UFZ-Discussion Papers

Department of Economics, Sociology and Law (OEKUS)

1/2003

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Felix Rauschmayer

March 2003

Felix Rauschmayer

UFZ Centre for Environmental Research
Department of Ecological Economics and Environmental Sociology (OEKUS)
PO–Box 500136
D–04301 Leipzig
Germany

e-mail: rauschma@alok.ufz.de
phone: +49 341 235–2074
fax: +49 341 235–2825

Integrated assessment of biological invasions

Felix Rauschmayer, UFZ Leipzig-Halle – Center for Environmental Research, Department of Economics, Sociology, and Law, Permoserstr. 15, 04138 Leipzig
rauschma@alok.ufz.de

Abstract

An assessment of the consequences of biological invasions and of the measures taken against must be at the base of each social decision in this field. Three forms of uncertainty can be distinguished that make such a decision difficult to take: (1) factual uncertainty, which encompasses not only risk, but also unknown probabilities of known consequences, and unknown consequences, (2) individual uncertainty, i.e. insecurity about the values to consider, and about the form how to consider them, and (3) social actor uncertainty, i.e. uncertainty about the social actors to consider and how to do it. This paper furnishes axiomatic reflections about the difficulties of assessments integrating these three uncertainties. Using this analytical separation, it restructures two main assessment techniques, and herewith shows the main differences between cost-benefit-analysis and multi-criteria decision aid in supporting public decisions about biological invasions. It is shown that the main difference between cost-benefit-analysis, the classical economic decision support, and multi-criteria decision analysis is less its mono- vs. multi-criteria approach, but its facility to be embedded in a social decision context. With multi-criteria decision aid it is more facile to lay open the uncertainties in all three dimensions and to make them an explicit topic for public discourse. Therefore, it seems more suitable as an assessment method for biological invasions.

Keywords: Biodiversity, Multi-criteria analysis, Uncertainty, Integrated Assessment, Biological Invasion, Cost-benefit analysis

1. Introduction

Plants and animals have been transported by human agents since long ago. The consequences of these transports attracted wide attention through large devastating effects on human environments. The first kind of environment affected by invasive species have been agricultural systems: Production systems in monoculture are fragile, and alien species have large effects easily. It is rather easy to determine the effects biological invasions have on agriculture: Agricultural goods are marketable goods and losses of goods are priced accordingly. Throughout this paper, biological invasions that threaten agriculture, forestry or fishery are regarded only as a part of the more general problem. The biological and social discussion about neobiota is more concerned by the effects those plants and animals have on natural or semi-natural ecosystems or on parts of these. The effects might be on biodiversity, but also on water availability, biochemical circles, aesthetics, or on human safety and health. It is more difficult to determine the impact biological invasions in general have on ecosystems (Parker et al. 1999), and – via ecosystems – on social and economic activities than just on agriculture.

The impact of an invading species depends on its host ecosystem. In some ecosystems, certain species do not appear as invasions, but establish themselves alongside native species whereas they are invasive in other ecosystems. There have been attempts to identify specific attributes of invasive species (cp. for plants in UK Thompson et al., 1995, Crawley et al., 1996, Williamson and Fitter, 1996, Prinzing et al., 2002), but these types of analyses have a rather low prognostic power for other species (Lewin, 1987, Gilpin, 1990). Furthermore, most species invade with a certain time lag, due for example to climatic adaptation (Kowarik, 1992, 1995). It is difficult to predict this time lag.

There are large differences in scientific opinion concerning the number of potentially invasive species. A fairly known rule of thumb is the “ten’s rule” (Williamson, 1996): If you introduce 100 species into new ecosystems, then (always approximately) 10 will establish self-sustaining populations, and 1 species will be regarded as a pest, as a biological invasion. For example, Rapoport (1991) regards 10 % of all 260.000 vascular plants species as potentially invasive. Only 4.000 of these 26.000 species have been introduced in other parts of the world up to now. Even if Rapoports estimation would be

50 % too high, and if only 10 % of the potentially invading species cause large damage, then there are still some 1.000 invasive species causing large damage and waiting for transport (Reichard and White, 2001). Mark Williamson (1999: 10) even states that "it could be that invasions are unpredictable in the way that earthquakes are", i.e. individually unpredictable. Vitousek et al. (1996) distinguish four different consequences of invasions: Damage to human health, damage to human wealth, alteration of ecosystem processes, and reduction of biological diversity.

Social actors have to decide how to handle the problem of biological invasions. Measures may be taken concerning 1) the import of foreign species, 2) their introduction into nature, 3) their establishment, and 4) their invasion. Measures on one stage may include measures on other stages: society may want to hinder further importation of an already established species, for example, and fight the established plants or animals at the same time. Rational decisions demand an assessment for the impacts of the decisions which should be as complete as possible. The assessment process which should be at the base of the decision may be divided into three steps. [1]

- A first step is to specify the underlying physical effects of invasions and of measures against invasions[2].
- The second step is the individual evaluation of the impacts of invasions on the social and economic environment of humans.
- In a third step, different individual evaluations have to be aggregated in order to reach a general decision.

