Drake & Lodge 2007). The annual cost of these measures is estimated to be US$31.4 million (2012 value; Williams *et al.* 2010).

International legislation will soon require a substantial increase in the private expenditure required to combat the transfer of IAS by the discharge of ballast water transported by ocean-going commercial vessels. In 2004, the International Maritime Organisation (IMO) adopted the **International Convention for the Control and Management of Ships Ballast Water & Sediments (BWM Convention).** The BWM Convention is not yet in force. The Convention, adopted on the 13th of February 2004 by IMO member states, will enter into force 12 months after ratification by 30 States, representing 35% of world merchant shipping tonnage. As of the 31st May 2012, there were 35 countries bound by the treaty, but representing only 28% of the worlds shipping tonnage. Therefore, this convention will not be enforced until the support is more representative of the major powers in the shipping industry. When the BWM Convention comes into force, it will require that on-board ballast water treatment systems are fitted to vessels. The technology will cost private companies between $425,000 for a 200 m^3/hr plant and $979,000 for a 2000 m^3/hr plant (2012 values, based on Williams *et al.* 2010). Any ocean-going cargo vessel built before 2009 must be retrofitted with a ballast water treatment system by 2014/2016 (depending on vessel size). In 2011, the world's cargo carrying fleet was estimated at 55,138 ships of 991 billion Gross Tonnage and 1, 483 billion Dry Weight (Maritime Knowledge Centre 2012). Thus the total cost for the existing global fleet (all vessels built before 2009) to be fitted with systems could be in the range of $23,433.7 to $53,980.1 million. In addition, based on an estimate of 3445 new merchant ships built per year (Williams *et al.* 2010), this will require additional capital expenditure by shipping companies of between US$1,464.1 and US$3,372.6 million per annum. The ballast water discharge systems will also incur annual operating costs, which, depending on the type and size of system installed on the vessel, will range from US$0.009 – 0.296 million per vessel (King *et al.* 2010). Based on the current fleet size alone, this would incur costs of some US$496 – 16,320 million.

9.3 Building capacity and legal frameworks

There have been several internationally-funded efforts recently to help developing countries to build their capacity in order to carry out effective biosecurity programmes. For example, the Global Invasive Species Programme (GISP) spent an average of $50 000 on legislative projects in each of Kenya, Senegal, Uganda, Mozambique. These were funded primarily by the World Bank BNPP, but also UNEP-Regional Seas. The projects entailed the building of legal and institutional capacity, the development of legal and institutional frameworks for IAS (with workshops related to this in developing countries) and the development of marine biofouling guidelines. Along with co-financing from government, the GEF partially funded several IAS projects in developing countries which enabled a baseline level of management to be established. In **Sri Lanka**, US$5.6 million was made available to strengthen capacity to control the introduction and spread of alien invasive species. In **Cameroon**, US$11.75 million was set aside for the development and institution of a National Monitoring and Control System (Framework) for Living Modified Organisms (LMOs) and Invasive Alien Species (IAS). **Cuba** developed a five year programme with budget of US$15.7 million to enhance the Prevention, Control and Management of Invasive Alien Species in Vulnerable Ecosystems. A multi-national four year project which aimed to remove barriers to invasive species management in production and protection forests in **Indonesia, Vietnam, Philippines** and **Cambodia** had an average budget of US$1.8 million per country. The overall average expenditure on building capacity in developing countries was $8.7 million per country, which could be extrapolated to a global cost of $1255.

The Global Ballast Water Management Programme (GloBallast) funded by GEF/UNDP/IMO is assisting developing countries to reduce the transfer of harmful aquatic organisms and pathogens in ships' ballast water, implement the IMO ballast water guidelines and prepare for the new IMO ballast water convention. Six developing countries (**Brazil, China, India, Iran, South Africa** and **Ukraine**) were selected to pilot this project which was initiated in 2000 and the final phase is expected to be completed in 2014 with a projected total cost of US$44.3 million (in 2012 values) for the six countries, equating to US$7.4 million per country on average. Based on 144 developing (low and middle income) countries (World Bank Database 2012), the global cost of undertaking similar work to establish a marine baseline could therefore be in the order of $1,000 million. Such interventions are also required for terrestrial systems and likely to be even more costly.

