UFZ-Discussion Papers

Department of
Economics, Sociology and Law (OEKUS)

7/2004

Economic evaluation of biological invasions – a survey

Wanda Born, Felix Rauschmayer, Ingo Bräuer *

July 2004

* UFZ Centre for Environmental Research Leipzig-Halle GmbH,
Permoserstr. 15, 04318 Leipzig, Germany

Email: Wanda.Born@ufz.de

Economic evaluation of biological invasions – a survey

Born, W.[1], Rauschmayer F. and Bräuer, I., Department of Economics, Sociology and Law, UFZ – Centre for Environmental Research Leipzig-Halle, Germany

Abstract

Invasive species are one of the main reasons for the loss of biodiversity. Therefore, national strategies are developed to deal with biological invasions. Economic evaluation as a tool of policy advice has to take into account three challenges: (1) reflecting ecological knowledge, which is characterised by high uncertainty, (2) taking into account the political framework shaped by the Convention on Biological Diversity (CBD), and (3) being methodologically sound, e.g. considering all types of values and avoiding general flaws.

In this paper we survey and critically analyse economic studies on biological invasions. We test with an evaluation grid whether the studies meet the challenges. We analysed 23 studies generally and 10 in more detail in order to assess their suitability as a policy advice and their methodical quality.

As a result we note three main gaps: (1) current studies mostly have methodological shortcomings compared to their theoretical basis; (2) they do not take into account the politically formulated needs of the CBD; and (3) they hardly reflect the high degree of uncertainty associated with biological invasions.

Key words: Biological invasions, economic evaluation, policy advice, Convention on Biological Diversity

[1] Corresponding author: Wanda.Born@ufz.de, tel: +49.341.235.2330; fax: +49.341.235.2825

1 Introduction

Since the UN Summit in Rio de Janeiro, 1992, invasive species have come to be regarded as one of the main reasons for the loss of biodiversity (Keane and Crawley, 2002;OECD, 96). According to the Convention on Biodiversity (CBD), an "invasive alien species refers to an alien species[2] whose introduction and spread threatens ecosystems, habitats or species with socio-cultural, economic and/or environmental harm, and/or harm to human health" (COP, 2002)[3]. Apart from the ecological difficulties in explaining when and why species become invasive, growing concern surrounds the socioeconomic aspects of the issue.

Although human activities are the main cause of biological invasions, humans also experience negative impacts of these invasions. Anthropogenic land-use change breaks natural barrier zones and advantage increasing dispersion rates of invasive species (Naylor, 2000). On the other hand, biological invasions have strong implications for human welfare. Considerable crop production losses due to non-native weeds have a direct economic impact, such as reduced income in the agricultural sector (Tisdell, 1990). The loss of non-native species may also result in decreasing water supply and biodiversity, and implies indirect economic impacts (Wit et al., 2001). In several countries, the costs caused by biological invasions are enormous. In New Zealand, for instance, the costs of invasive species' impacts are estimated to amount to about 1% of GDP (Bertram, 1999). However, some species also create benefits: *Acacia* species in South Africa generate income through use as timber and firewood, while secondary industries involving for example the employment of people on eradication programmes pose a considerable local income source (Turpie and Heydenrych, 2000; Wit et al., 2001).

Economic analyses of invasive species have the potential to aid decisions on the allocation of scarce financial resources. Studies of costs and benefits can identify what measures concerning invasive species should be undertaken by evaluating both the impacts of biological invasions and measures designed to counter them. The aim of these studies is to assess all the relevant impacts in monetary units, hence representing the complex multidimensionality of the impacts on a one-dimensional scale. A wide range of studies addresses the economic dimension of biological invasions, each using a different focus,

[2] that is “a species, subspecies or lower taxon occurring outside of its natural range (past or present) and dispersal potential and includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce (COP, 2002).

[3] Whereas the scientific biological definition neglects the perspective of impacts and describes the "naturalisation and unintended spread of unwanted organisms in areas where they have not previously occurred naturally" (Jay et al., 2003, p. 121).

method and object of assessment. In this article we intend to bring these studies together and survey them under the central question: "To what extent are current economic evaluation studies suitable for policy advice?" In other words, do they provide appropriate information to aid actual policy processes? Are the numbers "hard enough" to be used as a decision aid? Do these studies aim to give a complete evaluation of all (relevant) impacts?

Since we place the emphasis on monetary analyses which consider costs and benefits closely together, our analysis can be attributed to the neo-classical branch of economic evaluation (Nunes and van den Bergh, 2001).

The objective of this paper is to analyse whether the studies undertaken so far are appropriate for aiding policy making. For that reason firstly we outline a framework for an economic analysis that comes up to a target state of sound economic analysis in the context of biological invasions[4]. Secondly we compare the studies with the framework as a reference system and illustrate the gaps. To answer our central question, we will:

(chapter 2) Illustrate and analyse the framework for economic analyses of invasive alien species (target state);
(chapter 3) Present and analyse selected cost-benefit studies (actual state);
(chapter 4) Discuss the extent to which these studies can contribute to decision-making about measures designed to counter biological invasions.

2 Framework for the economic evaluation of invasive alien species

The framework for the economic evaluation of studies intended to guide the selection of measures is mainly characterised by four constraints and should take them into account:

(i) The ecological knowledge base has to be reflected in the evaluation methods.
(ii) Analyses should take into account the political framework of this field constituted by the Convention on Biological Diversity.
(iii) The quality of an economic evaluation depends on the extend of inclusion of relevant consequences. The concept of the Total Economic Value will be used to estimate the extend of inclusion.

[4] Hence we define four major aspects and assume them as the minimal consensus of an integrated assessment in chapter 2.

(iv) Economic analyses aimed at societal decision-making have to correct biased market prices and internalise external effects.

2.1 Ecological knowledge base

The level of knowledge of the direct impacts of a biological invasion on an ecosystem depends on the step in the invasion process.[5] Before the introduction of a species, it is still fairly impossible to predict whether a species will become invasive or not (except for species already invasive elsewhere). Williamson (1999, p. 10) even states that "it could be that invasions are unpredictable in the way that earthquakes are". Once the invasion has been accomplished, its impacts are clearer, though; one is "only" confronted with the usual uncertainty about ecosystem processes. At the stages between introduction and full invasion, uncertainty prevails concerning what ecosystems will be invaded and what impacts an invasion will have within these ecosystems.

Hence, to specify the central question of our paper: *Do evaluation studies take explicit account of the high degree of uncertainty linked to biological invasions, especially at a prevention stage*?

2.2 Political framework and the measures demanded

National policies regarding nature conservation and the issue of biological invasions should be in line with international agreements. The appropriate political framework is constituted by the Convention on Biological Diversity (CBD). Article 8h stipulates: "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". Guiding Principle 2b recommends a three-stage hierarchical approach for the implementation of Art. 8h: (1) Prevention, (2) Eradication, (3) Control. Figure1 matches the invasion process with the recommended measures by the CBD. The clause on appropriateness in Art. 8h demands an integrated assessment and evaluation of the consequences of biological invasions and of measures selected to prevent the introduction, eradicate or control the alien species.

[5] Richardson et al. (2000) distinguish between four stages of the invasion process: (i) introduction, i.e. a plant or its propagule overcomes, through human agency, a major geographical barrier; (ii) establishment, i.e. many introduced individuals survive as casuals, reproducing sexually or vegetatively but failing to maintain or establish their populations over a long time period and hence relying on repeated introductions for their persistence; (iii) naturalisation, i.e. a plant overcomes geographical or environmental barriers and reproduction, i.e. it reproduces consistently; (iv) invasion, i.e. naturalised plants produce reproductive offspring, often in very large numbers at considerable distances away from parent plants.