Even if these three steps are intertwined in practice, it is nevertheless important to distinct them analytically. In the following, the main difficulties of these three steps will be highlighted and linked to three different types of uncertainty. It will become clear that social decision making in the field of biological invasions is a complex task.

Assessments of measures concerning biological invasions may use different techniques. The following questions concerning science, ethics, technique and institutions are relevant touchstones in order to decide which assessment technique is useful in which case. The questions will be deduced from a discussion of different dimensions of uncertainty that are at stake in the field of

[1] Cp. the description of invasive processes in Richardson et al. (2000).

[2] It is clear that the assessment of an existing biological invasion without any measure taken actively against is just the same as the assessment of the measure "do nothing". In the following, assessment of invasions or assessment of measures against invasions will be used interchangeably.

social decisions on biological invasions. Answers will be given in the last section of the paper.

- Is the knowledge base reflected adequately by the assessment technique?
- Is the use of the technique consistent with the moral base of the society?
- Is the technique a useful base within the existent institutional conditions?
- Are the yardsticks used a good measure of the overall aim?

Uncertainty in the field of biological invasions will be the topic of the next chapter in a factual, individual, and social dimension. An integrated assessment, opposed to a partial assessment, will have to consider these three dimensions[3]. The third chapter describes main principles of cost-benefit-analysis as the classical economic analysis and some applications to the problem of biological invasions. The content of the fourth chapter is the multi criteria decision aid as a form of an integrated assessment. In answering the touchstone questions, the concluding fifth chapter gives an exploratory evaluation of which assessment technique – or combination of techniques – might prove useful for the evaluation of measures against biological invasions.

2. Three Dimensions of Uncertainty

Decision makers in the field of biological invasions are confronted with three different dimensions of uncertainty:

- factual uncertainty about the predicted factual consequences of the decision,
- individual uncertainty about the relative importance of the different problem dimensions, and
- social actor uncertainty about the selection of and the importance given to decision actors to be considered.[4]

In this chapter, these three dimensions of uncertainty are analysed succinctly and related to the problem of the assessment of biological invasions. Each one of these uncertainties can be related to a step in the assessment process. Such an assignment makes sense analytically – in real processes, there are interdependencies. The analysis of the three types of uncertainty constitutes the background against which the appropriateness of different assessment techniques can be evaluated.

[3] See Rotmans and van Asselt, 2002, for an extensive discussion about different practices of integrated assessment.

[4] Social actor uncertainty as defined here, is a short form of individual uncertainty concerning the social actors to be considered. Nevertheless, it will be separated here.

2.1 Factual uncertainty

Factual uncertainty relates mainly to the first step of the assessment process, i.e. the specification of the physical effects of an invasion.

As said before, it is difficult to predict the time lag a species needs to establish itself or – after its establishment – to invade a foreign ecosystem. It is very difficult to predict the "success" of a species to get established, or to become a pest. It is also difficult to predict the effects of a species on an ecosystem once it has become a pest. In the language of decision theory: the probability of such an event (establishment after introduction or invasion after establishment) is approx. 10 % (cp. "ten's rule", cited above), and the outcome of the event is unknown. This is, still in the language of decision theory, not just a case of risk, where potential outcomes of a decision and their probabilities are known, but it is a case of uncertainty, where it is impossible to calculate the expected value. Furthermore, there is still a lot of ignorance on this issue[5]: Who could have imagined, for example, the Great Mullein (*Verbascum thapsus*) originated in moderated zones of Eurasia, to invade tropical mountains such as happened in the islands of Réunion or Hawaii (Kloetzli 1994)? And who did imagine the impact of Australian tree species *Acacia, Eucalyptus* and *Hakea* growing in South Africa on local water cycles (Van Wilgen et al. 2001)? Probabilities of events, such as introduction, and even more establishment or invasion of a new plant or animal are unknown as well as the potential outcome of such an event.

Going more into detail of the risk aspect, one notices that (1) the probabilities of the single species to establish or invade vary to a large extent; there are – at least in moderated or arctic regions – a lot of species for which the risk of establishment is nearly zero due to frost in winter, (2) there are some species, normally unknown, with the potential outcomes close to a catastrophe (up to now, there is less evidence for terrestrial regions in continental Europe, but there is high evidence for tropical islands or marine or estuarine systems[6]). It is clearly rational not to take drastic measures concerning species with nearly no probability of establishment, and it is also rational to take measures which inhibit catastrophes. Risk-based assessment of biological invasions makes only sense in cases where the risk, i.e. the probabilities of the outcomes, can be calculated. This is the case for invasions which take place already (see on risk assessment for biological invasions: Shogren, 2000 and Smith et al., 1999). It is

[5] Look at Faber and Proops 1998 for a more specific treatment of ignorance, risk, and uncertainty.
[6] Compare Lonsdale 1999 on global patterns of plant invasions.

almost impossible to stop an invasion which is going on, and, generally, it is very costly to slow its extension (Sharov and Liebhold, 1998).

