(19) SOCIO-ECONOMIC IMPACTS AND ASSESSMENT OF BIOLOGICAL INVASIONS

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(19.)1 Introduction

Biological invasions have been object of ecological research for years. As one objective, natural scientists investigate the effects of invasive species on ecosystems and their functioning (Levine et al. 2003). However, impacts on ecosystems are also of relevance for society. Changes in ecosystems affect humans in so far as ecosystems provide goods and services, such as fresh water, food and fibbers or recreation, which might be altered due to invasive species. Therefore impacts of biological invasions should be an object of socio-economic interest, which is also demanded by the Convention on Biological Diversity (2002).

The following chapter aims at providing elements for the analysis of impacts of invasive species from the socio-economic point of view. Such an analysis is politically relevant, since impacts are the focal point of every decision to establish a proper management regime. For an encompassing analysis an integrative framework is needed to structure the information on impacts. For that purpose, the concept of Ecosystem Services is introduced (see Sect (19.)2). Alternative decisions on the appropriate management of invasive species face trade-offs between outcomes and impacts. For handling such trade-offs evaluation is needed. As it is discussed in Sect. (19.)3), perception presents the prerequisite of an explicit evaluation. Finally, different evaluation methods are introduced so as to value the information about impacts during the decision-making process (see Sect. (19.)4).

(19.)2 Impacts on ecosystems from the perspective of human well-being

Identifying the impacts of invasive species is required in order to evaluate the consequences of invasion processes and to implement management measures. The purpose of this section is to
present an integrated framework for structuring the information on impacts to describe what happens if an invasion occurs. First, this is done by defining what type of impacts can be associated with bioinvasions. Secondly, the concept of Ecosystem Services is used for classifying these impacts. As humans depend on ecosystem and ecosystem processes, effects caused by biological invasions can have high socio-economic relevance. Perceptions and assessment of these effects will determine policy-making.

From a socio-economic point of view, impacts are changes of recipient ecosystems that are perceived by humans and caused by biological invasions. Next to impacts on Ecosystem Services, biological invasions can also have impacts on human made goods and services, such as road systems or artificial waterways and reservoirs. Although damages to human made infrastructure can be considerable, in the following the focus is on impacted services supplied by natural or semi-natural ecosystems (Kühn et al. 2004).

Two types of impacts can be identified. The first type includes direct impacts of invasions on ecosystem functions and on human well-being. The second type refers to indirect impacts that stem from the implementation of response actions, such as control costs or side-effects of the introduction of biological control agents (Tisdell 1990). A comprehensive decision-making process demands reviewing both types of impacts. However, impact assessment studies do not always distinguish both types of impacts.

(19.)2.1 Impacts of biological invasions on Ecosystem Services

By affecting the ecological processes at the level of genes, species and ecosystems, biological invasions modify the provision of Ecosystem Services. Defined as “the conditions and the processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life” (Daily 1997), Ecosystem Services are foundations of human well-being. Thus, Ecosystem Services encompass ecological and socio-economic aspects of ecosystems, illustrating the human dependence on ecosystem functioning. Impacts of biological invasions on ecosystems are of socio-economic concern as they alter the benefits provided by ecosystems for human life.

The Millennium Ecosystem Assessment (2003) works with a taxonomy of Ecosystem Services encompassing four main categories (see also Figure 19.1):

1. Supporting services are those necessary for the production of all other Ecosystem Services;
2. Provisioning services refer to the products obtained from ecosystems;
3. Regulating services are benefits supplied by self-maintenance properties of ecosystems;
4. Cultural services generate non-material benefits derived from ecosystems;

Insert figure 19.1 around here
Table (19.)1 compiles examples about impacts of various well-known invasive species. It reveals impacts of invaders on certain Ecosystem Services by describing their alteration.

As can be noted, there are many mechanisms how biological invasions can impact different types of Ecosystem Services. The most evident examples are effects on the provisioning of food. For instance, agricultural and forestry yields are affected by pests as Russian wheat aphid (*Diuraphis noxia*) (Brewer et al. 2005), sirex wasp (*Sirex noctillo*) and the skeleton weed (*Chondrilla juncea*) (Cullen and Whitten 1995), to mention some. Commercial catches and aquaculture are also damaged by species like comb jelly (*Mnemiopsis leidyi*) (Knowler 2005).

