Ecological Economics 208 (2023) 107799

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Insurance value of biodiversity in the Anthropocene is the full resilience value

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ARTICLE INFO

Keywords:
Insurance value of ecosystems
Natural insurance value
Ecosystem services
General resilience
Specified resilience

ABSTRACT

Recently two distinctly different conceptualisations of insurance value of biodiversity/ ecosystems have been developed. The ecosystem framing addresses the full resilience value without singling out subjective risk preferences. Conversely, the economic framing focuses exactly on this subjective value of risk aversion, implying that the insurance value is zero for risk neutral persons. Here we analyse the differences conceptually and empirically, and relate this to the broader socio-cultural dimensions of social-ecological resilience. The uncertainty of the Anthropocene blurs the distinction between subjective/objective. We show that the economic framing has been operationalised only in specific cases while the broader literature on resilience, disaster risk reduction, and nature-based solutions tend to address the full value of resilience. Yet, the empirical literature that relates to insurance value of biodiversity is hardly consistent with resilience theory because the slow underlying variables defining resilience are rarely addressed. We suggest how the empirical literature on insurance value can be better aligned with resilience theory. Since the ecosystem framing of insurance value captures the essence of the resilience, we propose using the concept "resilience value" as it may reduce the present ambiguity in terminology and conceptualisation of insurance value of biodiversity.

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https://doi.org/10.1016/j.ecolecon.2023.107799
Received 21 April 2022; Received in revised form 28 February 2023; Accepted 1 March 2023
Available online 13 March 2023

1. Introduction

In the Anthropocene, the global economy has become a major force creating vulnerabilities by converting much of the biosphere to an increasingly homogenous, highly connected global production ecosystem (Nyström et al., 2019). Climate change, environmental degradation, and social inequities (IPBES, 2019) are rapidly turning environmental risks into global economic and financial risks (Keys et al., 2019). For example, the insurance industry now identifies climate change as the top risk, with the failure of climate change mitigation and adaptation strategies ranking among the top three risks most likely to significantly influence the global industrial sector (Rudolph, 2019). The World Economic Forum and the Zurich insurance group rank climate action failure and biodiversity loss as two of the top risks (World Economic Forum, 2021) and this is reinforced by scientists' ranking (Future Earth, 2021).

1.1. Insurance value of biodiversity: The ecosystem framing

Since the mid-1950s some ecologists have suggested that ecosystems provide a form of risk reduction and insurance to society (Green et al., 2016), variously called natural insurance value or insurance value of biodiversity (inclusive of genes, species, and ecosystems). Resilience theory acknowledges that keystone process species provide "natural insurance", which prevents ecosystems from flipping into another regime (Folke et al., 1996). Similarly, the "insurance hypothesis" of biodiversity (Yachi and Loreau, 1999) focuses on stabilizing biodiversity.

Different ecological-economic conceptualisations of the insurance value of biodiversity have emerged over the past decades. Building on Gren et al. (1994), who relate "insurance" to resilience and redundancy, The Economics of Ecosystems and Biodiversity (TEEB) linked insurance value to ecosystem resilience, defining it as "*the value of ensuring [sic!] that there is no regime shift in the ecosystem with irreversible negative consequences for human well-being*" (Pascual et al., 2010: 4). Similarly, the shadow price of resilience has been defined as "*the present discounted value of future improvements in welfare accrued from the reduced regime flip risk due to a unit increase in the concurrent resilience stock*" (Mäler and Li, 2010: 717). "Improvements in welfare" arguably includes both the objective (mean) and subjective (variance) components of risk reduction.

For the purpose of this paper, we refer to these conceptualisations as the *ecosystem framing* of insurance value. Ensure and insure are metaphorically identical in this framing, related to reducing variance in outcome where "insurance value" refers to the value of resilience. Resilience in social-ecological systems (SES) is not about recovery or bouncing back, but about having capacities to persist and develop in the face of change (Folke, 2006).

The insurance value is related, but not limited, to what economists call option value and quasi-option value. Option value is the value of maintaining an option for future use in excess of anticipated future use, while quasi-option value is the value of delaying a decision and thereby maintaining an option for future use in case new information is available (Leroux et al., 2009). However, in the Anthropocene, future ecosystem benefits cannot be anticipated or taken for granted and are therefore a moving target. TEEB distinguished between the "output value" (of the current state of ecosystems) and the insurance value. Insurance value is theoretically *additional* to the output value and captures increased stability, acknowledging uncertainty, in future benefits (uncertain use value) provided by more resilient ecosystems in the face of disturbance and change (Pascual et al., 2010).

Regime shifts have been empirically identified for a number of SES (Rocha et al., 2018), and are situations in which resilience plays a central role. But insurance value may also be defined as the (full) value of resilience, without notions to distinct regime shifts, e.g., as the capacity for sustained provisioning of ecosystem services in the face of uncertainty, including enhancing options for adaptation (Pascual et al., 2015; Hahn et al., 2017).

1.2. Insurance value of biodiversity: The economic framing

In contrast to the ecosystem framing described above, insurance value has also been conceptualized following insurance and financial economics, as "*the value of one very specific function of resilience: to reduce an ecosystem user's income risk from using ecosystem services under uncertainty*" (Baumgärtner and Strunz, 2014: 22). In this literature, the risk and time preferences of the individual ecosystem user are emphasised (Quaas et al., 2019). Here, we refer to this conceptualisation as the *economic framing* of insurance value, consistent with a foot-note in Baumgärtner and Strunz (2014: 22) that they are "concerned with the economic insurance value of resilience here, as opposed to the so-called 'ecological insurance hypothesis' of biodiversity".

1.3. Aims and objectives

The above suggest that there are quite divergent viewpoints as to what is the insurance value of biodiversity and how it can be conceptualized. While Baumgärtner and Strunz (2014) clearly refer to their own conceptualisation as an improvement, by addressing the shortcomings of the ecological/ecosystem framing, we regard both of these framings as legitimate, answering different research interests. When 'insurance value' is operationalised as risk reduction or otherwise, it's important to know if it addresses only the subjective part of resilience, related to risk aversion, or the objective part (expected mean value), or the full resilience value. This is rarely clarified in the academic and science-policy literature (e.g., Primmer and Paavola, 2021; Dallimer et al., 2020; Jørgensen et al., 2020; Reguero et al., 2020). This ambiguity is problematic because, as we shall see, in the few empirical papers where the distinction is made, the subjective part of resilience value (the insurance value according to the economic framing) has only been a fraction of the expected ("objective") economic value of resilience. Indeed, economic analysis of environmental management under uncertainty usually includes expected ("objective") value and sometimes *only* the expected value (when information about risk preferences is not available). It should be clear by now that the economic insurance value of resilience, the economic framing, does not capture the full economic value of resilience.

