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Managing Biological Invasions:
The good, the bad, and the ambivalent

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Abstract

What can economics say about the management of ambivalent biological invasions? Contrasting with the usual assumption according to biological invasions are necessarily a public bad to be prevented or eradicated, the key of this paper is to ask, from an economics standpoint, how positive and ambivalent ecological and economic impacts affect policy making. Reviewing the literature, we highlight the gap between ecological and economics perspectives and discuss the importance of ecological and economic functioning in designing an appropriate policy response to biological invasions. In order to derive methodological insights, we describe a typology of ambivalences and discuss the economics of bio-invasions in the light of this typology presenting a road map for future researches.

1. Introduction

In a comment recently published in *Nature*, Mark Davis and 18 other ecologists advocate the need not to judge species on their origins Davis et al. (2011). Recalling that most human and natural communities are a mix of long term residents and new incomers, they claim the impracticability of ecosystem restoration to some previous "rightful" historical state. Instead, they want to study "novel ecosystems" as they stand, i.e. modified by human actions and global changes. Following this approach, they wish to incorporate many alien species into management plans rather than to reach for an often impossible goal of eradication, or for a drastic reduction of their abundance. Without suggesting the abandonment of mitigation efforts in front of serious problems caused by some invaders, they advocate the potential positive effects and usefulness of several alien species. They urge practitioners to set priorities on invasive species not only on the basis of their geographical origin, but also according to their effective level of benefits or harm to biodiversity, human health, ecological services and economies.

To set priorities is important but we also need to better understand the implications of this prioritization for policy makers. If we choose to reject "eco-bigotry" as the tendency to protect and conserve ecosystems as they currently or recently stand, what "novel ecosystem" paths should we prescribe and what policy making should we implement and how? Reinterrogation of objectives and foundations of public policies on biological invasions is a growing concern among ecologists. The key of this paper is to give echoes to this questioning among economists.

The literature on the economics of biological invasions follows two principal research avenues: a "local" approach analysing optimal measures of prevention and control to respond to invasions; and a "global" approach focusing on provision and cooperation issues for the elaboration of global policies, or studying the links between trade and invasion policies. In both approaches, the objective function of public policy is rarely questioned and no mention is clearly made to the ambivalence of invasions impacts and ecosystem dynamics. These approaches mainly view ecosystems as stable systems that one needs to preserve as they stand. In other words, economists stick in their analysis to the "eco-bigotry" scenario denounced by that Davis et al. Furthermore, biological invasions are usually assimilated to strict public bad and it is often implicitly assumed that a first best world is a world without bio-invasions.

The goal of this paper is to compare ecological and economics perspectives on this issue, and to define a road map for economics research on the topic. The key question we want address is how public policy may account for ambivalent invasive species in a world where ecosystems are viewed as constantly evolving systems. In this perspective, our contribution is twofold.

First, it questions the basic objectives of public policies dealing with bio-invasions and more generally with biodiversity. We argue that both concepts of a well-defined ecological state and associated optimal policy are ill-founded given the inherently dynamic character of ecosystems. Instead, it may be more relevant to view public policies as measures accompanying ecosystem dynamics within a corridor of acceptable evolution paths. We study how species management may consider co-adaptive arguments and we discuss what could be the objective of local and global decision-making on bio-invasion.

Second, it sheds light on the necessity for local and global measures to account for the ambivalence of bioinvasions processes. We stress the need for measures dealing with bio-invasions to account for the "ambivalence" of invasive species. We pay particular attention to the definition of ambivalence that refers to the diversity of situations in which an invasion may occur, leading to various consequences depending on the geography, the ecological dynamics and even social perceptions where the invasion occurs. Our principal argument is that diversity of contexts and impacts of an invasion is a crucial challenge for public policies but also a key feature to bear in mind for local and global management. Locally, prevention and control strategies should always account for ecological and economic feedbacks that could lead to differentiated and ambivalent impacts. Globally, policy-making is mostly related to the control of invasion drivers and the consequent transfer scheme to compensate negative amenities, which needs to account for positive feedbacks related to bio-invasions.

The paper is organized as follow. Section 2 reviews the economic and ecological literature on bio-invasion management. We examine their contributions to nature management in general and to the understanding of multifaceted invasion ambivalence. Section 3 defines a typology of multifaceted ambivalence and examines what economics can say about local and global governance issues related to ecosystem dynamics. Section 4 concludes.

2. The gap between economics and ecology perspectives

The two terms ecology and economics came from the same ancient Greek root "*oikos*" meaning "house" or "habitat". They differ however in their purpose. Ecology is the "science" of the house (*oikos* - *logos*) and aims therefore to study the physical conditions of existence of organisms. Economics are the "rules" or "administration" of the house (*oikos* - *nomia)*, and therefore dedicated to the organization of society. As a consequence, economics is dedicated to the design of policy making and the analysis of their properties. If the purpose of ecological sciences is directly related to the environment and its resources, economic sciences aims at studying policy-making to achieve a desired goal of biodiversity management. This desired goal of biodiversity management and the rationale behind its choice is subject to many controversies in both disciplines, either on the motivations behind the choice of this objective or on the way to achieve it.

The way both disciplines consider and study biological invasions are a very instructive on that matter. Although ecology recognizes the constant evolution of ecosystems, many authors still implicitly assume the necessity to preserve them from anthropogenic influences, among which the "plague" of biological invasions. This vision is criticized by some ecologists like Davis et al. (2011), Hobbs et al. (2006) or Sousa et al. (2011) who studied the role of "novel ecosystems" and their potential importance for ecosystem functioning. For economics, the objective of policy-making is defined in order to reach a well-specified stationary state of the ecosystem, mostly chosen as a current or previous state before the invasion happened. In other words, invasions are mostly considered by economists as a "global threat" and a univocal public bad to be prevented or eradicated, and ecosystem transformations resulting from anthropogenic actions are considered as necessarily harmful.

In this part, we put forward the differences observed between the ecological and economic approaches of biological invasions, and build on those differences to propose potential evolutions of the economic perspective on the question. Based on the debate initiated by Davis et al in 2011 about invasive species, we first study the birth of this debate in ecology, and emphasize questions about equilibrium and ambivalence of biological invasions at the heart of this debate. Building on this approach, we will review its implications for three economic perspectives on invasions issue, namely public good analyses, optimal policies determination, and evaluation processes.