Going more into detail of the uncertainty and ignorance aspect, one notices that it has not been possible to make general statistics concerning the invasion probability dependent on any variables. We are not in a position to isolate reasonable hypotheses concerning the real probability of a certain species to get established or to become a pest. We only have the ten's rule concerning all species together. Consequently, as we do not know whether a species will be the invading one or one of the 999 that might be imported without a great harm, we are not able to calculate expected values of measures. Therefore, is rational to choose the measure with the smallest potential negative effects.

This does not necessarily mean to carry out the most draconian measures against biological invasions: the most draconian and most effective method against invasions for an island would be its complete isolation from the traffic of goods and persons. But isolation will certainly be judged catastrophically in our societies for social and economic reasons. Consequently, such a measure has to be avoided, too.

It is difficult to give further general rules on how to deal with factual uncertainty (cp. Hübner, 2001, Arrow and Hurwicz, 1972, Wald, 1950). But assessment techniques must supply an appropriate way of dealing with factual uncertainty without limiting the considerations to the risk aspect only in reinterpreting uncertainty and ignorance as risk or in leaving these aspects without consideration.

2.2 Individual uncertainty

Individual uncertainty relates mainly to the second step of the assessment process, i.e. the individual evaluation of the physical impacts on the economic and social sphere.

What is special about biological invasions compared to buying a loaf of bread, for example? In the first case, the decision maker[7] is confronted with a decision that will have implications for many moral entities (humans, non-humans, existing and not yet existing) and for many aspects of human and non-human life, some of them irreversible. Therefore, different questions have to be

[7] The decision maker may be an individual or a group. The female singular is used in this paper for reasons of simplicity only.

answered before being able to decide whether a decision is a “good” decision or not:

- Do only humans count? If yes:
- Do only existing humans count? If yes:
- Do only persons [8] count? If yes:
- Do persons always know best what is good for them?

If the decision maker says „no“ to one of the first three questions, then she has to integrate the „good“ of entities into her decision who/which are not able to express them on their own. The issue of how this may be done will partly be discussed in the third point of this chapter: Social actor uncertainty. This paragraph will first focus on the last question which is already difficult enough, and then consider the first three questions.

If persons know best themselves what is good for them, the decision maker just has to ask them and may consider this in her decision[9]. Here are different ways how to ask the persons concerned and how to aggregate the answers. I offer three perspectives which are far from being fully representative for all perspectives one may take reasonably.

1. Utilitarianism as a very influential monistic ethics states that the “good” is mono-dimensional, and that all kinds of utility and dis-utility may be aggregated inside each of us. Therefore, each of us would be able to calculate his resulting positive or negative utility out of a measure and to express it in monetary or other terms.
2. Other ethics, e.g. Aristotelian ethics (e.g. O'Neill, 1993, 2001), start from a multi-dimensionality of the personal “good”. In other words, there is no (complete) substitutability of the different dimensions, and each dimension has to be considered separately. Only reflecting on the different effects of a decision in the different dimensions may result in a good decision without an ethically founded possibility to enounce a worth that this decision would constitute to the person. Here, even if the decision maker is convinced of a

[8] In the current philosophical debate, necessary conditions for a person are i.a.: Self-awareness, capability of epistemic differentiation, emotive expression, communication, education, temporal awareness, and emotional and social relations with other persons.

[9] I do not treat the question how the good of other persons will be included in the decision. Here, it is neither assumed that the decision maker is a benevolent dictator nor that she is an egoist, but it is assumed that the interests of others which are motivated by their quest of the good, is relevant for the decision in one or another way. But it is intended to provide for an assessment technique that assists benevolent decision makers.

"yes" to all four questions asked at the beginning of this sub-section, this does not mean that she knows what to do with the different perceptions of "good". Any assessment technique would have to be open to different conceptions of "good".

3. Some authors (Sen, 1987, 1995: 23 pp., Sagoff, 1988a, Norton, 2002) believe that there are differences between the preferences of individuals and the preferences for a community. The latter preferences are less revealed through private, but more through common acts. If both preferences are of any relevance to the decision maker, then assessment techniques must be open to group discourse as well as to individual answering.

Some authors (cp. the discussion in economics about merit goods, e.g. Ver Eecke 2002) challenge that persons do know best what is good for them. Especially when dealing with complex systems and high uncertainty, lay-persons may not be able to distinguish what is really good for them. Even if one might challenge this opinion on theoretical grounds, it is still highly plausible for practical reasons. Therefore, scientific expertise should enter the assessment directly, and not only via an additional information of concerned lay-persons which they use for an altered evaluation of the situations.

For most philosophers, it is clear that non-person humans have the right that their interests are respected by the persons whose acts have impacts on them. For many philosophers, this is still true for non-human beings which suffer from our decisions in a way that is somehow similar to human suffering (prominently: Singer, 1993). For some philosophers, this is still so for entities which cannot suffer, i.e. "lower" animals, plants or even processes (e.g. Callicott, 1980). I will not go into detail and take a stand, but conclude two consequences from the discussion of environmental ethics: (1) There is a great diversity of arguments, and the decision maker may feel insecure about the arguments to follow, and (2), if the third question of the list above is negated, then she has to search for a way on how to integrate interests of those who/which are living non-persons.