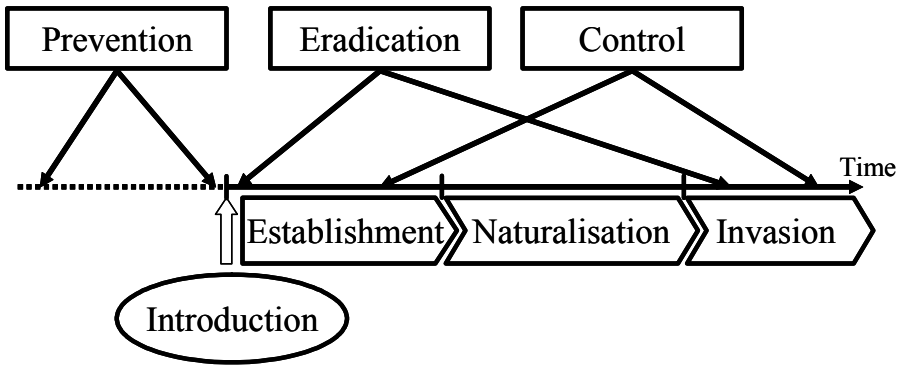

Figure 1: The invasion process in stages and respective measures recommended by the CBD (own source)

Economics provides one basis for policy-makers to decide whether a prevention, eradication or control measure is appropriate depending on its cost-benefit ratio. Prevention takes place even before initial introduction. Both eradication and control are applied after the introduction or secondary release. Measures of prevention, eradication and control can be all subsumed under “mitigation measures”. Mitigation has been defined by Perrings (2003) as measures "to reduce the likelihood of invasions by reducing the invasiveness of species or the invasability of ecosystems."[6]

Economic evaluation studies of mitigation measures and strategies that are meant to advise policy better link their study and their results to the political framework. Such a link, by referring to the hierarchical approach and to the clause of appropriateness in the CBD context, would allow policy makers to use the studies more directly.

Here, our question can be refined again: *Do studies of economic evaluation constitute an appropriate decision aid and to what extent do they consider the three-stage hierarchical approach*?

2.3 Frame of reference for an economic evaluation

First of all, each invasive species has an impact on ecological functions. The extent of this impact depends on site-specific conditions, i.e. the prevailing ecosystem and its set of native species, dispersal potentials and available resources. Dispersal potentials are characterised by

6 Another type of measure, which is not mentioned in the CBD, is adaptation, whose aim is "to reduce the impact of introduction, establishment or spread without changing the likelihood that it will occur" (Perrings, 2003). However, such measures have not yet really been evaluated, and we do not include them in our analysis.

"intrinsic traits" of, e.g., morphology and competition comportment in connection with other species as well as by "extrinsic traits", e.g. human land use promoting seed dispersal and discouraging predators (Curnutt, 2000). For biological invasions, White and Harris (2002, p. 115) describe five main categories of impacts.

Table 1: Main categories of impacts according to White and Harris (2002)

Consumption via predation or herbivory	Competition	Introduction and maintenance of disease	Inbreeding with native species or populations	Disturbance of the environment

Each category of impacts implies ecological effects that, in turn, have to be transformed into economic effects. One economic concept developed to analyse the full spectrum of values depending on the impacts on the natural environment is the concept of the Total Economic Value (TEV). Several value categories are added up in the TEV (see Figure 2), each value being quantified in terms of monetary values.[7] A main distinction is drawn between use and non-use values. Use values can be divided into direct-use and indirect-use values. Option values, i.e. values attributed to maintaining the option of using services of the ecosystem later, may be attributed to use values and/or to non–use values. Non-use values go beyond usage and beyond a restrained economic assessment. Nevertheless, their disappearance poses a utility loss to individuals.

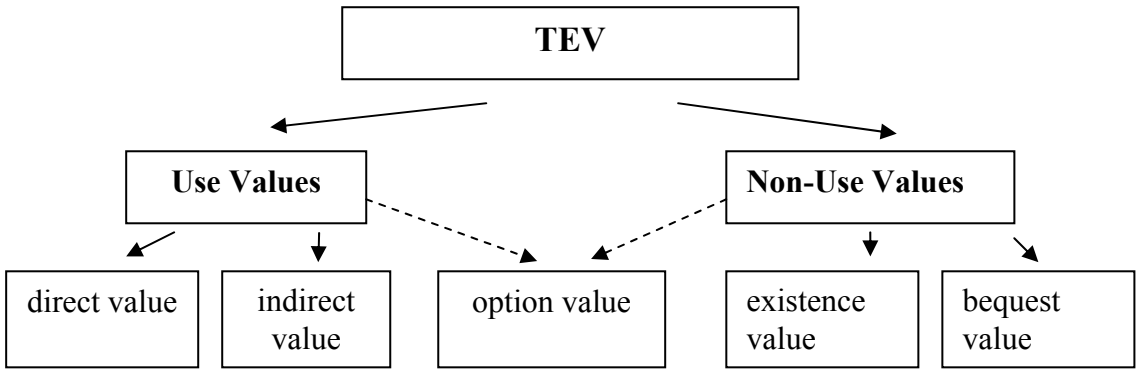

Figure 2: Components of the Total Economic Value, after (Pearce and Turner, 1990)

In respect of the concept of the TEV, impacts of biological invasions can be attributed to TEV categories.

[7] We refrain from entering into the comprehensive debate about the monetarisation of environmental goods and services. See on this for example (Munda, 1996; O´Connor, 2002; Turner et al., 2003).

An example is the Cape Floristic Region with its typical fynbos vegetation (Turpie et al., 2003), encompassing all value categories. Direct-use values, such as building materials and non-timber forest products, are affected by the invasive *Acacia* species that compete with native flora. Consumption via predation or herbivory leads to an alternation in species composition, which in turn might decrease indirect-use values of for example recreation. The option value of potential pharmaceutical components in the fynbos is mainly considered to be a use value. An example of non-use values might be the pure existence of the integer fynbos ecosystem and the possibility of bequeathing such an ecosystem to future generations.
However, clear boundaries have not yet been drawn clearly between the value types and an accurate assessment still implies several difficulties (Turner et al., 2003).
Even though this "taxonomy of environmental values is often criticised" (Turner et al., 2003, p. 2), mainly because intangible values outside an anthropocentric value system are neglected, we shall refer to this concept for the purposes of this review.

A biological invasion relates to all value categories. Therefore, we can refine our question thus: *Do evaluation studies of a biological invasion (and of the impacts of measures against it) take into account all relevant value categories of the TEV*?

2.4 Possible aims of evaluation studies

There are various ways in which economic evaluation studies can contribute to decision-making. An initial differentiation can be carried out depending on the level of analysis. Studies can provide advice on the business level ("which measure is profitable for my business?") or economically ("which measure has in social terms more benefits than costs?").

The assessment of costs and benefits on the business level means accounting for expenditures and earnings for the private sector, often for one single business, e.g. a farm.[8] Direct income effects are involved. For example, defensive costs arise through the spraying of pesticides and the release of biological control agents. It is appropriate to calculate both the costs and the benefits caused by the impacts of invasive species in terms of market prices. Only direct-use values are considered. However, the range of values affected by the issue of biological invasions is not taken into account by business data.