2.1. The ecology of bio-invasions: a discordant view of nature

2.1.1. An history of division among ecologists upon our relationship to Nature

The debate initiated by Davis et al. paper is emblematic of the persistence of the discordant view in ecology about ecosystem dynamics and anthropogenic interferences. It echoes an old debate at the beginning of the 20th century between the naturalists John Muir and Gifford Pinchot, reflecting two ideas of nature and views of human-nature interactions. For the traveller and writer John Muir, the idea of nature *wilderness* reflects the perfection of God's Creation that must be preserved integrally in most its original form. On the opposite, the forest engineer Pinchot supported an idea of sustainable use of natural resources that must contribute to human well-being. He is therefore considered as one of the precursor of the "sustainable development" concept (Holdgate et al. (1999)). All along the 20th century, this opposition between aesthetic *versus* utilitarian view shaped and influenced the debate over our relationship to nature. Intentions and discourses of the following years were characterized by a constant swing between those two standpoints.

After the birth of the International Union of the Conservation of Nature (IUCN) in 1948, the utilitarian view progressively gained ground. The rise of the sustainable development concept tipped the balance in favor of a view of nature helping the maintenance of human livelihoods. The usual terminology about nature progressively turned into the terms "natural resources", "living resources", and finally "biodiversity" used for the first time in a National forum in Washington in 1986. This shift in terminology reached its peak in 1992 with the Convention on Biological Diversity (CBD) in which the word "nature" does not appear once. Evolution of terminology mirrors an evolution in paradigms about Nature, and the way humans consider their relationship to Nature. The way humans consider their relationship to nature is indeed a key concept to think about what may be done in a world where human interferences cannot be simply isolated. Progressively, the objective of nature management moved from strict nature protection towards a more general goal of biodiversity management (Blandin (2007)).

If the interest of an increasingly managed vision of Nature seems obvious, the ideology of a completely unspoiled nature remains a central thought in the discourse of many ecologists and nature defenders, for which human activity is considered as a perturbation element external to the order of nature. The biological invasion literature is no exception and human beings in their quality of principal vector of introduction and spread makes naturally non-native species disruptive of an ideal nature absent of human interferences.

2.1.2. Implications for equilibrium analysis

This progressive change in human views about nature and in conservation objectives is directly related to the evolution of equilibrium concepts used in the study of Nature dynamics by ecologists. Up to the eighties, references to "*natural equilibrium*" of nature are omnipresent. At the scientific conference on natural resources use and conservation organized in 1949 in Lake Success, the ecology community was asked to explain some natural equilibrium laws and the impact of human action on this equilibrium. Several authors acknowledged rapidly their lack of confidence in the concept of fixed equilibrium: "*this "equilibrium of nature" […] is an excessively dynamic concept which never maintains itself but moves constantly*" (Ira Gabrielson, 1950). The first milestones of an ever-lasting debate between fixed stability versus perpetual dynamic modifications of natural equilibrium were set, still considering man as an external perturbation agent.

The adoption of the "ecosystem" concept by Eugen P. Odum in 1953 contributed to reinforce the idea of equilibrium stability and the objective for those systems to reach a "climax[1]". The ideology of a "Balance of Nature" is therefore progressively replaced by a more technical vision of ecosystems stability, seen as a collection of species perfectly adapted to each other and interacting such as the system's equilibrium is maintained. Evolution is here

[1] A climax is considered as a stable association of species. It materializes the last development state of a community which is able to maintain itself more efficiently than any other community, living in a perfect equilibrium with physical environment. It traduces also an idea of maximal regulation capacity of this community when subjected to "perturbations".

considered as the process establishing those optimally co-adapted species. Perturbations remain negatively connoted and considered as obstacles on the road to stability.

However, some researchers progressively tried to think about the role of those perturbations in structuring ecological systems, or “ecosystems” (Loucks (1970), White (1979), Pickett & White (1986)), paving the way to “landscape ecology” and accounting increasingly for spatial heterogeneity. Perturbations create “patches” and “mosaics” of different ecosystems, allowing the coexistence of several ecological units corresponding to different succession states. A kind of “metaclimax” has yet to be reached at the landscape scale, therefore accounting for the succession of ecosystem history, both ecological and social. A step toward the reintegration of human behavior in the analysis of Nature was done. Therefore, ecosystem equilibriums are increasingly considered as inherently dynamic and as temporal singularities in a general context of change. Those changes have strongly accelerated in the last few years, leading to major changes in the structure and dynamics of ecosystems.

2.1.3. Implications for invasive species ecology

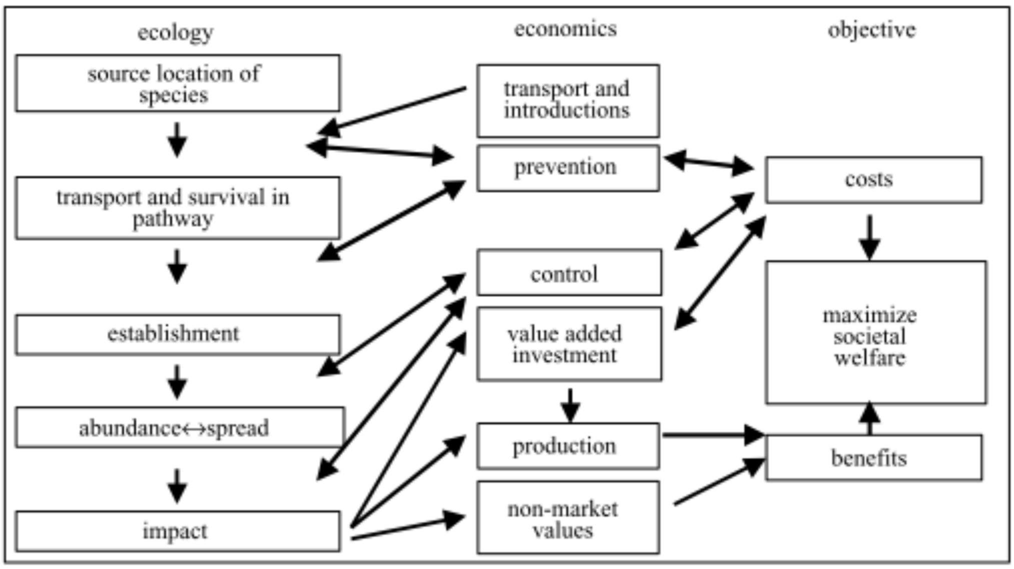
The observation of invasive species is one of the consequences of those rapid changes occurring on a global scale due principally to human activity. This afflux of invasive species has long been considered has leading to some “imbalance” of natural equilibrium (Elton (1958)). However, some authors progressively considered that those new situation weren’t exactly an imbalance of some previous ecosystem state, but rather a novel transitional and punctual equilibrium toward a new ecosystem state. Ricklefs (1987) realized that local diversity was determined by both local processes inside the biological community and global processes such as species formation (speciation) and dispersion, unique historical accident or circumstances related to past climate, and geographic position of barriers or corridors for dispersal. He was one of the first to consider that species immigration from other zones could be a structuring factor of local diversity, counterbalancing the effect of diversity reduction induced by the selection pressure.