10 Summary of global estimates

A summary of the above estimates is presented in Table 6. An estimated total initial investment of some $75,000 million is required for enabling effective prevention systems and eradicating IAS in situations where this is possible (i.e. mainly from small islands). About half of this cost is to be borne by the private sector in the form of installing ballast water treatment systems. Recurrent expenditures for prevention are approximately $19,000 million, with just more than half of this is borne by the transport industry. Estimated recurrent expenditures for the control and eradication of IAS during the period up to 2020 are expected to be far higher, at over $54,000 million. These are the estimated costs to reach the Aichi Target 9 by 2020, to achieve a measurable reduction in the prevalence of and damage caused by IAS. Our estimates are incomplete in that not all costs have been fully taken into account. But on the other hand, a significant increase in global-efforts can also be expected to lead to increased efficiency and the reduced threats generally, thus potentially reducing the expenditures required over time. Furthermore, assuming that these programmes are efficient and effective, the prevention and control actions carried out during this period should lead to a reduction in recurrent expenditures in future periods.

Table 6. Summary of estimated costs of control, eradication and prevention measures

Measures	**Basis for estimate**	**Initial investment ($ millions)**	**Recurrent expenditures ($ millions)**
Control of mainland IAS (including marine, terrestrial and freshwater IAS)	Median control costs for 14 groups of Ias, and total control costs of 12 countries in relation to numbers of IAS		$54,300
Eradication of priority IAS on small islands	Costs of former eradications, related to island size and adjusted for other parameters	$1 389	
Subtotal control and eradication		**$1 389**	**$54 300**
Developing capacity and legal frameworks	Expenditure by GISP	$8	
Government biosecurity measures (quarantine & surveillance, rapid response systems, public awareness)	Annual expenditure by a few developed countries in relation to import value and number of alien species; initial costs based on Australia initial investments relative to ongoing costs.	$32,356	$8089 ($7,677 -$8,500)
Baseline biological surveys	Expenditure on marine surveys in a few developing countries	$3,000	
Ballast water treatment systems fitment and operating costs	Installation and operating costs for the fleet; recurrent costs include annual fitting of new ships	$38 707 ($23,434 -53,980)	$10,827 ($1960 – 19,693)
Commercial vessel hull maintenance			$31.4
Subtotal prevention		**$74,071**	**$18,947**
TOTAL		**$75,460**	**$73,421**

11 Discussion

Along with the growing interest and awareness in the economic value of biodiversity and ecosystem services during the last two decades, so too has there been a growing interest in the costs of environmental degradation as a result of a range of threats, one of which is IAS. Thus much of the initial focus on economic aspects of IAS has concentrated on valuing the losses in production as a result of IAS. In particular, interest has centred on the IAS that impact on production in the primary sectors - agriculture, forestry and fisheries, species that affect human health, and those that incur significant management costs, such as the clearing of water intake pipes fouled by invasive mussels. Those whose main impact is on biodiversity have received less attention, with the exception of IAS on small islands. Different studies estimating the economic impacts of IAS use a variety of approaches, and whether a study includes non-market impacts has a significant bearing on value estimates (Williams *et al.* 2010). Compounding the matter is the fact that not all studies provide descriptions of what types of costs were considered or how the estimates were derived, and there is a need for standardisation of these estimates (Simberloff 2004). Nevertheless, since non-market costs are difficult to estimate, most estimates tend not to include these. Similarly, studies vary in whether they describe direct impacts on economic output or total economic impacts which include multiplier effects. Obtaining data on government expenditure on dealing with IAS (and other environmental problems) is one of the more challenging aspects of this research. This should also be addressed in the way in which information is presented in the National Biodiversity Strategy and Action Plans, which are mostly given in terms that are too vague to be useful. Thus achieving an estimate of global damages is fraught with difficulty, and estimation of prevention and control costs is equally tricky.

