

This is an Open Access document downloaded from ORCA, Cardiff University's institutional repository: <https://orca.cardiff.ac.uk/id/eprint/126523/>

This is the author's version of a work that was submitted to / accepted for publication.

Citation for final published version:

Dallimer, Martin, Martin-Ortega, Julia, Rendon, Olivia, Afionis, Stavros, Bark, Rosalind, Gordon, Iain J. and Paavola, Jouni 2020. Taking stock of the empirical evidence on the insurance value of ecosystems. *Ecological Economics* 167 , 106451. 10.1016/j.ecolecon.2019.106451

Publishers page: <http://dx.doi.org/10.1016/j.ecolecon.2019.106451>

Please note:

Changes made as a result of publishing processes such as copy-editing, formatting and page numbers may not be reflected in this version. For the definitive version of this publication, please refer to the published source. You are advised to consult the publisher's version if you wish to cite this paper.

This version is being made available in accordance with publisher policies. See <http://orca.cf.ac.uk/policies.html> for usage policies. Copyright and moral rights for publications made available in ORCA are retained by the copyright holders.



Taking stock of the empirical evidence on the insurance value of ecosystems

Martin Dallimer¹, Julia Martin-Ortega¹, Olivia Rendon², Stavros Afionis¹, Rosalind Bark³, Iain J Gordon⁴, Jouni Paavola¹

¹Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, United Kingdom

²Sea and Society Group, Plymouth Marine Laboratory, Plymouth, United Kingdom

³School of Environmental Sciences, University of East Anglia, United Kingdom

⁴Division of Tropical Environments & Societies, James Cook University, Australia

Abstract

Ecosystems can buffer against adverse events and, by so doing, reduce the costs of risk-bearing to society; benefits which have been termed ‘insurance value’. Although the terminology is recent, the concept is older and has its roots in ecological resilience. However, a synthesis of studies through the lens of the insurance value concept is lacking. Here we fill this important knowledge gap by conducting a rapid evidence assessment on how, where and why the insurance value of ecosystems has been measured. The review highlighted the often substantial positive values that were associated with restoration, rehabilitation or avoidance of loss of natural ecosystems. However, many regions, ecosystems and hazards are not widely researched. Most studies focused on forests, agriculture and wetlands, often with an emphasis on habitat restoration to reduce flood risks. Over half the studies provided non-monetary or monetary estimates of value, reporting, for example, improved ecological function, achieved/achievable cost reductions or willingness-to-pay. Nevertheless, the evidence-base remains fragmentary and is characterised by inconsistent reporting of valuation methodologies. This precludes drawing general conclusions. We recommend that future studies of insurance value adopt a common approach to facilitate the development of a more robust evidence-base.

Keywords

Ecosystem services; insurance value; natural hazards; risk; resilience; rapid evidence assessment

Highlights

- We assess the existing empirical research on the insurance value of ecosystems;
- There is a mismatch between research topics and hazard types, location and severity;
- Values can be substantial, but there is little consistency in how they are calculated;
- We recommend a common approach to facilitate mainstreaming of insurance value.

Introduction

Globally, the frequency and severity of natural hazards is increasing (e.g. Royal Society, 2014), exposing a growing number of households, businesses, public authorities and infrastructure to multiple and new risks (e.g. Guha-Sapir et al., 2017; United Nations, 2016). This trend has been, and will continue to be, aggravated by climate change (IPCC, 2014), human population growth, demand for food and urbanisation, all of which can result in land use change, environmental degradation and biodiversity loss. Mitigating and adapting to new levels of risk will require novel ways to ensure that the positive aspects of ecosystems for human societies are integrated into decision and policy-making. One such possibility is to recognise how ecosystems can buffer against adverse events (Baumgartner, 2007) and thus reduce the costs of risk-bearing to individuals and wider society (Quaas and Baumgartner, 2008). This so-called ‘insurance value’ of ecosystems (Baumgartner, 2007) has emerged from the study of resilience, which is defined in the ecological literature as the capacity of a system to absorb shocks and reorganize itself to maintain its structure and functions, (Ehrlich and Becker, 1972). The term has been used to denote an ecosystem’s ability to maintain function (and by extension the provision of ecosystem services to humans) under abrupt and gradual disturbances (Carpenter et al., 2001; Holling, 1973). As Baumgartner and Strunz (2014, p21) state “The economic relevance of ecosystem resilience is obvious as a system flip may entail huge welfare losses”. Ecosystem resilience has, therefore, been recognised as an important ecosystem service (e.g. Maler, 2008; Maler and Li, 2010; Perrings, 1995).

However, insurance is not solely against catastrophic changes between system states. For people, reducing the severity, intensity and frequency of natural hazards is also of value, whether or not those hazards are associated with an abrupt system change. For example, maintaining a biodiverse and resilient forest ecosystem can provide ‘natural protection’ if it reduces the likelihood of a pest or disease outbreak within the forest itself and thus maintains the range of ecosystem services it provides. If the biodiverse, resilient forest is located upstream of an urban area, such services could reduce the adverse consequences of a flood, which could have considerable social value. This type of reasoning suggests close linkages between resilience, insurance value and sustainability (Brand, 2009).

Ecosystems can offer both protection, which can be defined as measures that reduce the likelihood of an adverse event, and insurance, which acts to reduce losses caused by an adverse event (Ehrlich and Becker, 1972). Baumgartner & Strunz (2014) refer to insurance value as the value of a specific function of resilience, namely the reduction of an ecosystem user's income risk from using ecosystem services under uncertainty. Thus, the insurance value of resilience is one additive component of total economic value (TEV) (Baumgartner and Strunz, 2014). Similarly, Pascual et al. (2015) consider ‘natural insurance value’ as a distinguishable component of the TEV of an ecosystem. Insurance value can then be further decomposed into self-protection (mitigation of risk) and self-insurance (adaptation to risk). The conceptualisation of insurance value, and the development and testing of solutions for measuring it, are, therefore, still being debated (Bartkowski, 2017; Baumgartner and Strunz, 2014; Mäler et al., 2007). Indeed, in studies reporting TEV it may not prove possible to disaggregate insurance value specifically. Therefore, while acknowledging its component parts, for the purposes of this review of existing empirical research, we use the term insurance value of ecosystems to refer to both insurance and protection components (Baumgartner and Strunz, 2014; Ehrlich and Becker, 1972; Pascual et al., 2015).

1 The economic conceptualisation of how we might value the protection and insurance
2 contribution of ecosystems is rapidly evolving. However, there remains a gap between the
3 theory of insurance value and the existing empirical research. Looking across the existing
4 research base could reveal pointers as to how the concept could be mainstreamed and
5 operationalised across a wide range of contexts. For instance, although the term ‘insurance’ is
6 rarely used (but see The Nature Conservancy, 2018 for a recent example), the importance of
7 insurance value of ecosystems is increasingly acknowledged in many related concepts. This is
8 exemplified by a growing emphasis on “nature-based solutions” (NBS) in urban regeneration,
9 flood risk management and other natural disaster risk reduction (Nesshover et al., 2017). Such
10 NBS often provide co-benefits of which insurance value is just one (see Sukhdev et al., 2010).
11 The International Union for Conservation of Nature (IUCN) also promotes NBS as an umbrella
12 concept for a range of ecosystem-related approaches to address societal challenges (Cohen-
13 Shacham et al., 2016). NBS, and related terms such as ‘nature-based infrastructure’, ‘working
14 with natural processes’ and ‘engineering with nature’ (Nesshover et al., 2017) refer to
15 interventions “which are inspired by, supported by or copied from nature” (European
16 Commission, 2015, p. 4). An example of ecosystem-based approaches and NBS is natural flood
17 management (NFM), which uses natural hydrological and morphological processes, features
18 and characteristics to manage sources and pathways of flood waters (SAIFF, 2011) instead of
19 hard-engineered flood defence infrastructure (Lane, 2017). Finally, ecological engineering has
20 emerged as an approach to ecosystem restoration (e.g. Nesshover et al., 2017), for enhanced
21 resilience of habitats and the communities that depend on them.

22
23 While the evidence base on ecosystem services and their values is growing (see e.g. Costanza
24 et al., 2014), the focus thus far has been on provisioning and cultural ecosystem services. In
25 contrast, insurance value is often related to regulating ecosystem services, such as the ability
26 of biodiverse forest ecosystems to buffer risks from floods, fire, disease spread and other
27 hazards. Despite the increasing interest in the buffering capacity of ecosystems and NBS to
28 mitigate risks and to provide a range of other co-benefits, the evidence base on the ability of
29 ecosystems to actually provide insurance value remains limited (e.g. Dadson et al., 2017).

30
31 Some caution is also needed when calculating monetary values for the extent to which
32 ecosystems ‘insure’ against natural hazards. As climate and environmental changes continue,
33 the resilience of ecosystems will be undermined, increasing the likelihood of systems tipping
34 into new and unknown states. This has already happened in several cases (e.g. Rockstrom et
35 al., 2009; Steffen et al., 2011), which suggests an emphasis on managing natural environments
36 should be a priority to avoid hazards and regime shifts in the first place (e.g. Green et al., 2016).
37 Regardless, the two are not incompatible, and the additional value of the insurance provided
38 by well-functioning ecosystems could add to the strength of both monetary and non-monetary
39 arguments for their preservation.

40
41 Acknowledging the difficulties of relying on past evidence to value the avoidance of unknown
42 and complex shifts in system properties, it is nevertheless important to understand and quantify
43 the current knowledge base. Interrogating the existing evidence on the quantification,
44 qualification and valuation of the insurance value of ecosystem services across multiple
45 contexts and ecosystems is a necessary starting point for mainstreaming and operationalising
46 the concept. This could involve integrating an ecosystem’s role in protection and insurance into
47 insurance policies and developing new public and private insurance models for resilience.

48
49 To understand the current state of knowledge, we assessed the existing evidence on the
50 insurance value of ecosystems, asking the following questions: (i) What existing empirical

evidence exists? (ii) Where has the research been carried out? (iii) How large are values associated with insurance as an ecosystem service, and how have they been measured? and, (iv) What lessons can we learn to ensure that future research allows us to more systematically 'value' the protection against, and avoidance of, natural hazards that ecosystems can provide? Although there is some literature explicitly discussing, or referring to, insurance value, it is relatively recent and limited. Therefore, we carried out a rapid evidence assessment using a suite of terms intended to capture the breadth of the existing relevant literature on valuing ecosystem services.

Methods

Rapid Evidence Assessment

To capture relevant knowledge from the existing literature, we undertook a configurative Rapid Evidence Assessment (REA). An REA is a constrained form of systematic review, which is limited to comprehensive database searches of the peer-reviewed literature and omits other forms of evidence gathering, such as manually searching the grey literature (Burton et al., 2007). REAs follow a transparent and reproducible procedure, decided on and articulated in advance, which minimises the chance of bias. The utility and value of REAs, and the evidence-based approach, is well established in the health, environmental and social policy sectors (Pullin and Stewart, 2006). Whereas classic quantitative aggregative reviews are likely to meta-analyse similar forms of data, configurative reviews seek to identify patterns provided by heterogeneity (Barnett-Page and Thomas, 2009). As such, they are ideal for synthesising evidence from different disciplines or methodologies.

REAs use published quantitative research data and centre on exploring frameworks, investigating complexity and placing research within its environmental and societal context (Greenhalgh et al., 2005). Through a detailed evaluation of existing conceptual, theoretical, modelling and empirical studies, an REA can explore whether the notion of insurance value of ecosystems offers novel ways to assess the value of natural environments for humanity. The objective of our REA was to synthesise findings from the existing literature on what value change in the quantity or quality of ecosystems has either in monetary or non-monetary terms that can be linked to any of the definitions of insurance value described above. Given that the notion of the insurance value of ecosystems is relatively recent, literature explicitly using the term has only emerged in the past decade. Nevertheless, the conceptual links between insurance value and resilience (e.g. Baumgartner and Strunz, 2014; Perrings, 1995), should mean that research which could underpin a better understanding of the quantification, qualification and valuation of the insurance value of ecosystems is likely to exist. To ensure that the review captured the breadth of existing studies, we developed a set of search terms to cover four main areas, namely: concepts of insurance and resilience, metrics of value, types of ecosystems and natural hazards (Table 1 and below).