The aim of this paper is threefold; to clarify the two main theoretical framings of insurance value (Section 2); to situate these framings in the challenges of the Anthropocene (Section 3); and to analyse to what extent empirical operationalisations are consistent with resilience theory (Section 4). The empirical part focuses on policy-making for risk reduction to climate change and biodiversity loss, which are two of the planetary boundaries that we have already exceeded by a wide margin in the Anthropocene (Rockström et al., 2009; IPBES, 2019). We specifically argue for a broader recognition of the long-term social, economic and cultural importance of resilient SES across scales.

2. Unraveling the theoretical framings of insurance value

2.1. General and specified resilience

The ecosystem framing of insurance value emphasizes the critical role of resilient SES to insure and sustain human wellbeing in times of disturbance and uncertain futures. This relates to notions of general resilience, which is the capacity of society to adapt or transform ecosystem management and governance "*in response to unfamiliar, unexpected and extreme shocks*" (Carpenter et al., 2012: 3249). Following this, the *general insurance value* of biodiversity and ecosystems is defined here as the value of sustaining the *general resilience* of a SES (Fig. 1). This is often interpreted as a benefit for society at large, in that by investing in natural capital and nature-based solutions (NBS), the overall risk for

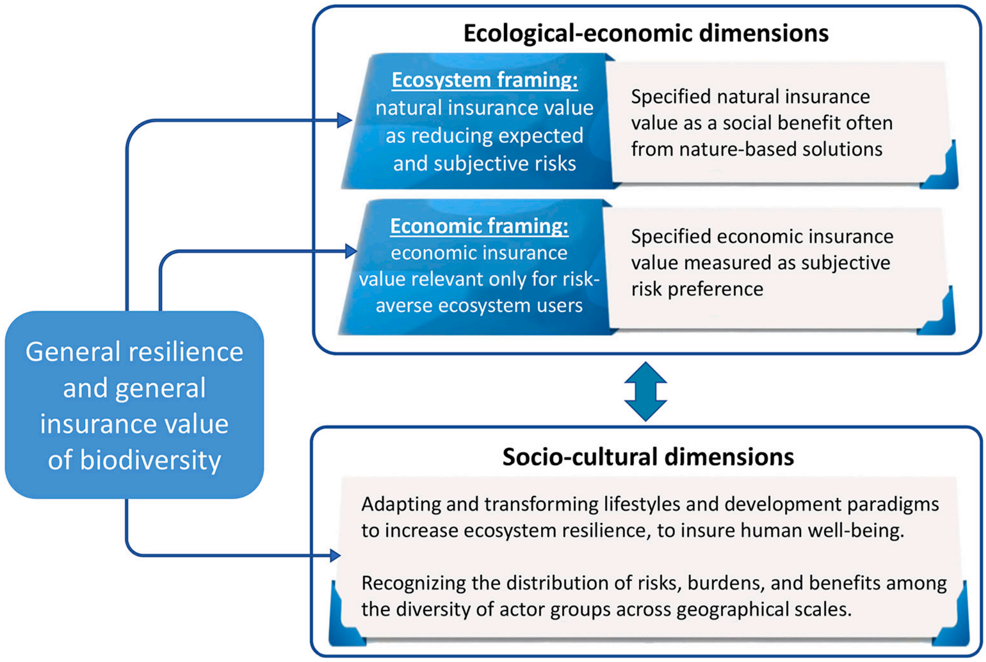

Fig. 1. Conceptual framework of the dimensions of insurance value of biodiversity.

society (the social cost) from all kinds of systemic risks and catastrophic scenarios is reduced (Carpenter et al., 2012). This notion should also account for social equity and environmental justice, i.e., for the distribution of benefits, costs and risks within society from investments in natural capital and NBS.

In policy contexts, resilience is often related to well-characterized disturbances like drought, floods, storms and fires (Liao, 2012). These shocks and disturbances are random but earlier experiences provide knowledge for building specified resilience, usually within one sector (Carpenter et al., 2012). Specified insurance value is therefore the value of resilient SES to reduce risks when facing specific and expected types of shocks and disturbances (Hahn et al., 2021). Building general resilience is a more complex challenge than reducing damage from known disturbances, which can be quantified and often focus on one risk at a time.

Resilience scholars have emphasised that operational definitions and uses of resilience should be consistent with theoretical definitions (Carpenter et al., 2001). This means distinguishing between the external shocks causing the disaster (e.g., fires, storms, floods and other fast variables) and the underlying slow variables causing the erosion of a system's resilience. Several empirical case studies have shown the interplay between sudden shocks, pushing a system across a threshold (tipping point), and the underlying dynamics, which determines if the system is resilient (i.e., retains the same functions), or if it will undergo a regime shift (Rocha et al., 2018). Here, we address the challenge of connecting the applied literature, often focusing on specified insurance value, to these underlying dynamics.

Investing in general insurance value, to enhance general resilience of SES, is largely about maintaining options, e.g., Nature's Contributions to People [NCP] #18 within the IPBES conceptual framework (IPBES, 2019; Díaz et al., 2018 Suppl. Mat.), or nurturing social and ecological diversity for reorganization and renewal (Folke et al., 2003). Social diversity concerns actor groups, knowledge systems, policy & institutional arrangements, and governance levels (Malayang III et al., 2006). Other relevant factors for building general resilience include the health of ecosystems and biodiversity at all levels, connectivity/modularity, nestedness, feedbacks across scales, monitoring, learning & experimentation, and reserves/legacy/memory (Carpenter et al., 2012).

Although difficult to quantify, the ecosystem framing of general insurance value is not only metaphorical but has made clear policy-relevant contributions. For example, the significance of focusing on both specified and general resilience was illustrated in work with the Goulburn-Broken catchment of the Murray-Darling river-basin in southeast Australia. After repeated failure of targeted approaches, building general resilience of broader support systems of the region became critical, like infrastructure, human and social capital, investments in back-up systems such as trust funds and capital reserves, diversification for responding to shocks, as well as capacities to anticipate, experiment, monitor, and learn (Walker et al., 2009). Another example is German forestry laws. Changing spruce monoculture to mixed-species forests is a strategy to increase specified resilience to storm damage. However, mixed-species forests may have some co-benefits and by combining this with a promotion of Continuous Cover Forestry and maximising clear-cuts to 2 ha, the German forestry legislation and Bavarian state legislation have addressed general resilience by explicitly aiming for more resilient forests, reducing damage risks from storms, drought, fire, and insect outbreaks (Borrass et al., 2017; Fichtenrichtlinie, 2009).

