Forthcoming in 'Ecological studies, Vol. 193: Biological invasions' (Wolfang Nentwig, ed.), Springer Verlag
DRAFT VERSION.

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

Binimelis, Rosa

Institute of Environmental Science and Tecnology (ICTA), Autonomous University of Barcelona, Spain

Born, Wanda

Department of Economics, UFZ – Centre for Environmental Research Leipzig-Halle, Germany

Monterroso, Iliana

Institute of Environmental Science and Tecnology (ICTA), Autonomous University of Barcelona, Spain

Rodríguez-Labajos, Beatriz

Institute of Environmental Science and Tecnology (ICTA), Autonomous University of Barcelona, Spain
Corresponding author

(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.

Insert table 19.1 around here

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; Piazzi 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[1]. 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.

[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).

(19.)4 Alternatives for the evaluation of impacts: from valuation to deliberation

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.

Insert table 19.2 around here

(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.

(19.)5 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.

Acknowledgements

We would like to thank Ingo Bräuer, Ingolf Kühn, Joan Martinez Alier, Johannes Schiller and Joaquim Spangenberg for useful comments on an earlier draft. The ICTA-UAB group on the socio-economics of biological invasions is funded by the EC within the FP 6 Integrated Project "ALARM" (COCE-CT-2003-506675), and Wanda Born by the project "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.

References

Andersen MC, Adams H, Hope B, Powell M (2004) Risk analysis for invasive species: general framework and research needs. Risk Analysis 24(4): 893-900

Batten KM, Six J, Scow KM, Rillig MC (2005) Plant invasion of native grassland on serpentine soils has no major effects upon selected physical and biological properties. Soil Biology and Biochemistry 37: 1177-1183

Baumol W, Oates W (1988) The Theory of Environmental Policy. Cambridge University Press, Cambridge, UK.

Beard KH, O'Neill EM (2005) Infection of an invasive frog *Eleutherodactylus coqui* by the chytrid fungus *Batrachochytrium dendrobatidis* in Hawaii. Biological Conservation 126(4): 591-595

Beever EA, Brussard PF (2004) Community- and landscape-level responses of reptiles and small mammals to feral-horse grazing in the Great Basin. Journal of Arid Environments 59(2): 271-297.

Berkhout F, Hertin J, Jordan A (2002) Socio-economic futures in climate change impact assessment: using scenarios as 'learning machines'. Global Environmental Change 12: 83-95

Bertram G (1999) The impact of introduced pests on the New Zealand economy. In: Hackwell K, Bertram G (ed). Pests and weeds, a blueprint for action. New Zealand Conservation Authority, Wellington, pp 45-71

Blancafort X, Gomez C (2005) Consequences of the Argentine ant, *Linepithema humile* (Mayr), invasion on pollination of *Euphorbia characias* (L.) (Euphorbiaceae). Acta Oecologica 28(1): 49-55

Born W, Rauschmayer F, Bräuer I (2005) Economic evaluation of biological invasions – a survey. Ecological Economics 55: 321-336

Brewer MJ, Noma T, Elliott NC (2005) Hymenopteran parasitoids and dipteran predators of the invasive aphid *Diuraphis noxia* after enemy introductions: Temporal variation and implication for future aphid invasions. Biological Control 33(3): 315-323

Buhle ER, Margolis M, Ruesink JL (2005) Bang for buck: cost-effective control of invasive species with different life histories. Ecological Economics 52: 355-366

Cavas L, Yurdakoc K (2005) A comparative study: Assessment of the antioxidant system in the invasive green alga *Caulerpa racemosa* and some macrophytes from the Mediterranean. Journal of Experimental Marine Biology and Ecology 321(1): 35-41

Chapman RA, Le Maitre DC, Richardson DM (2001) Scenario planning: understanding and managing biological invasions in South Africa. In: McNeely JA (ed) The great reshuffling. Human dimensions of invasive alien species. IUCN, Gland and Cambridge, pp 195-208

Chu D, Strand R, Fjelland R (2003) Theories of complexity. Common denominators of Complex Systems. Complexity 8(3): 19-30