Insurance, resilience, risks and ecosystem restoration

Search terms covered two of the main concepts of insurance value developed in the literature thus far, namely protection and insurance (Baumgartner and Strunz, 2014; Pascual et al., 2015). Given these concepts are directly related to resilience (Pascual et al., 2010) and the capacity of a system to remain at a given ecological state or avoid regime shifts (Walker and Meyers, 2004), search terms included 'resilience' and 'regime shift' in addition to 'insurance', 'protection' and their synonyms. A further concept of insurance relates to how ecosystems can

internalise risk, and reduce the costs of risk-bearing to individuals and society (Quaas and Baumgartner, 2008). This argument has been developed around the idea that ecosystems provide insurance against the uncertain provision of ecosystem services in the same way that diversity in an asset portfolio does in financial markets investments (Baumgartner, 2007). Search terms also included various formulations of risk reduction, risk mitigation and risk management (

Table 1). Finally, given our specific interest in how ecosystems can be managed to prevent or reduce the occurrence and severity of risks and hazards, searches included terms such as ecosystem restoration and rehabilitation.

Metrics of value and valuation methods

A common approach to understanding the importance of ecosystems for human well-being is to assign monetary values to changes in ecosystems and the services they supply (e.g. Hanley and Barbier, 2009). This helps in making direct comparisons with other costs and benefits in decision-making processes (Kahneman and Sugden, 2005; Kumar, 2010). The notion of monetary value has been conceptualized in various ways; for instance, assigned values can be thought of as the measurement of a certain quality or level of importance (Schulz et al., 2017). This concept of value is rooted in neoclassical economics which considers humans as rational actors who seek to satisfy their preferences and maximise their personal utility through their choices (Dietz et al., 2005; Pearce and Turner, 1990). Accordingly, value is defined as “the change in human wellbeing arising from the provision of [an environmental] good or service” (Bateman et al., 2002; p1). These welfare changes can be compared by conducting monetary valuation studies that estimate people’s willingness to trade-off scarce means (usually money) to achieve an environmental change, such as reduced flooding.

People’s perceptions of nature’s value, and shared or social values, often differ from standard economic models, and a broader range of values needs to be considered. Conventional economic valuation may not be appropriate for all facets of environmental goods such as non-use values (Nunes & van den Bergh 2001). Further aspects of ecosystem services are still more difficult to address, and the monetary amounts generated through an economic valuation framework may not capture the full value of ecosystems to beneficiaries (e.g. the role of intact ecosystems in maintaining system resilience; García-Llorente et al., 2011; Walker et al., 2008). For example, the Common International Classification of Ecosystem Services (CICES) identifies at least 11 groups of cultural ecosystem services (Haines-Young and Potschin, 2018), suggesting that a full account of the cultural value of ecosystems would require the consideration of them all (Dallimer et al., 2014). Understanding the multi-dimensionality of value increasingly requires the application of deliberative and participatory approaches (Kenter et al., 2015; Raymond et al., 2014). Our search terms reflected all these concepts, and are specifically intended to ensure that studies that have not valued benefits in monetary terms are included (Table 1).

Monetary and non-monetary measurement is one step in ensuring that values are recognised and, when appropriate, captured in decision making. Monetary values of ecosystems can be incorporated into decision-making through specific mechanisms such as incentives and price signals or via decision-making frameworks such as cost-benefit analysis or payments for ecosystem services (PES) schemes (Kumar, 2010; Martin-Ortega et al., 2019; Primmer et al., 2018). They have been criticised for converting nature into a tradable commodity, often associated with a process of privatisation (Gomez-Baggethun and Ruiz-Perez, 2011), thereby marginalising other frameworks for ecosystem conservation (Raymond et al., 2013). However,

value capture does not have to lead to commodification (Hahn et al., 2015) or privatisation as property rights can be held collectively (Farley and Costanza, 2010), nor do schemes have to be driven by profit (Muniz and Cruz, 2015). In fact, public or self-provision of insurance value is a more likely scenario than market-like arrangements for the provision of insurance value (Paavola and Primmer, 2019). By exploring whether insurance values have subsequently been used to support instruments/tools/policies or other form of management arrangements we examined the extent to which measuring insurance value has thus far had an applied purpose, rather than being largely a result of scientific curiosity.

Ecosystems

An ecosystem is “a biological community of interacting organisms and their physical environment” (Millennium Ecosystem Assessment, 2005). In order to keep the review manageable, we focused on terrestrial and freshwater ecosystems and excluded coastal and marine ecosystems. Our search terms cover generic concepts (e.g. ecosystem, nature, environment, habitat, catchment), as well as specific habitats and land cover types (e.g. forest, city, grassland), taken from the IUCN definitions of terrestrial and freshwater habitats (IUCN, 2012). Previous reviews (e.g. Pascual et al., 2015; Perrings, 1995) and research (e.g. Chavas and Di Falco, 2012; Di Falco and Chavas, 2008; Isbell et al., 2015) have demonstrated the importance of biodiversity in ecosystem resilience, and its potential economic value. However, the focus of our review is on the impacts of ecosystem degradation/loss and rehabilitation/restoration, rather than associated changes in biodiversity. Our search terms, therefore, explicitly excluded biodiversity, its synonyms and mention of specific taxonomic groups.

Natural hazards

The framework was further bounded by a focus on natural hazards only. Geophysical and anthropogenic hazards were excluded with the exception of landslides and other mass movement events, as they are frequently managed through ecosystem-based approaches, such as the retention or restoration of forests. The list of search terms for hazard types was based on Guha-Sapir et al. (2017). Initial searches using generic terms for disease were refined based on a list of vector-borne diseases (WHO, 2017; Supplementary Material Table S1).

Table 1. Search terms used within the rapid evidence assessment of the insurance value of ecosystems. The list of vector-borne diseases is given in the supplementary material (Table S1). UK and US spelling variants, wildcards (*/?), common acronyms (e.g. WTP) and word stems were used in the database searches, but are not shown here for readability.

Insurance, resilience, risks and ecosystem restoration	Metrics of value and valuation methods	Ecosystems	Natural hazards
Risk	Value	Ecosystem	Flood
Hazard	Benefit	Nature	Erosion
Regime shift	Cost	Environment	Waterlog
Prevention	Price	Habitat	Inundation
Mitigation	Monetary	Catchment	Drought
Protection	Economic	Watershed	Avalanche
Reduction	Non-monetary	Forest	Fire
Avoidance	Willingness to pay	Savannah	Landslide

Defence	Willingness to	Shrub	Storm
Restoration	accept	Grassland	Eutrophication
Management		Meadow	Vector-borne
Resilience		Tundra	Disease (see list
Insurance		Wetland	Table S1)
		River	Pest
		Stream	Extreme temperature
		Bog	
		Marsh	
		Swamp	
		Fen	
		Peatland	
		Lake	
		Desert	
		Arable	
		Pasture	
		Plantation	
		Farm	
		Agriculture	
		Urban	
		City	

The search process

Searches were carried out in July 2017, with no other time restrictions applied. Searches were conducted using Web of Science, which is one of the largest and most comprehensive publication databases covering both natural and social sciences, providing a powerful tool for identifying relevant literature. Search terms (

Table 1) were actioned in two steps. We first conducted a joint search of “risk / hazard / regime shift & prevention / mitigation / protection / reduction / avoidance / defence / restoration / management” and then of “resilience / insurance”. The results from the two searches were aggregated into a single library and duplicates were removed. Search queries yielded 10,371 results. To ascertain the relevance of individual studies, all papers were subjected to three sequential filters: i) examination of title; ii) examination of abstract; and iii) examination of full paper. After titles were checked for relevance, 1,171 papers were retained; this was reduced to 302 papers after reading the abstracts. After full papers were read, 154 were retained for data extraction (Supplementary Material Table S2).

Papers excluded at the full text stage consisted of studies: (i) of attributes that affect adoption of innovative practices, e.g. by farmers of biological control; (ii) solely of perceptions or attitudes to natural hazards and their management; (iii) on community involvement in disaster prevention; (iv) on technical engineered interventions; (v) of governance and procedures to reduce risk; (v) which estimated economic losses without discussing risk reduction; and (vi) those which only included notions of insurance value as part of their introductory context. An additional suite of papers had an ecological focus or only discussed environmental management, such as the expansion of vegetation, forest thinning, storm water drainage, societal impacts of hazards and spatial planning.

Data extraction and analysis

Due to the heterogeneity of the retained articles, in terms of research design, measures, and involvement of stakeholders or other participants, data were analysed using narrative synthesis. Its purpose was to identify the approaches that have been used to study concepts of the insurance value of ecosystems in the existing literature (Popay et al., 2006). Data were extracted covering four information categories: 1) study description; 2) insurance, hazards and ecosystems; 3) valuation, and; 4) wider context. In addition, vote counting was used to describe the frequency of specific approaches used to examine insurance value of ecosystems. While vote counting has deficiencies (e.g. giving equal weight to studies of different types, with different strengths of evidence, not accounting for publication biases), it is useful for preliminary interpretation of results across studies (Popay et al., 2006).

Study description

The study description included the year of publication and the year when the study took place; the type of study (whether it was a conceptual, theoretical, empirical or modelling work or a review); country/countries or global regions on which the research focused; and the specific location (as defined in the study itself).

Insurance, hazards and ecosystems

For each paper, we characterised how the notion of insurance was conceptualized, e.g. whether it referred to risk or hazard prevention, mitigation, avoidance or resilience. We also characterized the ecosystem and spatial scale (e.g. global, regional, national, or catchment) of the analyses, as described in the study itself. Information on the type of hazard was extracted and categorised based on Guha-Sapir et al. (2017), together with any further details, such as the frequency or timescale of the hazards. Hazards were classified into five broad categories: geophysical (for the purposes of this review, landslides and other mass movement events only), hydrological (flood, landslide, wave action), meteorological (storms, extreme temperature, fog), climatological (drought, lake outbursts, wildfire) and biological (animal accidents, epidemics, insect infestation).

We considered insurance with respect to ecosystem-based interventions or approaches. These included any changes in the ecosystem that result in a change in exposure to/protection from natural hazards or the mitigation of, or increase in, risk. Interventions that could mitigate a risk include, for example, the restoration or establishment of a habitat type and could include NBS and NFM (Dadson et al., 2017; Nesshover et al., 2017). In contrast, alterations to ecosystems such as habitat fragmentation, land-use conversion, river morphology alteration could result in increased exposure to hazards. We recorded the ecosystem services that these changes referred to (e.g. reduced water levels mitigating flood risk; soil loss abatement reducing erosion). Ecosystem services were classified using CICES (Haines-Young and Potschin, 2018) in order to identify which services are mentioned in the publication in relation to insurance value. CICES itself consists of three 'sections' of services (Regulating and Management, Provisioning, Cultural) which are further divided into 90 categories.

Undisturbed ecosystems offer in most, if not all, circumstances greater overall benefits than highly modified ecosystems (Balmford et al., 2002), albeit via a combination of a greater number of narrower benefit streams than ecosystems converted to intensive production (see also Turner et al., 2003). A similar argument for retaining and/or restoring ecosystem properties is central to global initiatives to achieve land degradation neutrality (Akhtar-Schuster et al., 2017) and mainstreaming the economic benefits of more sustainably managed agricultural

lands into policy (ELD Initiative, 2015). We might expect that a similar rationale would apply to the role that ecosystems play in protection against, and avoidance of, natural hazards. We therefore categorised papers according to whether the alteration of ecosystems was an increase in extent/quality, a decrease in extent/quality, both or neither. Increases could include rehabilitation and restoration of habitats, enhanced vegetation complexity or improved diversity of habitats. Decreases could cover varieties of habitat loss, such as the conversion of natural habitats to agricultural production or urbanisation.

Valuation

We recorded whether studies associated changes in ecosystem service provision with a metric of value, even when the term ‘value’ was not explicitly used. We recorded if ‘value’ was expressed in non-monetary or monetary terms. When monetary values were reported, we recorded how the value was estimated (i.e. what type of valuation technique was employed), figures and units of those estimated values, as well as the year of the estimated values, and time scale of the value analysis (e.g. if the paper included an estimation of WTP for the delivery of ecosystem services over, for example, 30 years). We also noted whether values referred to marginal or total values. Studies differed as to whether they reported realized or anticipated values, where realised values were defined as those calculated as an estimation of the impact of an event that had already taken place (e.g. flood damage), and anticipated values as those calculated in anticipation of a future event (e.g. WTP to prevent future floods). Finally, we recorded whether the valuation exercises were associated with any policy instrument, such as a PES scheme, through which the value of the ecosystem, which is associated with insurance against natural hazards, could then be used to inform or underpin decision making.