Other impacts such as the ones caused by zebra mussel (*Dreissena polymorpha*) affect human-made goods and services, damaging different hydraulic infrastructures worldwide (Minchin et al. 2002). Similar impacts are associated to the Asian green mussel (*Perna viridis*) (Hayes et al. 2005). Other damages to infrastructure are caused by species like common pigeon (*Columba livia*), Formosan termite (*Coptotermes formosanus*) and shipworm (*Teredo navalis*) (Pimentel et al. 2005).

Table (19.1) also illustrates that one single species can have a variety of effects. For instance, the black wattle (*Acacia mearnsii*) affects the regional water table, local vegetation cover, i.e. species composition, and also alters the recreational function of the Cape region in South Africa, since people gain less access to rivers and lakes (Galatowitsch and Richardson 2005).

By structuring the information about impacts using the Ecosystem Services categories, some general characteristics can be outlined:

1. the variety of impacts caused by invasive species and
2. the complexity of impacts on Ecosystem Services;

Ecosystem Services and impacts on them are not only manifold, but also complex, as it can be illustrated with the example of the Nile perch (*Lates niloticus*). Its intentional introduction to some African lakes for aquaculture and sport fishing resulted in the extirpation of 200 native fish species (Kasulo 2000). That led to a shift of the whole ecosystem as the availability of phytoplankton changed, altering the local fish species composition (Chu et al. 2003). This introduction favoured a prospering fish industry around the lake due to increased profits from perch exports. However, while native fish was not any longer available, local habitants could not afford high prices of the perch and could not complement their diet. Additionally the availability of fuel wood decreased because it was used to dry the perch, which was necessary to preserve it but had not been necessary with the small native fish, which could be sun-dried instead of being smoked. In this example the intentional modification of the ecosystem to improve the services of recreation (sport fishing) and the provisioning of food for exports...
(aquaculture) had side effects such as the decrease of habitat stability. Furthermore, cultural practices and social relations changed and the diet base of locals worsened instead of being improved.

The Nile perch example does not only serve to highlight the complexity of affected Ecosystem Services. It also shows the interlinked ecological and socio-economic dimensions of impacts as in this case, some impacts show a direct influence on human well-being, such as the alteration of the provisioning service of food and fuel.

(19.)3 Perception as a prerequisite for valuation

Invasive species cause manifold effects. How they are valued depends on human perception at a given point in time. Interests embedded in cultural contexts and the production patterns configure the personal attribution of the positive or negative character to a given effect. Then, when including these individual or collective appraisals in the decision-making process their context dependency should be taken into account (see Sec. (19.)4).

Certain impacts of invasive species are of public concern, such as health problems, like asthma and allergies caused by the rag weed (*Ambrosia artemisiifolia*) (Zwander 2001). Others, such as alterations in ecosystem integrity are not an object of the public discussion. For instance, ecosystem integrity in Canada is strongly affected by the common reed (*Phragmites australis*) (Maheu-Giroux and Blois 2005). Although it changes habitat conditions, it is generally outside the set of social concerns. As the linkage between its impacts on ecosystems and human well-being is not obvious, people that are not involved in conservation issues care little. Invasions in waters take place mostly in a hidden manner (Nehring 2005). Lack of social concern about the ecologically damaging green alga (*Caulerpa racemosa*) is a good example (Cavas and Yurdakoc 2005; Piazzì et al. 2005; Ruitton et al. 2005). In fact, plant invaders (not only aquatic) that affect the ecosystem integrity are often not of public concern.