Convention of Biological Diversity (2002) Decision VI/23. Alien species that threaten ecosystem, habitats or species, Sixth Ordinary Meeting of the Conference of the Parties to the Convention on Biological Diversity, The Hague

Cullen JM, Whitten MJ (1995) Economics of classical biological control: a research perspective. In: Hokkanen H, Lynch MT, James M (ed) Biological control: benefits and risks. Cambridge University Press, Cambridge, pp 270 - 276

Daily GC (ed) (1997) Nature's services. Societal dependence on natural ecosystems. Island Press, Washington, D.C.

De Groote H, Ajuonu O, Attignon S, Djessou R, Neuenschwander P (2003) Economic impact of biological control of water hyacinth in Southern Benin. Ecological Economics 45: 105-117

Dehnen-Schmutz K, Perrings C, Williamson M (2005) Controlling *Rhododendron ponticum* in the British Isles: an economic analysis. Journal of Environmental Planning 70: 323-332

De Wit MP, Crookes DJ, Van Wilgen BW (2001) Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion. Biological Invasions 3: 167-178

Enright WD (2000) The effect of terrestrial invasive alien plants on water scarcity in South Africa. Phys. Chems. Earth. 25(3): 237-242

EPA (1998) Guidelines for Ecological Risk Assessment. Report No. EPA/630/R-95/002F. Risk Assessment Forum, Washington D.C.

Galatowitsch S, Richardson DM (2005) Riparian scrub recovery after clearing of invasive alien trees in headwater streams of the Western Cape, South Africa. Biological Conservation 122(4): 509-521.

Gilbert M, Svatos A, Lehmann M, Bacher S (2003) Spatial patterns and infestation processes in the horse chestnut leafminer *Cameraria ohridella*: a tale of two cities. Entomologia Experimentalis et Applicata 107: 25-37

Griffiths R, Madritch M, Swanson A (2005) Conifer invasion of forest meadows transforms soil characteristics in the Pacific Northwest. Forest Ecology and Management 208(1-3): 347-358

Hails RS, Hernandez-Crespo P, Sait SM, Donnelly CA, Green BM, Cory JS (2002) Transmission patterns of natural and recombinant baculoviruses. Ecology 83: 906-916

Hánel L (2004) Colonization of chemical factory wastes by soil nematodes. Pedobiologia 48(4): 373-381

Hayes KR, Cannon R, Neil K, Inglis G (2005) Sensitivity and cost considerations for the detection and eradication of marine pests in ports. Marine Pollution Bulletin 50(8): 823-834

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

Knowler D (2005) Reassessing the costs of biological invasion: *Mnemiopsis leidyi* in the Black sea. Ecological Economics 52(2): 187-199

Knowler D, Barbier E (2005) Importing exotic plants and the risk of invasion: are market-based instruments adequate? Ecological Economics 52(3): 341-354

Kühn I, Brandenburg M and Klotz S (2004) Why do alien plant species that reproduce in natural habitats occur more frequently? Diversity & Distributions 10(5/6): 417-425

Landis WG (2003) Ecological risk assessment conceptual model formulation for non-indigenous species. Risk Analysis 24(4): 847-858

Lages BG, Fleury BG, Ferreira CEL, Pereira RC (2006) Chemical defense of an exotic coral as invasion strategy. Journal of Experimental Marine Biology and Ecology 328(1): 127-135

Le Maitre DC, Van Wilgen BW, Gelderblom CM, Bailey C, Chapman RA, Nel JA (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

Lesica P, Miles S (2004) Ecological strategies for managing tamarisk on the C.M. Russell National Wildlife Refuge, Montana, USA. Biological Conservation 119(4): 535-543

Levine JM, Vilà M, D'Antonio CM, Dukes, JS, Grigulis K, Lavorel S (2003) Mechanisms underlying the impacts of exotic plant invasions. The Royal Society Review 270: 775-781

Maguire LA (2004) What can decision analysis do for invasive species management? Risk Analysis 24(4): 859-868

Maheu-Giroux M, Blois SD (2005) Mapping the invasive species *Phragmites australis* in linear wetland corridors. Aquatic Botany, 83: 310-320

McConnachie AJ, De Wit MP, Hill MP, Byrne MJ (2003) Economic evaluation of the successful biological control of *Azolla filiculoides* in South Africa. Biological Control 28: 25-32

Millennium Ecosystem Assessment (2003) Ecosystems and human well-being. A framework for assessment. Island Press, Washington, D.C.