Results and discussion

Study description and aims

The 154 articles retained for analysis were published between 1996 and 2017 (Figure 1) with the majority (86%, 133 papers) published after 2010. The growth of the literature manifests the uptake of the ecosystem service approach and the concepts that were popularised by the *Millennium Ecosystem Assessment* (Millennium Ecosystem Assessment, 2005). The largest number of studies was published in 2016, the last complete year in our review. Almost all of the retained articles were empirical (63 papers; 41%), or modelling (59 papers; 38%). The remainder were conceptual/theoretical (17 papers; 12%) or reviews (16 papers; 10%). Although the bulk (86%) of empirical and modelling articles was published after 2010, we could not ascertain whether earlier publication of theoretical work was driving a greater implementation of empirical studies. As expected because of our search parameters, the final set of articles did not include key theoretical outputs (e.g. Baumgartner and Strunz, 2014; Maler and Li, 2010), nor work on biodiversity underpinning ecological resilience (e.g. Isbell et al., 2015; Perrings, 1995).

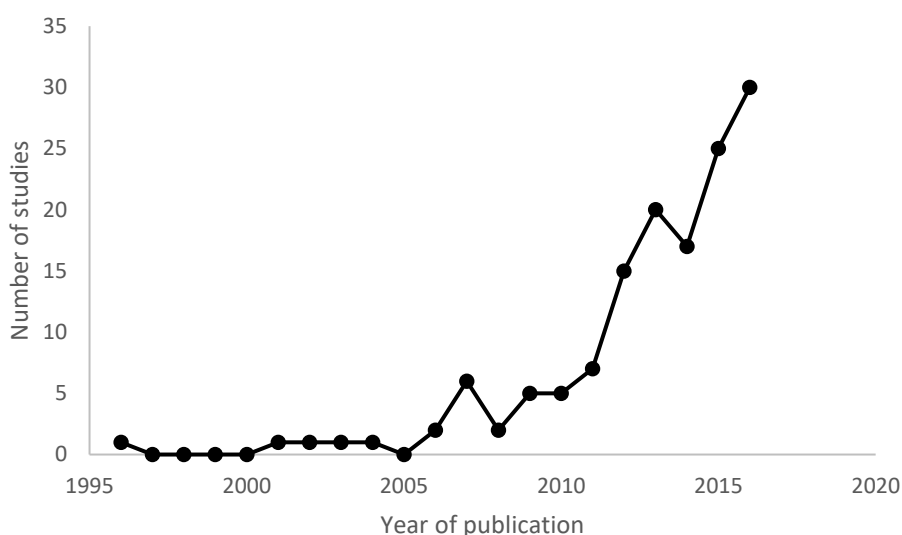


Figure 1. Number of studies addressing the insurance value of ecosystems published each year up to and including the final full year (2016) covered by the REA. A further 14 studies that were included in the review process, were published in 2017 prior to the search cut-off date (July 2017).

A wide range of aims were pursued in the reviewed studies, but the largest proportion (41%) investigated the effect of interventions to mitigate risk or to address environmental degradation. Common interventions were ecosystem restoration, reforestation and changes in land management practices. The second most common aim (17%) was the assessment of alterations to the ecological quality of the ecosystems, such as the diversity of forest cover, or the structure of riverbanks or wetlands. About a half of these included the value of ecosystem services. The role of forests, and forest cover, was a particularly common subject, as were the effects of altering river morphology, and the restoration or loss of wetlands. Approximately 6% of studies provided novel frameworks, conceptualizations or methodological approaches to address or integrate some of the above aspects of insurance value (e.g. effects of interventions and

environmental conditions), often with the aim of supporting improved ecosystem or landscape management.

Insurance, hazards and ecosystems

Of the retained studies, 24 had a global focus (Figure 2). In the global studies, hydrological and climatological hazards were most often examined through empirical analyses (e.g. Bradshaw et al., 2007; Shreve and Kelman, 2014) or conceptual models (e.g. Kiedrzyńska et al., 2015). More studies focus on regions in the Global North than on the Global South. Western Asia (2), South Asia (2), South-eastern Asia (5) and Eastern Europe and Central Asia (3) were relatively understudied. This is concerning because these regions experience the greatest proportion of natural disasters (Guha-Sapir et al., 2017).

The majority of studies in North America and Africa focused on climatological disasters, whereas hydrological disasters were the focus of studies on Europe, Eastern Asia, South-eastern Asia and Oceania. For Africa, this reflects not so much the number of events (there are more hydrological than climatological events) but the fact that climatological disasters kill and affect more people than do hydrological events (Guha-Sapir et al., 2017). For North America, the inconsistency between the focus of studies and the type of disaster is greater. Meteorological disasters are the most frequent and costly; yet climatological disasters were studied more often. A similar pattern was found in other regions.

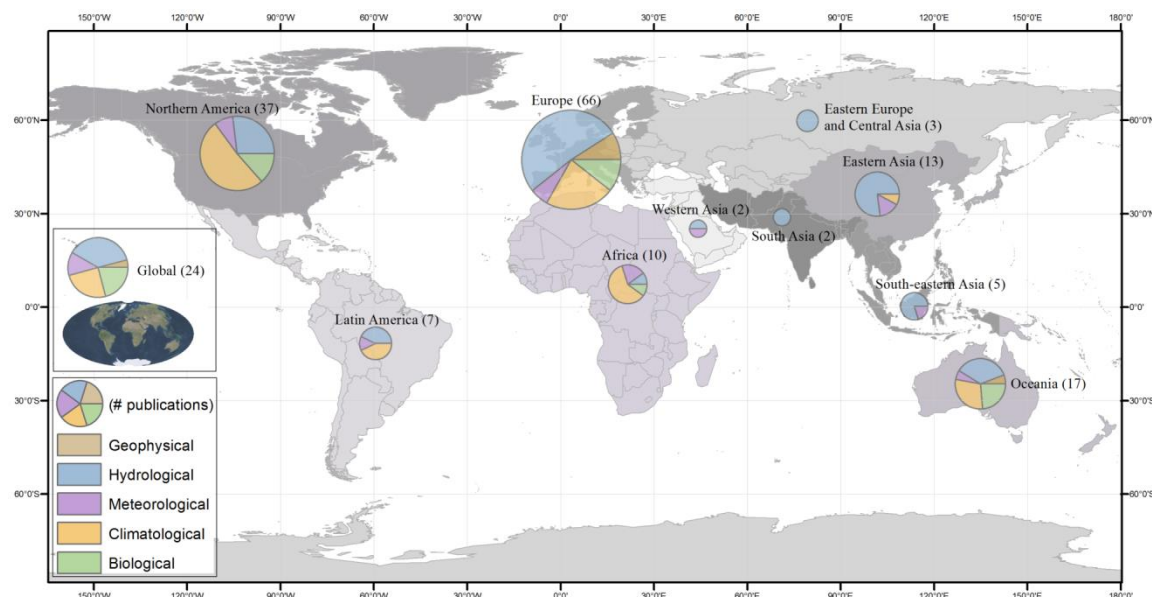


Figure 2. Number of studies per hazard type across 10 global regions and for global studies (inset). Circle size indicates the number of studies and the breakdown indicates the relative frequency of the five hazard types. Hazards were classified into five broad categories (Guha-Sapir et al., 2017): geophysical (earthquake, mass movement, volcanic activity), hydrological (flood, landslide, wave action), meteorological (storms, extreme temperature, fog), climatological (drought, lake outbursts, wildfire) and biological (animal accidents, epidemics, insect infestation).

The majority of studies focused on forests, agricultural lands and wetlands/floodplains (**Error! Reference source not found.**), with an emphasis on how habitats can reduce flood hazards associated with rainfall events. For example, forests can mitigate floods because they act as a “sponge” and slow down the flow of water (e.g. Dymond et al., 2012). The peri-urban and

urban studies were often on fire management in natural or semi-natural vegetation systems. For example, Miller et al. (2017) examined a bond-financed wildfire risk mitigation partnership, which focused on watershed forest management to prevent flood damage and to protect water supplies from impacts of large-scale and/or severe wildfires.

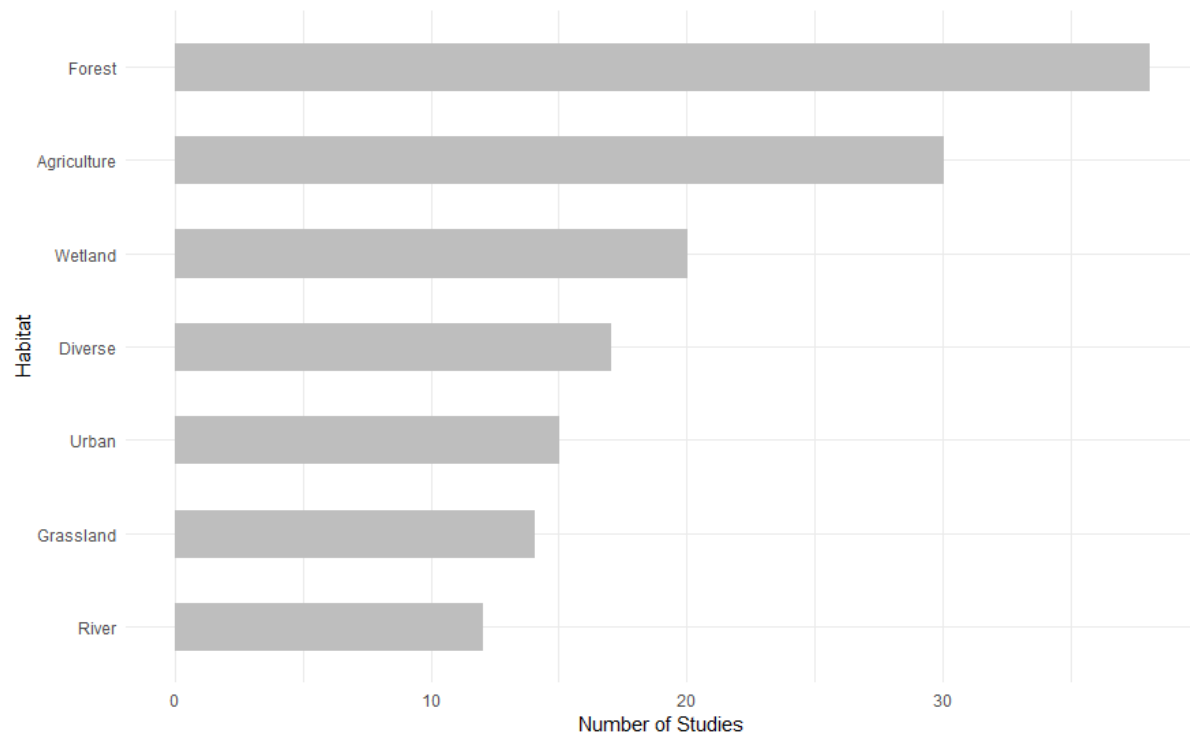
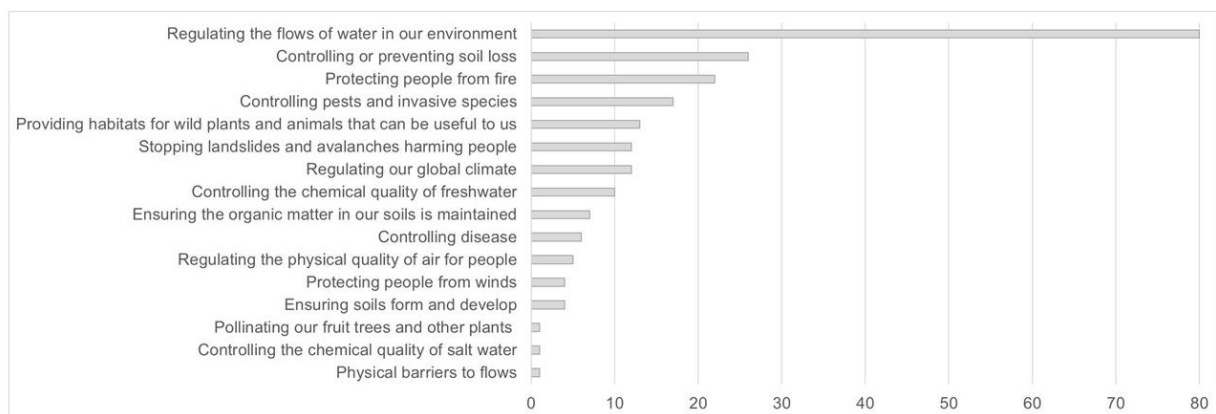


Figure 3. The number of studies in which a specific habitat or land cover is mentioned. Ten studies did not indicate a habitat type. Studies that referred to more than one habitat (e.g. a forest/agriculture matrix) are included in the “Diverse ecosystems” category.

