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Are diverse ecosystems more valuable? A conceptual framework for economic valuation of biodiversity

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Abstract

Biodiversity is an important environmental public good. However, the literature suggests that it is not clear how its economic value should be estimated; there is no established framework for doing this. This paper summarises concepts of biodiversity value from the ecological and economic literatures and combines them to a comprehensive and consistent framework. It is argued that biodiversity is the main carrier of insurance value, option value and spill-over value, and also influences the aesthetic appreciation of ecosystems. On that basis, an extension of the TEV framework is proposed to incorporate biodiversity values better. Furthermore, a number of specific challenges of biodiversity as an economic good are identified and used as criteria to inform the choice of suitable valuation methods.

Keywords biodiversity, economic valuation, insurance value, option value, TEV

1 Introduction

Public concern about the ongoing loss of biodiversity across spatial levels suggests that it can be considered valuable from an economic, i.e., preference-driven, point of view (MEA, 2005; Rockström et al., 2009). While much of this concern can be attributed to the loss of ecosystem services or individual species, some of it has to do with biodiversity sensu stricto (Bakhtiari et al., 2014). Not surprisingly, there exist a large number of economic valuation studies that estimate the value of biodiversity. However, as reported in a recent review of existing biodiversity valuation studies (Bartkowski et al., 2015; see also Farnsworth et al., 2015), the approaches used in most studies are deficient in that they do not really capture their valuation object. Some provide values for at least parts of biodiversity, most misinform by valuing other environmental goods. Moreover, since 'there is certainly not yet an established framework for valuing biological variety' (Nijkamp et al., 2008, p. 218), the overall picture drawn by available biodiversity valuation studies is rather inconsistent. It is unclear which of the many economic values of biodiversity can really be used to inform decision-making processes.

This paper develops a conceptual framework for economic valuation of biodiversity. It is based on state-of-the-art ecological knowledge regarding both the concept of biodiversity itself (its definition and measurement) and its *ecological value*, i.e., the role biodiversity plays within ecosystems. Using an interdisciplinary perspective, a framework of biodiversity's economic value is developed. The paper is not an attempt to provide many genuinely new insights into the economic value of biodiversity—rather, its contribution consists in identifying relevant arguments and combining them to form a consistent conceptual framework. Also, some implications for the common total economic value (TEV) framework are given. The findings are then used to identify valuation methods that are particularly well-suited for economic valuation of biodiversity.

There are a few surveys of the literature on the economic value of biodiversity which provide important insights. However, their purpose was either more encompassing, effectively reviewing the entire field of economic valuation, often under a loosely defined heading 'biodiversity' (Nijkamp et al., 2008; Nunes et al., 2003; Nunes and van den Bergh, 2001; Pascual et al., 2010); or it was more narrow, focusing on the application of a given valuation method (Bakhtiari et al., 2014) or in a given valuation context (Christie et al., 2006, 2004).[1] Also, biodiversity's role in other frameworks, especially the ecosystem services framework, remains unclear (Atkinson et al., 2012; Jax and Heink, 2015). Many publications focus on specific aspects of biodiversity and its economic value, yet there is still a need for a consistent, unifying framework to inform future valuation studies if they are to provide meaningful information for decision-making processes involving biodiversity.

The paper is structured as follows: in section 2 a definition of biodiversity is given, on which the remainder of the paper is based. In section 3 the ecological value of biodiversity, i.e., its influence on ecosystem functioning, is briefly discussed. In section 4 sources of economic value of biodiversity are presented and brought together in a framework. Also in this section implications for the TEV framework are drawn. In section 5 specific challenges posed by the economic good biodiversity are identified and used as a set of criteria to inform the choice of valuation methods suitable for biodiversity. Section 6 concludes.

2 What is biodiversity?

A major problem of dealing with biodiversity is that it has no established definition (Meinard et al., 2014). Moreover, it is a value-laden concept, an 'epistemic-moral hybrid' (Potthast,

[1] Christie and colleagues came closest to developing a conceptual framework of biodiversity's economic value. However, from the perspective of the present paper, their approach lacked a clear identification of the ways through which biodiversity influences human well-being. The present paper offers an alternative and more general perspective.

2014; see also Takacs, 1996), which is the reason why the term is often used very vaguely, especially in public discussions. Even in scientific discourses, different definitions are used, explicitly or implicitly, which partly reflects the fact that the concept has evolved over time—for instance, the still highly influential CBD definition from 1992 does not mention functional diversity, simply because this concept, now considered very important (see next section), is of more recent origin. This paper is based on a combination of two definitions from the literature, which is both encompassing so as to account for the multidimensionality of biodiversity, and precise by not including non-biodiversity elements in it (Bartkowski et al., 2015).