Minchin D, Lucy F, Sullivan M (2002) Zebra mussel: impacts and spread. In: Olenin S (ed) Invasive aquatic species of Europe - distribution, impact and management. Kluwer Academic Publishers, Dordrecht, pp. 135-146

Monterroso I (2005) Comparison of two socio-economic assessment methods for the analysis of the invasion process of *Hydrilla verticillata* in Lake Izabal, Guatemala. Master dissertation. Ph.D. Program of Environmental Sciences, Universitat Autònoma de Barcelona, Bellaterra

Munda G (2004) Social multi-criteria evaluation: methodological foundations and operational consequences. European Journal of Operational Research 158: 662-677

Nehring S (2005) International shipping - A risk for aquatic biodiversity in Germany. In: Nentwig W, Bacher S, Cock MJW, Dietz H, Gigon A, Wittenberg R (eds) Biological Invasions - From Ecology to Control. Neobiota 6: 125-143.

OTA (1993) Harmful Non-Indigenous Species in the United States. U.S. Congress, Office of Technology Assessment, Washington DC.

Piazzi L, Balata D, Ceccherelli G, Cinelli F (2005) Interactive effect of sedimentation and *Caulerpa racemosa* var. *cylindracea* invasion on macroalgal assemblages in the Mediterranean Sea. Estuarine, Coastal and Shelf Science 64(2-3): 467-474

Pimentel D, Zuniga R, Morrison D (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52(3): 273-288

Quist MC, Hubert WA (2004) Bioinvasive species and the preservation of cutthroat trout in the western United States: ecological, social, and economic issues. Environmental Science & Policy 7(4): 303-313

Rodríguez-Labajos B (2006) Interlinked biological invasions in the Ebro River. A multi-scale scenario approach. Master dissertation. Ph.D. Program of Environmental Sciences, Universitat Autònoma de Barcelona, Bellaterra

Rotmans J, van Asselt M, Anastasi C, Greeuw S, Mellors J, Peters S, Rothman D, Rijkens N (2000) Visions for a sustainable Europe. Futures 32(9-10): 809-831

Ruitton S, Javel F, Culioli JM, Meinesz A, Pergent G, Verlaque M (2005) First assessment of the *Caulerpa racemosa* (Caulerpales, Chlorophyta) invasion along the French Mediterranean coast. Marine Pollution Bulletin 50(10): 1061-1068

Sharov AA, Liebhold AM (1998) Bioeconomics of managing the spread of exotic species with barrier zones. Ecological applications 8(3): 833-845

Simberloff D (2005) The politics of assessing risk for biological invasions: the USA as a case study. Trends in Ecology and Evolution 20(5): 216-222

Stenseth NC, Leirs H, Skonhoft A, Davis SA, Pech RP, Andreassen HP, Singleton GR, Lima M, Machangu RM, Makundi RH, Zhang Z, Brown PB, Shi D, Wan X (2003) Mice and rats: the dynamics and bioeconomics of agricultural rodents pests. Front. Ecol. Environ. 1(7): 1-12

Takahashi LT, Maidana NA, Ferreira J, Wilson Castro P, Yang HM (2005) Mathematical models for the *Aedes aegypti* dispersal dynamics: travelling waves by wing and wind. Bulletin of Mathematical Biology 67(3): 509-528

Tisdell CA (1990) Economic impact of biological control of weeds and insects. In: Mackauer M, Ehler LE, Roland J (ed) Critical issues in biological control. Interdept Lt, Andover, pp 301-316

Vitousek PM, D'Antonio CM, Loope LL, Westbrooks R (1996) Biological invasions as global environmental change. American Scientist 84: 468-478

Webster CR, Nelson K, Wangen SR (2005) Stand dynamics of an insular population of an invasive tree, *Acer platanoides*. Forest Ecology and Management 208(1-3): 85-99

Williamson M (1996) Biological Invasions. Chapman & Hall. London.