Focus of research in ecology is then the comprehension of temporal trajectories of ecological systems, taking into account their natural and human components. In this vein, some authors recently developed their vision for the management of what they call “novel ecosystems” which present new species combinations as a result of human activity, global environmental changes and impacts of intentional and unintentional introduction of species”

(Hobbs et al. (2006)). This approach clearly places human perturbations as a central element in the analysis, and emphasizes on finding some successional pathways of co-evolution.

Despite this recent evolution of approaches in invasion ecology, many literatures still make implicit reference to an original and unspoiled view of Nature in which human beings are considered as external perturbing elements. Echoing this observation, 19 ecologists voiced their concern in the recent advocacy by Davis et al. (2011), asking not to judge species on their origins. They claim the impracticability of ecosystems restoration to some "rightful" historical state and embrace the reality of novel ecosystems. In this perspective, they advocate the need for policy and management decisions to take into account the potential positive effects of many non-natives and the possibility for ecosystems to evolve into new states.

This necessary evolution of policy and management objectives is the responsibility of both ecology and economics disciplines. Ecology seeks to understand the relationships between living organisms and ecosystems; it contributes therefore to the comprehension of different scenarios of conservation and the impact from the choice of policy alternatives on ecosystems. In the choice among those different alternatives, social sciences and among them economics also have their role to play by considering socio-economic impacts of ecosystem co-evolutions and by designing policies able to curb it in the desired direction.



From Leung et al. (2002)

Choosing this desired direction could be an inducement for common work between ecologists and economists in order to provide the right incentives for Nature protection. In the following section, we will try to describe how economics think of biological invasions, through a description of their most commonly used tools.

2.2. The economics of bio-invasions: prevention and eradication

The categorization of good, bad or ambivalent species is far from being trivial. Impacts from an invasion are generally ecosystem and history dependent: it may harm one ecosystem but not another, affect negatively some ecological services but positively impact biodiversity indices. Overtime, the status of invasive species can even shift from pest to asset, or the reverse. If some literatures suggest this complexity and reveal the ambivalence of biological invasions, the rationale behind the elaboration of economic policies or instruments remains mainly the strict public bad characteristic of invasions. Economics focuses therefore principally on pest management, assuming implicitly that a first best would be to isolate this pest and halt its proliferation. Small attention was hence paid to management problems facing ambivalent impacts or non-stationary characteristic of ecosystems, and much literature concentrate on prevention and control.

Methodologically, economic literature can be classified into three different approaches: optimal policy, public good analyses and evaluation techniques. *Optimal policy* approaches deal with optimal prevention or control policy to manage an invasion within a specific local context, whereas *public good provision* analysis is generally applied to a global scale, and leads to study how to limit collectively the global public bad. Finally, *economic valuation* considers economic impacts from alien species either at a local or at a global scale, and attempts to monetize the costs and benefits of invasions management. This last approach is commonly seen as the principal contribution of economics to the topic, although it represents only part of it. Although those three approaches analyze several aspects of public policy, they are deeply interdependent or at the least complementary. In this next part, we will make a short review of the economic literature organized around those three approaches, and try to highlight systematically their contribution to the understanding of biological invasion ambivalences.

2.2.1. Optimal policies

Analyses of optimal policies to limit, eradicate, or prevent a local invasion is an important part of the literature on the economics of invasive species. Optimality usually starts from the assumption of a regulator able to implement and enforce policies, using cost-efficiency, optimal control or optimal prevention methods. Those models derive the necessary conditions for this control to be optimal. Early contributions in the field are based on bioeconomic theory of natural renewable resources (Jaquette (1972), Jaquette (1974), Regev et al. (1976)) and focus on the protection of crop production against an invasive pest. One result is that several socially efficient levels of invasion control may exist, ranging from laissez-faire to eradication or stabilization of invasion at an intermediary level through a permanent control effort.

The choice between those different levels of control can depend on various parameters reviewed by the economic literature. First of all, we can look at the actual level of invasion direct control costs (Eiswerth & Johnson (2002), Perrings (2002b), Myers et al. (1998)). If we consider those control costs as the only adjustment variable for the determination of the optimal level of invasion, then full control is by assumption always prescribed if this control cost is zero. In this case, a first best world according to economics would be a world free of invasions. Other parameters are also considered to explain the trade-off between those different levels of control or current optimal level of invasion. Non exhaustively, they can be the importance of damages in the host ecosystem (Eiswerth & Van Kooten (2002)), species dynamics (determined by its intrinsic growth rate as well as the loading capacity of the ecosystem) and the state of invasion at the time of intervention (Burnett et al. (2006)).

Hence, even if many economic studies on biological invasions remains oriented towards an objective of control, some of them recognize implicitly the importance of considering the invasion context in the determination of control efforts. They also consider the influence of different external elements in the determination of this optimal level. For instance, environmental perturbations may have a different impact on control efficiency, depending on the characteristics of the host ecosystem and the sensitivity of native and exotic species (Olson & Roy (2002)). Similarly, accounting for risk and uncertainties on policy returns associated with processes of invasions tends to decrease optimal effort (Buhle et al. (2005), Hastings et al. (2006), Settle et al. (2002), Jerde & Lewis (2007)). Conversely, potential irreversibility in damages or risk aversion may increase optimal level of control (Saphores & Shogren (2005), Horan et al. (2002)). Agents' behavior also leads to altered levels of equilibrium stock. This is the case for instance when accounting for the value that native or invasive species may have for visitors/tourists (Settle & Shogren (2006) ; Shogren et al. (2006)), or when users are also vectors of invasion (MacPherson et al. (2006)).

Therefore, those different parameters identified in the economic literature of optimal policies have an impact on the optimal level of control. In the end, they contribute to refine the direct control costs over invasion, in order to adjust more accurately the optimal policy objectives. However, even if this approach focuses on the different contexts that would impact the optimal level of control, it doesn't take explicitly into account the potential benefits from an invasion. In other words, those parameters have a positive or negative impact on the costs of control, but do not allow for the possibility to account for potential benefits for humans or ecosystems from this invasion.

Nevertheless, at least three papers account for potential positive externalities of invasions as well as their potential implicit value depending on some type of control, as trapping versus hunting. Junqueira-Lopes et al. (1996), Zivin et al. (2000) or Horan et al. (2005) study optimal management of a local invasion - i.e. crayfish, pigs, deer - that disturbs an ecosystem but can become an asset, e.g. through fishing or hunting. Although the problematic is very much focused on the management of a single invasion in isolation from the ecosystem, those approaches are the premises to account for ambivalence of invasions.