Biological invasions impose more than such direct costs and derogate social welfare through external effects. Thus, a second, broader level of impact assessment than mere business

[8] The analysis of such business data is sometimes known as “financial analysis”.

analysis needs to be found. The economic level provides such a basis for assessing societal costs and benefits. Economic analysis also considers external effects, which are a central characteristic of invasive species due to the public good nature of the invaded ecosystem and its multiple properties.

As we are concerned in this paper with nature conservation issues, it is reasonable that we focus on economic and not on business evaluation. This involves evaluating whether the completion of a specific measure is detrimental or positive for society – in other words: Is the benefit/cost ratio positive or not? Carrying out a measure with a positive benefit/cost ratio corresponds to a move towards more efficiency. Furthermore, different measures can be compared in order to rank them.[9]

Therefore, the last specification of our question is: *Do the evaluation studies reflect economic analysis methodologically by integrating external effects and using economically unbiased market prices*?

The next section, which gives an overview of existing studies, provides additional touchstones for the methodical rigour of economic environmental studies.

3 Survey of existing studies

The aim of this paper is to examine recent studies in terms of their suitability for nature conservation policy advice. The status quo analysis consists of two steps: (i) what are the general aims and potential fields of application of the existing studies and (ii) how is their methodical quality? We start by carrying out an analysis to obtain information about the types of measures and the stages of the process examined by economic studies of biological invasions (3.1). We then go into greater detail by analysing selected studies using a set of criteria expedient for the overall objective (3.2). Within the analyses we only consider studies with quantitative economic results relating (more or less) clearly to a spatial and temporal framework of analysis and which provide a basis for general cost-benefit reflections.

3.1 Overview of the literature

To obtain an initial overview, the available literature is surveyed in accordance with the measures demanded by the CBD. This shows the extent to which economic assessment

[9] The debate about the different ways of comparing different measures and the impact of distribution effects on comparison is outside the scope of this paper.

approaches meet the hierarchical approach demanded by the CBD. The survey distinguishes between the two general areas of application:

1. **Decision aid:** Economic assessment can serve as decision aid for policy advice in three different ways:
   (i) Evaluation of possible measures. This objective equates to an *ex-ante* assessment of different measures. It helps to prioritise the area where measures are urgently needed and to evaluate the likely cost-benefit ratio of a successful measure.
   (ii) Evaluation of implemented measures. The objective of this type of evaluation is to examine whether a measure proved efficient or not by measuring its *ex-post* cost-benefit ratio.
   (iii) Comparison of measures. This evaluation building on (i) and (ii) helps to identify the most cost-efficient strategy out of a set of alternative measures, e.g. mechanical, chemical or biological control mitigation strategies.

2. **Monetised impact assessment**. These studies just record monetised damages either as costs due to alternations regarding the categories of the TEV and/or costs of measures. The results can be used as an indicator for the overall impact of invasive species.

The introduction of the second category is necessary, because many studies do not comply with the three above mentioned classical economic procedures of decision aid. However, such figures can be regarded as a kind of impact assessment to decide where and whether any action should be considered (Bräuer, 2003).

Table 2 gives an overview of 23 current research studies of costs and benefits.[10] It contains information about the dispersal of the underlying economic field of application (decision aid or impact assessment) and the stage of evaluation (*ex-ante* or *ex-post*), and about the evaluated measure (prevention, eradication and control).

3.1.1 General character of the studies

The aim of the majority of the investigated studies was to serve as a decision aid in respect to different management strategies. While *ex-post* studies evaluate all three different management strategies or do a comparison of different strategies, *ex-ante* studies concentrate on control measures (see Table 2).

[10] The broad overview also entails ecological economic and bioeconomic studies and papers. We did not review all existing studies, instead focusing on studies with a rather scientific background, i.e. scientific books and peer-reviewed articles. Due to double mentioning of some studies in several categories, the total number of studies in Table 2 is 28.

Seven studies belong to the so called impact-assessment group and record costs of special invasive species. These studies assume a laissez-faire strategy (e.g. Turpie et al., 2003) and consider the costs of the impacts of biological invasions. Costs of biological invasions are not only estimated through production losses (e.g. in the field of agriculture Pimentel et al., 2001; Wilgen, 2001) but also by the costs of the applied mitigation strategies. Examples for the latter are Reinhardt et al. (2003) who assess the costs of *Ambrosia artemisiifolia* in terms of treatment expenditures of the induced allergic reactions and Pimentel et al. (2001) who equate the extra-costs for weed control of alien species with their general costs for society.

The majority of studies evaluating measures designed to counter biological invasions treat the avoided costs of impacts as benefits of mitigation measures. This procedure is methodologically questionable due to the fact that mitigation measures normally do not eliminate all impacts (see Chapter 3.2.4).

However often it is difficult to draw a firm boundary between studies aiming at policy advice or at impact assessment, since the initial intention of the considered papers is not clear to us.

3.1.2 Decision aid studies

Within the decision-aid studies we find examples for all three different possible objectives. Studies evaluating possible measures, i.e. *ex-ante*, largely employ ecological-economic models to provide different management regimes (Higgins et al., 1997; Higgins et al., 1996; Settle et al., 2002; Sharov and Liebhold, 1998). Economic-ecological models offer the advantage of pure economic evaluations without being restricted to the status quo. Expected developments can be outlined and included into the calculations (Barbier, 2001). This is essential when the appropriateness of mitigation strategies is discussed at an early stage of the invasion process. Settle et al. (2002) model feedback´s from the economic and ecological system. The interspecific interaction of an invasive and a native species is shaped, taking into account human intervention through use. A scenario approach is that taken by Wit et al. (2001) comparing two strategies: “do nothing” and “mitigation”. Reinhardt et al. (2003) and Cullen and Whitten (1995) evaluate different mitigation strategies. However, mitigation mostly refers to control strategies in all studies.

Studies evaluating measures already implemented (i.e. *ex-post*) constitute the vast majority of decision-aid studies. Quantifying the costs *ex-post* of, for instance, border control activities is possible by accounting for certain cost types, such as labour and material costs. For example,

Bertram (1999, p. 69) investigates New Zealand's measures of "pest surveillance & response, vector control, pest control and conservation, other biosecurity activities" from 1991 until 1999. (*Ex-post* studies are analysed in detail in 3.2).

In a review of efficiency of biological control measures, Cullen and Whitten (1995) report different studies which have done *ex-post* as well as *ex-ante* evaluations of biological control strategies. Aim of this report is to explore the benefits (potential as well as real) of research in the field of biological control.

Decision-aid objective 3, the possibility to ascertain the most efficient mitigation measure by comparing the efficiency of different options, has by now only been used *ex-post*. Three studies compare different strategies. A comparison of measures for an individual species is conducted by McConnachie et al. (2003), who compare a set of alternative control strategies (mechanical, chemical and biological control). Hill and Greathead (2000, p. 220) review several classical biological control programmes with the result that *ex-ante* studies would offer "better means of assessing the scope of problems associated with invasive species". Headrick and Goeden (2001, p. 249) provide two case studies of biological control and its general role to "have the best chance for success in ecosystem management" and its mutually compatible research goals.

To sum up: So far economic evaluations are rather used to legitimate measures already undertaken than to opt for and design new mitigation strategies.