The first of these two definitions is a general definition of diversity, proposed by Stirling (2007), who frames diversity as the combination of three properties of systems: variety (number of items in a category; the more items, the higher diversity, ceteris paribus), balance (distribution of elements across items in a category; the more even the distribution, the higher diversity, ceteris paribus) and disparity (degree of difference between items in a category; the less similar the items, the higher diversity, ceteris paribus). Translated into ecological terminology, these three properties are richness, relative abundances (evenness) and phylogenetic distance (or a similar measure of dissimilarity).

Maier (2012) defines biodiversity as the multiplicity of kinds in biotic and biota-encompassing categories. This implicitly stresses three things: first, trivially, biodiversity is about biotic (living) items of ecosystems. Second, it is about the multiplicity of these items, not about their identity. Third, it is multidimensional and cannot be sensibly reduced to, e.g., species diversity (Lyashevska and Farnsworth, 2012).

By combination we acquire the definition of biodiversity that is underlying the present paper:

> Biodiversity is a property of ecosystems; it is the diversity of kinds in biotic or biota-encompassing categories, where diversity consists of (i) variety, (ii) balance, and (iii) dissimilarity.

This definition is consistent with the arguments put forward by Lyashevska and Farnsworth (2012) and Farnsworth et al. (2015), who stress the multidimensionality of biodiversity and develop a three-dimensional biodiversity metric, which consists of the three 'axes' of structural complexity, taxonomic diversity and functional diversity; they show that conventional biodiversity measures miss a significant amount of information (Lyashevska and Farnsworth, 2012).

3 Ecological value of biodiversity

There exists a large and long-standing literature on the relationships between biodiversity and ecosystem functioning (BEF). It cannot be attempted here to summarise all the different strands of this body of research. The influence of biodiversity on ecosystem productivity, stability, resilience etc. has been investigated in a large number of both theoretical and experimental studies. There is agreement among most researchers in the field that, while details may be controversial and there remain knowledge gaps, the general picture provided by experimental studies supports the initially posed hypothesis that high levels of biodiversity and ecosystem functioning coincide (Balvanera et al., 2006; Cardinale et al., 2012; Isbell et al., 2015), even though the magnitude of the respective effects depends on which measure of ecosystem functioning is in focus (Pimm, 1984; Schmid et al., 2002).

The central mechanism behind biodiversity's positive influence on ecosystem functioning is *functional redundancy*: the existence of species '[w]ithin the same functional effect type' that, however, exhibit 'different requirements and tolerances' (Díaz and Cabido, 2001, p. 653), *functional effect types* being groups of species that influence ecosystem processes in similar ways. The notion of functional redundancy is closely related to the *insurance hypothesis* (Folke et al., 1996), which amounts to the 'idea that increasing biodiversity insures ecosystems against declines in their functioning caused by environmental fluctuations' (Yachi and Loreau, 1999, p. 1463). As will be argued in the next section, this ecological hypothesis can be extended by including human preferences and risk-aversion so as to arrive at the concept of the *insurance value* of biodiversity.

An important point to note at this place is that, most likely, biodiversity as such does not have meaningful influence on ecosystem functioning. It is concrete species or groups of species and the interactions between various elements of ecosystems that determine ecosystem functioning (cf. Grime, 1997; Haines-Young and Potschin, 2010). However, as our knowledge of these processes, dynamics and interactions is inherently limited, we are forced to recur to the 'crude' notion of biodiversity, which is a useful proxy concept that allows to approximate the effects of species assemblages on ecosystem functioning. In this sense, the concept of biodiversity is only useful as a second-best solution, where the first-best solution (understanding the exact roles of the various components of an ecosystem for its proper functioning) is not available.[2]

4 Economic value of biodiversity

The ecological value of biodiversity, briefly discussed in the previous section, is only one source of biodiversity value from an economic point of view. In what follows, further sources are introduced and combined in a conceptual framework. Also, implications of these ideas for the TEV framework are briefly discussed.

4.1 Sources of value

There are four ways through which biodiversity, as defined in section 2, influences human well-being: it is an insurance against disturbances to the supply of ecosystem goods and services; it is a pool of options to accommodate unknown future needs and preferences; it provides spill-overs for other ecosystems via migrating species; and it influences the aesthetic appreciation of landscapes.

4.1.1 Insurance

As mentioned in section 3, the interpretation of biodiversity as insurance is quite common in recent ecological literature on biodiversity and ecosystem functioning. Insurance is, of course, a genuinely economic concept. For something to be considered economic insurance, three conditions must be fulfilled: (i) the provision/supply of some good (e.g., the services provided by an ecosystem) must be uncertain; (ii) relevant stakeholders must be risk-averse; (iii) there must be a mechanism for hedging/lowering the probability of losses/reductions in supply (cf. Baumgärtner and Strunz, 2014). Obviously, the provision of ecosystem services is uncertain due to both natural perturbances (storms, diseases etc.) and anthropogenic factors such as land-use change or climate change (Pereira et al., 2012); people in general tend to exhibit risk-aversion (e.g., Dohmen et al., 2011); and, as discussed in section 3, biodiversity has a positive influence on the stability and resilience of ecosystems.