Wynne B (1992) Uncertainty and environmental learning. Reconceiving science and poliby in the preventive paradigm. Global Environmental Change 2(2): 111-127

Zwander H (2001) Der Pollenflueg im Klagenfurther Becken (Kärnten) 1980 bis 2000. Carinthia II 191(111): 117-134

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

Table (19.)1. Impacts of biological invasions on Ecosystem Services

Ecosystem Service		Impact description / Effect	Associated species (examples)	Reference
Supporting services	**Soil formation**	Changes in biochemical characteristics of soils	Grand fir (*Abies grandis*)	Griffiths et al. 2005
		Increase in soil aggregation	Barb goatgrass (*Aegilops triuncialis*)	Batten et al. 2005
	Nutrient cycling	Reduction of food and oxygen availability	Zebra mussel (*Dreissena polymorpha*)	Minchin et al. 2002
		Alteration of soil nitrogen levels	Grand fir (*Abies grandis*)	Griffiths et al. 2005
			Black wattle *(Acacia mearnsii)*	De Wit et al. 2001
	Primary production	Alteration of biomass production of native plants	European purple loosestrife (*Lythrum salicaria*); black wattle (*Acacia mearnsii*)	Pimentel et al. 2005
		Reduction in aquatic vegetation	Grass carp (*Ctenopharyngodon idella*)	Pimentel et al. 2005
		Competition for grazing primary production	Horse (*Equus caballus*)	Beever and Brussard, 2004
	Habitat stability	Changes in vegetation cover affecting community	Green alga (*Caulerpa taxifolia*) and *Caulerpa racemosa*)	Cavas and Yurdakoc, 2005