We have presented a rapid estimate of the global cost of achieving a significant target in the reduction of IAS. The estimate is based on crude estimates and assumptions, which are not statistically robust. In an analysis of the estimates of costs of IAS from 16 countries (many of these partial estimates), Williams *et al.* (2010) failed to find any consistent trends in terms of factors such as country size and GDP influencing overall costs. The estimates used in the study were more comparable in terms of the types of IAS considered and the level of coverage for each country, but the relationships were still weak in the case of control costs. An exception was that in the case of estimating the cost of eradication of IAS on small islands, data have been collected in a more standardised way, so that a more robust model could be developed from which to future costs. Estimating the cost of dealing with IAS is also a dynamic problem, in that actions in any given year will affect costs in subsequent years. These dynamics are driven by the biology of the IAS themselves, which vary considerably between species. Without incorporating such dynamics into the analysis, our estimates remain crude, but are likely to be in the right order of magnitude for the period under consideration. Our estimate is a preliminary first estimate, and much more could be done with existing information given sufficient time, with the combination of geographic information systems and bio-economic modelling. The quality of information produced from several years of research on IAS in the UK, as well as the recent assessment of the national value of ecosystem services in the UK, is testament to the value of investing in this kind of research. Future research should concentrate on producing more detailed estimates of damage costs and the prevention and control costs required for a larger sample of countries.

Taking indirect impacts (multiplier effects) into account, the cost of damage caused by invasive species has been estimated as being about 5% of global GDP (Pimental 2001), which equates to some US$6.5 trillion per annum. A more conservative estimate of damages of about 1.5% of GDP (e.g. based on Xu *et al.* 2006) would equate to about US$2 trillion. The recurrent expenditure of $73,000 million estimated in this study is equivalent to less than 4% of the more conservative estimate of damage costs.

Is this level of investment justified? Certainly in the case of small islands, up-front investment in the form of eradication is justified in that it obviates future costs and timely and complete action will make a critical difference to endangered species. For mainland infestations, control will only be achieved if enough resources are devoted to the problem. Alternatively it might be necessary to focus on priority species and priority areas in order to be more manageable (van Wilgen *et al.* 2012). Insufficient, unfocussed expenditure will be money wasted. There is considerable evidence from both models and empirical data of the cost savings achieved by early action. An analysis of five IAS in Great Britain (Asian long-horned beetle, carpet sea squirt, water primrose, grey squirrel and coypu) showed that costs of control increase exponentially as an invasion progresses, demonstrating that early intervention is worthwhile (Williams *et al.* 2010). Thus, as with any form of restoration or mitigation expenditure, the expectation is that heavy investment in this period will pay off in future periods in terms of damage costs avoided. From an economic perspective, the level of investment required in each period is an optimisation problem which should take the rate of time preference into consideration through discounting costs and benefits in future time periods (Turpie *et al.* 2004). If studies continue to focus on the impacts of IAS on economic sectors such as agriculture, then such an analysis might not necessarily yield the level of control of all groups of IAS required by the Aichi Targets by 2020. However, better understanding of the losses of ecosystem services and their intangible and non-market values is likely to justify greater investment in some types of IAS that receive less attention. For example, Nunes *et al.* (2004) used stated preference methods to elicit public willingness to pay for a hypothetical marine protection programme on the North Holland coast which is subject to harmful algal blooms. These IAS affect marine health and recreational activities on beaches, to an extent that beaches are often closed to members of the public. The public's willingness to pay justified an expenditure of €225-326 million on the installation of a local ballast water disposal facility.

Even with sound economic justification, meeting this target will require significant financial resource that might be difficult to access in some situations. (still to complete) Funding opportunities – brief overview of protential sources, including innovative financing, opportunities for funding from wider programmes, examples, short case studies.

12 Acknowledgements

Still to write

13 Bibliography

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