3.1.3 Evaluated measures

The surveyed economic analyses focus mainly on control measures (18 studies), and here primarily on biological control[11]. On the one hand, this results from intensive agricultural and sylvicultural efforts in biological control. Due to its "sustainable and self-renewing nature", such measures use to turn out to be cost-effective and have been employed since 1888 (Hill and Greathead, 2000, p. 216). On the other hand, the invasion process explains why control measures are mostly applied: an invasive species only becomes apparent after its introduction and mainly when it is already dispersing invasively. Once the final invasion stage is reached, control strategies are often more reasonable than eradication. This can be explained by two

[11]Biological control is defined as "the purposeful introduction and permanent establishment of exotic natural enemies of pests and weeds, with a view to permanently suppressing their abundance within a prescribed region or country (Hill and Greathead, 2000, p. 208). Confusingly, several studies subsume control and eradication efforts under "management ". We differentiate between these two management options as far as possible, in line with the original papers.

reasons: (1) Eradicating a population is more expensive than mitigating and keeping the invasive population at an acceptable level (Sharov and Liebhold, 1998). (2) ecological studies indicate a high probability of eradication failure due to missed steps to reduce post-eradication susceptibility to re-invasion (Bertolino and Genovesi, 2003; Zavaleta et al., 2001).

Due to this, it is not astonishing that economic literature on eradication measures is limited to three studies. Anaman (1994) and Bertram (1999) make *ex-post* analyses of successful eradication measures. The former calculates the costs of a successful programme combating the screwworm fly in Australia with a dynamic bio-economic model; the latter subsumes and charges eradication costs under "management".

Even though prevention is the approach preferred by the CBD, it is economically investigated the least (one study). Only prevention activities of border control and quarantine in New Zealand are assessed *ex-post* and have been part of the national prevention program for years (Bertram, 1999).

Table 2: Economic Studies of biological invasions in terms of general aim, stage of evaluation and CBD measures

Aim		Study	Content	Evaluated measure*			
				Pre	Era	Con	Comp
Decision Aid	*Ex-ante*	Reinhardt et al., 2003 [1]	Economic impact assessment of 20 invasive species, Germany		x	x	
		Barbier, 2001	Bioeconomic model of interspecific competition between invaders and indigenous species			x	
		Cullen and Whitten, 1995[1]	C&B** of biocontrol, Australia			x	
		Higgins et al., 1996	Ecological economic model of fynbos ecosystem functions and management, South Africa			x	
		Higgins et al., 1997	Dynamic ecological economic model for conflict solution in invasive species management, South Africa			x	
		Sharov and Liebhold, 1998	Bioeconomic model of C&B** of invasive species' spread rates, USA			x	
		Settle et al., 2002	Dynamic model of interaction between exotic invaders (lake trout), native species (cut trout) and human use, USA			x	
		Wit et al., 2001	Economic scenarios of black wattle management, South Africa			x	
		Studies ∑ 8	**Records ∑**	**0**	**1**	**8**	**0**
	Ex-post	Bertram, 1999 [1]	Blueprint for action, impact assessment of pests, New Zealand	x	x	x	
		Anaman, 1994	Input-output analysis of secondary impacts of screwworm fly, Australia		x		
		Reinhardt et al., 2003[1]	Economic impact assessment of 20 invasive species, Germany		x	x	
		Cullen and Whitten, 1995[1]	C&B** of biocontrol, Australia			x	
		Le Maitre et al., 2002	Invasive alien trees and water resource management, C&B, South Africa			x	
		Odom et al., 2003	C&B of control strategies of Scotch broom, Australia			x	
		Tisdell, 1990	C&B** of invasive weeds, Australia			x	
		Wilgen, 2001[1]	Review of economic evaluation studies of invasive species, South Africa			x	
		White and Newton-Cross, 2000	Ecological and economic effects of rabbit calicivirus disease, Australia			x	
		Pimentel, David, 2002[1]	Economic evaluation of invasive species, Australia, Brazil, British Isles, India, New Zealand, South Africa, USA			x	
		Sharov and Liebhold, 1998[1]	Bioeconomic model of C&B** of invasive species' spread rates, USA			x	
		McConnachie et al., 2003	Economic evaluation of biocontrol of red water fern, South Africa			x	x
		Hill and Greathead, 2000 [1]	Economic evaluation of biocontrol strategies,			x	x
		Headrick and Goeden, 2001	C&B** of biocontrol, case studies, USA				x
		Studies ∑ 14	**Records ∑**	**1**	**3**	**12**	**3**
Impact Assessment		Kasulo, 2000	Impacts of invasive species on African lakes	-	-	-	-
		McNeely, 2001	General impact record of biological invasions	-	-	-	-
		Pimentel, David, 2001[1]	Economic evaluation of invasive species, Australia, Brazil, British Isles, India, New Zealand, South Africa, USA	-	-	-	-
		Reinhardt et al., 2003[1]	Economic impact assessment of 20 invasive species, Germany	-	-	-	-
		Turpie and Heydenrych, 2000	C&B** of invasive species' impacts on fynbos ecosystem, South Africa	-	-	-	-
		Turpie et al., 2003	C&B** of invasive species' impacts on fynbos ecosystem, South Africa	-	-	-	-
		Studies ∑ 6	**Records ∑**	-[2]	-[2]	-[2]	-[2]
		Total Studies ∑ 28	**Records ∑**	**1**	**4**	**20**	**3**

[1] Multi-species studies in which several studies/methods are integrated.

[2] Per definition are no measures evaluated.

(*Pre = prevention; Era = eradication; Con = control; Comp = comparison; **C&B = costs and benefits)

3.2 Detailed analysis of selected studies

As indicated above, the political framework is only one aspect of the suitability of economic analyses as a policy advice. Also important is their quality and hence the credibility of their results. In the following analysis, we focus on studies that quantify the costs and benefits of biological invasions in detail and that provide sufficient information. Out of the above described studies a set of ten meet these demands for a detailed survey. These studies are analysed using a set of 6 criteria: area of impact, economic sector, object and level of assessment, source of data, methods, total costs and inclusion of uncertainty. Each criterion is explained below. The full analysis is shown in Table 2.

3.2.1 Area of impact: region, invasive species and affected landscape

Study regions, the respective invasive species and the landscape affected illustrate the area of impacts. This information serves to provide details about site-specific conditions, the distribution of studies on invasive species, and about the influence invasive species have on continents, countries and ecosystems.

Concerning the distribution of studies, most research has been undertaken outside Europe. For the most part, economic studies are conducted in South Africa, America and Australia/New Zealand. Studies from Asia and South America are not included as relevant analyses are not available.[12]

3.2.2 Economic sectors

If economic analysis is to support decision-making, it is important to take into account the given political structures. As far as policy advice is concerned, it is therefore necessary to identify the sectors that have to be addressed. Regarding the constellation of actors, distinction is drawn between the following sectors: agriculture, fishery, forestry, health, nature conservation (= nature cons.), municipal, recreation.

[12] Owing to the lack of economic data on these countries, it cannot be concluded that biological invasions do not pose a problem on these continents (Marambe et al., 2001; Vitousek et al., 1996).

Studies focus on the analysis of impacts on the agricultural sector. Other land use sectors, such as forestry (7 times) and fishery (once) are also represented, as are the health (4) and municipal sectors (6). Surprisingly, impacts on nature that indirectly affect recreation and nature conservation are only considered once.

3.2.3 Object and level of assessment

The objects of assessment were explained in Chapter 2.2, where a distinction was drawn between strategies of prevention (**Pre**), eradication (**Era**), control (**Con**) and comparison of measures (**Comp**). Quantifications of monetised impacts and the measures employed are addressed as impact assessment (**ImpA**). The assessment level describes the geographical or political area for which figures are produced and the spatial framework of analysis. A distinction is drawn between the regional and national level.

Within the land use sectors described, as in Table 2, control strategies prevail again (70% of surveyed studies). Prevention strategies are assessed once, namely by Bertram (1999); a detailed analysis of eradication measures is not available. General records on the costs of the biological invasions are found in a third of all the studies examined.