Strategies for investing in specified insurance value is related to the factors listed above but typically focuses on targeted approaches and controlling or responding to shocks (fast variables). These are common in the disaster risk reduction (DRR) literature and include monitoring, early-warning systems, and diversification of supply chains, often including quantifications and monetary analysis (Walker et al., 2010; Dallimer et al., 2020). However, focusing on single expected risks may not enhance society's adaptive capacity. Considering the interconnected risks and underlying systemic features of the Anthropocene, science and policy may shift focus from responding to single shocks and surprises to prepare for and build general resilience to shocks and surprises (Clark and Harley, 2020). This requires understanding the present connected, simplified and therefore vulnerable global production ecosystem and transforming the underlying dynamics (Nyström et al., 2019).

2.2. Socio-cultural dimensions of insurance value

So far, we have focused on the ecological and economic aspects of resilience. However, resilient agricultural and fishing SES may also provide equity by insuring/safeguarding livelihoods for a significant share of the global population (Pattanayak and Sills, 2001; Coomes et al., 2010). Socio-cultural dimensions of insurance value emphasise how communities need to adapt and transform life-styles and development paradigms (GDP focus) to increase ecosystem resilience (IPBES, 2019), which in turn insures human wellbeing (Fig. 1). For example, resilient SES sustain livelihoods, quality of life, material culture and expressive culture, often at the same time, integrating instrumental, relational and intrinsic values (Pascual et al., 2017; Haider and van Oudenhoven, 2018). In this frame, the co-benefits of NBS can enhance both the general insurance value and the socio-cultural insurance value. These are largely public goods (Paavola and Primmer, 2019), i.e., benefits which nobody can be excluded from and which are not being reduced when they are used.

Just like environmental burdens are often unequally distributed (Schlosberg, 2014), NBS can also have unequal distributional effects (Suárez et al., 2021). Therefore, analysis of insurance value can benefit from a framework that explicitly acknowledges recognitional, procedural, and distributive dimensions of equity (Leach et al., 2018). Similar to ecosystem resilience, governing the social and cultural values of insurance value represents an inherent cross-scale collective action dilemma (Duraiappah et al., 2014). The plurality and divergence of worldviews, values and interests, appreciation for the role of ecosystems, and forms of governance increases with scale (Brondizio et al., 2009). In such context, participatory approaches, international dialogue and cooperation can enhance coordination and governance of insurance value (Schultz et al., 2018).

2.3. Ecosystem vs. economic insurance value

Based on this broad framework of general resilience and socio-cultural values, we distinguish between two conceptualisations of the general insurance value of biodiversity: (i) the ecosystem framing where natural insurance value includes both the objective risk (expected value) and the subjective risk (variance), often operationalised as the value of NBS, and (ii) the economic framing where economic insurance value is relevant only to risk averse ecosystem users and operationalised as subjective risk preferences (Fig. 1). We refer to these two notions as the ecological-economic dimensions.

In the economic framing the insurance value captures only one part of the economic value of resilient ecosystems, namely the contribution to reduce subjective risks. The other part is the increase in expected (objectively assessed) income provided by resilient ecosystems (Baumgärtner and Strunz, 2014). This separation makes insurance value relevant only for risk-averse ecosystem users. In this framing, insurance value is measured as changes in the risk premium, which is *"the maximum amount of money an ecosystem user is willing to pay to avoid any adverse variations in income and to instead receive the expected income"* (Unterberger and Olschewski, 2021:2). Mäler and Li (2010) also distinguish between two costs of eroded resilience: *"one is the risk aversion loss due to the uncertain realization of the resilience stock and the other is the expected welfare loss due to a possible flip over the period"* (p. 717). However, the insurance value, which Mäler and Li (2010) refer to as the shadow price of resilience, includes both components, i.e., all future improvements in welfare, which makes their analysis consistent to the ecosystem framing.

The ecosystem framing concerns disaster risk reduction in general, where risk reduction is about reducing mean (expected value) and variance of outcome, although variance is rarely framed as an income lottery to analyse risk aversion. Instead, both "objective" and subjective risk reduction are addressed in relation to the precautionary principle: "In daily practice, dimensions of insurance values are difficult to measure, justifying a precautionary approach to ecosystem and biodiversity conservation." (TEEB, 2009: 8).

When insurance value is operationalised as specified insurance values (boxes on the right in Fig. 1), the differences become even more obvious. The economic framing focuses on the income risk reduction for risk-averse people, and therefore the insurance value is zero *"if the ecosystem user was risk neutral"* (Baumgärtner and Strunz, 2014:27). This framing excludes the expected (objective) value of resilience as well as the external costs to society. In contrast, the ecosystem framing concerns expected and subjected risk reduction, including the external (social) costs and hence the full value of resilience in an uncertain future; this value is typically estimated as the benefits that NBS can provide for society.

3. Situating insurance value in the Anthropocene

We acknowledge the logic of the economic framing of insurance value and its consistency with the literature on insurance and financial economics. This makes sense in the research context of market insurance. However, when considering the characteristics of the challenges that humanity faces in the Anthropocene and the need to understand the value of general resilience, we emphasise that the ecosystem framing with its socio-cultural dimensions is of great significance for three main reasons: (i) inclusivity, (ii) risk and uncertainty, (iii) limits to substitutability.

First, the ecosystem framing is more inclusive, as it includes both the "objective" (scientifically assessed) expected value of resilient SES as well as the "subjective" value for risk averse individuals and governments. The Covid-19 pandemics in 2020–2021 reveals that governments, not only individuals, may take risk averse actions. In the Anthropocene it is arguably more relevant to discuss how resilient ecosystems ensure human adaptations, hence the full value of resilience, rather than focusing on the subjective risk aversion aspect of risk reduction. For example, droughts do not only affect individuals like farmers and the food industry but the wider society through food shortage, price increase, or even famine when crop failures become systemic. Baumgärtner and Strunz (2014) are clear that the insurance concept "refers to both the objective characteristics of risk… and people's subjective risk preferences", but argue that "explicit reference to people's risk preferences is needed to meaningfully discuss insurance, to specify the insurance value of resilience" (p. 28). This is meaningful for consistency with neoclassical economic theory and commercial insurance provision but we argue that the "objective" component of risk reduction and insurance in relation to resilient ecosystems is at least of equal importance for decision-making in the Anthropocene.