It is the "no" to the second question that constitutes generally the greatest motivation to an attitude and to acts that respect the environment. Many actors protect the natural environment because they accept the right of future human generations to fulfil their needs. This right of other generations is difficult to concretise in detail, but it is clear that having a sufficient natural resource base is a part of it – this right incorporated in the concept of sustainable development is widely acknowledged. Measures without irreversible negative consequences

on the natural resource base are therefore, ceteris paribus, to be preferred to measures with negative consequences.

Taking decisions about biological invasions means to take decisions (1) where many entities are concerned by a decision, (2) where it is not sure who these entities are, (3) where the decision touches upon many aspects of life, and (4) where irreversible consequences are to be expected. All these aspects contribute to the individual value uncertainty of the decision maker. Due to this type of uncertainty, any assessment method must be open to different ethical conceptions, open to integrate non-persons as well as to respect the right of future generations. A narrow basis of the assessment method which allows only to consider certain of these individual moral aspects, i.e. for example a limitation to a monistic consideration of individual evaluations of living persons, would be fatal for a full consideration of individual and social values that go well beyond this aspect.

2.3 Social actor uncertainty

In an assessment process, it is not sufficient to consider individual and social values, even if these are considered in their full range. The decision maker has to decide on how to aggregate these evaluations. Here, two aspects of this social actor uncertainty can be distinguished: Whom to consider and how to consider. Aggregation can be done using an algorithm which counts all different evaluations available, considering the valuing entities equally or to different extents. On the other side of the scale of aggregation methods is a discursive process with a decision based on arguments rather than on numbers. Before using either aggregation method on this scale, the decision maker has to know, though, whom to consider. Apart from the individual moral uncertainty considered above, this is even a problem when only living persons are considered. If it is not clear who are the persons concerned, it is much more difficult to use only algorithmic procedures, whereas in discursive procedures, a representativeness of the discoursing persons might be easier to identify (cp. on the problems of the concept of representativeness O'Neill 2001).

Before a biological invasion takes place, it is often impossible to tell who will be concerned by this invasion. It is much easier to tell who might be concerned by active measures against an invasion. Experience has shown that in many fields, decisions are more efficient and implemented more effectively if they are based on a consensus or quasi-consensus of the actors concerned. This is even more

valid in fields touching on nature conservation in semi-natural or cultural habitats. Apart from this functional argument that speaks in favour of participatory decision making, there are ethical-normative arguments which will not be considered here (see on this Webler and Renn, 1995). Once an invasion has taken place, it becomes rather clear who is concerned by it, even if the further impacts of the invasion are partly uncertain. In decisions on the stages before, i.e. on import, introduction or establishment, it is less obvious who is concerned. Therefore, decision processes at these stages have to be open to a large array of stakeholders.

Furthermore, the aspects of individual value uncertainty discussed above call for participation of persons and for participation of an advocate for non-persons or non-living persons.

In the following two chapters, two assessment methods, cost-benefit-analysis and multi- criteria decision aid are presented and discussed, especially concerning their integration of the three dimensions of uncertainty.

3. Classical Economic Assessment

The classical economic approach for the assessment and evaluation of a measure is to calculate the Total Economic Value (TEV) using a cost-benefit-analysis (CBA) of the consequences of this action. Cost-benefit-analysis, being the classical economic assessment and evaluation method, is based on one main methodological assumption. This main assumption of most economists and many other social scientists is methodological individualism herewith referring any valuation to concerned individuals only. Costs and benefits are assessed by and with respect to the individuals concerned by the measure, and not by scientists or with respect to holistic entities such as state, nature, humanity, etc.

The application of CBA to environmental fields has grown ever more in the last decades and years[10]. Here, it became more and more apparent that costs and benefits are not only costs and benefits that are exchanged on markets and therefore “naturally” expressed in monetary terms, but all kinds of pain and pleasure, as J. Bentham, the founder of utilitarianism, called it. This is practised through the following proceeding: To calculate the TEV of a measure, one has

[10] Compare for example: Hampicke, 1991; Hampicke et al., 1991; Perrings et al., 1992; Swanson and Barbier, 1992; Kopp and Smith, 1993; Spash and Hanley, 1995; Perrings and Opschoor, 1994; Perrings, 1995; Smith, 1996; Garrod and Willis, 1999.

to integrate different kinds of values: use values and non-use values. The former comprise benefits and costs for the concerned individuals arising in direct and indirect actual or later use (which would be hindered or furthered by that measure). Non-use values on the other hand, are not caused by using some goods altered by the measure: existence values denote values that individuals give to a good only because it exists, altruistic and bequest values are designated to goods because of their potential or actual use or non-use values for others. The ideal classical economic valuation via a CBA considers the monetary evaluations of all effects a measure has on individuals aggregated over time, space, and persons. The aggregated value, the TEV, may then be compared to the TEV's of concurring measures[11].