The idea that biodiversity has economic insurance value has been present in environmental economics for some time. For instance, Figge (2004) compared biodiversity to a financial portfolio ('bio-folio'). Portfolio theory (Markowitz, 1952) shows that in order to minimise the

[2] A similar point was raised by Mainwaring (2001) in the debate on the Noah's Ark problem initiated by Weitzman (1998); she pointed out that 'redundancy' does not mean obsoleteness of 'redundant' species, if only because we usually do not know which ones they are. See also Weikard (2002).

risk of holding financial assets, one should spread this risk by investing one's money in a portfolio of different, uncorrelated assets. A biodiverse ecosystem can be seen as such a portfolio of assets with different proneness to particular disturbances. Redundant species (sensu functional redundancy) decrease the probability of flips in the state of an ecosystem, which is closely related to the notion of resilience, i.e., the ability of the system to return to its initial state after a disturbance (Baumgärtner and Strunz, 2014; Mäler, 2008; Matsushita et al., 2016; Walker et al., 2010). In the context of biodiversity's insurance value, it suffices if 'state' is defined as the capacity to provide a given supply of ecosystem services.

Insurance value is 'a value component in addition to the usual value arguments […] which hold in a world of certainty' (Baumgärtner, 2007, p. 90). Thus, it can be defined as the change in the risk premium of the 'lottery' (i.e., future state of the world) due to a change in biodiversity. Following Ehrlich and Becker (1972), Baumgärtner and Strunz (2014) differentiate between two basic forms of insurance: an insurance contract and *self-protection*, the latter amounting to attempts of the interested actor herself to reduce uncertainty on her own. The insurance function of biodiversity is much closer to this latter notion, as societies can 'insure' against future declines in the provision of ecosystem services by deliberately maintaining and increasing biodiversity in ecosystems (see also Pascual et al., 2015). For an application along similar lines, see Finger and Buchmann (2015).

The role of biodiversity as insurance against exogenous shocks is perhaps most obvious in agriculture (e.g., Matsushita et al., 2016): the use of different varieties of crops (or different races of livestock), including crop rotation, decreases the proneness of a harvest to pests:

> [T]he more prevalent is the host, the bigger is the size of the evolutionary dining-room area within which the host-specific parasites have leeway to play with new genetic combinations, or to experiment with the increased comparative advantage that comes from specializing to finer-grained subniches within the host organism (Weitzman, 2000, p. 237).

Two specific interpretations of insurance value are available: first, biodiversity can be argued to promote *acute stability* in the sense of resilience or resistance of the biodiverse ecosystem against exogenous shocks, e.g., storms (Thompson et al., 2009) or climatic events such as droughts (Isbell et al., 2015). Second, when biodiversity positively influences the temporal stability of an ecosystem, this can be valuable if coupled with intergenerational equity concerns. People may appreciate the fact that a relatively biodiverse ecosystem is more likely to be available to future generations, on top of its availability to themselves—a notion closely related to the TEV category of bequest value. However, this temporal stability is not to be understood in the sense of a non-changing state but rather the more general 'capacity to produce well-being' (Anand and Sen, 2000, p. 2035).

4.1.2 Options

In addition to providing insurance value, biodiversity can be viewed as *container of future benefits* or *carrier of options*. Since future is uncertain, it may be wise, according to this interpretation, to keep components of ecosystems intact (thus maintaining their diversity), even if we do not have use for them now. As understood here, option value is not about future uncertainty regarding future states of ecosystems themselves (for this, see the previous section on insurance value), but rather regarding future preferences. Obviously enough, these two interpretations are inherently interlinked; however, they depend on different types of uncertainty, which makes the differentiation sensible. Option value can be linked directly to biodiversity: the more biodiverse a given ecosystem is, the higher the probability that it contains goods which will be beneficial for human beings in the future.

The view of biodiversity as carrier of option value stems from the recognition that a biodiverse ecosystem, which contains many different species and genomes, can best accommodate unanticipated desires (preferences) of both current people in the future and future people. As in the case of insurance value, this can be coupled with considerations of intergenerational equity: high levels of biodiversity now mean many different options for our grandchildren (cf. Birnbacher, 2014), who may want to extract from ecosystems technological blueprints, substances and genes which we currently have no use for.[3] According to Goeschl and Swanson (2007, p. 273), '[o]f the many ways in which biodiversity might be conceptualised, one of the most important is as the diversity of the set of genetic resources.' Building upon Weitzman (1998), they invoke the notion of biodiversity as a 'legacy library,' i.e., a pool of (genetic) information bequeathed to our descendants. Under this perspective, biodiverse ecosystems are potential sources of basically three categories of future benefits: genetic knowledge (relevant especially for agriculture), models or blueprints for new technologies (a classic example being aircraft, which is an attempt to mimic birds) and