Watersheds or catchments were the most common spatial scale of research (47 studies; 31%), reflecting the large number of studies focusing on water management and floods. Other scales included forests (12 studies, 8%), urban areas (16 studies; 10%) or even single hazard events. Across the reviewed papers, spatial scales tended to reflect relevant governance units, be that local (Miguez et al., 2015), regional (Holec and Hanewinkel, 2006) or national (Felton et al., 2016), even though the management of many ecosystems is carried out by private landowners. However, 39 studies did not provide data on the examined spatial scales, limiting our ability to assess the financial implications of the threat or the mitigation provided from ecosystem services.

Study timescales also varied. Fourteen studies provided evidence about the frequency of events (flood or fire) whereas 31 studies looked at a single growing season or year. Seven studies analysed historical data to estimate the benefits of ecosystem services, whereas the largest number of studies (22) took a forecasting approach, spanning periods of years to tens of years. The forecasts varied in their determination of the frequency of events in the future, with some (19) taking into account specific climate change predictions, whereas others (3) used the historical frequency of events in their extrapolations.

1 Around 80% (124) of the papers referred to more than one ecosystem service, with a total of
2 243 different ecosystem services mentioned across studies. Of these, six were cultural and 16
3 provisioning services. However, the majority (221; 220 biotic and one abiotic) were regulatory
4 and maintenance services. Sixteen of the 22 CICES sub-categories of the regulation &
5 maintenance services were covered in the papers included in the review. Over a third of studies
6 (36%) were about “Regulating the flows of water in our environment”, 12% about “Controlling
7 or preventing soil loss”, 10% about “Protecting people from fire” and 8% about “Controlling
8 pests and invasive species” (e.g. Cai et al., 2011; Cross et al., 2015; Jones et al., 2016; Miller
9 et al., 2017 respectively) (Figure 4). A further group of studies examined improved ecosystem
10 resilience more generally (e.g. Holman et al., 2011; Li et al., 2015), indicating potential gains
11 across a wider set of hazards; an approach which might be particularly appealing for
12 policymakers.



14 Figure 4. Classification of the insurance value of CICES regulation & maintenance ecosystem
15 services in the reviewed studies. (Supplementary Material Table S3).

17 Over two thirds of the studies (106, 68%) examined the insurance concepts associated with an
18 increase in extent/quality of an ecosystem, 21 studies (14%) looked at insurance in the context
19 of a decrease in extent/quality, and 18 studies (12%) involved changes to both directions: e.g.
20 the loss and restoration of mangroves (Everard et al., 2014). The remaining studies did not
21 specify, or were not explicitly concerned with, changes *per se*. Increases in extent/quality
22 included: (i) reforestation (Galve et al., 2015); (ii) urban green infrastructure interventions
23 (Connop et al., 2016); (iii) NFM, such as wetland construction and restoration (Babbar-Sebens
24 et al., 2013); (iv) increased vegetation complexity (e.g. retaining ground cover in orchards to
25 enhance populations of natural enemies of pests (Colloff et al., 2013)); (v) sustainable land
26 management practices (e.g. Speranza, 2013); and, (vi) more diverse systems (Newton et al.,
27 2012; Schlapfer et al., 2002). In all cases, papers studying increases of these types hypothesised
28 that changes would lead to an increase in protection from, or avoidance of a natural hazard.
29 Conversely, decreases in extent/quality of ecosystems were associated with increased actual or
30 perceived risks of exposure to natural hazards. Decreases in extent/quality included: (i) the
31 conversion of natural habitats for production purposes (e.g. the conversion of natural forest to
32 a rubber plantation (De Graff et al., 2012)); (ii) urbanisation (Brandolini et al., 2012); and, (iii)
33 the loss of natural habitats such as forests (Brang, 2001) and wetlands (Brody et al., 2007).

35 Only 24 studies (15%) explicitly related changes in ecosystem properties and service provision
36 to an insurance value. Although specific references to insurance value were rare, the most
37 common related concepts included the reduction of a risk or hazard (59 papers; 38%), its

mitigation (44 papers; 28%) or how an ecosystem provides resilience against risks or hazards (41 papers; 26%;

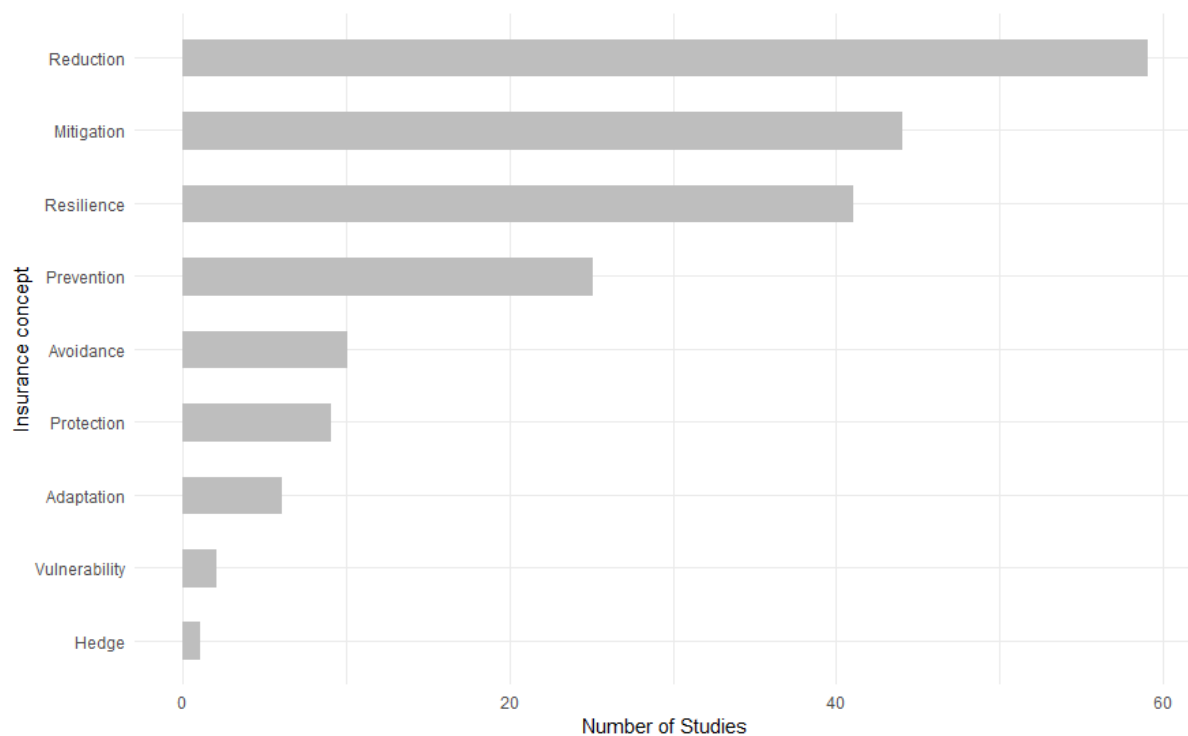


Figure 5). Studies examining how risks were reduced following changes in ecosystems included estimating the WTP of downstream agricultural water users for forest restoration to reduce wildfire risk (Mueller et al., 2013), and modelling how alterations in agricultural land use could reduce flood risk in large catchments (Schilling et al., 2014). The deterioration in ecosystem resilience as result of vegetation losses was investigated in drylands using a spatially explicit model (Mayor et al., 2013). Brown et al. (2012) examined the importance of mitigating flood risk in a conceptual paper on building urban resilience against climate change. Another study explored whether ecosystem properties could provide a hedge against future uncertainty (Boughton and Pike, 2013). It conceptualised insurance as the hedging role that floodplain restoration plays against climatic uncertainty (storm size, frequency, intensity). Rehabilitation expanded the opportunity fish had to migrate by 16-28%, and lessened the risk to fish migration of fewer, larger storms. Barbedo et al. (2014) modelled the effects of river restoration on flow rates around the city of Paraty, Brazil, in order that the benefits of river restoration could be considered in decision-making. However, overall Few studies were linked to decision-making, indicating an opportunity to better mainstream insurance values in ecosystem restoration.

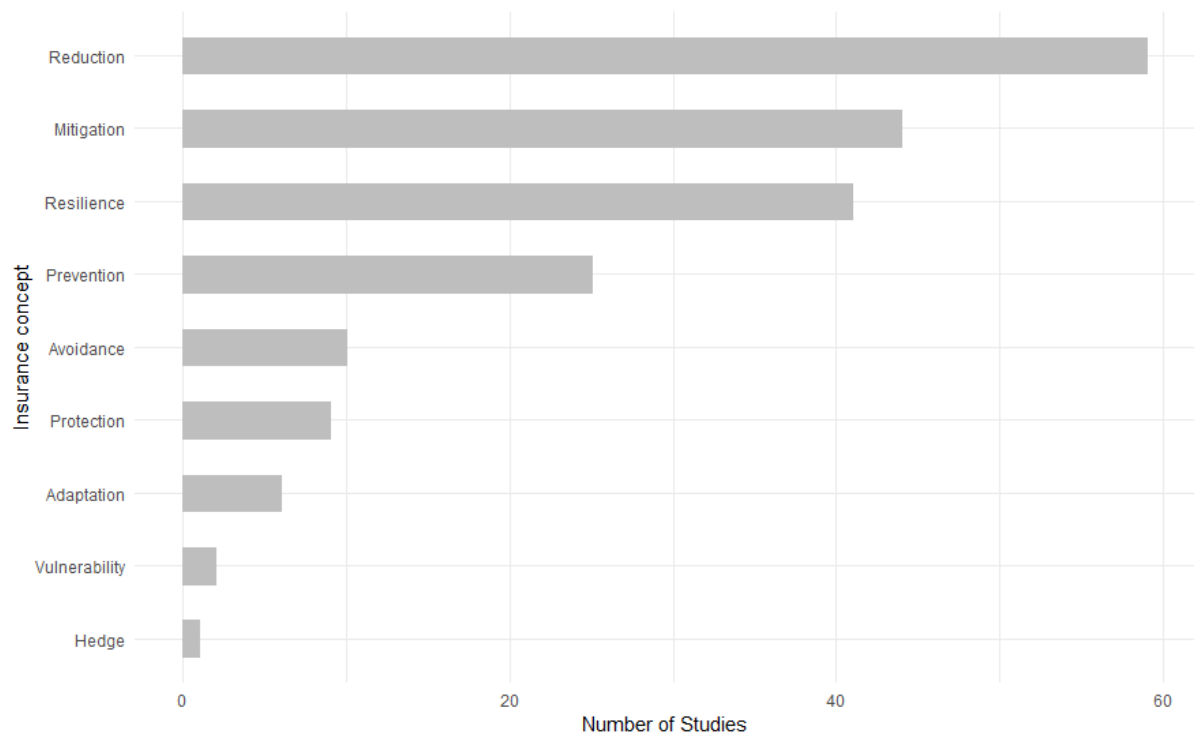


Figure 5. Number of reviewed studies using different concepts of insurance value of ecosystems.

Valuation

In total, 88 studies referred to some notion of value: 55 mentioned at least one monetary value and 18 a non-monetary value (in dark and light grey respectively;

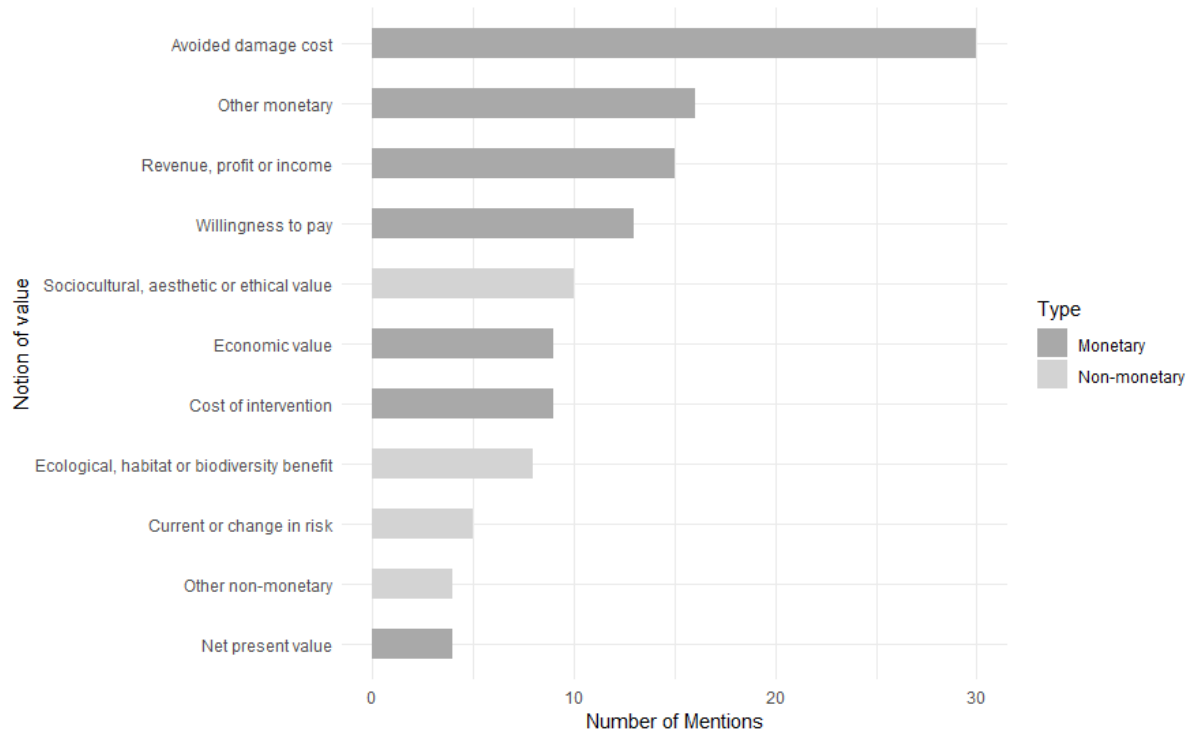


Figure 6), and 10 both types of value. Studies that referred to non-monetary values assessed sociocultural, aesthetic or ethical values (10 papers), ecological, habitat or biodiversity benefits (8 papers), or other non-monetary values (4 papers). Non-monetary valuation represented a modest proportion (17.9% of the reviewed papers) of the research carried out thus far. This perhaps reflects the relatively recent understanding of the importance of incorporating the multi-dimensionality of value in assessments of ecosystem services (Kenter et al., 2015). It further illustrates the need for more research to ensure that, among other aspects, altruistic, shared, social and socio-cultural facets of the insurance values of ecosystems are investigated (Kenter et al., 2015; Raymond et al., 2014; Schmidt et al., 2017).