Table 3: Detailed analysis of quantitative studies on the costs and benefits of biological invasions

	Source	Area of impact region/*IS* (Lscp)	Economic sector	Object/ Level of assessment	Method	Source of data			Total costs (B/C)	Including uncertainty
						Business analyses i) Direct C (B)	ii) Indirect C (B)	Economic analyses iii) C (B)		
1	Bertram, 1999	New Zealand weeds	Agriculture Fishery Forestry Health Nature cons.	Con, Pre Era/ National	i)-iii) prod.c, opp.c, CVM	C of production loss (NZ$400 million)	C for intermediate goods (NZ$ 220 million/year)	management (quarantine, biolog. control = NZ$151 million)	**NZ$ 840 million/year (=1%of GDP)**	Border control and quarantine as insurance payments
2	Turpie and Heydenrych, 2000	South Africa (Fynbos)	Agriculture Recreation Municipal	ImpA/ Regional	i) prod.c, opp.costs ii) opp.c iii) opp.c, CVM, lit.	C for harvest loss of: wild flowers - thatch - sour figs - tea - medicine - honey (= ∑ US$1–25/ha)	C of less: - water supply - (US$7-163/ha) - less pollination by fynbos bees - (US$8.3–114.6/ha)	C for loss of: -genetic resources (US$ 80-700 million) -existence value (1,35 US$/ha).	**US$65 million**	No explicit remarks
3	Wit et al., 2001	South Africa *Black wattle tree* (Fynbos)	Agriculture Forestry Municipal	Con (Biol. Control)/ National	i)-iii): opp.c, prod.c, lit	B of IS harvest (US$528 million)	C of increased fire hazards (US$1 million)	B of IS carbon sequestration (US$24) C of reduced surface stream flow (US$1425)	**US$ 552 million (2.6:1)**	Sensitivity analysis on key uncertainties
4	McConnachie et al., 2003	South Africa *Azolla filiculoides*	Agriculture Recreation Municipal	Comp (Biol. Control)/ National Comp.	i) prod.c	1. Control C: Herbicides, Labour (∑US$1308) 2. Biolog. control C: Salaries infrastructure, survey (∑ US$1511) 3. Damage C: Pumps, miscellaneous, livestock, alternative water facilities (∑US$7940)			**US$1511/ha (2.5:1)**	Sensitivity analysis

	Source	Area of impact region/*IS* (Lscp)	Economic sector	Object/ Level of assessment	Method	Source of data			Total costs (B/C)	Including uncertainty
						Business analyses **i) Direct C (B)**	**ii) Indirect C (B)**	**Economic analyses iii) C (B)**		
5	Wilgen, 2001	South Africa (Fynbos)	Agriculture Forestry Recreation	Con (Biol. Control)	Review with CBA approach			US$20 million labour costs counted as benefits	**Over US$11.75 billion**	No explicit remarks
6	Reinhardt et al., 2003	Germany 20 IS	Nature cons. Agriculture Forestry Health Municipal	ImpA, Era, Con,; (Biol. Control)/ National	i) – ii) prod.c, opp.c	C of: - measures against IS (labour, material) - economic damages (yield loss, infrastructure damage)	C of: - increased demand of sustaining infrastructure, medical treatment		**€160 million annually**	No explicit remarks
7	Cullen and Whitten, 1995	Australia *Rubus fructicosus, Echium plantaginetum*	Agriculture	Con (Biol. Control)/ National	i) prod.c, opp.c	C of: - production loss - control costs			**AS$07-2 million (20-42:1)**	Highest costs would be risk (= if control fails)
8	Tisdell, 1990	Australia Project 1*:* *4* weed *species* Project 2*:* *Echium* -species	Agriculture	Con (Biol. Control)/ National	i) prod.c, opp.c	C of: - reduced crop pollination - implementation costs - income loss by apiarists B of: - reduction of chem. control - increased wheat production (income) - increased livestock grazing			**Project 1: A$33 million (1.5:1)** **Project 2: A$17 million (8.7:1)**	No explicit remarks
9	Pimentel et al., 2002	USA 50,000 IS (incl. beneficial species)	Agriculture Forestry Health Municipal	ImpA/ National	i)-iii) lit	C of: - production loss - control	C of: - environmental damage - indirect damage		**US$137 billion/year**	No explicit remarks, several discount rates

	Source	Area of impact region/*IS* (Lscp)	Economic sector	Object/ Level of assessment	Method	Source of data			Total costs (B/C)	Including uncertainty
						Business analyses i) Direct C (B)	ii) Indirect C (B)	**Economic analyses** iii) C (B)		
10	Pimentel et al., 2001	World (UK, India, USA, South Africa, Brazil) 120,000 IS (incl. beneficial species)	Agriculture Forestry Health Municipal	ImpA; Comp/ Global .	i)-iii) lit	Production loss in: - crop: US$216.1 billion/year - pasture: US$7.5 billon/year - forest: US$4.2 billion/year Health: US$6984.7 million/year	C of: - environmental damage		**US$336 billion/year**	No explicit remarks, several discount rates

Used abbreviations

Area of impact	**Object of assessment**	**Method**	**Total costs**
Country, region (**region**) Harmful invasive species (**IS**) Affected landscape (**Lscp)**	Prevention (Pre) Eradication (Era) Control (Con) Comparison (Comp) Impact Assessment (ImpA)	Opportunity costs (opp.c) Production costs (prod.c) Contingent Valuation (CVM) Literature analysis (lit)	Benefit-Cost ratio (B/C)

Ad 1: Remarks on non-use values of populations, but no figures available due to lack of data. Intermediate goods comprise the purchase of livestock, feed and grazing, animal health.

Ad 2: Employment of the TEV concept. Indirect-use values are assessed by business data: the value of water is derived from municipal water supply costs, pollination values of fynbos vegetation from on gate farming prices for honey and trough less fruit and crop production. Estimations about the potential value of genetic resources vary from US$80 million to US$700 million. The aggregation to the total value of R455 million is unclear (R7 = US$1).

Ad 3: Analysis of 8 scenarios with different benefit-cost ratios. Ecological impacts are identified by a questionnaire survey. Impacts are evaluated via ordinal values without quantitative numbers. Benefits are: nitrogen fixation, possible medicinal use of astringents and styptics, combating erosion. Cost are: increased erosion after increased fire intensity, destabilisation of river banks, loss of recreational opportunities, aesthetic costs, nitrogen pollution, loss of grazing potential, loss of biodiversity. Fire hazards, water supply and carbon sequestration are quantified indirect values. The last two come from economic data. Fire hazards are evaluated in terms of increased fire management costs. No remarks on whether business or economic data are used.

Ad 4: 2 scenarios of costs. (1) current mechanical and chemical control costs of US$1308 and (2) biological control costs of US$1511 at 2000 prices. Biological control is supposed to be more cost-effective due to the extinction of *A. filicoides* populations plus damage costs are avoided. No remarks on whether damage costs occur with control to keep the status quo of invested areas, or whether damages are avoided by control. Miscellaneous costs mainly cover loss of property prices in housing estates bordering on infested water bodies. Costs refer to economic data with high standard deviation.

Ad 5: Stated costs of US$11.75 billion are not reproducible. The eradication programme "working for water" creates income in a region with high unemployment. Wit et al. account for this investment as a benefit of US$20 million. It is unclear whether the amount corresponds with a utility transfer for a programme financed by the government. Survey of economic consequences of South African invasive species infestation without detailed analysis of business and economic data.