2.2.2. Public good

Public good analyses study how to collectively limit the flow of bio-invasions. In order to raise insights on collective management of bio-invasion, it is first important to define this peculiar public bad. The characteristics of the public bad “invasions” or public good “invasion management” differ from those of a public good or bad as commonly defined in economics, such as carbon dioxide emissions or ozone depletion. A public bad “invasion” may be considered both as pollution and natural renewable resource, which is also therefore self-perpetuating once released in the environment. Because of this self-perpetuating character, identification and direct intervention on the sources of this pollution is particularly difficult. It raises some important cooperation issues, somehow different from the traditional literature on international cooperation over classic public goods. As suggested by Barbier & Shogren (2004), Perrings (2002a), Pimentel (2000) or Sumner et al. (2005), invasive species management displays several characteristics of classic and international publics goods, i.e. non rivalry, non-excludability, international and intergenerational scope. However, because efficient provision of this public good depends on the efforts made by the least efficient agent, it falls under the category of “weak- link” public good (Perrings (2002a), Burnett (2006), Fernandez (2006)). Indeed, if a single agent holds back its efforts in containing the invasion, it will keep happening despite the implementation of a strict policy in many countries. As an example, the management of an invasion such as the zebra mussel, which requires a systematic cleaning of boat hulls and ballast water: collective efforts collapse if a single boat carries the mollusk. The weakest-link characteristic of the public good leads to look at incentives for its provision (Cornes (1993), Burnett (2006), Fernandez (2008)), and identify the participatory means to find common solutions to a potentially global phenomenon (Monterroso et al. (2011), Liu et al. (2010)).

This public good characteristic leads to conclude to the existence of two types of failure. First, a failure of market allocation mechanisms, revealing an externality from human transport and activity where every agent involved is not faced with the true cost of invasion supported by society. Second, a failure of cooperation mechanism, since the existence of free riders is not simply a moral issue in public policy, but also an externality in itself since the mere presence of free riders to the policy may render collective efforts entirely useless. As a result, invasion management must be elaborated in order to overcome those two types of failure.

In an attempt to reintegrate the costs from invasions to society into the objective functions of involved stakeholders, some economic mechanisms have been proposed such as – non-exhaustively – quarantine (Jenkins (1996), quotas and optimal use mix of tariffs, inspection or subsidies (Margolis et al. (2005), McAusland & Costello (2004), Fernandez (2006)), ambient taxes (Jones & Corona (2008)), tradable permits as a complement to local management (Ring et al. (2010), (Horan & Lupi (2005b); Feng & Hennessy (2008); Knowler & Barbier (2005)), or intergovernmental fiscal transfer (Sumner (2003)). Economic efficiency of several compliance strategies is reviewed by Horan & Lupi (2005a). The properties of those mechanisms are often described in an efficiency perspective and systematically applied to prevention or eradication policy goals.

The second type of failure reveals the global character of invasion management provision, and the necessity for public policy on invasive species to be supported by an efficient global or partial collective financing. In order to establish the conditions of the efficiency of this common burden sharing, some authors look more closely at invasion drivers and pathways (Pysek (2010)), or at linkages between invasions and the aggregated level of capital stock in the economy (Barbier & Shogren (2004)). Those approaches in economics are related to the larger question of issue linkages, revealing the relations existing between invasions problems and some international issues like trade or international transport. In this sense, biological invasions could be integrated in international regulations on trade as a co-occuring effect.

Therefore, two principal approaches may be used to analyze this peculiar public good. The first consider voluntary contributions and incentives for its collective provision, the second is more related global issues. In other words, we learn from those literatures how to efficiently provide the public good and how to bypass cooperation problems. However, the potentially positive impacts from invasions in some contexts are not explicitly considered in this literature. Even if international cooperation is mainly based on prevention against any potentially invasive species, the elaboration of global policy on bio-invasions will also need to deal with neutral or positive invasions impacts for some ecosystems and their economies. Account for this possibility could considerably change the outcomes of efficient public good provision.

2.2.3. Economic valuation

Finally, a third and complementary branch of the literature are valuation studies, which assess potential impacts of invasion. Whereas optimal control models used more frequently cost-efficiency analyses, valuation studies resort to different functional forms of costs and benefits. Economic valuation is used to assess the impact of invasive species and economic consequences of some policy decisions (McIntosh et al. (2010), Settle & Shogren (2006), Shogren et al. (2006)). Assessment of biological control programs on a local scale were made on the basis of cost-benefit analysis (Hill & Greathead (2000) , McConnachie et al. (2003) or Van Wilgen et al. (2004)), in order to compare the value of ecosystem services before and after invasion with different costs of control (Higgins et al. (1997)).

Some recent literatures try to account for spatial and temporal variations in biological invasions impacts, using some innovative modeling methods based on spatially referenced data or GIS, or providing explicit linkages between ecological and economic processes into some bioeconomic models (Sharov & Liebhold (1998), Lodge et al. (2009)). The paper by Holmes et al. (2010) proposed to evaluate the notion of “Area of Economic Damages” (AED) by combining microeconomic analyses of site-specific damages and larger spatial-dynamic models of forest value change, using spatially referenced data. This approach helps to account increasingly for the differentiated impacts of invasion spatially and overtime, and opens the door to a quantification of ecosystem value change following an invasion, which may be potentially positive or negative. But such an approach raises the question of the aggregation from different micro- or macroeconomic damages from bioinvasions and its significance for public policies.

This problem is also acute when providing global cost estimates of invasions impacts for society, which is made by only a few economic studies. The two main publications on that topic are one of the Office of Technology Assessment in the US (OTA (1993)), and the work by Pimentel (Pimentel (2000), Pimentel et al. (2005)). They faced the issue of aggregation of extremely heterogeneous costs, ranging from direct economic consequences to more indirect welfare and ecological impacts, and lack systematic use of empirical methods for estimating costs. Furthermore, impacts on ecosystem services or potential benefits provided by some invasive species are rarely accounted for. Those estimates are a first step towards estimating the global impacts from invasion and may be a mean to an end in order to catch public attention on the problem. However, they poorly take into account impacts at smaller scale of aggregation and need to be refined in order to provide insights for policy making and management.

This short overview of the economic literature on biological invasion tends to reveal the inherent ambivalence of biological invasions, without explicitly considering the potential benefits of invasions. Each approaches tend to show the extremely context dependent and integrated character of invasions. Optimal policies approach shows how different parameters may influence significantly the optimal level of control. They reveal implicitly a potential benefit or at least a weaker impact from an invasion in some contexts. If the public good approach explains how to provide efficiently this peculiar "weakest-link" public good and try to solve cooperation problems, it traditionally considers that species movements and invasions are strictly negative events to be prevented. The same is observable in economic valuation, with very large studies looking at aggregation of global costs, without putting particular emphasis on the potential benefits from invasions – except the benefits from the economic activity involved into the spreading of the invasive – for humans or ecosystems. Economics hasn't engage yet into the analysis of "novel ecosystems" economic characteristics. In order to provide informed insights to policy makers about invasions, we have to reconsider the traditional objectives of environmental economics to define public policies, and account increasingly for the ambivalent character of invasions, at all level of studies. In this second part of our paper, we will focus on the rationale behind the determination of those objectives, using the prism of the "novel ecosystem concept". We emphasize the necessity to account increasingly for ambivalent impacts and dynamic trajectories of ecosystems, and discuss the implications for the three different economic approaches.