Baumgartner & Strunz (2014) refer to insurance value as the value of a specific function of resilience, which reduces an ecosystem user's income risk associated with using ecosystem services under uncertainty. In contrast, Mäler and Li (2010) estimate a broader shadow price for resilience. It was not possible to separate out these theoretical concepts of 'insurance value' in the reviewed articles; this is unsurprising given the relatively recent emergence of the concepts in the literature. Nor, as expected, was it possible to separate out values specifically for insurance from calculations of TEV made in the papers (cf. Pascual et al 2015).

Monetary valuation studies used avoided damage cost, revenue or WTP approaches. TEV, marginal values and various use and non-use values were all estimated by these means. Ten studies did not specify which value was used. When monetary values were estimated, numerous different methods were applied. The most common were avoided cost or damage cost methods (e.g. using parcel level analysis, production function to estimate the expenditure needed to mitigate or compensate for the negative effects of a change in the environment), replacement cost method (e.g. assuming that the costs of replacing or repairing a deteriorated environmental service provides a reasonable estimate of its value (Logar and van den Bergh, 2013), such as replanting a forest or resettling people), choice experiments and contingent valuation (

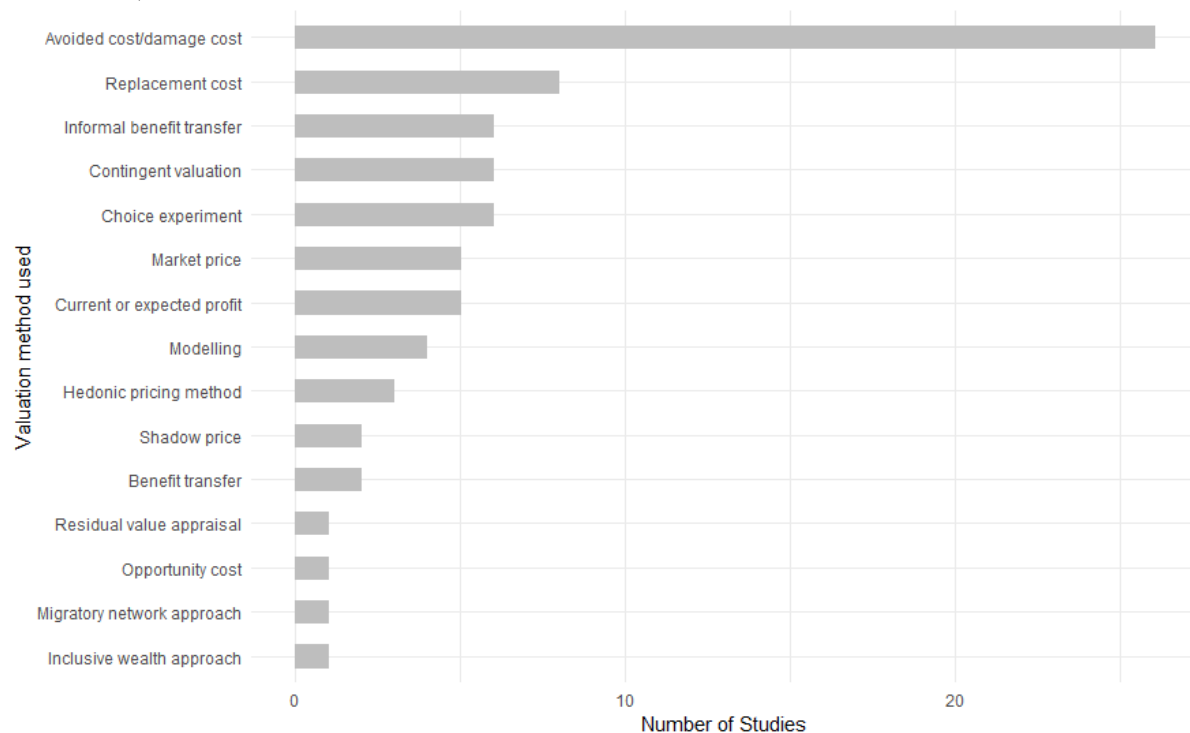


Figure 7).

Option and quasi-option values were not explicitly considered in any of the papers, despite the relationship between insurance and option values (i.e. the value of having the option of future use of an ecosystem service). An option value is, therefore, an insurance premium or the value of waiting for the resolution of uncertainty. Although difficult to quantify, quasi-option values, or the welfare gain associated with delaying decisions when there is uncertainty about the costs or benefits of a given course of action, may also constitute a significant portion of the value of retaining resilient ecosystems, in the face of increasing uncertainty driven by environmental or climate change.

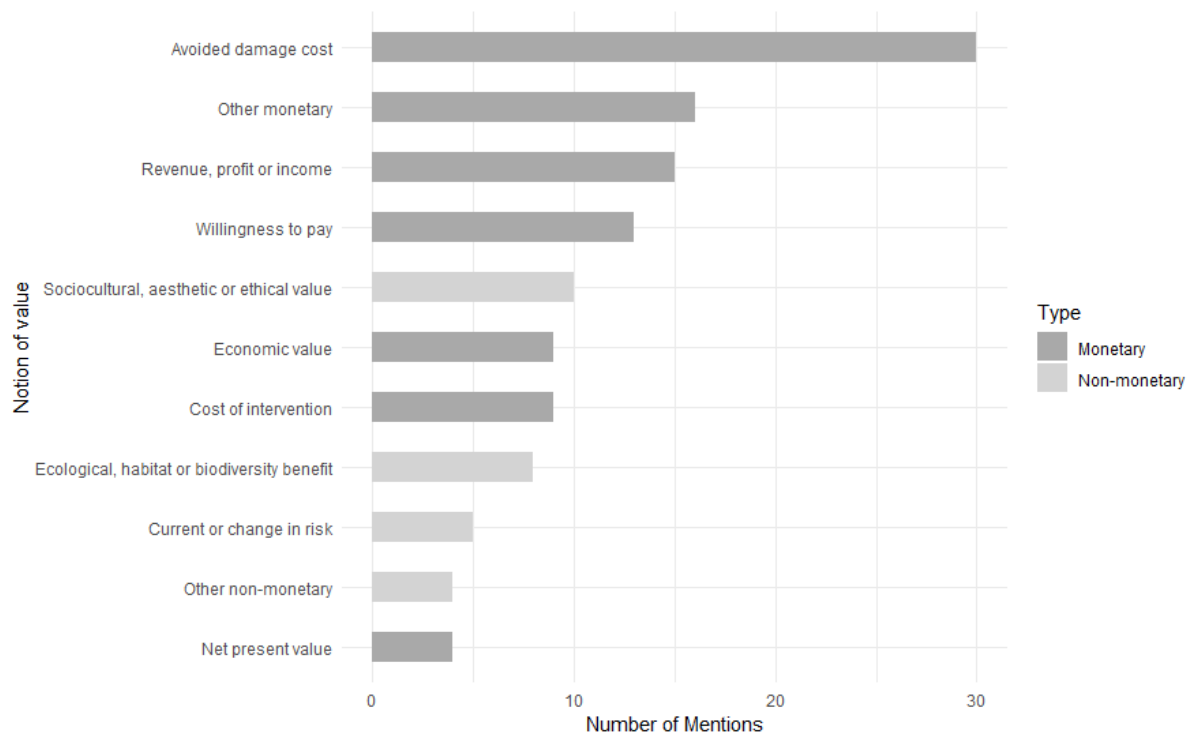


Figure 6. Number of times each notion of value (monetary in dark grey, non-monetary in light grey) was used in the reviewed studies.

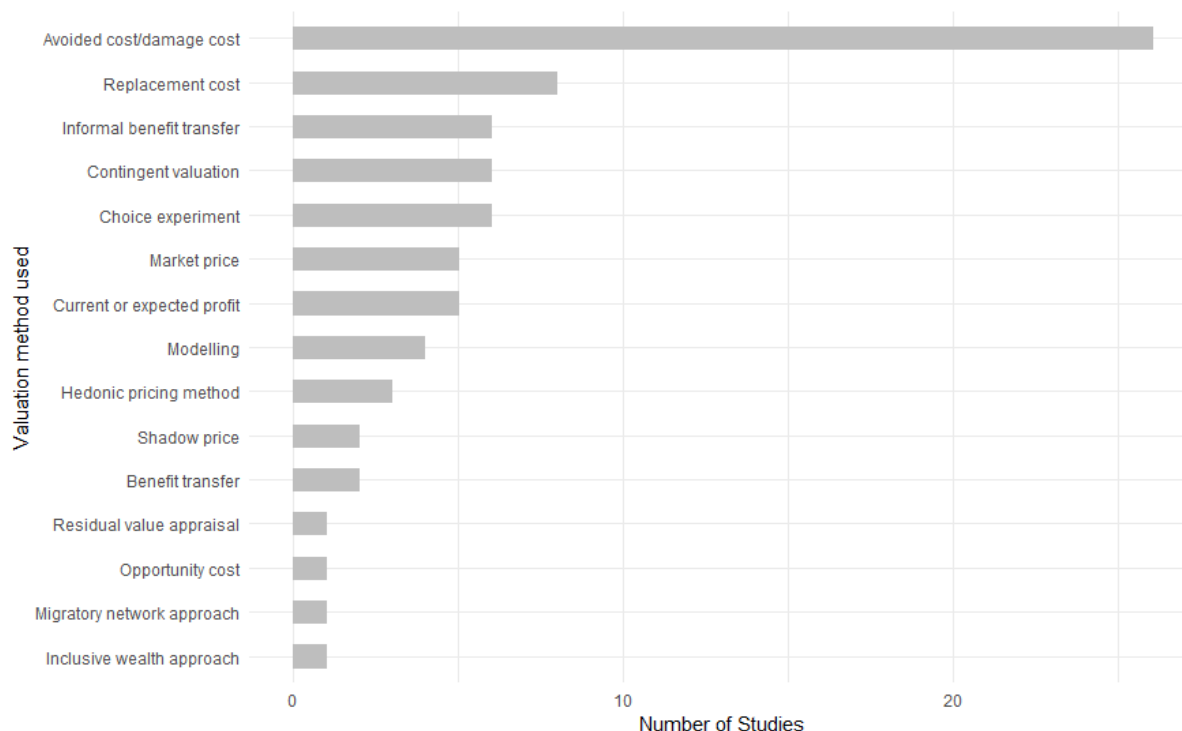


Figure 7. Valuation methods used to assess the monetary value of insurance services provided by ecosystems.