[3] This interpretation of option value of biodiversity is a part-response to a criticism of neoclassical environmental economics and the preference utilitarian foundation of economic valuation by Scholtes (2010), whose concept of *environmental dominance* emphasises the problem that our current use of ecosystems has repercussions for the freedom of choice of future generations; he thus seeks concepts which would help alleviate and justify our environmental dominance. Preserving future options would be one possible approach.

substances for future use in the chemical and pharmaceutical industries (Myers, 1997). Especially the recognition of the latter aspect has had direct economic repercussions, as exemplified by the phenomenon of bioprospecting (Costello and Ward, 2006; Goeschl and Swanson, 2002; ten Kate and Laird, 2000). Also, preservation of biodiversity of wild forms may have direct implications for agriculture. There are many cases of non-commercial wild varieties of agricultural crops such as rice or coffee whose genetic material could be used to counter diseases or pests (Di Falco, 2012; Di Falco and Chavas, 2009). In times of increasingly widespread use of biotechnology, this is even truer: genetic engineering enables the use of genetic information from completely unrelated organisms, which increases the significance of (the diversity of) non-agricultural wild species for agriculture.[4] To put it poignantly, 'a relatively cheap way of buying catastrophe insurance is to cultivate or hold small positive amounts of as many different kinds of potential domesticates as it may be possible to preserve' (Weitzman, 2000, p. 261).[5]

4.1.3 Spill-overs

A biodiverse ecosystem can be expected to be diverse in (micro-)habitats. Some of these (micro-)habitats can be essential for migratory species (salmonids, cranes, geese), whose main habitats lie outside the investigated ecosystem, but for which this ecosystem is one (potential) station in their migratory life-cycle. An example of such ecosystems are the dehesas in the Spanish region of Extremadura, where numerous species of migratory birds from Northern Europe spend winters (Diáz et al., 1997). This is possible because of the high habitat diversity of these agro-silvo-pastoral ecosystems. Seen from this perspective, biodiversity in such ecosystems has spill-over effects on other ecosystems. The idea behind biodiversity's spill-over value is related to the *maintenance of life cycles of migratory species* or *nursery-service* in the TEEB classification (Elmqvist et al., 2010).

Under the assumption that the relevant migratory species contribute to human well-being, the contribution of a biodiverse ecosystem to their life cycles can be argued to contribute to the overall value of this ecosystem. Importantly, the contribution of biodiversity consists not in the fact that there is a (micro-)habitat for a specific migratory species, but that there is a multiplicity of habitats within one ecosystem which can (potentially) be used by such species.

[4] The advent of the CRISPR/Cas technology (e.g., Cong et al., 2013) makes it possible to transfer, knock of or silence genes with unprecedented precision at very low cost. It revolutionises the field of green biotechnology and thus increases the economic value of natural biodiversity.
[5] A controversially discussed issue is whether this kind of precautionary preservation of varieties should happen in situ or ex situ (Maier, 2012, chap. 7.2.3).

In a certain sense, this might be called 'efficient,' as it is possible to support a number of migratory species within one single ecosystem, thus minimising the area needed for their support.

Spill-over value may well be criticised as an instance of double counting (Hamilton, 2013). This is certainly true in the context of environmental-economic accounting and large-scale cost-benefit analyses, in which the ecosystem(s) of the migratory species' origin are included as well. However, these are not the only, not even the main purposes of economic valuation (cf. Costanza et al., 2014). For example, for communication of the importance of intact, biodiverse ecosystems to the public and policy makers, spill-over value's importance consists in showing that ecosystem services, which provide direct benefits to humans and thus have use value, are embedded in a larger, highly complex dynamic system and should not be viewed atomistically or in a static way (Fromm, 2000). More generally, when the purpose is to demonstrate the economic value of a specific ecosystem, spill-overs to other ecosystems are a relevant component of this value.

4.1.4 Aesthetics

Another way through which biodiversity can contribute to the value of an ecosystem is via aesthetics. Exceptionally biodiverse ecosystems are also perceived as exceptionally beautiful by many people. Thus, ecosystems might be valuable partly because they are biodiverse, as reflected, e.g., in the appreciation of diverse forests indicated by related tourist and recreational activities (Giergiczny et al., 2015; Siikamäki et al., 2015). However, the opposite might also be the case, i.e., biodiverse ecosystems might be conceived by some people as 'unsightly' (see Horne et al., 2005; Kimmins, 1999). Whether the effect of biodiversity on subjective appreciation of an ecosystem's 'beauty' is positive or negative, is a matter for empirical investigation.