Cost-benefit-analysis integrates the different aspects of the evaluation with the help of the revealed preferences of the individuals in using market prices for market goods and pseudo market prices for non-market goods. These pseudo market prices are calculated using functional equivalents for the altered natural functions or using prices that are given by respondents to questionnaires constructing a hypothetical market (this method is called contingent valuation method and is the mostly used method in economic environmental assessment). In this latter case, integration of different aspects happens within the heads of isolated individuals. All individual valuations of all aspects are then integrated on a monetary scale. Therefore, these values do not only cover costs of agriculture, forestry and other economic sectors, but also, for example, monetarised expressions of individual concern about the endangerment of species.

Whenever following the three steps of the procedure, i.e. specify physical effects, individual evaluation and aggregation of evaluations, in order to assess the impacts of biological invasions or of measures taken against invasions economically, one has to know the specific impacts of an invasion (or of the measures) on the ecological system, on individuals, and finally, one has to aggregate them. The knowledge of the ecological impacts implies that all ecological impacts such as impacts on biochemical cycles, world-wide homogenisation, replacement or extinction of indigenous species, altered species spectrum, different succession, etc. has to be known. Furthermore, it

[11] Such a comparison of interpersonally aggregated valuations is, strictly speaking, not compatible with the combination of two main assumptions of economics, i.e. methodological individualism and ordinal utility, as the gains and losses do not have the same distribution in all compared measures.

has to be clear which impacts these ecological changes have on the individuals, directly or via social changes. These impacts are then evaluated by the concerned persons themselves. The aggregation is done by summing up the individual monetary evaluations.

By comparing the TEV of different measures of control or prevention, economists are able to propose efficient measures which further most the well-being of the concerned individuals. Up to now, though, no complete evaluations of measures in the context of biological invasions have been made. (Cp. Pimentel et al. 2001 for an overview of existing economic appraisals of the invasion of specific species in specific areas, or Wilgen et al., 2001 for South Africa). The great majority of studies is centred around use values, i.e. the narrow economical effects of invasions resp. measures against them on agriculture, forestry, fishery, etc. For example, Barbier (2001) uses a two species model with limited interactions between the two species in order to calculate the loss of direct use of the endemic species due to the invasion. Pimentel et al. (2001) calculate a damage of at least US$ 314 billion per year in United States, United Kingdom, Australia, South Africa, India, and Brazil. 248 billion $ are due to crop, pasture, and forest losses. The greatest part of the resulting costs are losses in fishery, power production, or due to control activities. It is evident that there is still a long way to go to a methodologically sound complete economic evaluation of a biological invasion let alone of the sum of different biological invasions in one country or region.

The main source concerning the economics of biological invasions is the book with the same name of Perrings et al. (2000). The authors see a strong necessity for further case studies in this new field of economic research. Shogren et al. (1999) state three main reasons why economics matters for endangered species protection: human economic behaviour determines the degree of risk to a species, the costs of any measure protecting species must be taken into consideration, and economic incentives are critical in shaping human behaviour.

The next three chapters show how cost-benefit- analysis copes with the three dimensions of uncertainty.

3.1 Factual uncertainty

Assessment techniques must supply an appropriate way for integrating uncertainty.

1. An explicit way to consider uncertainty in CBA is to consider only those impacts that can be assessed clearly, and to take the lowest estimation of environmental damages in order not to overestimate the damages (Cp. for example Costanza et al., 1998). This practice of conservative estimation is in opposition to rational precautionary principles in cases of great uncertainty.
2. According to methodological subjectivism, only the concerned persons evaluate the consequences of a decision. The probabilities used in economic assessments are not objective, but subjective, and may be very vague. The problem of lay-person evaluation is enhanced by using their own subjective probabilities. Assessing and evaluating complex processes in complex systems may go well beyond the intellectual capacities of lay-persons, especially if these evaluations are done individually without possibilities of interactive communication. Even if the ecological consequences of measures against invasions would be known exactly, it would still be quite difficult to monetarise these consequences sensibly. Misconceptions or misinterpretations are unreproducible and thus incorrigible in contingent valuation studies.

Consequently, ignorance and uncertainty can not be addressed by evaluating physical or social effects with the help of monetary values (cp. O'Connor 2002). One way to account for ignorance would be to add some politically defined value to the costs or benefits, but it would prove difficult to find a methodologically sound reasoning for this proceeding.

3.2 Individual uncertainty

Due to this type of uncertainty, any assessment method must be open to different ethical conceptions, be it a multi-dimensional view of the "good", open to integrate non-persons, and to respect the right of future generations.

CBA is open only to a mono-dimensional view of the "good". Other views enter the calculus only by means of their expression and interpretation as monistic values (Sagoff, 1988b, calls this a categorical mistake). The trade-offs between different dimensions are partly explicit, partly – in contingent valuation – implicit.

The assumption of an overall substitutability of all effects may only be abandoned with the help of ad-hoc decisions on threshold values which do not really fit into the methodological frame. Irreversibility is not considered as a special topic. Non-persons or future persons are considered only via the amount of money contemporary individuals want to pay so that the former can use (or non-use) the evaluated good. The „good“ of future persons is furthermore considered via the integration of future evaluations. Mostly, the length such a consideration does not exceed 20 years, and if it does, the discounted evaluations are close to zero. This means, that, in practice, future generations do not count.