Ad 6: Surveys of economic and ecological impacts and qualitative remarks on both. The need for willingness-to-pay studies is addressed. Health costs are economic costs.

Ad 7: Potential double-counting within analysis of 2 projects. Project 1: impacts of orchard mites, *Skeleton weed, Sirex* wasps and *Chondrilla juncea.* Project 2 depicts economic effects of *echium*-species.

Ad 8: Potential benefit-cost ratio analysis of *an ex-ante* scenario of preventive mitigation. No remarks on diminishing effects of control.

Ad 9: "Beneficial" species are agricultural crop species as well as domestic plants and animals. Figures based on 1975 prices, discount rate of 10%. Indirect damage one includes fouling damage caused by *dreissena polymorha*, outages by *Boiga irregularis*.

Ad 10: Quantification of environmental costs mainly match control costs. **"**Benfecicial species", see 9.

3.2.4 Methods

Monetary positive (benefits) and negative (costs) effects of impacts are assessed with different methods, and can be based on both business and economic data.

Opportunity costs (**opp.c**) illustrate the monetary value of a missed alternative use. Wit et al. (2001) measure the value of fresh water loss (indirect-use value) caused by invasive species via the value of alternatively produced crops. Production loss (direct-use value) is measured via forgone benefits in the agricultural or forestry sector.

The production costs (**prod.c**) approach is a method to "measure the effect of an environmental externality on production possibilities, often by measuring the expenditure which individuals are willing to undertake to avert damage" (Bertram 1999, p. 47). Production costs can also simply add up the direct (e.g. cost of labour, pesticides, machinery) and indirect (e.g. medical treatment) costs of measures. The Contingent Valuation Method (**CVM**) is the only method employed to assess relevant values of nature conservation aspects. Some studies use information derived from literature (**lit**).

Concerning production and opportunity costs, we note the following aspects that should be considered:

(i) Many control strategies tend to fail or are ineffective (Curnutt, 2000). Therefore, measuring the costs and benefits of such strategies is not the right approach for assessing the costs and benefits of biological invasions. On the one hand it implies an overestimation of impacts if there are more effective alternatives, and on the other it may lead to underestimation due to the imperfect assessment of external effects.

(ii) The higher production costs caused by invasive species will normally not completely vanish after appropriate mitigation measures. For example, Pimentel et al. (2001) assume that 73% of US American weeds are invasive species and that therefore 73% of weed costs are caused by invasive species. Few invasive species may cause major costs due to their ubiquitous predominance in ecosystems. However, their niche will be occupied by other species after their eradication or control. Therefore, costs would probably arise at any rate due to native weeds causing the same effects. Distinguishing between different species with their respective share of the total amount of costs seems necessary in terms of the effectiveness of different measures. Additionally, it might be more cost-effective to just reduce the population size and keep it at a low level instead of enforcing the eradication of the species (Sharov and Liebhold, 1998).

3.2.5 Source of data

Analysis is supposed to clearly indicate (1) whether the data used is unchanged business data or data that has been adapted or obtained using the method of cost-benefit-analysis, and (2) the scale involved. In the majority of cases it will not be appropriate to scale up regional data to a national level (as is done for instance by McConnachie et al., 2003).

The following difficulties are identified in respect of the source of data and its importance regarding the political relevance of the results:

(i) Business data neglect external costs. In such analyses "there has been substantial (economic) considerations (on measures), but no quantitative costing of a whole set of 'externalities', e.g. reduced hazards to users and the public from reduced chemical usage, lack of undesirable residues and decreased disruption of the environment and effects on non-target species", as remark Cullen and Whitten, (1995, p. 272) in an economic evaluation study on biological control.

(ii) Subsidies distort market prices. Mitigation measures in the European agricultural sector will apparently turn out to be more costly if subsidies under the Common Agriculture Policy (CAP) are subtracted (which has been neglected e.g. by Reinhardt et al., 2003). Providing policy advice has to take such distortions into account. On the other hand, subtracting subsidies would also decrease the opportunity costs of for example cultivating *Quercus rubus,* an invasive species in German forests. One effect would be the encouragement of respective eradication programmes.

(iii) It is questionable whether aggregated business data are representative. Very often data collected for a certain area are extrapolated, which disregards different site conditions. Invasive species impacts may differ, as may the success of a certain measure. It might be helpful to consider the range of costs of minimal and maximal scenarios.

(iv) Lacking and reduced economic data on external effects are a problem. It is still difficult to identify (much less monetarise) external effects. One result is an extreme reduction of data. For example, Pimentel et al. (2001) reduce so-called "ecological costs" to ecological damage of (1) purple loosestrife and (2) aquatic weed control (Pimentel et al., 2001). There are certainly more control costs for other species; furthermore, ecological costs cannot be reduced to control costs. In this context, the external effects of ecological impacts of invasive species are totally neglected.

When comparing source of data and the level of assessment, it becomes obvious that there is a discrepancy between the aim of the studies and the data used. Many studies aim to provide

nationally relevant information but use unaltered business data, implying shortcomings on the methodological side (see 3.2.4).

In general we notice that few economic data are used. This is mainly due to the lack of figures available on economic costs and benefits caused by invasive species. However, respective studies also fail to assess the monetary value of changes to indirect and non-use values. Turpie and Heydenrych (2000) present the only study conducting a willingness-to-pay analysis regarding the loss or alternation of the option and existence values due to biological invasions. No other direct or indirect assessment approaches are to be found.

One general problem is the data themselves. Vague explanations on their source and generation generate suspicion of double-counting: (i) whether damage costs arise with or without a certain control measure (McConnachie et al., 2003) or (ii) whether government fundings are subtracted from total expenditure (Bertram, 1999).

3.2.6 Total costs

The column containing total costs represents the total costs resulting in each study. In addition, the benefit-cost ratio (**B/C**) is noted in brackets as stated in the original papers.

Although in some cases we cannot reconstruct the total costs, we still illustrate them. It emerges that costs rise as the extent of a study increases. Two (or more) studies and their figures cannot be compared even if information is available about many of the criteria surveyed within the studies. For example, stating that the impact of biological invasions on New Zealand is exactly twelve times higher than in South Africa would be not sound. The studies by Bertram (1999) and Turpie and Heydenreych (2000) are too different for their figures to be compared owing to the different spheres of influence of the respective invasive species, the different assessment methods used, and different focus of either study.

3.2.7 Uncertainty

To answer the central question of the extent to which studies include uncertainty, it turns out that uncertainty does not play a vital role in economic studies. During the course of classical cost-benefit analyses, a sensitivity analysis is mostly conducted, either by employing different discount rates (Cullen and Whitten, 1995; Pimentel et al., 2001; Tisdell, 1990) or by comparing different management regimes (McConnachie et al., 2003; Wit et al., 2001). However, it does not refer to ecological behaviour. Sensitivity analyses neither consider the continuing dispersal of species into adjacent ecosystems nor reflect the possible degradation of ecosystem functions in the course of further impacts or re-invasion after eradication.

Bertram (1999, p. 49) remarks on New Zealand's "expenditure on border controls and quarantine services which is akin to the payment of insurance premiums against catastrophic events … as means of confronting risks and uncertainties".

3.3 Studies and the TEV

As noted in Chapter 2.3, we refer to the concept of the TEV as a system of reference for economic evaluation. It illustrates the comprehensiveness of current studies.