3. Guiding principles for IS governance

Building on those differences between economic and ecology perspectives on biological invasions, this part is an attempt to provide an echo to the debate launched in the ecological community by Davis et al in 2011. We wish to interpret this debate in the wake of economic approaches, building on two principal insights from ecology: the co-evolutive nature of ecosystems on the one hand, the diversity of bio-invasions and the ambivalence of their impacts on the other hand. Those considerations have implications for public policies since the objective will vary considerably according to the context. As a consequence, public policy will have to be intrinsically co-adaptive that is to contribute to shape ecosystems dynamics toward one path or the other, rather than to design tools to freeze ecosystems as they stand.

3.1 Policy making in a co-adaptive paradigm

Before exploring the implications of co-evolution from an economic perspective, we start this section discussing a more general, albeit fundamental question. What is the goal for biological invasion management and more globally of biodiversity management? Reviewing all parcels of answers to this question raised in the literature goes far beyond the scope of this paper. We will nevertheless explore some important dimensions to any economist interested in the topic of the elaboration of public policies to manage bio-invasions and biodiversity in general.

3.1.1 What goal for biodiversity management and for IS management in particular?

Although appreciation of human impacts remains quite debated, their interferences with almost every natural area in the world are nowadays undeniable. Biodiversity and biological invasions problems have therefore important social science aspects, in terms of their causes, effects and remedies. For economists, objective function is a crucial aspect to determine the type of public policies to be pursued. This implies to clarify our expectations about the use of biodiversity, and about the purpose of maximization to reach our goals. If answers to those questions are not straightforward and stand mostly at the crossroads of many disciplines, environmental ethics seems a good entry point to re-interrogate biodiversity management objectives and to provide reflexions beyond the views of particular disciplines. Based on a review of the literature on ethics, Maris (2010) distinguishes five moral principles to face biodiversity erosion: the *autonomy* across generation, *responsibility* towards other person and species, *benevolence*, *humility* in front of what we cannot measure completely and *diversity* as a potential for the future. On the basis of this approach, we will derive several insights about biodiversity governance.

Biodiversity management should first respect the *autonomy* principle, i.e. the right of moral agents to self-determination. As a consequence, biodiversity management must preserve current and future choices of individuals. In this sense, it constitutes a mutual duty leading moral agents to maximize the utility of others, and to expect others to do the same. This observation leads to the next principle of *responsibility*. The concept of equal consideration asks moral agents to consider other agents' and species' affected interests when taking a decision (Singer (1993)). In order to avoid the dilemma of anthropocentric judgment in the choice of species, Taylor (1986) proposed an egalitarian biocentric view assigning an equal weight to each species in the maximized utility. A solution to this maximization problem is very questionable, because of the high number of constraints and improbability of all species playing an equal role on earth's processes. The idea of a potential hierarchy between species leads to consider the *benevolence* principle, which supports a maximization of the diversity of species interests. Some authors proposed a maximization of natural needs, such as reproduction capacity (Attfield (1994)), individual species survival (Rolston (1986)) or collective or species chain survival (Callicott (1994)). This prioritization problem is crucial to policy-making and needs therefore to be discussed through what Maris calls a principle of *humility*, asking to take into consideration any species' life even if we fail to understand their importance in terms of biodiversity. Following this observation, the *diversity* principle taken as a production factor for biodiversity must be preserved at all costs. As there is no reason why the current distribution of species and population is preferable to another, the author asks for a governance preserving biodiversity processes based on evolutionary considerations.

Maris recognizes that those principles may be contradictory with respect to the same preservation policy. Instead of an arbitrary and anthropocentric hierarchy between principles, she proposes a pragmatic approach asking for a change in moral attitudes toward biodiversity. This approach promotes a plural view in which moral principles should be followed on a case-by-case basis, considering that several solutions have to be promoted in a context of scientific and normative uncertainty. To narrow down the object of biodiversity preservation, she proposes an adaptive management as a learning-by-doing protocol allowing for solving scientific uncertainty, responding to a plurality of objectives and rejecting a univocal view of biodiversity preservation. In Maris' view, this contributes to a resolution of the co-adaptive paradigm defended by ecologists: "nature needs to be thought as the dynamic set of all phenomenon and processes, human phenomenon being part of it" (Maris quoting Dewes, 1925).

This incursion into environmental ethics provides at least three insights for biodiversity and invasion management. Firstly and most importantly, there is not a single objective but a plurality of objectives to be pursued that may differ according to the geography, the time horizon and even the perception of individuals. This echoes the call by Davis (2011) to consider the ambivalence of impacts when designing biological invasion management policies. Second, invasion management has to be co-adaptive, meaning that policies must iteratively adapt to an uncertain evolutionary path. Third, biological invasion management could rely on some key principles to be kept in mind – in particular diversity, responsibility and humility principles – which could help us to prioritize the efforts to be performed on a case-by-case basis. Those considerations should be important aspects of a policy-making able to influence ecosystems toward one path or another. Following Blandin (2007), any choice is deemed to be wrong. Future generations will definitely understand that we took the wrong choice. But if any choice is wrong, the important is to be able to explain why we took this choice rather than another. This is what Blandin and Bergandi (2000) calls the principle of responsibilisation. This principle is distinct from the responsibility principle defined above. Responsibilisation means that we should be responsible of our choices concerning our inferences with nature.

3.1 Policy making in a co-adaptive paradigm

Ethical and ecological considerations lead us to view ecosystem management as a set of policies enabling ecosystems to evolve within desired evolution paths. Bio-invasions are drivers of evolution and arrival of new species exacerbates ecosystems changes. In this perspective, economics of bio-invasion should contribute the definition of policies enabling ecosystems to evolve within corridors framing acceptable evolution paths. It translates into defining short and mid-term policies able to bind ecosystems' dynamics toward "chosen" directions. To prescribe policy targets delineating those corridors is to be performed in a case by case basis. First of all, because the arrival of a new species may well affect positively the functioning of an ecosystem and negatively the functioning of another. Second because the introduction of an invasive species may affect positively the economy of a region and negatively the economy of another. And third because of the dependencies of policy-making on ecosystems characteristics like physical, chemical or technical constraints. Following Baker (1995) or Dietz (1998), systems in equilibrium are temporal singularities in a context of global change and in this prospect, situations must be interpreted according to their history, the principal goal of research being to understand temporal paths of ecosystems considered in their natural and human components.