3.3 Social actor uncertainty

CBA is by itself a decision making process which takes into account the interests of all concerned persons (or less than all, as this is not practicable). It does so in an individualised way, using market values that are created by an atomised process, or asking persons separately and only with the possibility of giving monetary values. The TEV can be integrated into a social decision making process insofar as it can be one of several decision bases (this goes against its theoretical integrative reasoning based on utilitarianism). When it is combined with social or environmental assessments, then it dominates them in practice because of its apparent accuracy. It is questionable whether the TEV is well suited as a base for an open and fair discourse, or for the explicit inclusion of advocates for non-persons.

Critics arise, in conclusion, against CBA for several reasons:[12]

- irreversibility and uncertainty are difficult to handle,
- monetarisation may not yield a good measure of the moral “good”,
- there are doubts concerning the assumed overall substitutability of all different values linked to biological invasions and their consequences, and
- scepticism is expressed about the practical utility of a classical CBA for many decision processes.

Nevertheless, not to make an economic appraisal of a biological invasion may lead to an underestimation of its negative effects and, therefore, to a policy of *laissez faire* which does not take measures that might prove sensible.

[12] Cp. also Munda 1996.

It will be examined whether multi-criteria decision aid as a form of an integrated assessment can overcome these four main difficulties without losing theoretical foundations. The embedding of a multi-dimensional evaluation method into a well structured decision process might be a way towards a decision aid that – without losing the social force of economic arguments – does more justice to expert knowledge from natural sciences and to non-economical values of individuals. In the next chapter, such an integrated assessment will be described and analysed on its ability to handle the difficulties of irreversibility and uncertainty.

4. Multi-criteria decision aid

Mono-criterion assessments which do not integrate all aspects of a problem may be part of a multi criteria decision aid (MCDA). This method includes only parts of a complete CBA and evaluates other impacts on non-monetary scales. These might be measures of natural scientists or qualitative evaluations of experts or of lay-persons. This can be especially important in cases of high uncertainty that are emblematic for cases of biological invasions (Drechsler, 2001).

In order to assess the physical, but also other impacts of invasions as the first step of an MCDA process, different criteria are identified or constructed that give a complete picture of the relevant problem aspects. These criteria are not integrated into one yardstick by the calculation of trade-offs, but remain separated. The different measures are then assessed on each of the criteria separately, yielding an impact matrix. The following step, i.e. evaluating the effects and aggregating them individually, is twofold and explicit: (a) The decision maker state preference functions within the criteria, i.e. she states whether all changes of the same amplitude are of the same importance, or whether there are thresholds, etc. The impacts are then evaluated accordingly on each criterion separately in comparison to the impacts of other options. (b) The weights (or weight functions) of the different criteria are elicited from the decision maker in order to calculate trade-off-functions for the evaluated differences of the impacts in the criteria assessments. Due to thresholds, incomparabilities of options may result. The decision maker may in the third step of interpersonal aggregation use criterial preference functions, the weight evaluations of the different criteria or the final rankings of other persons

concerned by the decision. Dendograms, as developed by Munda (1995), might help in the social decision making.[13]

Multi-criteria decision aid proposes structures to decision makers. These structures are open to participation and may include scientific knowledge. They propose an analytical approach to the problem (i.e., problem definition, elaboration of a coherent family of criteria, designation of possible actions, criterial evaluation of the actions, and aggregation of the evaluations). Uncertainty and ignorance is relevant on each of these steps and it is possible to include uncertainty explicitly. Common feature of all decision aid methods is the assumption that the preferences are formed during the decision process. The aim is not necessarily the choice of one option, but more generally the elaboration of preferences, criteria, actions, and evaluations (Roy, 1996, Roy and Bouyssou, 1993). Such soft decision tools recognise ignorance as an inherent property of the decision process.

The main difference in the aim of CBA and MCDA is that the latter wants to compare different alternatives and not, as the former, identify the right value of one measure. Comparing different measures to each other leads to the danger that the ranking of the measures may change if one otherwise irrelevant alternative is added or omitted (Arrow and Raynaud, 1986). This disadvantage has to be balanced against the methodologically improper comparison of different TEV's (see above).

Multicriteria Analysis has, to my knowledge, not yet been applied to the problem of biological invasions. How could this be done? The example of the invasion of the brown tree snake (*Boiga irregularis*) in Guam, a pacific island belonging to the US, shows different dimensions of effects of an invasion. Before the invasion (probably through a military transport in the 1950's), Guam had no snakes and a rich endemic bird life. Now, 75% of the bird species have disappeared along with lizards, bats, and other species (Jaffe, 1994, Rodda and Fritts, 1992). These ecological effects are not the only impacts of the invasion: There were losses in poultry farming, electricity cuts, and also endangerment of human safety: babies and infants have been bitten while sleeping by the snake. As the poison of *Boiga irregularis* is slightly narcotising, the children continue to sleep. Snakes are even able to reach children sleeping in between their parents

[13] The methodological problem of interpersonal aggregation will not be discussed here. See on this: Arrow, 1997; Sen, 1997.

due to their sense of smell (Kregel, 1999). This last impact also implies changing of ways of behaviour and a sentiment of uncertainty and danger.