Second, if we acknowledge genuine uncertainty, or even ignorance, which characterizes the Anthropocene (Lidskog and Waterton, 2016), the distinction between subjective and objective risk becomes blurred. Insurance value of biodiversity concerns fundamental uncertainty in addition to risk, and such uncertainty is not commercially insurable (Perrings, 1995). In neoclassical economics, uncertainty is sometimes modelled as a calculated risk, with known outcomes distributed over known probabilities (Pascual et al., 2010). This is needed to assess specified resilience, optimise outcomes, and identify individual risk aversion (Hahn et al., 2021). However, in the context of the Anthropocene, even the expected value, the "objective" risk, is scientifically uncertain, because the resilience of the broader system can no longer be taken for granted. Ontologically, genuine uncertainty blurs the separation of resilience into an "objective" and a subjective part.

In the ecosystem framing, insurance value is provided by resilient SES. The difficulty to measure insurance value does not make it metaphorical but rather suitable for governance analysis (Primmer and Paavola, 2021), justifying a precautionary approach, safe minimum standards, protected areas, and other forms of legislation and recognition in institutions (TEEB, 2010). Hence, rather than monetary valuations, the insurance value is expressed (recognised) in governance analysis, e.g., investments in NBS. This includes both an understanding and valuation of the expected ("objective") risk as well as a subjective political-ethical judgement of the importance of ensuring resilience and wellbeing of future generations.

Third, the economic framing opens up for the critique regarding the limits of substitution between financial capital formation and natural capital loss (Neumayer, 2003; Green et al., 2016). Market/financial insurance is not a good substitute for natural insurance since the reliance of market insurance may justify unsustainable agriculture that degrades natural capital (Jørgensen et al., 2020). For an individual farmer or forester it makes sense to buy private financial insurance which, however, provides a moral hazard to choose a management associated with higher expected returns and higher risks (Müller et al., 2017). Thereby the cost of disturbance is simply re-distributed to society (Reguero et al., 2020) rather than lowered by management adaptations, unless adaptation efforts are rewarded in financial insurance contracts (Jørgensen et al., 2020). While financial insurance and post-disaster financial compensations by governments provide moral hazards, investments in natural capital (often called NBS) reduce risks and provide co-benefits for society in terms of public goods (Paavola and Primmer, 2019).

To conclude, both framings are based in anthropocentrism and consequential ethics and are therefore 'economic' in that sense. The economic framing is rooted in utilitarianism, which is a specific version of consequentialism, based on the idea that "the goodness of a state of affairs be a function only of the utility information regarding that state" (Sen, 1987:39). The ecosystem framing embraces uncertainty and takes a more inclusive approach to insurance and risk reduction. The two framings serve different research interests.

4. Operationalizing insurance value

4.1. Recent developments

The concept of resilience has gained policy relevance since UN Secretary General Ban Ki-Moon's speech 'Resilient People, Resilient Planet,' which is clearly about building general resilience "at a time of heightened risk — whether as a result of climate change, resource scarcity, financial instability or spikes in the prices of food and other basic goods" (UN, 2012, p. 45). The policy target is sometimes general resilience rather than specific risks, and the full value of resilience rather than the subjective insurance premium (e.g. UN, 2016; EU, 2018; Fischer et al., 2018). Since future shocks are difficult to anticipate and are likely to coevolve in the Anthropocene, it is important to operationalise the concept of insurance value in policy and practice in ways that address the underlying causes of eroded resilience and provide co-benefits in terms of resilience to other shocks (Barrett et al., 2011; Romero-Lankao et al., 2016), including unexpected ones (ARUP, 2015). Based on reviews from the scientific and grey literature we make four observations.

First, in the applied science-policy literature, issues related to specified resilience (specified insurance value) dominates with DRR as a common proxy. There are different approaches for reducing specific risks, where some studies focus on specific disaster mitigation and coping mechanisms to reduce costs of particular shocks (Stanganelli, 2008), while other studies focus on building specified resilience by implementing various adaptation strategies (Cai et al., 2018). Early-warning systems are especially widespread in DRR and public health research because of its ability to save lives (Haines and Ebi, 2019). A review of the grey literature on actual projects at the interface of risk reduction, resilience and NBS found that a majority of cases were related to reducing flood risk (hydrological), followed by storm and drought related disasters (climatological) (Sioen et al., in review). The focus on specific climatological and hydrological risks is confirmed by reviews of the scientific literature (Fernandez-Milan and Creutzig, 2015; Dallimer et al., 2020). Specified shocks are targeted rather than building general resilience by acting upon the slow underlying causes, e.g., reducing vulnerability of simplified production ecosystem (Nyström et al., 2019).

Second, empirical analysis is generally consistent with the ecosystem framing of insurance value in one sense, i.e., the focus on the expected damage cost rather than the subjective risk premium. In a review of 154 articles, Dallimer et al., (2020) adopts the ecosystem framing of insurance value and relate it to regulating and habitat/supporting ecosystem services, e.g.,"*the ability of biodiverse forest ecosystems to buffer risks from floods, fire, disease spread and other hazards*" (p. 2). In their review they cite the economic framing but found no attempts to operationalise it, i.e., to separate the subjective income risk from the *"broader shadow price for resilience"* (Dallimer et al., 2020: 7). Instead, the literature they reviewed generally focused on the value of NBS and the value of building resilience by reducing/mitigating risks and hazards.

The economic framing of insurance value has been operationalised in specific case studies. For example, an analysis of forest protection from avalanches and rock-falls found a high willingness to pay for forest management that reduced these risks. In particular, through a choice experiment the subjective insurance value was calculated by calibrating the willingness to pay with the respondents' risk preferences. The insurance value (the subjectively perceived reduction in risk premium when resilience increased by new forest management) was found to be much smaller than the "objective risk" (the expected value, even for very risk averse respondents (Unterberger and Olschewski, 2021). Similarly, in a study on changes in farm income from greater plant diversity it was found that 90% of the welfare gain concerned the expected (objective) increase in revenues, while only 10% was the subjective insurance value, by lowering risk for risk averse farmers (Schaub et al., 2020).