Ecosystem evolution paths are difficult to predict and as noted by Schmitz and Simberloff (1997), « the effects of introduced species are so poorly understood and the record of predicting which ones will cause problems is so bad that one can question how much credence to place in a risk assessment ». This complexity and our unpredictability of the ability of ecosystems and individuals to adapt suggested authors such as Holling (1978, 1995), Glouberman et al. (2003) or Norton (2005) to propose adaptive management. The underlying idea justifying the use of adaptive policy is that the management of systems can never be understood or predicted with complete accuracy. They therefore reject the perspective of looking for a first best optimal response deemed to be inappropriate. Variability, unpredictability and uncertainty would require policy making to rely on experimentation, flexibility and participative democracy. In their view, policy making should be experimental and truly flexible in that it should be provisional, adaptive and able to reflect new discoveries about the managed resource. This view which is poorly developed in economics but shared by several environmental scientists would allow to avoid the trap of what Holling (1995) refers as institutional pathology : the tendency of institutions to set inflexible policies unable to adapt ecosystem and value changes over time.

If we subscribe to the idea that the interaction of humans and nature through socio-economic and ecological processes are complex adaptive systems, or that policy making is to adapt over time to this complexity, this is insufficient as an argument to discard optimality approaches and a fortiori other environmental management approaches. Optimal control as a scientific tool can cope with uncertainty about the objective function. Maximization or minimization of an objective function may well maximize other objectives than net benefits. Optimization methods may be used in order to define policies able to maximize the participation to a collective effort and this independently or jointly to a maximization of net benefits. It can give insights on flexible policy making able to minimize a cost or to reach a specific goal such as an ecological one. In this sense, instead of prescribing an optimal path able to realize a maximization of net benefits, optimal control may be used the other way around prescribing a set of policies able to bind ecosystem evolutions within a given path. Mismatch can then be avoided by making a clear distinction between objectives and policies.

Adaptive management is certainly a possible management approach to deal with uncertain ecological dynamics, but as suggested by Failing et al. (2004) or Gregory et al. (2009), it is is not so much a general approach to environmental management but one of potentially many– that could be adopted to address a specific, closely targeted sub-problem within a broader decision process.[2] Environmental management including environmental economics share with adaptive management the general objective of enhancing ecological values while minimizing the losses of economic or social concerns, of reducing uncertainty, responding surprises and be flexible. Key questions to address are then, how can we improve scientists ability to make good predictions about environmental variables with imperfect information? Which goals do we want to achieve and what is the most efficient methods to achieve them? In this perspective, emphasis on the need to perform bottom up analysis able to avoid disastrous anthropogenic interferences with the ecosystem and therefore, setting prioritizes arguing about the objectives we should realize is essential but criticisms and theorizing on methods and means to achieve these objectives is counterproductive. For example, the experimental approach consisting of trying one alternative policy after the other is certainly, in certain conditions or situation, the most efficient method to unveil uncertainty. However there are also situations where research and monitoring, expert judgment or the experience in other jurisdiction, is sufficient. Moreover, even if an experimentation approach is to be followed, several competing alternatives from start will require a trade-off which involves efficiency criteria. Similarly, experimentations will need to be compared using efficiency criteria. The same remarks apply for the use of participative democracy. This can be a right tool to reveal the range of preferences and can be essential for solving certain ecological issues. It can also entangle decisions in situations where urgent action is needed.

As a whole, although adaptive management is certainly not the right solution to address any ecological dynamics decision making problem (comprising invasive species management), it raises interesting questions and insights that should be taken into consideration when dealing with ecosystem evolution management. We think in particular of the emphasis put by this approach on the objective of public policies targeted as an acceptable ecological corridor. Bio-invasion policy is to be thought of as a broad purpose and process for regulating ecosystem dynamics. We need to initiate policy making processes in order to pilot ecosystem dynamics. This means to implement policies in order ecosystems to remain within acceptable evolution corridors. Then, analysis of ecosystem trajectories will allow us, over time, to increasingly refine our responses in order to impact ecosystem trajectories in the most desirable way.

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[2] For criticisms related to the applicability of adaptative management approaches refer to Stankey et al. (2003), Allan and Curtis (2005), Williams et al. (2009) or Allen and Gunderson (2011)

3.2 Towards a typology accounting for ambivalence

Many not to say most invasions do harm neither the ecosystem nor the economy. Depending on the context in which it spreads, invasions are often economically and ecologically neutral and can even in some cases be assimilated to public goods. Furthermore, the self-perpetuating character of a bio-invasion once introduced into an ecosystem and its direct interactions with natural biota separate them from traditional environmental public bad. In other words, their occurrence under some conditions may be a mix of public good and public bad characteristics, depending on the grid used to determine impacts. It is therefore necessary to get a finer vision of what may influence impacts from invasions in one way or the other. This is a challenge in particular for economics that could use a more accurate framing of the different ambivalence cases of biological invasions to design accurate policies and help to take informed decisions. Here we do not pretend to have a complete understanding of the diverse cases of invasion impacts in the world, neither do we attempt to provide an exhaustive list from the different situations that may influence impacts. Instead, we provide some insights to bear in mind for the elaboration of policies and which may influence their efficiency. In this part we will consider the ambivalence of biological invasions impacts and detail its policy implications, notably through the proposition of a preliminary typology of impact ambivalences. We will illustrate our ideas through some examples derived from case studies.

3.2.1. The ambivalence of impacts

A common denominator available to compare different situations of biological invasions is the impact criterion. From an economic and social science perspective, direct impacts from invasions may be differentiated into direct impacts on the ecosystem processes, direct impacts on the economy and human well-being, and impacts on social and psychological aspects related to the intrinsic value given to ecosystems by different members of a society. Indeed, if impacts on ecosystem functioning or economy may be formally described, we must recognize that many negative or positive aspects from invasions result from our own representation of nature, and from the implicit choices made by that humans and society relatively to their relationship to Nature. From a natural science and ecology perspective in which man is considered as part of the ecosystem, impacts on ecosystem processes have indirect impacts on the economy and humans' well being. Therefore, we choose here to discriminate between direct impacts on the economy, on ecosystems and on social representations, bearing in mind that those different dimensions may overlap and influence each other in terms of impacts.

From the results of different empirical models, as well as studies focusing on the choice of the most efficient regulation instruments, it seems that a few bioeconomic key parameters influences the scope of invasion, therefore requiring policy adjustements. Those parameters are principally: *invasion dynamics* (determined by some characteristics of the invasive species and its intrinsic growth rate, as well as the loading capacity of the ecosystem); the *state of invasion* and the *level of damages* at the time of the analysis; the *importance of control costs* (mainly dependant on the invasion type and the efficiency of chosen technology) and the *level of the discount rate* considered reflecting the type of choice made by society in front of invasions. In addition to those parameters, we have seen previously that effects like environmental perturbations, economic ambivalence of some invasions and agents behavior regarding invasions may have an impact on the elaboration of solutions and selection of optimal levels.