However, it might be very difficult to disentangle the various components of the aesthetic value of an ecosystem, so as to filter out biodiversity's contribution to it.[6] For instance, it would be necessary to distinguish the appreciation of the diversity of ecosystem components (species, landscapes etc.) from the appreciation of some specific elements in the mix (Jacobsen et al., 2008). Another caveat is that aesthetic value is likely to have strongly diminishing returns in terms of increasing biodiversity—most people would hardly be able to

[6] Note, however, that recent research on the economic valuation of landscapes suggests ways of disentangling various objective components that influence the aesthetic appreciation of landscapes (Tagliafierro et al., 2016).

notice changes in biodiversity beyond a certain saturation point. Empirical studies indicate that laypeople's ability to distinguish species is very limited (Bebbington, 2005; Pilgrim et al., 2008; Voigt and Wurster, 2015). This is potentially problematic because it can lead to differences between actual and perceived diversity; the problem arises irrespective of whether stated preference or revealed preference methods are applied. It is important for conceptual reasons to keep in mind that biodiversity influences aesthetics, but most likely it is not advisable to distinguish between the different factors which determine aesthetic appreciation in actual valuation studies.

4.2 Conceptual framework of biodiversity's economic value

In previous section, a perspective on biodiversity as an economic good was stepwise developed. Based on a specific definition and with emphasis laid on biodiversity's multidimensionality, a catalogue of sources of value was attributed to it. In Figure 1 this is summarised in a conceptual framework of biodiversity's economic value.

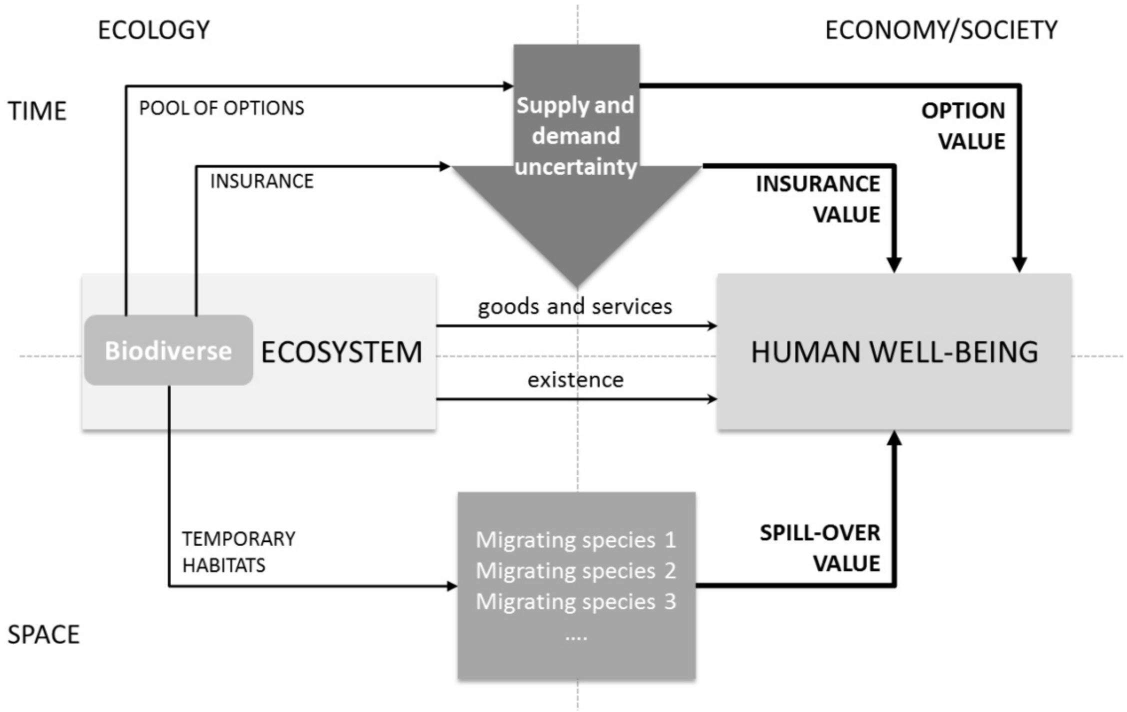

Figure 1 Conceptual framework of biodiversity's economic value. Capitalised terms at thick arrows indicate biodiversity values; the light dashed lines indicate the stylised boundaries between ecological and socio–economic systems as well as temporal and spatial dimensions.