Two more studies conform to this pattern: First, an empirical study of biological control also found that the subjective insurance value was only a fraction of the full resilience value (Peled et al., 2020). Second, in a study of the resilience value provided by a wild pollinator habitat to neighbouring farmers, the subjective insurance value was much smaller (about 10%) than the expected net present value of resilience, but negative due to the low ecosystem resilience in this case study (Matsushita et al., 2018). None of these four empirical studies discuss the policy relevance of singling out the subjective income risk from the broader resilience value. The World Economic Forum (2021) and the Zurich insurance group are arguably more concerned about the uncertainty of the expected damage cost than the revenues of the insurance industry, i.e., the insurance premium.

Third, while the empirical scientific literature generally refers to more than one ecosystem service (Dallimer et al., 2020), the grey literature often addresses one risk at a time (e.g., Stanganelli, 2008; Fernandez Milan and Creutzig, 2015). In a review of the grey literature, co-benefits or "notions of values" provided by NBS were acknowledged in half of the cases. Particularly, biodiversity at large, sociocultural, aesthetic, or ethical values were described in addition to the resilience value of reducing hydrological and climatological risks, while issues of equity and environmental justice were almost absent (Sioen et al., in review).

Fourth, although co-benefits of NBS are often discussed or even emphasised, they seem to be hard to include in cases where the NBS benefits are demonstrated in monetary terms, resulting in underestimations of total benefits. For example, a UNDP project analysed the resilience value of mangrove, coral reef, and seagrass conservation and restoration for reducing risks from meteorological disasters in the Philippines (UNDP, 2020). Monetary valuation would require stocktaking of all major ecosystem services provided by these targeted ecosystems, but data limitations of stocks and flows resulted in only a fraction of the benefits being included in the analysis.

4.2. Insurance value in the Anthropocene

We have identified key divergences in how the general insurance/resilience value of biodiversity has been defined and operationalised. The economic framing emphasizes one aspect of resilience, namely the subjective aspect of risk aversion rather than the objectively calculated expected risk. This framing has obvious merits when comparing natural insurance with market insurance (e.g., Jørgensen et al., 2020; Reguero et al., 2020) and when risk aversion is explicitly addressed, as in the four papers mentioned above. These four empirical papers are also consistent with the theoretical framework as laid out by Baumgärtner and Strunz

(2014).

Our conceptual analysis following the critical reading of the literature suggest that the ecosystem framing, the full resilience value, is more policy-relevant in the context of the risks and uncertainties that humanity faces in the Anthropocene. Subjective risk preferences are still relevant, both at individual and collective levels, as emphasised by recent discussions on tipping points (Lenton et al., 2019). Such risk preferences concern political-ethical values which go beyond the utilitarian economic framing of risk aversion.

The empirical literature addresses socio-cultural values to some extent, particularly aesthetic and ethical values, whereas issues of equity and environmental justice have been less pronounced. The question 'resilience of what?' includes normative deliberation on what system properties should be resilient. Besides being a scientific question of identifying underlying causality and co-benefits, the design of NBS raises normative issues of desirable futures including distributional implications: insurance value of what and for whom (Leach et al., 2018)? These issues are part of the insurance value framework (Fig. 1) but have only to a limited extent been synthesised with the ecosystem framing. Some of the more relevant distributional aspects include socio-cultural values co-produced in resilient SES (Dìaz et al., 2018; Brondizio et al., 2016).

4.3. Challenges for the ecosystem framing

We will now turn our attention to the empirical operationalisation of the ecosystem framing of insurance value. This is relevant because even if the empirical cases generally apply an ecosystem framing, there are clear challenges ahead to advance empirical analysis more consistently with resilience theory.

First, arguably, if insurance value, risk reduction and NBS are directly related to resilience in SES, then this empirical literature needs to pay attention not only to the shocks, but also to the slow underlying variables defining resilience. For example, a forest which presently provides valuable ecosystem services may, or may not, persist a disturbance such as a storm, fire or pest outbreak. If the (underlying) resilience of the forest is not assessed or even addressed, then it is impossible to say anything about the expected future value of this forest. For example, fire suppression may give a false sense of control which may delay or prevent more systematic changes in management and governance (Holling and Meffe, 1996). Hence, empirical analysis of DRR may better estimate risk reduction of NBS if more attention is given to analysing resilience, in particular at the systemic level in a manner that captures the changes in the capacities and underlying variables that generates and sustain resilience, as well as the interlinked and changing risk landscape that characterizes the Anthropocene (Keys et al., 2019).

Indeed, there are signs of improvements in this direction. The Sendai Framework for Disaster Risk Reduction, which was adopted at the Third UN World Conference on DRR, emphasizes the need for preservation of ecosystem functions that help to reduce disasters (UNDRR, 2015). This is slowly being consolidated in the emerging literature on eco-DRR (Marchal et al., 2019). The frequent reporting on NBS co-benefits may also be interpreted as a sign of recognising the challenge of moving from specified to general insurance value. Strategies for safeguarding and enhancing specified resilience may be good proxies for safeguarding general resilience when they focus on NBS and their associated co-benefits.

Second, clear distinctions between, or even notions of, option value, use value, output value and insurance value are rarely made in empirical analyses (e.g., Fernandez-Milan and Creutzig, 2015; Dallimer et al., 2020; Sioen et al., in review). We conclude that a reasonable ambition for empirical studies of the specified insurance value of biodiversity is to analyse the expected risk reduction from management change (Hahn et al., 2021), or the increase in expected (objective) future values from an investment in NBS, which may include options for future adaptations, while acknowledging uncertainty and ecosystem resilience.

Third, reviews of the empirical literature reveal different aims. One aim of analysing specified insurance value is to advance knowledge on "*retaining X ha of forests on mountain slopes delivers $Y per year in avoided damage costs for Z thousand people*" (Dallimer et al., 2020: 10). This would add precision but, perhaps, at the expense of analysing co-benefits, general resilience and the underlying ecosystem processes which determine the interlinked risk landscape of the Anthropocene. If certain conditions are satisfied, monetary analysis may still be helpful for decision-makers concerned about resilience. These conditions include: (i) a clear distinction between general and specified resilience; (ii) underlying drivers of resilience are acknowledged; (iii) co-benefits are addressed; and (iv) the monetary analysis is consistent with the ordinary sector planning, to facilitate policy integration (Hahn et al., 2021).

5. Conclusion: Towards resilience value?

When considering these divergent conceptualisations and operationalisations, the question becomes: what do we do with the concept "insurance value"? There is always a risk for interdisciplinary confusion when concepts, that already have a precise meaning in one discipline, are used by researchers within another discipline. "Insurance" has since long been well defined in the academic field of economics and finance and it concerns risk, probability, uncertainty and information in an optimisation framework (Dionne and Harrington, 1992). It is no wonder that many economists think of subjective risk aversion when they hear "insurance value". However, we believe that reducing uncertainty and complexity into an optimising framework based on subjective risk preferences is not consistent with the original insurance hypothesis of biodiversity, nor to resilience theory. Hence, we may conclude that the concept "insurance value" makes less sense to ecosystem and SES scholars.