Another aspect of perception is that from a utilitarian point of view, not all the effects are damages. For instance soil aggregation is enhanced by barb goatgrass (*Aegilops triuncialis*) (Batten et al. 2005) and black wattle (*Acacia mearnsii*) increases nitrogen levels in soils (De Wit et al. 2001; Le Maitre et al. 2002). While ecologically concerned people may regard these changes as indifferent or undesirable, farmers might take advantage of them. In fact, many introduced species are valued both positively and negatively by different stakeholders. An example is brown trout (*Salmo trutta*) that displaces native species and affects cultural practices dependent on them. However, it also promotes economic activities related to recreational angling (Quist and Hubert 2004). Indeed, invasive fish species favouring emergent sport fisheries often feature a positive social opinion in spite of adverse ecological impacts. This example illustrates that personal or social interest can give importance to some effects of an invasive species while neglecting others.
As explained above, valuation is dependent on perception. The perception of impacts is heterogeneous, context-dependent and dynamic. The alien invasive species acacia (*Acacia sp.*) was introduced for pulp production and tanning compounds extraction in plantations in South Africa (De Wit et al. 2001). Its spread out of control has been associated with changes in water regulation. Different positions that stakeholders have on the impacts of this species show its heterogeneous character, i.e. on the one hand, communities suffer from water scarcity while on the other hand, they benefit from increased access to fuel wood and timber for building materials. The example also shows the dynamic and context dependent character of valuation. The effects of acacia on water regulation hit a main concern of the affected communities. Information on the effects allowed the creation of social partnerships for its control. The fight against plant invaders in this country has been boosted by means of the ‘Working for Water Program” (www.dwaf.gov.za/wfw). In this case, information led to higher awareness. The previous reasoning demonstrates the need of identifying the stakeholders and their roles as prime perceivers and promoters of impacts. Due to the reflexive nature of the invasion processes (new relevant attributes are continuously added to the relationship between people and invasive species), participation of stakeholders in both identification of outcomes and analysis of priorities is needed in the evaluation processes. The advantage of the concept of Ecosystem Services lies in the structuring of information about impacts. Further analysis can be done to discuss stakeholders perception on the impacts. Such impacts can be taken into account in the valuation concerning the appropriate management of the species.

(19.) 3.1 The consideration of uncertainty

By revealing the direct and indirect influence of invasive species on human well-being the Ecosystem Service concept also supports the reflection on uncertainty and ignorance. One key feature of invasive species processes is often the lack of knowledge. Due to the complexity of the interlinked ecological processes the predictive power of information available about dispersal rates, traits and ecological behaviour is small (Williamson 1996). Furthermore, often there is no such information, especially not on the social impacts of invasive species. However, for decision making it is necessary to structure the available information on impacts. The use of the Ecosystem Services concept can serve this aim because it reveals whether the information about impacts is available or not. Under conditions of uncertain outcomes and irreversible effects, a precautionary approach should be employed concerning the management decisions on invasive species.

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1 Uncertainty exists if outcomes are known but the distribution of probabilities cannot be identified. Ignorance can be defined as the situation where neither the probability for the potential outcome nor for the outcome itself are known. In other words, “we don’t know what we don’t know” (Wynne 1992).
Decision-making requires evaluation because trade-offs between different management options occur, e.g. if a certain management option promotes one impact and at the same time diminishes another. For instance, eradicating the black wattle (*Acacia mearnsii*) in the Cape Region on the one hand implies diminished access to fuel wood for the local population while on the other hand it increases fresh water availability. Furthermore, decisions about invasive species management should take the perceptions of affected people into account. The acceptance and outcome of the decisions will be highly dependent on the individual or social perception of the impacts due to the invasive species.

Management means how to deal with impacts of biological invasions. It takes place at different stages of the invasion process, either preventing an introduction (accidental or intentional) or managing an invasive species once it is established. Uncertainties linked to the process will vary depending on the invasion stage. A sound decision-making process should also reflect on that (Born et al. 2005).

The purpose of this section is to introduce five approaches to the evaluation of management alternatives concerning invasive species. In this context, operational implications when assessing impacts of biological invasions by means of these approaches are discussed. Table (19.)2 presents the main characteristics of each approach. However, it is important to note that every approach features a variety of specific methodologies and techniques. Therefore, the specific processes and operational constraints can differ depending on the specificities of the implementation process. Additionally, a combination of methods is sometimes advisable.

(19.)4.1 Risk Assessment

One of the approaches most used as a predictive tool concerning biological invasions is risk assessment. It aims at measuring risk by determining the likelihood of an introduction and the potential adverse effects, given available knowledge about alien invasive species and the recipient ecosystem. Risk assessment for invasive species is generally adopted in order to assess decisions regarding the introduction of potentially invasive species, their pathways and vectors before establishment. However, it might also be used for allocating resources to management measures once the species is already established. For instance, the US Environmental Protection Agency developed a framework for using three main steps: a) problem formulation; b) analysis of exposure and effects and c) risk characterisation (EPA 1998). For invasive species exposure, analysis involves estimating the likelihood of introduction, establishment and/or spread, taking
into account quantity, timing, frequency, duration and pathways of exposure as well as number of species, their characteristics and the characteristics of the recipient ecosystem (Andersen et al. 2004). As this approach is based on expert judgement, participation of other interested groups is not foreseen. Results from the assessment can be both quantitative and qualitative, although the former is usually the goal (Simberloff 2005). Expenditure and time requirements usually remain low, since it mainly involves standard procedures (e.g. guidelines established by the European and Mediterranean Plant Protection Organization EPPO (www.eppo.org)).