Various elements of an ecosystem provide goods and services to humans, thus influencing their well-being. Furthermore, ecosystems (and some of their elements) can have existence value, at least for some people. This is nothing surprising and describes in very general terms the idea behind the ESS and TEV frameworks (see also next section). However, an ecosystem has a number of properties, one of which is biodiversity, i.e., the multiplicity of dissimilar items in various biotic categories. Depending on how biodiverse the ecosystem in question is, it has additional value to society. The relevant effects of biodiversity are depicted as thick arrows in Figure 1. First, in accordance to the redundancy hypothesis, biodiversity provides *ecological insurance* to the ecosystem itself. In and of itself, this effect is not economically relevant. It becomes relevant (as *economic insurance*) when a number of conditions are fulfilled: (i) the ecosystem under consideration must provide some goods/services or have existence value; (ii) its future state must be uncertain (large arrow at the top of Figure 1); (iii) those affected must be risk-averse. If these three conditions are fulfilled, the ecosystem's biodiversity has not only ecological, but also *economic insurance value*. It alleviates the severity of supply uncertainty. The second source of biodiversity value has a more direct effect on human well-being: the more biodiverse an ecosystem, the more options (potential future benefits) it contains. Here, again, uncertainty about future preferences and risk-aversion are crucial. The preservation of options in an uncertain world enhances the utility of a risk-averse individual. Thus, biodiversity has *option value*. These two categories of biodiversity value, insurance and option value, have in common that they are only relevant if uncertainty about the future is taken into account. They are contingent upon intertemporal effects. Therefore, both are higher, ceteris paribus, if people care about the well-being of future generations.

The third element of the conceptual framework is *spill-over value*. A biodiverse ecosystem offers temporary habitat to a potentially high number of migrating species. If these species are themselves economically valuable (be it as providers of ecosystem services or just because of their sole existence), this biodiversity-induced spill-over influences human well-being. Contrary to the first two categories of biodiversity value, spill-over value can be located along a spatial dimension, as it is dependent on interactions between different ecosystems.

The last category of *aesthetic value* is omitted from Figure 1 because, as was argued in last section, biodiversity is only one of many factors influencing the ecosystem service of landscape aesthetics and it does not appear sensible to disentangle these factors.

4.3 Biodiversity within TEV framework

The total economic value (TEV) framework in its most common form consists of three main value categories: use values, non-use values and option value (e.g., Pascual et al., 2010, fig. 5.3). In earlier publications, if insurance value was included in TEV, it happened as a category additional to the 'output value' of an ecosystem, which corresponded there to the usual TEV (e.g., Pascual et al., 2015). Spill-over value has been absent to date.

So, how can biodiversity's contribution to the economic value of an ecosystem be properly included in the TEV framework? To do that, TEV has to be restructured and extended—two dimensions have to be added. An extension along a temporal axis helps to include insurance value (and make better place for option value, which is often in a kind of limbo somewhere between use and non-use values in many versions of the framework), while spill-over value necessitates the addition of a spatial dimension. Both extensions are depicted in Figure 2.

To integrate the two dimensions, two additional levels are added to the usual TEV scheme: first, *local values* and *external values* are distinguished (spatial dimension); second, we have *certain-world values* and *uncertain-world values* (temporal dimension). In Figure 2, values attributable to biodiversity are highlighted in darker grey.

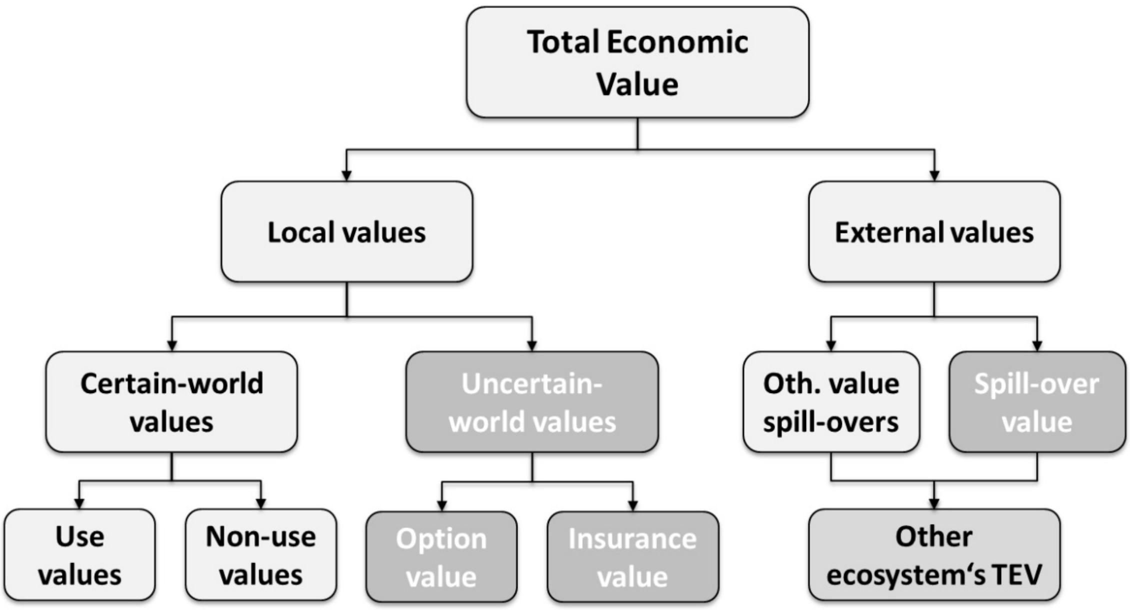

Figure 2 TEV framework with insurance value of biodiversity. Biodiversity-related values are in darker grey boxes with white font.