A narrow economic analysis would not make much sense here. Before assessing the damage, it has to be clear why it should be done. Is it for limiting the negative impacts of this invasion on Guam (1992, there were 12.000 snakes per km^2 on Guam, cp. Rodda et al. 1992) or for making people choose the right strategy against the invasion of *Boiga irregularis* on other tropical islands (the snake already reached, for example, Hawaii and Saipan, cp. US OTA 1993)?

A Multicriteria analysis would, as a cost-benefit-analysis, first try to estimate all ecological, social, and economic effects of an invasion, but would focus more on non-economic data than a CBA. The criteria and the measuring rods are elaborated during the concrete process, as well as the different policy options which are evaluated. The evaluation is done in comparing each alternative option against the others. The aim is not to find the efficient solution, but to structure the reflection process, clarify the necessities and trade-offs, and to make the decision process comprehensible.

How does multi criteria decision aid cope with the three dimensions of uncertainty?

4.1 Factual uncertainty

There are different conceptions of integrating factual uncertainty in MCDA: it may be integrated via a range of possible impacts, via a definition of a probability function or via fuzzy sets. As the assessments are compared to each other only in one criterion at a time, there is less danger of substituting different factual uncertainties concerning ecological, social or economic criteria among each other. There is no practice of conservative estimation – it is decided from case to case how to consider extreme values. Some criteria may be assessed by lay-persons, others by experts. The decision maker can interact with the assessor and learn to understand the systems and processes to some extent.

The problem of missing knowledge about probabilities and extent of damages is still existent, but it can be laid open. It is less the factual uncertainty itself that is different from the handling in CBA than the handling of it in the social and value discourse.

4.2 Individual uncertainty

Due to this type of uncertainty, any assessment method must be open to different ethical conceptions, be it a multi-dimensional view of the “good”, a way to integrate non-persons, and to respect the right of future generations.

Any multi-dimensional conception of the “good” may be represented in MCDA (cp. Funtowicz et al. 2002). Different methods of aggregation range from a transformation into mono-dimensional evaluation to a simple identification of dominating, dominated, and incomparable measures. It is up to the decision maker to decide on the aggregation form which is a reversible decision.

Non-persons or future persons may be considered either by means of advocates that weigh criteria for them or by means of special criteria. The latter way is an explicit consideration via the moral reflections of the decision maker.

It is possible to include explicitly persons hypothetically representing future generations in the decision team. Here, it is possible to guarantee a certain standard of intergenerational equity in giving each of the concerned generations the same weight. One has to take into account, though, that all dimensions of uncertainty accrue when trying to represent future generations.

4.3 Social actor uncertainty

MCDA allows to address many critical questions explicitly, and to open them up to a public discourse. This is especially valid for the question on who will evaluate, and on which ways this will be done. Apart the openness to multi-dimensional conceptions of the “good”, MCDA addresses most questions of uncertainty by making them explicit. This assessment technique therefore is a suitable basis for an open and fair discourse. In times of decisions about complex issues with high levels of uncertainty, ignorance, and irreversibility, and in complex societies with pluralistic moral convictions, the open and fair discourse is the most convenient way to make acceptable and well-founded decisions. MCDA can support many different forms of public discourse (see on this Wittmer et al., 2003, Rauschmayer and Wittmer, 2003).

Main differences to CBA are the following:

- Different forms of uncertainty, i.e. uncertainty about the relative importance of the different dimensions, uncertainty about the prognostics of the impacts,

and uncertainty about the decision actors to be considered, can be taken into account separately.

- It gives the possibility to use explicit thresholds, partially due to irreversibility, in distinct fields of impacts hereby reducing overall substitutability.
- Such an approach needs less transformation of expert knowledge into citizens' values by avoiding overall monetarisation.
- Finally, this decision aid process may be designed transparent for outsiders and open to changes occurring during the process, hereby adapting to the evolving needs of the decision actors. Changes might concern the impact dimensions, the different alternatives, the participating decision actors and the relevant alternatives for preventing or fighting the invasion.

5. Discussion

This chapter deals shortly with the four critical touchstones for choosing assessment or evaluation techniques, herewith treating (1) a fact-related question concerning the adequate representation of scientific and idiosyncratic knowledge in the decision process, (2) a fundamental question concerning ethics, (3) a methodological question concerning the right measure, and (4) a practical question concerning the feasibility of the chosen assessment technique.

- Is the knowledge base reflected adequately by the assessment technique?

CBA allows to integrate the actual knowledge of every concerned person. Using contingent valuation technique, this knowledge normally is enriched by information chosen by the team responsible for the evaluation. There is a very limited amount of information, normally at a very basic level that can be given to the questioned people. Enlarging their information base and their knowledge of the natural and social processes concerning an invasion is not really possible. Using focus groups (cp. Kontogianni et al., 2001) before the contingent valuation may help the team to enrich their idiosyncratic knowledge base and to include some of this information in the questionnaires, but normally no exchange of arguments and time of reflection in order to evaluate better is available to the questioned people. CBA must rely on three hopes: that the team identified the relevant impacts, that they condense the relevant information into the questionnaire, and that the questioned people believe the information given to them.