(19.)4.2 Cost-Benefit Analysis

Cost-benefit analysis is the traditional evaluation instrument in the framework of welfare economics analysis. It assesses current and future costs and benefits in monetary units, associated with a range of alternatives, projects or policy instruments. It intends to consider all impacts of invasive species that can be valued in monetary terms, including the direct costs and benefits of invasives. This implies that the valuation of environmental damages as well as of environmental services has to be conducted in monetary units, allowing the substitutability between Ecosystem Services and human made goods and services, even if no markets exists for the service at hand. This method provides an “optimal solution” by ranking the alternatives. Participation of social groups is not necessary but might be considered, for instance in the assessment of their willingness to pay. Time and costs requirements will depend on the specific techniques employed in the assessment. For instance, doing a contingent valuation (assessing the willingness to pay or willingness to accept) will increase costs compared to the use of secondary source data. A representative example of this method is the extensive work on the fynbos biome of the Cape Floristic Region in South Africa, where cost-benefit analysis was used to analyse the consequences of plant invasions (e.g. Acacia sp., Eucaliptus sp.) on water supply (Enright 2000; De Wit et al. 2001; McConnachie et al. 2003). Another contribution consistent with this approach is the highly referenced work developed by Pimentel et al. (2005). To consider all impacts, again uncertainty must be ruled out. Essentially, cost-benefit analysis is a monetisation of risk assessment to generate substitutability. Thus, it allows obtaining optimal solutions.

(19.)4.3 Cost-Effectiveness Analysis

When benefits of control actions of invasive species are difficult to assess, economics can use Cost-Effectiveness Analysis to find the policy instrument or alternative best suited to avoid surpassing a given threshold of invasion. To reach the defined goal several alternatives are compared so as to obtain an optimal solution by evaluating the direct and indirect costs
associated with the implementation of these management options. The costs of keeping the invasion below the threshold are expressed in monetary units but the threshold itself is in physical terms (Baumol and Oates 1988). Assume the objective to diminish the presence of an invasive species by 50%, this method reveals the cheapest control option - the most “cost-effective instrument” - to decrease current infestation level to this socially desired threshold. Reduction thresholds are established from outside strict economic reasoning, so this approach can require a higher level of participation. Expenditure and time associated with the implementation of this method may vary according to the employed techniques. This approach has been used by Dehnen-Schmutz et al. (2005) to analyse private and public expenditure allocated to different control options to manage *Rhododendrum ponticum* in the British Isles. All ignorance/uncertainty around the definition of the threshold is outside the methodology. For the impacts of the management options again uncertainty is assumed not to exist (otherwise no well-defined optimum exists).

(19.)4.4 Multi-Criteria Analysis

Limitations in achieving monetary accountings of impacts, existence of conflicting values and uncertainties inherent to the invasion and the decision-making process are challenging conditions to assess invasive species. A methodological response are multi-criteria analysis, a family of methods rooted in operational research. It compares different alternatives by contrasting the performance of this set of alternatives according to different criteria (Munda 2004). In the context of invasive species alternatives exist concerning the choice of management options to encounter impacts. The Multi-Criteria approach allows incorporating multiple dimensions of effects and including both qualitative and quantitative information associated with impacts of invasive species and those related to implementation of management responses. Results from most of the multi-criteria methods provide a ranking of feasible alternatives. These can be achieved either by a vertical approach where no compensability exists (no trade-offs) (e.g. lexicographic methods) or by a horizontal approach that allows varying degrees of compensability (e.g. multi-attribute theory, outranking methods). It has been used by Maguire (2004) to analyse trade-offs among conflicting objectives for controlling feral pigs (*Sus scrofa*) in Hawaii. In multi-criteria evaluation, the selection of alternatives and criteria may be decided during a participative deliberation exercise; therefore, attention is placed on the learning process and achieving a compromise solution rather than an optimal solution. Application will usually require longer time and higher costs.