The recurrence of those parameters in explaining invasions in the literature may be classified under different ambivalence types when considering invasions. A rather *"geographic" ambivalence* (related to dynamics and state of invasion, loading capacity of host ecosystem and its perturbation level); an "agent" or *"stakeholder ambivalence"* (referring to the different agents behavior in front of invasion, the choice of an appropriate discount rate, or differentiated economic impacts for the different stakeholders); and a *"population ambivalence"* (linked to the existence of threshold effects in population level in terms of damages).

Each of those ambivalences may be refined through the identification of different parameters, depending on the context. Such a refined analysis is particularly useful when facing invasions with inherently very ambivalent impacts, making it particularly difficult to choose the best way of action. Further, we propose to identify and refine this typology to identify the different sources of ambivalence to choose efficient policies. We will illustrate those different dimensions with the help of several case species.

3.2.2. A typology of ambivalence

A typology of ambivalences of impacts allows for clarification and refinement of the different components that may influence invasions' impact, either positively or negatively. Some typologies of biological invasions have already been elaborated in ecology on the basis of taxonomic information helping to establish some sort of "robot portraits" of a typical invasive species. We want here to change the focus and describe a typology of invasions based on their impacts for humans and ecosystems. As noted at the beginning of this section, analysis of impacts both on human well being and on ecosystems remain a crucial element to compare different situations of invasion and choose adapted and evolving policies depending on the context. As said before, the objective is not to provide an exhaustive typology of all possible cases of impacts, but rather to provide an open and flexible framework to start thinking about adaptive management of invasions. This may be an important tool to screen the different dimensions that must be kept in mind when elaborating and choosing among different invasion policies.

The following table is an attempt to provide a schematic view of such a typology. The combination of the different factors could potentially enter an impact function of this invasion. The general level of harm caused by an invasion can only be deduced from an analysis of those different factors in combination, as they mutually reinforce and impact each other.

Impacts from invasion / *Ambivalence variables*	***Ecological impacts***		***Economic and human impacts***		
	Diversity	*Functions and processes*	*Ecosystem services*	*Economic activities*	*Cultural / psychological*
GEOGRAPHIC AMBIVALENCE					
Past					
- previous state of ecosystem (history of pressures (perturbations, land conversion, emblematic species…)	Indices		Indices		
- natural pressures on ecosystems (erosion, water	Indices		Indices		

shortages , inundations, land conversion…)					
Present					
- state of invasion (density of population, repartition…)					
- damages caused by invasions (declining species, habitat modifications…)					
- current pressures (source of introductions, existing dissemination vectors)					
Future					
- future pressure trends (new sources of introduction, projects of land use changes, infrastructure projects)					
ASSESSMENT AMBIVALENCE					
Past					
- State of invasion in cultural habits and heritage					
- Emblematic species					
Present					
- Perceptions of invasion (stakeholder 1)					
- Perception of invasion (stakeholder 2)					
- Perception in collective imagery					
Future					
- Projects regarding the invasion (commercialization, individual eradication…)					
POPULATION AMBIVALENCE					

Past					
Previous dynamics (threashold effects, peak of invasions and population…)					
Present					
Invasion dynamics					
- intrinsic growth rate (depending on natural birth, natural deaths and predation)					
- characteristics of the species : functional traits, structure of invasion (e.g. creating new habitats)					
Loading capacity of ecosystem					
Future					
- intrinsic growth rate (depending on natural birth, natural deaths and predation)					
- characteristics of the species : functional traits, structure of invasion (e.g. creating new habitats)					

An edifying example of invasion ambivalence, for which such a reading grid could be used is the invasion by the American crayfish Procambus clarkii. This crayfish has already been observed taking over a significant ecological role in the Camargue delta, mainly as a new prey source for flagship bird species (e.g. Heron). Considered a keystone species by some, the introduction of P.clarkii will undoubtedly have consequences for regional biodiversity and associated ecological services. The population of P. Clarkii in Camargue increased rapidly but remains poorly documented and subject to many debates. Its plasticity, predative capacities and ability to modify ecosystems (building of galeries, destruction of vegetal communities) and its contribution to the foodweb makes it a keystone specie. However, implications of the invasion of P.clarkii on ecosystems and in particular its role on the trophic chain relies on its abundance, on the speed of the invasion process, on the management of the ecosystem and on the nature of the trophic chain (species potentially predated and predative vis a vis P.clarkii, abundance of species).

Up to 30 years ago, the functional role of the swamp cray fish in the mediteranean was considered as low given the scarcity of the population (Barbaresi & Gherardi 2000). Introduction of exotic species (e.g. Orconectus limosus) had largely contributed at this relative scarcity, autochonous swamps being sensitive to diseases carried by those species. Those invasions had not however brought major impact on ecosystem functioning. Introduction of P. clarkii modified this situation, due to its high reproductive capacities and demonstrates important mecanical skills, e.g. increases turbidity (Degani & Kaplan 1999, Angeler et al. 2001). P.clarkii consume a large variety of preys (Elvira et al. 1996, Geiger 2005) with a potential impact on vegetation but also on the fauna. That species is also predated by numerous fishes, birds and mamifers (Beja 1996, Elvira et al. 1996). As a consequence, also it is widely agreed that P.clarkii introductions have had negative impacts on macrophyte dominated mediterranean habitats, there is question as to how it will affect biodiversity in the mid-term. In a trophic feedback loop were amphibians, aquatic reptiles and inbertebrates, and fish populations continue to decline, the removal of the exotic species is a particularly central consideration, as it has become an important factor in increasing flagship predator abundance, such as Bautorus Stellaris. Current observation suggests that a tropic shift has already occurred, and therefore the hypothetical elimination of Procambarus Clarkii could be seen as having a catastrophic short term effect for predators that rely on it as a prey source. For example, studying optimal control of an invasion such as the red swamp crayfish (Procambarus clarkii) calls for the assessment of potential positive feedbacks. As exhaustively documented in the literature, crayfish expansion may be a bad in that it unbalances ecosystems threatening local crayfish and species of fish. It can also be a good in that its concentration may attract new species as observed in Camargue (France) where several bird species settled down durably thanks to the profusion of food. Economically, decreasing fish population may also harm fish-related activities but the red swamp is also the principal crayfish consumed in the international market and optimal control should care of accounting for economic opportunities of exploiting this new resource.