Including the spatial dimension necessitates the distinction between local values, i.e., values occurring to the ecosystem in question itself, and external values, i.e., spill-overs to other ecosystems. Usually, the TEV has no notion of inter-ecosystem value spill-overs—the notions of altruistic value and existence value only take preference-based effects between locations (since they are based on the idea that the *valuer* is located elsewhere than the *object of value*). External values, on the other hand, amount to contributions of one ecosystem to the value of another, where it can be distinguished between biodiversity-related spill-over value and other, non-biodiversity related value spill-overs, such as for instance the contribution of an ecosystem to the value of a particular ‘visiting’ migrating species (in contrast to *multiple* contributions to the value of *multiple* migrating species, i.e., spill-over value). Spill-over value might be viewed as a kind of *value export* from the ecosystem under consideration to other ecosystem(s).

The temporal dimension is rooted in the idea that uncertainty ‘creates’ value—both insurance and option value derive from the fact that there is irreducible uncertainty about the future. Without this uncertainty, these values would be non-existent. The basic idea of the extension presented in Figure 2 is related to Pascual et al.’s (2015), the difference being that here, option value and insurance value are put together under the heading of *uncertain-world values*, i.e., values which result from uncertainty about the future, whereas use and non-use values are *certain-world values*. From what was said above, it is obvious that biodiversity’s contribution to the TEV of an ecosystem is mainly via uncertain-world values—both of the latter’s components can be directly attributed to biodiversity.

5 From value to valuation: identifying suitable valuation methods

Biodiversity is an unusual environmental good and thus poses particular challenges to valuation. These are, specifically: (i) the non-market nature of components of biodiversity value; (ii) high levels of uncertainty involved in the relationship between biodiversity and human well-being; (iii) the multidimensionality of the concept; and (iv) its abstractness and complexity. These can be used for a stepwise, narrowing-down identification of suitable valuation methods (see Table 1 for summary).

Table 1 Suitability of valuation methods to handle biodiversity-specific challenges. Symbols: - cannot handle issue; + can handle issue to some extent; ++ can handle issue well. If a specific method within a class is particularly well suited to tackle a given challenge, it is named in brackets (and the symbolic evaluation applies to this method only). Explanations see main text.

	Production function	Revealed preferences	Stated preferences
non-market aspects	-	++	++
uncertainty			
- subjectivity	+	-	++
- two-level	+	++ (HP)	++ (CE)
multidimensionality	+	++ (HP)	++ (CE)
abstractness	-	-	++ (DMV)

The first challenging biodiversity characteristic that can be used as criterion for the identification of methods suited for its economic valuation is related especially to the notion of insurance value. This value results from the influence biodiversity is supposed to have on ecosystem stability and resilience, thus ‘insuring’ the delivery of ecosystem goods and services. Accordingly, it was argued that biodiversity’s economic value can be estimated by means of production function and related methods (Farnsworth et al., 2015), and related approaches specifically targeting the insurance value of biodiversity have been developed and applied (Baumgärtner, 2007; Finger and Buchmann, 2015; Henselek et al., 2016). However, such approaches can only be sensibly used to estimate the insurance value of biodiversity towards marketed ecosystem goods and services, effectively excluding all others. This would result in serious underestimation in many cases, which suggests the application of stated preference methods or revealed preference methods instead, which can provide information on the economic values of non-marketed goods.

Biodiversity's economic value is inherently linked to issues of uncertainty about the future. This link offers another 'filtering' criterion for choosing methods suitable for the economic valuation of biodiversity. First, deep uncertainty is involved: especially in the case of option value neither relevant probability distributions nor the relevant 'events' are known: we simply don't know future preferences; that is, indeed, the point about option value. As a result of this, the option value of biodiversity is based on inherently subjective judgements of stakeholders—judgements which, in many cases, cannot be linked to any observed behaviour in (surrogate) markets other than, possibly, markets for bioprospecting. This is another argument in favour of stated preference methods, though bioprospecting contracts could be used as proxy here. Furthermore, as was pointed out in section 3, it is not entirely clear if and how biodiversity has an influence on ecosystem functioning: the exact relationship between biodiversity and ecosystem functioning (in terms of stability, resilience or other related concepts) is still controversial and contested.[7] From the perspective of economic valuation, this amounts to a *two-level uncertainty*: first, it is uncertain whether a given land-use change will in fact result in a specific change in biodiversity— this type of uncertainty is, however, common in valuation studies in general; second, it is uncertain whether and how the change in biodiversity will affect ecosystem functioning, which is less common for other environmental goods. For instance, when the economic value of an endangered species is to be estimated, respondents in stated preference surveys are asked for their willingness-to-pay for a change between two states of the world: the status quo and a world in which the abundance of the species in question is significantly raised. This can then be directly compared with the costs of a suitable protection programme. Conversely, since biodiversity is the property of an ecosystem, changes in it cannot be sensibly valued in isolation—rather, they can only be