Table 4 simply shows that all studies mainly emphasise on economic figures of direct-use values. This can be explained by the availability of data on production decrease, weed and pest control and management within land use sectors. The more we leave the field of palpable use values, the more such values become disregarded. Although indirect-use values such as decreased pollination functions, water availability and fire hazards within ecosystems, and the carrying capacity of pasture land are considered by the studies by Turpie and Heydenreich (2000), Bertram (1999) and others, a whole string of possible alternations in indirect-use values and option values are neglected. Reinhardt et al. (2003) for instance account for health costs caused by *Ambrosia artemisiifolia.*

Table 4: Assessed value types of the studies surveyed (own source)

Source	Use Values			Non-Use Value
	1. Direct-use Value	2. Indirect-use Value	3. Option Value	4. Existence / Bequest Value
Bertram, 1999	X	X	X	
Turpie and Heydenreich, 2000	X	X	X	X
Wit et al., 2001	X	X		
McConnachie et al., 2003	X			
Wilgen, 2001	X	X		
Reinhardt et al., 2003	X	X		
Cullen and Whitten, 1995	X			
Tisdell, 1990	X			
Pimentel et al., 2001	X	X		
Pimentel et al., 2002	X	X		

They consider the costs of medical treatment to combat allergic reactions in humans. In this case it seems necessary to conduct a willingness-to-pay analysis addressing the avoidance of being threatened by the species in question. Costs would certainly rise by adding such results. Alternative landscape functions, e.g. for tourism (recreation by hiking, bird-watching) are normally disregarded.

4 Conclusion and future directions

> "*Attempting an objective analysis and summary of the studies (of economics of biological invasions) that have been done is frustrating, as every study has used a different approach, making an accurate assessment of aggregate impacts impossible*" (Wilgen et al. 2001, p. 154).

Our review confirms the impression Wilgen et al. (2001) had in their overview of South-African studies. The analysis underlines its world-wide context. However, with a systematic approach we are able to present an overview of current studies with some general features to be discussed. Next to the heterogeneity of approaches the analysis illustrates also methodological shortcomings by using comprehensible criteria that integrate a wider than just an economic perspective. The results of our analysis of studies of the costs and benefits of biological invasions and can be summed up as follows:

1. There is an imbalance in all examined studies: they focus on *ex-post*-evaluation, on control measures, on few countries, on agriculture, and on use values. Clearly missing are *ex-ante* studies, evaluation of prevention measures, the consideration of a larger range of countries, the consideration especially of biodiversity protection issues, the inclusion of indirect-use and non-use values, and the integration of uncertainty.
2. None of the decision-aid studies considers all the relevant economic effects in either a comprehensive (with respect to the TEV) or a methodologically correct way (e.g. by considering only economic data).
3. Studies regarding impact assessment monetise impacts and respective measures mainly focus on the agricultural and sylvicultural sector and mostly assess biological control measures. A comparison of evaluation studies (far less an aggregation of their results) is not meaningful, as the range of methods, TEV categories assessed, the spatial framework and the number of invasive species differ too much. However, these studies certainly illustrate the urgency of action.
4. Uncertainty, especially arising in the ecological context of the invasive process, is not explicitly considered or included.
5. Even though many studies investigate a single case of invasion in detail, total cost figures should be used with caution as the only basis for decision-making due to uncertainty and the existence of values which are difficult to assess in monetary terms.

6. Economic studies tend to focus on control rather than on prevention strategies and mostly do not mention the hierarchical three-stage approach contained in the CBD. Without the link to the CBD such studies are less suitable as policy advice.

The results indicate the need to further develop future economic studies about the costs and benefits of biological invasions (see also Perrings et al., 2000). The first way of doing so would be to carry out more comprehensive studies.

This would imply more and better studies regarding the ecological, political, and economic framework. They would be more expensive and would take longer (at least as far as the economic methodology is concerned since all TEV categories would be assessed), they would focus more on prevention (political framework), and would take uncertainty into consideration (ecological framework, especially in combination with the political framework). Such time-consuming, expensive analyses would be less compatible with the political decision-making process, because future decisions will become increasingly urgent.

Due to these difficulties, one might be tempted to abandon the mono-dimensional approach of monetary evaluation. A multidimensional approach would enable to consider better the aspect of uncertainty and the complex multidimensionality of impacts and its subjective perception of decision makers. Ecological knowledge is still not very strong and must be used cautiously, implying a high degree of uncertainty. Cost-benefit analysis is not well equipped to consider this uncertainty (O'Connor, 2002; Munda, 1996). Multi-criteria decision aid, being able to structure the decision process on measures designed to counter biological invasions, especially the evaluation stage, and to aggregate this information into a ranking of different measures (Bouyssou et al., 2000; Vincke, 1992; Rauschmayer, 2001), has not yet been employed in this field (Rauschmayer, 2003). Using it would provide a way of including aspects of uncertainty and qualitative as well as quantitative evaluation. By combining ecological knowledge and economic evaluation, multi-criteria evaluation opens up new ways of producing policy-relevant results to justify or reject the hierarchical demands for prevention contained in the CBD. Hence, instead of intensifying the mono-dimensional approach of monetary evaluation, we think it is time to venture new, broader approaches of the economic assessment of the complex problem of biological invasions.

Acknowledgements

This paper uses results from studies in two research projects: (1) "Invasions: The Invasion Potential of Alien Species - Identification, Assessment, and Risk Management", within the

BioTEAM-Programme (Grant 01 LM 0206), financed by the German Federal Ministry of Education and Research, and (2) "Foundations for the development of a national strategy against invasive alien species" (FKZ 803 11 221) financed by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

Reference List

Anaman, K.A., 1994. Input-output analysis of the secondary impacts of a screwworm fly invasion of Australia on the economy of Queensland. Preventive Veterinary Medicine, 21:1-18.

Barbier, E.B., 2001. A note on the economics of biological invasions. Ecological Economics, 39:197-202.

Bertolino, S. and Genovesi, P., 2003. Spread and attempted eradication of the grey squirrel (sciurus carolinensis) in Italy, and consequences for the red squirrel (Sciurus vulgaris) in Eurasia. Biological Conservation, 109:351-358.

Bertram, G., 1999. The impact of introduced pests on the New Zealand economy, Pests and Weeds a blueprint of action. Report, New Zealand Conservation Authority, 45-71.

Bouyssou, D., Marchant, T., Pirlot, M., Perny, P., Tsoukias, A. and Vincke, P., 2000. Evaluation and decision models: a critical perspective. Dordrecht, Kluwer.

Bräuer, I., 2003. Money as an indicator: to make use of economic evaluation for biodiversity conservation. Agriculture, Ecosystems & Environment, 98:483-491.

COP, 2002. Review and consideration of options for the implementation of article 8(h) on alien species that threatens ecosystems, habitats or species. Conference of the parties to the Convention on Biological Diversity (COP). UNEP/CBD/COP/6/18/Add.1/Rev.1. 26-3-2002.

Cullen, J.M. and Whitten, M.J., 1995. Economics of classical biological control: a research practice. In: H. Hokkanen and J. Lynch (Editors), Biological Control - Benefits and Risks. Cambridge University Press, pp. 270-276.

Curnutt, J.L., 2000. Host-area specific climatic-matching: similarity breeds exotics. Biological Conservation, 94:341-351.

Headrick, D.H. and Goeden, R.D., 2001. Biological Control as a Tool for Ecosystem Management. Biological Control, 21:249-257.

Higgins, S.I., Esteban, J.A., Cowling, R.M., and Morris, M.J., 1997. A dynamic ecological-economic model as a tool for conflict resolution in an invasive-alien-plant, biological control and native-plant scenario. Ecological Economics, 22:141-154.