3.3.3. Potential extension in an impact function

Once the typology is established and precisely described on a local level for a specific invasion, all the parameters identified may be written under the form of an impact function, taking into account the different essential variables. Further work will be to attempt to assess and refine those variables in order to determine a valid and flexible typology of cases and elements to consider when facing a complex and by definition multidimensional biological invasion.

$$Impact = \propto \cdot (\textbf{population density}) + \beta \cdot (state\ of\ environment) + \gamma . (perceptions)$$
= *"Population" ambivalence +"Geographic" ambivalence+"Assessment" ambivalence*

$$Impact = \propto . (propagule\ pressure, threshold\ effect) + \beta . (environmental\ perturbations, pathogens, predators) + \gamma . (perceptions\ by\ actor 1, actor\ 2, mean\ population, level\ of\ cultural\ implications)$$

One of the main challenges would be to determine the weights attributed to the different aspects of invasion, and especially to the different variables explaining the importance of an effect.

4. Discussion: a road map for the economics of biological invasion

How can economics of biological invasion include these two key insights from ecology? From the analysis of a simple public bad to be prevented or eradicated efficently, economics is to deal with an ecological process that may be good or bad according to situations and circumstances. This ambivalence of impacts questions significantly economics problematic and notably the questioning on invasive species management at a global scale. As well, uncertainty surounding ecosystems evolution and the role of biological invasions into it, questions the true goal of what is to be done for the ecosystem. The idea of novel ecosystems calls for approaches that go closer to the purpose of viability theory than simple optimal control problems. In this concluding section, we present a road map for the economics of biological invasion. We first, question what should be the prerequisite of any economics approach on the topic, and second, review the implications for the economics of biological invasion, of ambivalence on the one hand, of ecosystem dynamics on the other.

Although prioritization is deemed to be partial and certainly inevitably wrong, this is a necessary step toward biological invasion management. Prioritization is the key to the definition of which evolution corridors we should favor and prevent. Considering that movements of species is natural, the choice turns to be, for each specific ecosystem, which species to preserve and what for? We saw that at least five principles should be considered when making this choice. However, they can be contradictory and to prioritize principles is necessarily situation specific. The typology grid of ambivalence is at that extent useful in that it allows to better understand economic and ecological impacts related to a specific invasion situation. This has however to be taken with caution given complexities of ecosystem processes. Blandin (2007) argues that evolution cannot be simply understood as a process of formation and extinction of species. Instead, this is a physical, chemical and biological transformation that involves biodiversity changes which, in return, modifies the physico-chemical environment. This virtuous or vicious circle of biodiversity creation is what is always to be preserved first. A key question for ecology remains then to better understand the relation between diversity and adaptability; a key question for economics to better understand the relation between diversity and ecosystem services.

A prerequisite for local and global biological invasion management is to better understand economics and ecological impacts of novel ecosystems resulting from invasions at a local and at a global scale. Ecology needs to develop empirical studies indicating how introduction of nonnative species impacts both species richness and biological productivity in local areas. Evaluation studies in economics should better grasp costs and benefits related to invasions and specific effort is to be made in order to also focus on positive economics impacts in novel ecosystems resulting from invasions. This point echoes our typology on ambivalence, it also echoes contradictions in the literature about ecological and economics impacts of biological invasions. Although influential studies of Pimentel et al. (2000) or Wilcove et al. (1998) state that biological invasions annually cause over $100 billion of damages in the United States (Pimentel et al., 2000) and that it represents the second greatest threat to the world's endangered species, just behind direct habitat destruction (Wilcove et al. 1998), other studies tend to contradicts those findings. Ewel and Putz (2004) for example, argue that desirable metrics are constantly underestimated. Going further, the same authors as well as Foster and Sandberg (2004) argue that invasive species have been shown to both promote species richness increases and perform ecological functions that are generally regarded as desirable. Sagoff (2005) and Evans et al. (2008) question whether the control activities are a necessary or effective method for correcting harms. Sagoff argues that invasion biology is plagued by an a priori interpretive bias assimilating non native species as harmful but also conflates costs associated with the control of biological invasions with the supposed damages caused by these species (cf. Pimentel et al. study). Quoting Gurevitch and Padilla (2004), the author also argues that the claim according to biological invasions imply significant extinction (cf. Wilcove et al.) is false. This statement is also defended by Davis (2003) but is viewed as a minimization of the problem by Simberloff (2008). This last, citing Clavero and Garcı´a-Berthou (2005), claims that analysis greatly underestimates extinctions and endangerment caused by introduced species. Risk assessments seem therefore highly desirable and a first recommendation for economics research on the topic is to pay an increasing attention to economic valuation of costs and benefits related to invasions.

Ambivalence inevitably impacts research on optimal prevention and control of invasions. Focusing on positive feedbacks from invasions and on negative feedbacks from control methods is likely to modify significantly research on the topic and to lead to the prescription of much more balanced policies. A second recommendation is to put effort in these studies on identifying positive and negative economic but ecological effects of invasions. We think here of adding intrinsic values in the policy goals and for example value biodiversity indexes. Because of the veil of uncertainty, if a policy goal is not perfectly identified or if the objective of invasion management is not to reach an optimal state but to avoid getting out of a corridor of acceptable situations, a third recommendation is to focus on viability theory (Aubin, 1991). Most optimal control approaches dealing with bio-invasions start from a prescribed policy scenario which is used as a principal input to the model. This scenario is usually the level of protection, of prevention or of eradication. The cause of the analysed problem is controlled and the optimal level identified is meant to be an optimal response to the effects we want to avoid. A key insight we derive from ecology is that causes and effects are highly uncertain and instead of looking for an optimal response to an uncertain problem, a solution is to invert the reasoning. We can indeed specify effects first or say a corridor of acceptable effects and then compute backwards to obtain the corresponding causes. Viability theory investigates the adaptation to viability constraints of evolutions governed by complex systems under uncertainty such as ecosystem dynamics. These constraints are derived from ecology objectives, ethical principles, scientific results or precautionary principles and delineate ,reference points to be avoided (Cury et al., 2005, Baumgartner and quaas, 2008). In our example this means that we infer a level of protection, prevention or eradication from a given ecosystem evolution corridor previously defined. This inversion can either be unique or ambiguous where more than one cause is related to the specified effect.

Finally, global issues related to the provision of the public good are also necessarily affected by ambivalence. If invasive species impact differently one ecosystem or the other, if it impacts negatively biodiversity but positively ecosystem services or the reverse, then the provision problem is to be thought differently because both aggregation technologies and provision costs will differ from the simple weakest link problem usually considered. Cooperation and coordination to respond collectively biological invasions is certainly an important issue but the nature of the public good is to be better understood before any incentive policy to increase the level of coordination is further studied. Our last recommendation for the economics of biological invasion is to define precisely what kind of public good we are dealing with in order to be able to adequately respond this potential "threat" at an international scale.

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