[7] As shown by Matsushita et al. (2016), the relationship might be dependent on the current regime (basin of attraction) in which a given ecosystem is located.

valued as a result of a specific land-use change. Then, the above-mentioned two-level uncertainty emerges. This uncertainty has also to be handled when biodiversity's economic value is to be estimated. Such uncertainty can be comparatively well-handled in discrete choice experiments (CE) and hedonic pricing (HP), though production function methods could be useful here as well. They all allow for estimation of marginal WTPs for different attributes of the problem at question. Thus, their results can then be flexibly linked to scenarios based on, e.g., ecological land-use models.

A third, closely related issue is multidimensionality—both biodiversity itself and its economic value are multidimensional. As mentioned above, multidimensionality can be well-handled in CE and HP, and to some extent in production function approaches.

On top of that, people are rather unfamiliar with biodiversity, as shown in a number of different studies and polls in different countries (Bakhtiari et al., 2014; Buijs et al., 2008; DEFRA, 2007; UEBT, 2013). This has important consequences for any attempt to estimate the economic value of biodiversity. In fact, it can be argued that biodiversity is even more problematic than so-called *experience goods* (e.g., Czajkowski et al., 2015), which pose a challenge to economic valuation because consumers learn about their preferences towards these goods in the act of consuming them. Biodiversity can be seen as a more extreme case, as there is no obvious way of 'consuming' it, so other ways of learning about one's preferences are necessary. In addition, ecosystems in general are complex and it takes years of full-time scientific training to understand them properly. Biodiversity is an especially complex and abstract concept (Meinard and Grill, 2011). Lack of knowledge of/experience with biodiversity and the concept's abstractness suggest that revealed preference methods may not be helpful (since they can only be used to derive pre-existent preferences people hold for things they know are valuable) and even that conventional stated preference methods may not be sufficient. Here, deliberative monetary valuation (DMV) could be a viable option, as this approach has been developed to tackle just such limitations involving limited knowledge and familiarity with environmental goods (Lienhoop and Völker, 2016; MacMillan et al., 2006).

According to the criteria emphasised here, stated preference methods are much better suited for the economic valuation of biodiversity than other methods which rely on observed data. Furthermore, a combination of CE with DMV, called *deliberative choice experiments* (Völker and Lienhoop, 2016)[8], seems particularly attractive because, as shown in Table 1, CE is particularly well-suited to handle non-market effects, uncertainty and multidimensionality, while DMV offers a powerful tool for dealing with complexity and abstractness.

6 Conclusions

In this paper, a conceptual framework for economic valuation of biodiversity was proposed. Such a framework is an essential basis for biodiversity valuation studies if they are to provide meaningful and consistent information for land-use decision-making processes.

On the basis of a definition of biodiversity informed by ecological literature, four sources of its economic value were identified and discussed: insurance value, which results from biodiversity's influence on ecosystem stability and resilience in combination with human risk-aversion and the uncertainty surrounding future supply of ecosystem goods and services; option value, which is the consequence of biodiverse ecosystems' being pools of options that allow to accommodate currently unknown future preferences; spill-over value, which results from interconnections between different ecosystems via migrating species, whereby biodiverse ecosystems provide potential habitats (and thus spill-overs) for multiple such species; and aesthetics, though biodiversity's influence on this is mainly of theoretical interest as there appears to be no rational reason to distinguish between biodiversity's and other factor's effect on the aesthetic appreciation of ecosystems. From this, implications were drawn for the TEV framework and a possible extension of it was proposed. Last but not least, challenges that biodiversity poses for economic valuation were identified and used as a set of criteria to identify suitable valuation methods. (Deliberative) choice experiments appear to fulfil the criteria best.

Of course, the conceptual findings of the present paper would need further refinement and adaptation before they can be applied in a valuation study conducted in a given ecosystem. However, the conceptual framework developed provides important information for future biodiversity valuation studies by clarifying the identity of this special valuation object, the ways through which it influences human well-being and its methodologically relevant characteristics.

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[8] The term *deliberative choice experiments* was first used by Kenter et al. (2011). However, their approach differs from the one advanced here, as they elicited collective preferences, while the deliberative choice experiments proposed here (and applied by Lienhoop and Völker 2016) are based on individual preference elicitation.

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