Our theoretical and empirical analysis suggests that two distinctly different "research programs" (Lakatos and Musgrave, 1970) on insurance value have developed and that "insurance value" no longer serves as an effective boundary object for integrating different research directions concerning resilience. The economic framing is a well-defined interdisciplinary research area consistent with neoclassical economics, using the insurance concept in a stringent manner. The ecosystem framing suffers from ambiguous use of the insurance concept which we believe can be solved by changing insurance value to "resilience value", which better captures the original idea of the insurance hypothesis.

This resilience value can be defined as *the increased social benefit, following an increase in resilience due to an investment or management change, acknowledging uncertainties of the underlying ecosystem processes*. "Increased social benefit" includes both the expected (mean) and subjective (variance) components of risk, beyond utilitarian metrics. We believe that the broader adoption of this concept would (i) avoid the confusion with economic insurance value, (ii) emphasise the public good characteristics of resilience and NBS, (iii) raise attention to the multifunctionality of ecosystem services (co-benefits), and (iv) increase the consistency between resilience theory and the empirical literature on DRR and NBS.

Since resilience is already a popular concept in the empirical literature on DRR and NBS, we believe "resilience value" will be helpful in both providing analytical clarity (i.e. what mechanisms and processes are to be analysed) and empirical evidence. Acknowledging the impossibility to quantify resilience by a universal metrics or analytic approach (Yi and Jackson, 2021), methods for analysing resilience value must remain plural and context-dependent.

Ethics declarations

None.

Author contributions

T.H., G.B.S., and T.E. conceived and wrote out the idea of this manuscript. T.H. made the conceptual framework and wrote most of the text. A.G. and E.B. made substantial text contributions. G.B.S., M.D.S., T. A., E.Y.A., M.P.J., and K.F. worked on data collection and literature review for the operationalization section. C.F., E.G-B. and K.T. contributed with substantial revisions of the manuscript. All authors contributed to the final manuscript.

Declaration of Competing Interest

The authors declare no competing interests.

Data availability

No data was used for the research described in the article.

Acknowledgement

The authors would like to acknowledge the Future Earth Urban Knowledge-Action Network; Mistra (DIA 2019/28); Formas (2021-00416); Japan Science and Technology Agency.