MCDA has to rely on the first hope, too. But the difference is that the team normally comprises of experts, stakeholders, and lay-persons who debate in a way structured by the multicriteria approach which should help to identify the relevant impacts. As there is a constant exchange between the evaluators and the team (who might be identical), it is assured to a high degree that the relevant information and knowledge base enters the evaluation process. Furthermore, as said before, factual uncertainties can better be identified and integrated into a MCDA than into CBA.

- Is the use of the technique consistent with the moral base of the society?

Each assessment of states or measures is reasonable if one knows the context of the assessment. At first sight, this context often is rather technical. E.g., in assessing an invading species, it makes only sense to determine the median flowering time of the species if this time is an indicator for some processes that influence for example the spread of the species (cp. Chittka and Schurkens, 2001). At second sight, and this becomes clearer in socio-economic assessment, the context is normative. We assess the impact of an invasion on agriculture because we think that such an impact (normally) is bad. Here, we have an anthropocentric impact, but the ethical context of other measures in the assessment might be biocentric, if we take the impact of an invasion on native species without clear economic functions. It has to be clear that the technique chosen is able to integrate all aspects that are judged relevant in the special context: It is the context that determines the technique. If we evaluate measures against invasions mainly in an economic environment where gains and losses can easily be measured in monetary terms (e.g. in assessing impacts of an invasion on agriculture), CBA may well represent the relevant normative aspects concerning contemporary monetary gains and losses. If the invasion concerns other aspects to a high extent, i.e. impacts on non-persons or future generations, or impacts that are not easily measurable in monetary terms, MCDA should prove to be the more appropriate assessment technique in respect to the moral base (cp. Rauschmayer 2001).

- Is the technique a useful base within the existent institutional conditions?

For reasons of practicality, assessment techniques have to be feasible. The institutional context of the issues differ from one another: Which actors are

concerned by a measure? Can they influence the impact of the measure? Do they have additional knowledge? Does legitimacy or legality require that some actors take part in the decision? Answers to these questions concern the assessment techniques insofar as the technique chosen might have to be open to participation and common decision making. Furthermore, assessments have to be done in different depths: assessments in urgent issues must be done rapidly, they have to be low cost, at least in a first stage. In a second stage, when one knows already that there are high stakes, i.e. that the consequences of the different measures might vary to a large extent, assessments may be expensive. As stated above, MCDA is more open to an active participation of actors than CBA. Furthermore, MCDA may be done on a very rough level and on a very detailed level, just as appropriate. It is more difficult to do a CBA on a rough level: Due to the principle of conservative evaluation, uncertain impacts are left out, and these are – in a rough evaluation – mainly non-monetary impacts (e.g. Pimentel et al., 2001). The resulting TEV is only a lower limit of the impacts, but it is usually given in sharp numbers, making the illusion of a detailed evaluation and not of a rough evaluation.

- Are the yardsticks used a good measure of the overall aim?

The assessment technique has to make sense in the given context and it is dependent on the aim of the assessment. At one side of the range is a mono-dimensional situation where e.g. a farmer wants to maximise his medium-range profit within the next 20 years. Here, everything can be calculated in monetary terms, as it is only money that counts. On the other side, there is a situation where many decision-makers with quite different ethical convictions want a sustainable management of a forest in a long-term perspective. Here, money counts, but also social cohesion of the forest users, soil quality, the self-renewing capacity of the forest, biodiversity within (above and beneath) the forest, etc. Here, it is hardly conceivable that one yardstick (monetary or any other) would make sense. Calculating trade-offs between income, water quality, and social cohesion would not make sense in such a context (Norton 2002). Whereas CBA makes sense, when it is the aim to reach a good monetary outcome for society or business, MCDA makes more sense in more complex situations. The different yardsticks will be chosen appropriate to the different criteria, and the aggregation of the different criteria (and potentially the different evaluators) will be made explicitly. There is no generally best way to aggregate

the different dimensions of the problem, and the context-dependent best way can only be found within the context itself.

In conclusion, there are four advantages of Multicriteria decision aid to cost-benefit-analysis as an integrated assessment of biological invasions:

1. It reflects better the existing knowledge base.
2. It allows a wider and more appropriate integration of moral points of view.
3. It can better be included in social decision processes.
4. It allows a better representation of the problem in most contexts.

The invasion of foreign species is a dynamic and specific process which is very difficult to predict and which normally has irreversible impacts on many aspects of human and non-human life. Therefore, a socially embedded multicriteria assessment is generally more appropriate than a cost-benefit-analysis. The latter may only be used sensibly in very special cases.

Acknowledgements

I am grateful to the UFZ – Centre for Environmental Research Leipzig-Halle for the facilitation of my research. I wish to thank my colleagues Jaroslav Mysiak and Ingolf Kühn for their helpful comments.

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