(19.)4.5 Scenario Development
Another analytical technique that has been used to face uncertainty and to integrate different values is scenario development. As opposed to predictions implying no uncertainties, this method is designed to deliver results in situations characterized by uncertainty. A variety of methods employ the term scenario referring to possible outcomes of different management alternatives. However, scenario development is also a method itself. Within this approach scenarios are descriptions of alternative images of the future, created from mental models that reflect different perspectives on past, present and future events (Rotmans et al. 2000). They provide representations of plausible futures and typically include a narrative element called storyline, sometimes supported by quantitative indicators (Berkhout et al. 2002). Impacts of alien invasive species and effects associated with the implementation of response measures can be included when conducting deliberation on causal processes and outcomes of biological invasions. Social participation is desired to increase internal coherence of scenario development and to incorporate different perspectives. Its main purpose is to decrease uncertainty by discourse-based decisions. Cost and time requirements can vary depending on the specific process, but as in other methods that pursue participation, they can be high. For instance, Chapman et al. (2001) used this approach to analyse different management scenarios of invasive species in South Africa to improve decision support.

Concluding remarks
This chapter illustrates impacts of invasive species from the socio-economic point of view under the integrative framework of Ecosystem Services. This framework allows for a comprehensive review of the variety of impacts caused by invasive species. It links ecological effects of invasive species with the foundations of human well-being, as humans are dependent on ecosystems and their functioning by supplying special services to the society. Invasive species can disrupt such Ecosystem Services. Throughout the variety of examples displayed in the chapter it can be seen that both the effects and the response impacts are perceived differently by social groups. Individual or social perception is considered to be a prerequisite for the valuation of the impacts in the context of decision making to take the appropriate management. Using Ecosystem Service categories helps to organize impacts when presenting information to interest groups, and it can help to include plural perspectives during the valuation processes. In this way, the multidimensional character of impacts is highlighted.

Additionally, assessment approaches deal with impacts differently. Every method has different potentials and constraints that shape its use for supporting decision making. Choosing the most suitable approach may respond to different reasons, such as the type of information employed, the participation potential, the consideration of uncertainty and, especially, the type of impacts.
that are taken into account. In fact, the further away the impact is from holding a market price, the most relevant is social participation in the deliberation process.

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References
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Figure 19.1 Classification of Ecosystem Services according to the Millennium Assessment categories.

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<th>Impact description / Effect</th>
<th>Associated species (examples)</th>
<th>Reference</th>
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<td>Soil formation</td>
<td>Changes in biochemical characteristics of soils</td>
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<td>Ecosystem Service</td>
<td>Impact description / Effect</td>
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Table (19.)2 Overview of evaluation approaches for the management of invasive species

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<td>Introduction and/or control</td>
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<td>Control</td>
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<td>Purpose of the evaluation</td>
<td>Risk level</td>
<td>Ranking (optimisation)</td>
<td>Ranking (optimisation)</td>
<td>Deliberation and ranking</td>
<td>Deliberation and prospective storylines</td>
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<tr>
<td>Type of impacts</td>
<td>Associated with invasion species</td>
<td>Caused directly by invasive species and those derived from</td>
<td>Associated with species management responses</td>
<td>Associated with invasive species and/or those</td>
<td>Associated with invasive species and/or those</td>
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<td>Type of information used</td>
<td>Quantitative and qualitative</td>
<td>Quantitative (monetary)</td>
<td>Quantitative and qualitative</td>
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<tr>
<td>Participation potential</td>
<td>Low</td>
<td>Low/Medium</td>
<td>Medium</td>
<td>High</td>
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<td>Consideration of uncertainty</td>
<td>Uncertainty reduced to probability or precautionary approach</td>
<td>Sensitivity analysis</td>
<td>Sensitivity analysis</td>
<td>Robustness analysis, accounting for fuzzy data,</td>
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<td>Operative constraints</td>
<td>Low cost and time requirement</td>
<td>Low-medium cost and time requirement</td>
<td>Low-medium cost and time requirement</td>
<td>Medium-high cost and time requirement</td>
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<tr>
<td>Methodological constraints</td>
<td>Intrinsic uncertainties, risk thresholds</td>
<td>Trade offs between natural capital and human-made capital, use of discount rate</td>
<td>Definition of thresholds</td>
<td>Lack of crisp results, non-replicable results</td>
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