Direct comparison of values between studies was difficult as they varied in the theme, spatial and temporal scale, the consideration of scenarios, units reported, year the study was carried out and the monetary amounts associated with the insurance service. For instance, Kousky and Walls (2014) reported avoided flood losses of over \$110 million (all values here in 2017 USD to facilitate comparison) for a 100-year event in a floodplain in Missouri, while Brody et al. (2007) reported \$149.6 million over a 5-year period for 383 floods across counties in Florida. Similarly, two contingent valuation studies found a mean WTP of \$5.22 per month, per household for hazard protection from wildfires, drought and floods in Arizona (Mueller, 2014), and a mean WTP of \$28.87 - 48.61 per person, per year across seven scenarios for flood risk reduction in a river basin of Japan (Zhai et al., 2006). The fire prevention WTP values range from \$87.83 per person, per year to \$509 per hectare, per year. Avoided flood losses ranged from \$0.02 to \$58.2 per household, per year, or avoided flood damage costs from \$21.76 to \$21,158 per hectare, per year. Even studies of similar hazards, using similar techniques, provide radically different estimates of value. This could be for a variety of reasons, not least because disaggregating insurance value from TEV is not straightforward (Pascual et al 2015).

The lack of consensus on the minimum criteria for assessing costs and benefits associated with disaster risk reduction (Shreve and Kelman, 2014) was reflected across the studies. For instance, while defining time horizons is essential in cost-benefit analyses (CBA), only thirty studies mentioned a time scale for the values generated, and these ranged from one to 115 years (median 6 years). There were 35 prospective studies on anticipated values and 11 retrospective studies estimating realised values of past events. Eight studies estimated both realised and anticipated values. Long-time scales may be particularly important when considering climate change, but do not necessarily overlap with relevant policy and decision making timescales. Bringing in other perspectives on value, and a consideration of long-term environmental and

climate change and vulnerability processes (Feuillette et al., 2016; Shreve and Kelman, 2014), may require greater use of participatory decision making and valuation tools, such as Multi-criteria analysis (MCA) (Shreve and Kelman, 2014).

Scale was an important concept in the reviewed studies, for instance as an argument for managing entire ecosystems to buffer against hazards (Berger and Rey, 2004). Studies largely reflected the scale of the ecosystems in question (e.g. catchments, particular high elevation ecosystems Mariotte et al., 2013) or scales at which relevant policies might operate (e.g. regional European Union adaption strategy (Holstead et al., 2017). Taking the latter approach is a pre-requisite for research to inform decision and policy making (Dallimer and Strange, 2015), and might be one reason why so few papers make the link between the values that they calculated and how these values might be used to influence decisions about land use and management. Value capture models were mentioned in 21 of the studies that estimated a monetary value. PES schemes were mentioned most frequently, followed by management plans and decision support tools, such as CBA or MCA (

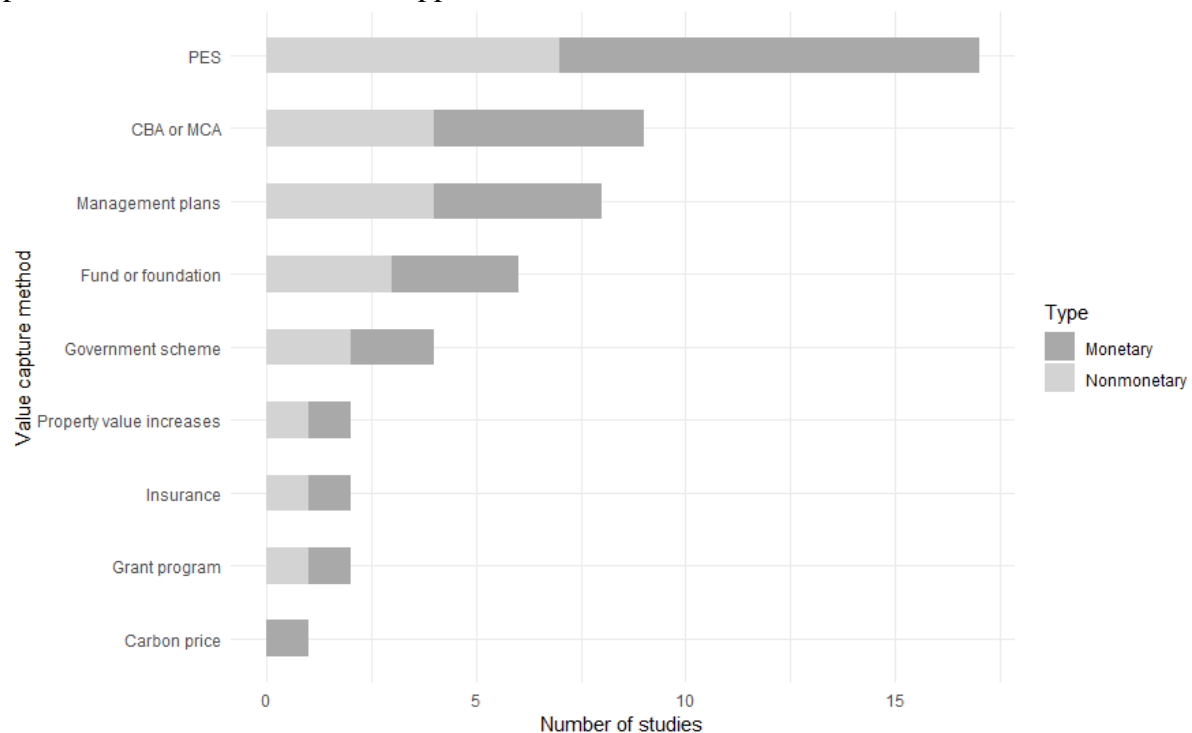


Figure 8). Innovative value capture models such as microfinance, crowdfunding and insurance trusts were not discussed (e.g. Abraham and Fonta, 2018; Beck et al., 2018; Dey et al., 2019; Gallo-Cajiao et al., 2018).

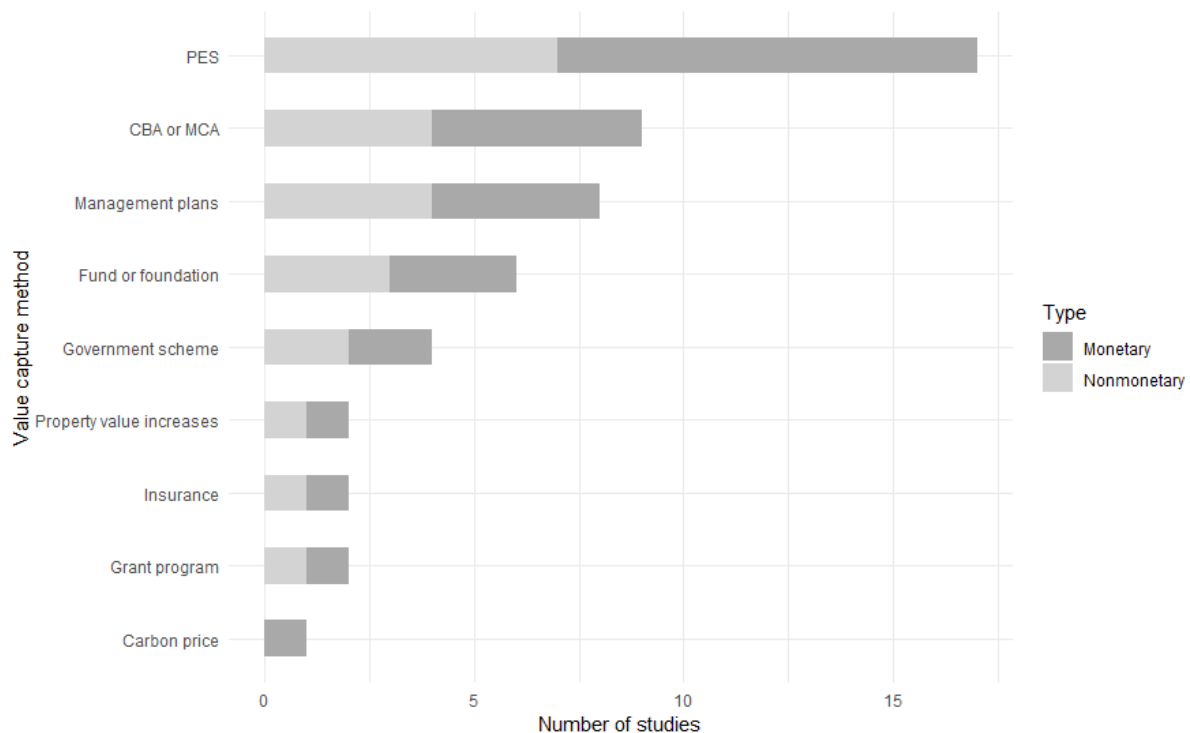


Figure 8. Number of reviewed studies (monetary in dark grey, non-monetary in light grey) distributed according to the value capture model(s) mentioned (n=21). CBA = cost-benefit analysis; MCA = multi-criteria analysis; PES = payment for ecosystem services.

Climate change and co-benefits

The frequency and intensity of natural hazards, as well as the number of people vulnerable to suffering losses, is predicted to increase with climate change (Royal Society, 2014). Despite this, climate change was an integral concern in only about a third of the reviewed studies (57 of the 154); for example, as a driver of biodiversity loss, or increased flood and desertification risk (Kelt and Meserve, 2016; Kiedrzyńska et al., 2015; Kulakowski et al., 2017; Oliver et al., 2015). There were also references to climate change mitigation through, for example, peatland carbon sequestration and soil management, and to adaptation using green urban infrastructure (Connop et al., 2016; Gilbert, 2013; Holman et al., 2011). A few studies discussed the insurance value of ecosystems as part of a strategy for climate change adaptation. For example, forest restoration could help reverse biodiversity loss, pest outbreaks, and human disease, thereby addressing cascading risks (Morlando et al., 2012), or resilience could be increased in a particular biome such as forests (Chapin et al., 2007; Colloff et al., 2016). Adaptation planning is also referred to in some studies (Koschke et al., 2013) in relation to specific circumstances such as agroforestry, reforestation (Lasco et al., 2014; Locatelli et al., 2015), and floodplain management (Kiedrzyńska et al., 2015).

Co-benefits (or the assessment of multiple benefits from ecosystems) are often used as an argument in favour of ecosystem-based approaches over hard-engineering infrastructure (Raymond et al., 2017). Co-benefits were referred to in 95 (62%) papers. In common with the wider literature, papers that did assess co-benefits noted that they can often dwarf the target benefit, e.g. water quality benefits from improved flood control (Brouwer et al., 2016; Dumenu, 2013; Richert et al., 2011). The potential for mitigating several risks simultaneously or for generating cascading benefits was a recurring theme (Felton et al., 2016; Morlando et al., 2012). Co-benefits were most commonly described as socio-economic (rather than

environmental) benefits, such as the protection of public infrastructure, public health and avoided costs from fire suppression or disruption (Huang et al., 2013; Kelly et al., 2015; Miguez et al., 2015).

Conclusions

The rapid development of initiatives such as NBS, NFM, integrated pest management and ecological engineering exemplify how ecosystems can provide a form of ‘natural insurance’ by enhancing socio-ecological resilience. Ecosystems can buffer against adverse events and gradual losses such as flooding and soil erosion, thereby reducing the costs of risk-bearing for individuals and wider society. These benefits have been conceptualized as the ‘insurance value’ of ecosystems. We conducted an REA across a heterogeneous body of literature to take stock of the existing empirical evidence on how, where and why the insurance value of ecosystems has been measured. REAs have the benefit of being transparent and repeatable, in terms of search terms used and data extracted. Although our framework had limitations (e.g. the explicit exclusion of biodiversity and related terms), following a documented process ensures subsequent reviews can easily build on this review.

Insurance values provide an additional rationale for the rehabilitation, restoration and conservation of intact, or relatively undisturbed natural ecosystems. In our review, the values associated with restoration, or the avoidance of loss, of natural ecosystems were universally positive, and in some cases, substantial. More nuanced findings were that (i) the number of studies does not match the frequency or the severity of types of hazards; and, (ii) at a global scale, the geographical focus of studies is not related to the spatial incidence of hazards. The existing literature is also dominated by studies focusing on a specific ecosystem or hazard, such as those based around catchment management and water use planning. These observations suggest that either the funding of academic research is not aligned with exposure to risks, or the pattern may reflect the relatively early stage of ecosystem services research and the longer history of work on water management and floods.

This study also highlights how little research has been conducted thus far to assess the ways in which resilience across ecosystems could be enhanced; despite the fact that a more comprehensive, systems-based approach would be better suited for informing ecosystem management, policy and planning. Furthermore, in many regions multiple hazards can occur simultaneously and/or as a cascade from a single original hazard (e.g. a landslide into a reservoir or glacial lake could lead to dam burst and subsequent downstream flooding). This suggests that the benefit of preventing or avoiding the initial hazard could be substantially magnified if subsequent damage from linked hazards is also avoided. In addition, few studies were explicitly linked to mechanisms through which the insurance value could be ‘captured’ for wider societal gain (e.g. Jellinek et al., 2013; Mueller, 2014; Mueller et al., 2013). This lack of applied research is a clear gap that should be addressed in future research.