References

ARUP, 2015. City Resilience Index. London, United Kingdom.
Barrett, C.B., Travis, A.J., Dasgupta, P., 2011. Biodiversity conservation and poverty traps special feature: from the cover: on biodiversity conservation and poverty traps. Proceed. Nat. Acad. Sciences 108 (34), 13907–13912. https://doi.org/10.1073/pnas.1011521108.
Baumgärtner, S., Strunz, S., 2014. The economic insurance value of ecosystem resilience. Ecol. Econ. 101, 21–32.
Borrass, L., Kleinschmit, D., Winkel, G., 2017. The “German model” of integrative multifunctional forest management—Analysing the emergence and political evolution of a forest management concept. Forest Pol. Econ. 77, 16–23. https://doi.org/10.1016/j.forpol.2016.06.028.
Brondizio, E.S., Ostrom, E., Young, O., 2009. Connectivity and the governance of multilevel socio-ecological systems: the role of social capital. An. Rev. Environ. Res. 34, 253–278.
Brondizio, E.S., O’Brien, K., Bai, X., Biermann, F., Steffen, W., Berkhout, F., Cudennec, C., Lemos, M.C., Wolfe, A., Palma-Oliveira, J., Arthur Chen, C.-T., 2016. Re-conceptualizing the Anthropocene: A Call for Collaboration. Global Environmental Change: Human and Policy Dimensions 39, 318–327.
Cai, H., Lam, N.S.N., Qiang, Y., Zou, L., Correll, R.M., Mihunov, V., 2018. A synthesis of disaster resilience measurement methods and indices. Int. J. Disaster Risk Red. 31, 844–855.
Carpenter, S.R., Walker, B.H., Anderies, J.M., Abel, N., 2001. From metaphor to measurement: resilience of what to what? Ecosystems 4, 765–781.
Carpenter, S.R., Arrow, K.J., Barrett, S., Biggs, R., Brock, W.A., Crépin, A.-S., Engström, G., Folke, C., Hughes, T.P., Kautsky, N., 2012. General resilience to cope with extreme events. Sustainability 4, 3248–3259.
Clark, W.C., Harley, A.G., 2020. Sustainability science: Towards a synthesis. An. Rev. Environ. Res. 45, 331–386.
Coomes, O.T., Takasaki, Y., Abizaid, C., Barham, B.L., 2010. Floodplain fisheries as natural insurance for the rural poor in tropical forest environments: evidence from Amazonia Fish. Manag. Ecol. 17 (6), 513–521.
Dallimer, M., Martin-Ortega, J., Rendon, O., Afionis, S., Bark, R., Gordon, I.J., Paavola, J., 2020. Taking stock of the empirical evidence on the insurance value of ecosystems. Ecol. Econ. 167, 106451.
Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Shirayama, Y., 2018. Assessing nature’s contributions to people. Science 359 (6373), 270–272. https://doi.org/10.1126/science.aap8826.
Dionne, G., Harrington, S., 1992. Foundations of Insurance Economics. Kluwer, Boston.
Duraiappah, A.K., Asah, S.T., Brondizio, E.S., Kosoy, N., O’Farrel, P., Prieur-Richard, A.-H., Takeuchi, K., 2014. The New Commons: Matching the Mis-Matches. Curr. Opin. Environ. Sustain. 7, 94–100. https://doi.org/10.1016/j.cosust.2013.11.031.
EU, 2018. Biodiversity Strategy for 2030: Bringing nature back into our lives. https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm.
Fernandez-Milan, B., Creutzig, F., 2015. Reducing urban heat wave risk in the 21st century. Curr. Opin. Environ. Sustain. 14, 221–231.
Fichtenrichtlinie, 2009. https://www.baysf.de/fileadmin/user_upload/04-wald_verstehen/Publikationen/Fichtenrichtlinie.pdf.
Fischer, M., Rounsevell, M., Torre-Marin Rando, A., Mader, A., Church, A., Elbakidze, M., Elias, V., Hahn, T., Harrison, P.A., Hauck, J., Martín-López, B., Ring, I., Sandström, C., Sousa Pinto, I., Visconti, P., Zimmermann, N.E., Christie, M., 2018. The regional assessment report on biodiversity and ecosystem services for Europe and Central Asia: Summary for policymakers. IPBES Secretariat, Bonn, Germany, 48 pages. https://www.ipbes.net/assessment-reports/eca.
Folke, C., 2006. Resilience: the emergence of a perspective for social-ecological systems analyses. Glob. Environ. Change 16, 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002.
Folke, C., Holling, C.S., Perrings, C., 1996. Biological diversity, ecosystems, and the human scale. Ecol. Appl. 1018–1024.
Folke, C., Colding, J., Berkes, F., 2003. Synthesis: building resilience and adaptive capacity in social-ecological systems. In: Berkes, F., Colding, J., Folke, C. (Eds.), Navigating social–ecological systems: Building resilience for complexity and change. Cambridge University Press, Cambridge, pp. 352–387.
Future Earth, 2021. Sustainability in the Digital Age, and International Science Council. In: Global Risks Perceptions Report 2021. Future Earth Canada Hub. https://doi.org/10.5281/zenodo.5764288.
Green, T., Kronenberg, L.J., Andersson, E., Elmqvist, T., Gómez-Baggethun, E., 2016. Insurance value of green infrastructure in and around cities. Ecosystems 19, 1051–1063.
Gren, I.-M., Folke, C., Turner, R.K., Batman, I.-J., 1994. Primary and secondary values of wetland ecosystems. Environ. Res. Econ. 4 (4), 55–74.
Hahn, T., Heinrup, M., Lindborg, R., 2017. Landscape heterogeneity correlates with recreational values: a case study from Swedish agricultural landscapes and implications for policy. Landscape Research 43 (5), 696–707. https://doi.org/10.1080/01426397.2017.1335862.
Hahn, T., Eggers, J., Subramanian, N., Caicoya, A.T., Uhl, E., Snäll, T., 2021. Specified resilience value of alternative forest management adaptations to storms. Scandinavian Journal of Forest Research 36 (7–8), 585–597. https://doi.org/10.1080/02827581.2021.1988140.
Haider, L.J., van Oudenhoven, F.J.W., 2018. Food as a daily art: ideas for its use as a method in development practice. Ecology and Society 23 (3), 14. https://doi.org/10.5751/ES-10274-230314.
Haines, A., Ebi, K., 2019. The Imperative for Climate Action to Protect Health. New England Journal of Medicine 380 (3), 263–273. https://doi.org/10.1056/nejmra1807873.
Holling, C.S., Meffe, G.K., 1996. Command and control and the pathology of natural resource management. Conservation Biology 10, 328–337.
IPBES, 2019. Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). IPBES secretariat, Bonn, Germany. 1148 pages. doi:https://doi.org/10.5281/zenodo.3831673.
Jørgensen, S.L., Termansen, M., Pascual, U., 2020. Natural insurance as condition for market insurance: Climate change adaptation in agriculture. Ecol. Econ. 169, 106489 https://doi.org/10.1016/j.ecolecon.2019.106489.
Keys, P.W., Galaz, V., Dyer, M., Matthews, N., Folke, C., Nyström, M., Cornell, S.E., 2019. Anthropocene risk. Nature Sustainability 2 (8), 667–673. https://doi.org/10.1038/s41893-019-0327-x.
Lakatos, I., Musgrave, A., 1970. Criticism and the Growth of Knowledge. Cambridge Univ. Press.
Leach, M., Reyers, B., Bai, X., Brondizio, E.S., Cook, C., Diaz, S., Espindola, G., Scobie, M., Stafford-Smith, M., Subramanian, S.M., 2018. Equity in the anthropocene: Towards a transformative research agenda for a fair and sustainable world. Global Sustainability 1 (e13), 1–13. https://doi.org/10.1017/sus.2018.12].
Lenton, T.M., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K., Steffen, W., Schellnhuber, H.J., 2019. Climate tipping points—too risky to bet against. Nature 575, 592–595. https://doi.org/10.1038/d41586-019-03595-0.
Leroux, A.D., Martin, V.L., Goeschl, T., 2009. Optimal conservation, extinction debt, and the augmented quasi-option value. Journal of Environmental Economics and Management 58 (1), 43–57.
Liao, K.H., 2012. A theory on urban resilience to floods—a basis for alternative planning practices. Ecology and society 17 (4).
Lidskog, R., Waterton, C., 2016. Anthropocene–a cautious welcome from environmental sociology? Environ. Sociol. 2, 395–406. https://doi.org/10.1080/23251042.2016.1210841.
Malayang III, B.S., Hahn, T., Kumar, P., 2006. Responses to ecosystem change and to their impacts on human well-being. In: Capistrano, D., et al. (Eds.), Ecosystems and Human Well-being: Multiscale Assessments: Findings of the Sub-Global Assessments Working Group of the Millennium Ecosystem Assessment. Island Press, Washington, DC, pp. 203–226 http://www.millenniumassessment.org/documents/document.347.aspx.pdf.
Mäler, K.G., Li, C.Z., 2010. Measuring sustainability under regime shift uncertainty: a resilience pricing approach. Environ. Dev. Econ. 15, 707–719.
Marchal, R., Piton, G., Lopez-Gunn, E., Zorrilla-Miras, P., van der Keur, P., Dartée, K.W. J., Pengal, P., Matthews, J.H., Tacnet, J.-M., Graveline, N., Altamirano, M.A., Joyce, J., Nanu Groza, I., Peña, K., Cokan, B., Burke, S., Moncoulon, D., 2019. The (re)insurance industry’s roles in the integration of nature-based solutions for prevention in disaster risk reduction—insights from a European survey. Sustainability 11 (2019), 6212.
Matsushita, K., Taki, H., Yamane, F., Asano, K., 2018. Shadow value of ecosystem resilience in complex natural land as a wild pollinator habitat. American Journal of Agricultural Economics 100, 829–843. https://doi.org/10.1093/ajae/aax075.
Müller, B., Johnson, L., Kreuer, D., 2017. Maladaptive outcomes of climate insurance in agriculture. Global Environmental Change 46, 23–33.
Neumayer, E., 2003. Weak versus strong sustainability: exploring the limits of two opposing paradigms. Edward Elgar Publishing.
Nyström, M., Jouffray, J.B., Norström, A.V., Crona, B., Søgaard Jørgensen, P., Carpenter, S.R., et al., 2019. Anatomy and resilience of the global production