Ecosystem Service		Impact description / Effect	Associated species (examples)	Reference
			Common reed (*Phragmites australis*)	Maheu-Giroux and Blois, 2005
Provisioning Services	Food	Loss in commercial production and harvest (agriculture, forestry, fisheries, aquaculture)	Russian wheat aphid (*Diuraphis noxia*)	Brewer et al. 2005
			Skeleton weed (*Chondrilla juncea*)	Cullen and Whitten, 1995
			Rice field rat (*Rattus argentiventer*)	Stenseth et al. 2003
			Comb jelly (*Mnemiopsis leidyi*)	Knowler, 2005
	Fuel, wood	Loss of forest products	Gypsy moth (*Lymantria dispar*)	Sharov and Liebhold, 1998
	Fresh water	Losses in water catchments	Acacia (*Acacia longifolia*); black wattle (*Acacia mearnsii*)	Galatowitsch and Richardson, 2005
	Genetic resources	Threat to the viability of endangered species	Indo-Pacific soft coral (*Stereonephthya* aff *Curvata*)	Lages et al. 2006
		Genetic hybridization	Baculo viruses (*Autographa californica nucleopolyhedrovirus* (AcNPV)	Hails et al, 2002
Regulating Services	Water regulation	Choking waterways	Hydrilla (*Hydrilla verticillata)*	Pimentel et al. 2005
	Water purification	Reduction of water quality	Acacia (*Acacia longifolia*); black wattle (*Acacia mearnsii*)	Galatowitsch and Richardson, 2005
		Increase in water filtration	Zebra mussel (*Dreissena polymorpha)*	Minchin et al. 2002
	Waste regulation	Colonization of industrial waste dumps	Bacterivorous nematodes (*Acrobeloides nanus*; *Panagrolaimus rigidus*)	Hánel, 2004
	Biological control	Displacement of native and endemic species	Brown trout (*Salmo trutta*)	Quist and Hubert, 2004
	Pollination	Reduction in the reproductive success of flora	Argentine ant (*Linepithema humile*)	Blancafort and Gomez, 2005
	Seedling survival	Depression of the diversity and abundance of seedlings	Shrub (*Lonicera maackii*)	Webster et al. 2005
	Disease Regulation	Infection of native fauna	Chytrid fungus (*Batrachochytrium dendrobatidis*)	Beard and O'Neill, 2005
		Production of toxic substances	Green alga (*Caulerpa racemosa*)	Cavas and Yurdakoc, 2005
		Vectors of human and livestock diseases (e.g. dengue).	Mosquito (*Aedes aegypti*)	Takahashi et al. 2005
	Natural hazard protection	Disruption in flood control mechanisms	Salt cedar (*Tamarix sp.)*	Lesica and Miles, 2004
		Increase predisposition to fires	Cheatgrass (*Bromus tectorum*)	Vitousek et al. 1996
	Erosion regulation	Intensification of soil erosion	Goat (*Capra hirus*)	Pimentel et al. 2005
Cultural Services	Recreational	Reduction of recreational use of rivers and lakes	Black wattle (*Acacia mearnsii*)	De Wit et al. 2001
		Emerging sport fisheries	Brown trout (*Salmo trutta*)	Quist and Hubert, 2004
	Aesthetics	Changes in the character of rural and urban landscapes	Rhododendron (*Rhododendron ponticum*)	Dehnen-Schmutz et al. 2005
			Horse chestnut leaf-miner (*Cameraria ohridella*)	Gilbert et al. 2003
		Use as ornamental flora	Saltcedar (*Tamarix ramosissima*)	Knowler and Barbier, 2005
		Residential weeds	Dandelion (*Taraxacum officinale*)	Pimentel et al. 2005
	Education	Threat to the value of protected areas	Saltcedar (*Tamarix ramosissima*)	Lesica and Miles, 2004
	Cultural diversity	Loss of subsistence fisheries that shaped local cultures	Brown trout (*Salmo trutta*)	Quist and Hubert, 2004

Table (19.)2 Overview of evaluation approaches for the management of invasive species

	Risk assessment	Cost-Benefit Analysis	Cost-effectiveness	Multi-criteria analysis	Scenario development
Management purpose	Introduction	Introduction and/or control	Control	Introduction and/or control	Introduction and/or control
Purpose of the evaluation	Risk level	Ranking (optimisation)	Ranking (optimisation)	Deliberation and ranking	Deliberation and prospective storylines
Type of impacts	Associated with invasion species	Caused directly by invasive species and those derived from	Associated with management responses	Associated with invasive species and/or those	Associated with invasive species and/or those

	(hazards)	management responses (cost of damage, cost of control and benefits)	(cost of control)	derived from management (criteria)	derived from management (reference indicators)
Type of information used	Quantitative and qualitative	Quantitative (monetary)	Quantitative (monetary and physical units)	Quantitative and qualitative	Quantitative and qualitative
Participation potential	Low	Low/Medium	Medium	High	High
Consideration of uncertainty	Uncertainty reduced to probability or precautionary approach	Sensitivity analysis	Sensitivity analysis	Robustness analysis, accounting for fuzzy data,	Integrated set of assumptions
Operative constraints	Low cost and time requirement	Low-medium cost and time requirement	Low-medium cost and time requirement	Medium-high cost and time requirement	Medium-high cost and time requirement
Methodological constraints	Intrinsic uncertainties, risk thresholds	Trade offs between natural capital and human-made capital, use of discount rate	Definition of thresholds	Definition of thresholds	Lack of crisp results, non-replicable results
References	Andersen et al. 2004; Landis, 2003; Simberloff, 2005; OTA, 1993	De Wit et al. 2001; Bertram, 1999; McConnachie et al. 2003; Le Maitre et al. 2002; Pimentel et al. 2005	De Groote et al. 2003; Dehnen-Schmutz et al. 2005; Buhle et al. 2005	Maguire, 2004; Monterroso, 2005	Chapman et al. 2001; Rodriguez-Labajos, 2006