Due to the weaknesses in the existing evidence base, drawing more definitive conclusions (e.g. retaining X ha of forests on mountain slopes delivers \$Y per year in avoided damage costs for Z thousand people) from the reviewed studies is difficult. There is great diversity in the methodologies used, temporal and spatial scales, and comprehensiveness across the studies. Many studies did not provide a transparent account of their analytical choices and parameters. This makes the results difficult to compare, transfer and synthesise.

Our review of the existing empirical evidence-base on the insurance value of ecosystems suggest that, as the field develops further, it will be essential that studies are conducted to: 1) provide more consistent and coherent statistics, scenarios and methods across studies and use consistent timeframes to facilitate subsequent reviews and benefits transfer exercises; 2) develop more integrated valuation approaches focusing on the inclusion of insurance value or its disaggregation from other values, such as TEV; 3) better account for climate change; and, 4) clearly define the human "community" benefitting from interventions, as well as the spatial and temporal scales over which these benefits are realised. Following these guidelines will facilitate uptake into policy and practice of insurance value concepts. As the field develops there may be benefit in researchers drawing on best practice from other fields, such as the use and definition of a 'core outcome set' of metrics that are always reported in standardised ways (Webbe et al., 2018; Williamson et al., 2012). As ecosystems continue to degrade, and are relied on by growing human populations for their insurance values, being able to track trends in values, across a diversity of ecosystems and contexts, will provide a powerful argument for the retention, rehabilitation and restoration of natural environments.

Acknowledgements

We would like to thank Eeva Primmer and Thijs Dekker for discussions and support in developing the paper, and Stephanie Duce for help with preparing Figure 2. We also thank attendees to the special session of the 2017 Conference of the European Society for Ecological Economics (ESEE) for their feedback on the search terms used in this study. SA and JP were supported by funding from the ESRC for the Centre for Climate Change Economics and Policy (CCCEP, grant number ES/K006576/1), RB was funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 659449, JMO by the Yorkshire Integrated Catchment Solutions Programme (iCASP) (NERC: NE/P011160/1) and MD by the UK government's Natural Environment Research Council (NERC; NE/R002681/1).

References

- Abraham, T., Fonta, W., 2018. Climate change and financing adaptation by farmers in northern Nigeria. *Financ. Innov.* 4, 17.
- Akhtar-Schuster, M., Stringer, L.C., Erlewein, A., Metternicht, G., Minelli, S., Safriel, U., Sommer, S., 2017. Unpacking the concept of land degradation neutrality and addressing its operation through the Rio Conventions. *J. Environ. Manage.* 195, 4-15.
- Babbar-Sebens, M., Barr, R.C., Tedesco, L.P., Anderson, M., 2013. Spatial identification and optimization of upland wetlands in agricultural watersheds. *Ecol. Eng.* 52, 130-142.
- Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rosendo, S., Roughgarden, J., Trumper, K., Turner, R.K., 2002. Economic reasons for conserving wild nature. *Science* 297, 950-953.
- Barbedo, J., Miguez, M., van der Horst, D., Marins, M., 2014. Enhancing ecosystem services for flood mitigation: a conservation strategy for peri-urban landscapes? *Ecol. Soc.* 19, 54.
- Barnett-Page, E., Thomas, J., 2009. Methods for the synthesis of qualitative research: a critical review. *BMC Medical Research Methodology* 9, 59.
- Bartkowski, B., 2017. Are diverse ecosystems more valuable? Economic value of biodiversity as result of uncertainty and spatial interactions in ecosystem service provision. *Ecosys. Servs.* 24, 50-57.
- Bateman, I.J., Carson, R.T., Day, B., Hanemann, M., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Mourato, S., Pearce, D.W., 2002. Economic valuation with stated preference techniques: A manual. *Economic valuation with stated preference techniques: a manual.*
- Baumgartner, S., 2007. The insurance value of biodiversity in the provision of ecosystem services. *Nat. Resour. Model.* 20, 87-127.
- Baumgartner, S., Strunz, S., 2014. The economic insurance value of ecosystem resilience. *Ecol. Econ.* 101, 21-32.
- Beck, M.W., Losada, I.J., Menendez, P., Reguero, B.G., Diaz-Simal, P., Fernandez, F., 2018. The global flood protection savings provided by coral reefs. *Nature Communications* 9, 9.
- Berger, F., Rey, F., 2004. Mountain protection forests against natural hazards and risks: New French developments by integrating forests in risk zoning. *Nat. Hazards* 33, 395-404.
- Boughton, D.A., Pike, A.S., 2013. Floodplain Rehabilitation as a Hedge against Hydroclimatic Uncertainty in a Migration Corridor of Threatened Steelhead. *Conserv. Biol.* 27, 1158-1168.
- Bradshaw, C.J.A., Sodhi, N.S., Peh, K.S.H., Brook, B.W., 2007. Global evidence that deforestation amplifies flood risk and severity in the developing world. *Global Change Biol.* 13, 2379-2395.
- Brand, F., 2009. Critical natural capital revisited: Ecological resilience and sustainable development. *Ecol. Econ.* 68, 605-612.
- Brandolini, P., Cevasco, A., Firpo, M., Robbiano, A., Sacchini, A., 2012. Geo-hydrological risk management for civil protection purposes in the urban area of Genoa (Liguria, NW Italy). *Natural Hazards and Earth System Sciences* 12, 943-959.
- Brang, P., 2001. Resistance and elasticity: promising concepts for the management of protection forests in the European Alps. *Forest Ecology and Management* 145, 107-119.
- Brody, S.D., Zahran, S., Maghelal, P., Grover, H., Highfield, W.E., 2007. The rising costs of floods - Examining the impact of planning and development decisions on property damage in Florida. *Journal of the American Planning Association* 73, 330-345.
- Brouwer, R., Bliem, M., Getzner, M., Kerekes, S., Milton, S., Palarie, T., Szerenyi, Z., Vadineanue, A., Wagtendonk, A., 2016. Valuation and transferability of the non-market benefits of river restoration in the Danube river basin using a choice experiment. *Ecol. Eng.* 87, 20-29.

- 1 Brown, A., Dayal, A., del Rio, C.R., 2012. From practice to theory: emerging lessons from
- 2 Asia for building urban climate change resilience. *Environ. Urban.* 24, 531-556.
- 3 Burton, E., Butler, G., Hodgkinson, J., Marshall, S., 2007. Quick but not dirty: rapid evidence
- 4 assessments (REAs) as a decision support tool in social policy. *Community safety: Innovation*
- 5 *and evaluation*, Chester: Chester Academic Press. IP 5.
- 6 Cai, Y.P., Huang, G.H., Tan, Q., Chen, B., 2011. Identification of optimal strategies for
- 7 improving eco-resilience to floods in ecologically vulnerable regions of a wetland. *Ecological*
- 8 *Modelling* 222, 360-369.
- 9 Carpenter, S., Walker, B., Anderies, J.M., Abel, N., 2001. From metaphor to measurement:
- 10 Resilience of what to what? *Ecosystems* 4, 765-781.
- 11 Chapin, F.S., Danell, K., Elmqvist, T., Folke, C., Fresco, N., 2007. Managing climate change
- 12 impacts to enhance the resilience and sustainability of Fennoscandian forests. *Ambio* 36, 528-
- 13 533.
- 14 Chavas, J.P., Di Falco, S., 2012. On the Productive Value of Crop Biodiversity: Evidence from
- 15 the Highlands of Ethiopia. *Land Economics* 88, 58-74.
- 16 Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., 2016. Nature-based solutions to
- 17 address global societal challenges. IUCN, Gland, Switzerland 97.
- 18 Colloff, M.J., Doherty, M.D., Lavorel, S., Dunlop, M., Wise, R.M., Prober, S.M., 2016.
- 19 Adaptation services and pathways for the management of temperate montane forests under
- 20 transformational climate change. *Clim. Change* 138, 267-282.
- 21 Colloff, M.J., Lindsay, E.A., Cook, D.C., 2013. Natural pest control in citrus as an ecosystem
- 22 service: Integrating ecology, economics and management at the farm scale. *Biol. Control* 67,
- 23 170-177.
- 24 Connop, S., Vandergert, P., Eisenberg, B., Collier, M.J., Nash, C., Clough, J., Newport, D.,
- 25 2016. Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits
- 26 approach to urban green infrastructure. *Environmental Science & Policy* 62, 99-111.
- 27 Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I.,
- 28 Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. *Glob.*
- 29 *Environ. Change-Human Policy Dimens.* 26, 152-158.
- 30 Cross, J., Fountain, M., Marko, V., Nagy, C., 2015. Arthropod ecosystem services in apple
- 31 orchards and their economic benefits. *Ecological Entomology* 40, 82-96.
- 32 Dadson, S.J., Hall, J.W., Murgatroyd, A., Acreman, M., Bates, P., Beven, K., Heathwaite, L.,
- 33 Holden, J., Holman, I.P., Lane, S.N., O'Connell, E., Penning-Rowsell, E., Reynard, N., Sear,
- 34 D., Thorne, C., Wilby, R., 2017. A restatement of the natural science evidence concerning
- 35 catchment-based 'natural' flood management in the UK. *Proceedings of the Royal Society a-*
- 36 *Mathematical Physical and Engineering Sciences* 473, 20160706.
- 37 Dallimer, M., Strange, N., 2015. Why socio-political borders and boundaries matter in
- 38 conservation. *Trends Ecol. Evol.* 30, 132-139.
- 39 Dallimer, M., Tinch, D., Hanley, N., Irvine, K.N., Rouquette, J.R., Warren, P.H., Maltby, L.,
- 40 Gaston, K.J., Armsworth, P.R., 2014. Quantifying Preferences for the Natural World Using
- 41 Monetary and Nonmonetary Assessments of Value. *Conserv. Biol.* 28, 404-413.
- 42 De Graff, J.V., Sidle, R.C., Ahmad, R., Scatena, F.N., 2012. Recognizing the importance of
- 43 tropical forests in limiting rainfall-induced debris flows. *Environmental Earth Sciences* 67,
- 44 1225-1235.
- 45 Dey, A., Gupta, A.K., Singh, G., 2019. Innovation, investment and enterprise: Climate resilient
- 46 entrepreneurial pathways for overcoming poverty. *Agricultural Systems* 172, 83-90.
- 47 Di Falco, S., Chavas, J.P., 2008. Rainfall shocks, resilience, and the effects of crop biodiversity
- 48 on agroecosystem productivity. *Land Economics* 84, 83-96.
- 49 Dietz, T., Fitzgerald, A., Shwom, R., 2005. Environmental values. *Annu. Rev. Environ.*
- 50 *Resour.* 30, 335-372.

1 Dumenu, W.K., 2013. What are we missing? Economic value of an urban forest in Ghana.
2 Ecosys. Servs. 5, E137-E142.

3 Dymond, J.R., Ausseil, A.G.E., Ekanayake, J.C., Kirschbaum, M.U.F., 2012. Tradeoffs
4 between soil, water, and carbon - A national scale analysis from New Zealand. J. Environ.
5 Manage. 95, 124-131.

6 Ehrlich, I., Becker, G.S., 1972. Market insurance, self-insurance, and self-protection. J. Polit.
7 Econ. 80, 623-648.

8 ELD Initiative, 2015. The Value of Land: Prosperous Lands and Positive Rewards Through
9 Sustainable Land Management. . Available from www.eld-initiative.org.

10 Everard, M., Jha, R.R.S., Russell, S., 2014. The benefits of fringing mangrove systems to
11 Mumbai. Aquatic Conservation-Marine and Freshwater Ecosystems 24, 256-274.

12 Farley, J., Costanza, R., 2010. Payments for ecosystem services: From local to global. Ecol.
13 Econ. 69, 2060-2068.

14 Felton, A., Nilsson, U., Sonesson, J., Felton, A.M., Roberge, J.M., Ranius, T., Ahlstrom, M.,
15 Bergh, J., Bjorkman, C., Boberg, J., Drossler, L., Fahlvik, N., Gong, P., Holmstrom, E.,
16 Keskitalo, E.C.H., Klapwijk, M.J., Laudon, H., Lundmark, T., Niklasson, M., Nordin, A.,
17 Pettersson, M., Stenlid, J., Stens, A., Wallertz, K., 2016. Replacing monocultures with mixed-
18 species stands: Ecosystem service implications of two production forest alternatives in Sweden.
19 Ambio 45, S124-S139.