ecosystem. Nature 575 (7781), 98–108. https://doi.org/10.1038/s41586-019-1712-3.
Paavola, J., Primmer, E., 2019. Governing the provision of insurance value from ecosystems. Ecol. Econ. 164, 106346.
Pascual, U., Muradian, R., Brander, L., Gómez-Baggethun, E., Martín-López, B., Verma, M., Armsworth, P., Christie, H., Eppink, F., Farley, J., Loomis, J., Pearson, L., Perrings, C., Polasky, M., 2010. The Economics of Valuing Ecosystem Services and Biodiversity. In: Kumar, P. (Ed.), The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Earthscan, London, pp. 183–256.
Pascual, U., Termansen, M., Hedlund, K., Brussaard, L., Faber, J.H., Foudi, S., Lemanceau, P., Jørgensen, S.L., 2015. On the value of soil biodiversity and ecosystem services. Ecosystem Services 15, 11–18.
Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Yagi, N., 2017. Valuing nature's contributions to people: the IPBES approach. Current opinion in environmental sustainability 26, 7–16.
Pattanayak, S.K., Sills, E.O., 2001. Do tropical forests provide natural insurance? The microeconomics of non-timber forest product collection in the Brazilian Amazon. Land economics 77 (4), 595–612.
Peled, Y., Zemah-Shamir, S., Israel, A., Shechter, M., Ofir, E., Gal, G., 2020. Incorporating insurance value into ecosystem services assessments: Mitigation of ecosystem users' welfare uncertainty through biological control. Ecosystem Services 46, 101192. https://doi.org/10.1016/j.ecoser.2020.101192.
Perrings, C., 1995. Biodiversity conservation as insurance. In: Swanson, T. (Ed.), The economics and ecology of biodiversity decline: The forces driving global change. Cambridge University Press, pp. 69–76.
Primmer, E., Paavola, J., 2021. Insurance value of ecosystems: an introduction. Ecol. Econ. 184, 107001.
Quaas, M., Baumgärtner, S., De Lara, M., 2019. Insurance value of natural capital. Ecol. Econ. 165, 106388.
Reguero, B.G., Beck, M.W., Schmid, D., Stadtmüller, D., Raepple, J., Schüssele, S., Pfliegner, K., 2020. Financing coastal resilience by combining nature-based risk reduction with insurance. Ecol. Econ. 169, 106487.
Rocha, J.C., Peterson, G., Bodin, Ö., Levin, S., 2018. Cascading regime shifts within and across scales. Science 362, 1379–1383. https://www.science.org/doi/abs/10.1126/science.aat7850.
Rockström, J., Steffen, W., Noone, K., Persson, A.A., Chapin, F.S., et al., 2009. A safe operating space for humanity. Nature 461, 472–475.
Romero-Lankao, P., Gnatz, D.M., Wilhelmi, O., Hayden, M., 2016. Urban sustainability and resilience: From theory to practice. Sustainability 8 (12), 1224.
Rudolph, M.J., 2019. Canadian Institute of Actuaries, Casualty Actuarial Society, and Society of Actuaries. https://www.soa.org/globalassets/assets/files/resources/research-report/2019/12th-emerging-risk-survey.pdf.
Schaub, S., Buchmann, N., Lüscher, A., Finger, R., 2020. Economic benefits from plant species diversity in intensively managed grasslands. Ecol. Econ. 168, 106488.
Schlosberg, D., 2014. Ecological justice for the Anthropocene. In: Wissenburg, M., Schlosberg, D. (Eds.), Political animals and animal politics. Palgrave Macmillan, United Kingdom, pp. 75–89.
Schultz, M., Hahn, T., Ituarte-Lima, C., Hällström, N., 2018. Deliberative multi-actor dialogues as opportunities for transformative social learning and conflict resolution in international environmental negotiations. International Environmental Agreements: Politics, Law and Economics 18, 671–688. https://doi.org/10.1007/s10784-018-9410-4.
Sen, A., 1987. On ethics and economics. Blackwell Publishers, Oxford.
Sioen, G. et al., In review. Insurance value trends of Nature-Based solutions around the world.
Stanganelli, M., 2008. A new pattern of risk management: The Hyogo Framework for Action and Italian practise. Socio-Economic Planning Sciences 42 (2), 92–111. https://doi.org/10.1016/j.seps.2006.10.001.
Suárez, A.E., Gutierrez-Montes, I., Ortiz-Morea, F.A., Ordonez, C., Suárez, J.C., Casanoves, F., 2021. Dimensions of social and political capital in interventions to improve household well-being: Implications for coffee-growing areas in southern Colombia. PLoS ONE 16, e0245971. https://doi.org/10.1371/journal.pone.0245971.
TEEB, 2009. The Economics of Ecosystems and Biodiversity for National and International Policy Makers.
TEEB, 2010. The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB. https://teebweb.org/publications/teeb/.
UN, 2012. Resilient People, Resilient Planet: A future worth choosing. The Secretary-General's high-level panel on Global sustainability. United Nations, New York.
UN, 2016. New Urban Agenda, Challenges. Quito. Available at: https://habitat3.org/the-new-urban-agenda/.
UNDP, 2020. Project Portal. https://www.gcfprojects-undp.org/tp/project/6095 (accessed December 2, 2020).
UNDRR, 2015. Sendai Framework for Disaster Risk Reduction 2015–2030. In: Third World Conference on Disaster Risk Reduction, Sendai, Japan (doi:A/CONF.224/CRP.1).
Unterberger, C., Olschewski, R., 2021. Determining the insurance value of ecosystems: a discrete choice study on natural hazard protection by forests. Ecol. Econ. 180, 106866.
Walker, B.H., Abel, N., Anderies, J.M., Ryan, P., 2009. Resilience, adaptability, and transformability in the Goulburn-Broken Catchment, Australia. Ecology and Society 14 (1), 12.
Walker, B.H., Pearson, L., Harris, M., Mäler, K.-G., Li, C.-Z., Biggs, R., Baynes, T., 2010. Incorporating resilience in the assessment of inclusive wealth: an example from South East Australia. Environ. Resour. Econ. 45, 183–202.
World Economic Forum, 2021. The Global Risks Report 2021. https://www.weforum.org/reports/the-global-risks-report-2021/.
Yachi, S., Loreau, M., 1999. Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis. Proceedings of the National Academy of Sciences 96 (4), 1463–1468.
Yi, C., Jackson, N., 2021. A review of measuring ecosystem resilience to disturbance. Environ. Res. Lett. 16, 053008.