Higgins, S.I., Turpie, J., Costanza, R., Cowling, R.M., Le Maitre, D.C., Marais, C., and Midgley, G.F., 1996. An ecological economic simulation model of mountain fynbos ecosystems dynamics, valuation and management. Ecological Economics, 22:155-169.

Hill, G. and Greathead, D., 2000. Economic evaluation in classical biological control. In: C. Perrings, M. Williamson, and S. Dalmazzone (Editors), The Economics of Biological Invasions. Edward Elgar, Cheltenham, pp. 208-225.

Jay, M., Morad, M., and Bell, A., 2003. Biosecurity, a policy dilemma for New Zealand. Land Use Policy, 20:121-129.

Kasulo, V., 2000. The impact of invasive species in African lakes. In: C. Perrings, M. Williamson, and S. Dalmazzone (Editors), The Economics of Biological Invasions. Edward Elgar, Cheltenham, pp. 183-207.

Keane, R.M. and Crawley, M.J., 2002. Exotic plant invasions and the enemy release hypothesis. Trends in Ecology & Evolution, 17:164-170.

Le Maitre, D.C., van Wilgen, B.W., Gelderblom, C.M., Bailey, C., Chapman, R.A., and Nel, J.A., 2002. Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. Forest Ecology and Management, 160:143-159.

Marambe, B., Bambaradeniya, C., Kumara, D.K.P., and Pallewatta, N., 2001. Human dimensions of invasive alien species in Sri Lanka. In: J.A. McNeely (Editor), The Great Reshuffling: Human Dimensions of Invasive Alien Species. IUCN, Cambridge, pp. 135-144.

McConnachie, A.J., de Wit, M.P., Hill, M.P., and Byrne, M.J., 2003. Economic evaluation of the successful biological control of Azolla filiculoides in South Africa. Biological Control, 28:25-32.

McNeely, J.A., 2001. The Great Reshuffling: Human Dimensions of Invasive Alien Species. IUCN International Unit for Conservation of Nature and Natural Resources, Cambridge.

Munda, G., 1996. Cost-benefit analysis in integrated environmental assessment: some methodological issues. Ecological Economics, 19:157-168.

Naylor, R.S., 2000. The Economics of Alien Species Invasions. In: H.A. Mooney and R.J. Hobbs (Editors), Invasive species in a changing world. Island Press, Washington, pp. 241-259.

Nunes, P.A.L.D. and van den Bergh, J.C.J.M., 2001. Economic valuation of biodiversity: sense or nonsense? Ecological Economics, 39:203-222.

Odom, D.I.S., Cacho, O.J., Sinden, J.A., and Griffith, G.R., 2003. Policies for the management of weeds in natural ecosystems: the case of scotch broom (Cytisus scoparius, L.) in an Australian national park. Ecological Economics, 44:119-135.

OECD, 1996. Saving Biological Diversity: Economic Incentives. Paris.

O´Connor, M., 2002. Reframing environmental valuation: reasoning about resource use and the redistribution of sustainability. In: H. Abaza and A. Baranzini (Editors),

Implementing Sustainable Development. Integrated Assessment and Participatory Decision-making Processes. Edward Elgar, Cheltenham, pp. 32-52.

Pearce, D.W. and Turner, R.K., 1990. Economics of Natural Resources and the Environment. The John Hopkins University Press, Baltimore.

Perrings, C., 2003. Mititgation and Adaptation Strategies in the Control of Biological Invasions. Conference Proceeding, BioEcon-Conference, Venice. http://www.bioecon.ucl.ac.uk/Venice.htm.

Perrings, C., Williamson, M., and Dalmazzone, S., 2000. The Economics of Biological Invasions. Edward Elgar, Cheltenham, UK / Northampton, USA.

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

Pimentel, D., Lach, L., Zuniga, R., and Morrison, D., 2002. Environmental and economic costs associated with non-indigenous species in the United States. In: D. Pimentel (Editor), Biological Invasions. CRC, Boca Raton, pp. 285-303.

Rauschmayer, F., 2001. "Reflections on Ethics and MCA in Environmental Decisions." Journal of Multi-Criteria Decision Analysis, 10:65-74.

Rauschmayer, F., 2003. Integrated Assessment of Biological Invasions, UFZ-Discussion papers: No. 1/2003. Leipzig, UFZ, http://www.ufz.de/data/oekus_diskpap2003_01382.pdf.

Reinhardt, F., Herle, M., Bastiansen, F., and Streit, B., 2003. Ökonomische Folgen der Ausbreitung von gebietsfremden Organismen in Deutschland. Umweltbundesamt, Berlin.

Richardson, D.M., Pysek, P., Rejmanek, M., Barbour, M.G., Panetta, F.D., and West, C.J., 2000. Naturalization and invasion of alien plants: concepts and definitions. Diversity and Distributions, 6:93-107.

Settle, C., Crocker, T.D., and Shogren, J.F., 2002. On the joint determination of biological and economic systems. Ecological Economics, 42:301-311.

Sharov, A.A. and Liebhold, A.M., 1998. Bioeconomics of managing the spread of exotic pest species with barrier zones. Ecological Applications, 8:833-845.

Tisdell, C.A., 1990. Economic Impact of Biological Control of Weeds and Insects. Critical Issues in Biological Control, 301-316.

Turner, R.K., Paavola, J., Cooper, P., Farber, S., Jessamy, V., and Georgiou, S., 2003. Valuing nature: lessons learned and future research directions. Ecological Economics, 46:493-510.

Turpie, J. and Heydenrych, B.J., 2000. Economic consequences of alien infestation of the Cape Floral Kingdom's Fynbos vegetation. In: C. Perrings, M. Williamson, and S.

Dalmazzone (Editors), The Economics of Biological Invasions. Edward Elgar, Cheltenham, pp. 152-182.

Turpie, J.K., Heydenrych, B.J., and Lamberth, S.J., 2003. Economic value of terrestrial and marine biodiversity in the Cape Floristic Region: implications for defining effective and socially optimal conservation strategies. Biological Conservation, 112:233-251.

Vincke, P. (1992). Multicriteria decision aid, Wiley. Originally published: (1989), L'aide multicritère à la décision. Bruxelles, Editions de l'Université de Bruxelles.

Vitousek, P.M., D'Antonio, C.M., Loope, L.L., and Westbrooks, R., 1996. Biological Invasions as Global Environmental Change. American Scientist, 84:468-478.

White, P.C.L. and Harris, S., 2002. Economic and Environmental Costs of Alien Vertebrate Species in Britain. In: D. Pimentel (Editor), Biological Invasions. CRC Press, Boca Raton, pp. 113-150.

White, P.C.L. and Newton-Cross, G., 2000. An introduced disease in an invasive host: the ecology and economics of rabbit calicivirus disease (RCD) in rabbits in Australia. In: C. Perrings, M. Williamson, and S. Dalmazzone (Editors), The Economics of Biological Invasions. Edward Elgar, Cheltenham, pp. 117-137.

Wilgen, B.W.v., 2001. The Economic Consequences of Alien Plant Invasions: Examples of Impacts and Approaches to Sustainable Management in South Africa. Environment, Development and Sustainability, 3:145-168.

Williamson, M., 1999. Invasions. Ecography, 22:5-12.

Wit, W.P., Crookes, D.J., and Wilgen, B.W., 2001. Conflicts of interests in environmental management: estimating the costs and benefits of a tree invasion. Biological Invasions, 3:167-178.

Zavaleta, E.S., Hobbs, R.J., Mooney, H.A., 2001. Viewing invasive species removal in a whole-ecosystem context. Trends in Ecology & Evolution, 8:454-459.