20 Feuillet, S., Levrel, H., Boeuf, B., Blanquart, S., Gorin, O., Monaco, G., Penisson, B.,
21 Robichon, S., 2016. The use of cost-benefit analysis in environmental policies: Some issues
22 raised by the Water Framework Directive implementation in France. Environmental Science
23 & Policy 57, 79-85.

24 Gallo-Cajiao, E., Archibald, C., Friedman, R., Steven, R., Fuller, R.A., Game, E.T., Morrison,
25 T.H., Ritchie, E.G., 2018. Crowdfunding biodiversity conservation. Conserv. Biol. 32, 1426-
26 1435.

27 Galve, J.P., Cevalco, A., Brandolini, P., Soldati, M., 2015. Assessment of shallow landslide
28 risk mitigation measures based on land use planning through probabilistic modelling.
29 Landslides 12, 101-114.

30 García-Llorente, M., Martín-López, B., Díaz, S., Montes, C., 2011. Can ecosystem properties
31 be fully translated into service values? An economic valuation of aquatic plant services. Ecol.
32 Appl. 21, 3083-3103.

33 Gilbert, L., 2013. Can restoration of afforested peatland regulate pests and disease? J. Appl.
34 Ecol. 50, 1226-1233.

35 Gomez-Baggethun, E., Ruiz-Perez, M., 2011. Economic valuation and the commodification of
36 ecosystem services. Progress in Physical Geography 35, 613-628.

37 Green, T.L., Kronenberg, J., Andersson, E., Elmqvist, T., Gomez-Baggethun, E., 2016.
38 Insurance Value of Green Infrastructure in and Around Cities. Ecosystems 19, 1051-1063.

39 Greenhalgh, T., Robert, G., Macfarlane, F., Bate, P., Kyriakidou, O., Peacock, R., 2005.
40 Storylines of research in diffusion of innovation: a meta-narrative approach to systematic
41 review. Soc Sci Med 61, 417-430.

42 Guha-Sapir, D., Hoyois, P., Wallemacq, P., Below, R., 2017. Annual Disaster Statistical
43 Review 2016 The numbers and trends. Centre for Research on the Epidemiology of Disasters.
44 Brussels, Centre for Research on the Epidemiology of Disasters (CRED) Institute of Health
45 and Society (IRSS) Université catholique de Louvain.

46 Hahn, T., McDermott, C., Ituarte-Lima, C., Schultz, M., Green, T., Tuvendal, M., 2015.
47 Purposes and degrees of commodification: Economic instruments for biodiversity and
48 ecosystem services need not rely on markets or monetary valuation. Ecosys. Servs. 16, 74-82.

1 Haines-Young, R., Potschin, M.B., 2018. Common International Classification of Ecosystem
2 Services (CICES) V5.1 and Guidance on the Application of the Revised Structure. European
3 Environment Agency, Copenhagen.

4 Hanley, N., Barbier, E., 2009. Pricing Nature: Cost-Benefit Analysis and Environmental
5 Policy. Edward Elgar, Cheltenham.

6 Holec, J., Hanewinkel, M., 2006. A forest management risk insurance model and its
7 application to coniferous stands in southwest Germany. *Forest Policy Econ.* 8, 161-174.

8 Holling, C.S., 1973. Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst.* 4,
9 1-23.

10 Holman, I.P., Hess, T.M., Rose, S.C., 2011. A broad-scale assessment of the effect of improved
11 soil management on catchment baseflow index. *Hydrological Processes* 25, 2563-2572.

12 Holstead, K.L., Kenyon, W., Rouillard, J.J., Hopkins, J., Galan-Diaz, C., 2017. Natural flood
13 management from the farmer's perspective: criteria that affect uptake. *Journal of Flood Risk*
14 *Management* 10, 205-218.

15 Huang, C.H., Finkral, A., Sorensen, C., Kolb, T., 2013. Toward full economic valuation of
16 forest fuels-reduction treatments. *J. Environ. Manage.* 130, 221-231.

17 IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II
18 and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
19 IPCC, Geneva, Switzerland.

20 Isbell, F., Craven, D., Connolly, J., Loreau, M., Schmid, B., Beierkuhnlein, C., Bezemer, T.M.,
21 Bonin, C., Bruehlheide, H., de Luca, E., Ebeling, A., Griffin, J.N., Guo, Q.F., Hautier, Y.,
22 Hector, A., Jentsch, A., Kreyling, J., Lanta, V., Manning, P., Meyer, S.T., Mori, A.S., Naeem,
23 S., Niklaus, P.A., Polley, H.W., Reich, P.B., Roscher, C., Seabloom, E.W., Smith, M.D.,
24 Thakur, M.P., Tilman, D., Tracy, B.F., van der Putten, W.H., van Ruijven, J., Weigelt, A.,
25 Weisser, W.W., Wilsey, B., Eisenhauer, N., 2015. Biodiversity increases the resistance of
26 ecosystem productivity to climate extremes. *Nature* 526, 574-577.

27 IUCN, 2012. Habitats Classification Scheme Version 3.1.
28 [http://www.iucnredlist.org/technical-documents/classification-schemes/habitats-](http://www.iucnredlist.org/technical-documents/classification-schemes/habitats-classification-scheme-ver3)
29 [classification-scheme-ver3](http://www.iucnredlist.org/technical-documents/classification-schemes/habitats-classification-scheme-ver3). IUCN, Geneva.

30 Jellinek, S., Parris, K.M., Driscoll, D.A., Dwyer, P.D., 2013. Are incentive programs working?
31 Landowner attitudes to ecological restoration of agricultural landscapes. *J. Environ. Manage.*
32 127, 69-76.

33 Jones, N., Duarte, F., Rodrigo, I., van Doorn, A., de Graaff, J., 2016. The role of EU agri-
34 environmental measures preserving extensive grazing in two less-favoured areas in Portugal.
35 *Land Use Pol.* 54, 177-187.

36 Kahneman, D., Sugden, R., 2005. Experienced Utility as a Standard of Policy Evaluation.
37 *Environ. Resour. Econ.* 32, 161-181.

38 Kelly, C., Ferrara, A., Wilson, G.A., Ripullone, F., Nole, A., Harmer, N., Salvati, L., 2015.
39 Community resilience and land degradation in forest and shrubland socio-ecological systems:
40 Evidence from Gorgoglione, Basilicata, Italy. *Land Use Pol.* 46, 11-20.

41 Kelt, D.A., Meserve, P.L., 2016. To what extent can and should revegetation serve as
42 restoration? *Restor. Ecol.* 24, 441-448.

43 Kenter, J.O., O'Brien, L., Hockley, N., Ravenscroft, N., Fazey, I., Irvine, K.N., Reed, M.S.,
44 Christie, M., Brady, E., Bryce, R., Church, A., Cooper, N., Davies, A., Evelyn, A., Everard, M.,
45 Fish, R., Fisher, J.A., Jobstvogt, N., Molloy, C., Orchard-Webb, J., Ranger, S., Ryan, M.,
46 Watson, V., Williams, S., 2015. What are shared and social values of ecosystems? *Ecol. Econ.*
47 111, 86-99.

48 Kiedrzyńska, E., Kiedrzyński, M., Zalewski, M., 2015. Sustainable floodplain management for
49 flood prevention and water quality improvement. *Nat. Hazards* 76, 955-977.

- 1 Koschke, L., Furst, C., Lorenz, M., Witt, A., Frank, S., Makeschin, F., 2013. The integration
- 2 of crop rotation and tillage practices in the assessment of ecosystem services provision at the
- 3 regional scale. *Ecol. Indicators* 32, 157-171.
- 4 Kousky, C., Walls, M., 2014. Floodplain conservation as a flood mitigation strategy:
- 5 Examining costs and benefits. *Ecol. Econ.* 104, 119-128.
- 6 Kulakowski, D., Seidl, R., Holeksa, J., Kuuluvainen, T., Nagel, T.A., Panayotov, M., Svoboda,
- 7 M., Thorn, S., Vacchiano, G., Whitlock, C., Wohlgemuth, T., Bebi, P., 2017. A walk on the
- 8 wild side: Disturbance dynamics and the conservation and management of European mountain
- 9 forest ecosystems. *Forest Ecology and Management* 388, 120-131.
- 10 Kumar, P., 2010. *The Economics of Ecosystems and Biodiversity: Ecological and Economic*
- 11 *Foundations*. Earthscan, London and Washington.
- 12 Lane, S.N., 2017. Natural flood management. *Wiley Interdisciplinary Reviews: Water* 4,
- 13 e1211.
- 14 Lasco, R.D., Delfino, R.J.P., Espaldon, M.L.O., 2014. Agroforestry systems: helping
- 15 smallholders adapt to climate risks while mitigating climate change. *Wiley Interdiscip. Rev.-*
- 16 *Clim. Chang.* 5, 825-833.
- 17 Li, C., Zheng, H., Li, S.Z., Chen, X.S., Li, J., Zeng, W.H., Liang, Y.C., Polasky, S., Feldman,
- 18 M.W., Ruckelshaus, M., Ouyang, Z.Y., Daily, G.C., 2015. Impacts of conservation and human
- 19 development policy across stakeholders and scales. *Proc. Natl. Acad. Sci. USA* 112, 7396-
- 20 7401.
- 21 Locatelli, B., Catterall, C.P., Imbach, P., Kumar, C., Lasco, R., Marin-Spiotta, E., Mercer, B.,
- 22 Powers, J.S., Schwartz, N., Uriarte, M., 2015. Tropical reforestation and climate change:
- 23 beyond carbon. *Restor. Ecol.* 23, 337-343.
- 24 Logar, I., van den Bergh, J., 2013. Methods to Assess Costs of Drought Damages and Policies
- 25 for Drought Mitigation and Adaptation: Review and Recommendations. *Water Resour.*
- 26 *Manage.* 27, 1707-1720.
- 27 Mäler, K., Göran, Li, C.-Z., Destouni, G., 2007. Pricing resilience in a dynamic economy
- 28 environment system: A capital theoretical approach.
- 29 Maler, K.G., 2008. Sustainable development and resilience in ecosystems. *Environ. Resour.*
- 30 *Econ.* 39, 17-24.
- 31 Maler, K.G., Li, C.Z., 2010. Measuring sustainability under regime shift uncertainty: a
- 32 resilience pricing approach. *Environ. Dev. Econ.* 15, 707-719.
- 33 Mariotte, P., Vandenberghe, C., Kardol, P., Hagedorn, F., Buttler, A., 2013. Subordinate plant
- 34 species enhance community resistance against drought in semi-natural grasslands. *J. Ecol.* 101,
- 35 763-773.
- 36 Martin-Ortega, J., Mesa-Jurado, M.A., Pineda-Velazquez, M., Novo, P., 2019. Nature
- 37 commodification: 'a necessary evil'? An analysis of the views of environmental professionals
- 38 on ecosystem services-based approaches. *Ecosys. Servs.* In Press.
- 39 Mayor, A.G., Kefi, S., Bautista, S., Rodriguez, F., Carteni, F., Rietkerk, M., 2013. Feedbacks
- 40 between vegetation pattern and resource loss dramatically decrease ecosystem resilience and
- 41 restoration potential in a simple dryland model. *Landscape Ecol.* 28, 931-942.
- 42 Miguez, M.G., Verol, A.P., de Sousa, M.M., Rezende, O.M., 2015. Urban Floods in Lowlands-
- 43 Levee Systems, Unplanned Urban Growth and River Restoration Alternative: A Case Study in
- 44 Brazil. *Sustainability* 7, 11068-11097.
- 45 Millennium Ecosystem Assessment, 2005. Synthesis report. Island, Washington, DC.
- 46 Miller, R., Nielsen, E., Huang, C.H., 2017. Ecosystem Service Valuation through Wildfire Risk
- 47 Mitigation: Design, Governance, and Outcomes of the Flagstaff Watershed Protection Project
- 48 (FWPP). *Forests* 8.
- 49 Morlando, S., Schmidt, S.J., LoGiudice, K., 2012. Reduction in Lyme Disease Risk as an
- 50 Economic Benefit of Habitat Restoration. *Restor. Ecol.* 20, 498-504.

1 Mueller, J.M., 2014. Estimating willingness to pay for watershed restoration in Flagstaff,
2 Arizona using dichotomous-choice contingent valuation. *Forestry* 87, 327-333.

3 Mueller, J.M., Swaffar, W., Nielsen, E.A., Springer, A.E., Lopez, S.M., 2013. Estimating the
4 value of watershed services following forest restoration. *Water Resour Res* 49, 1773-1781.

5 Muniz, R., Cruz, M.J., 2015. Making Nature Valuable, Not Profitable: Are Payments for
6 Ecosystem Services Suitable for Degrowth? *Sustainability* 7, 10895-10921.

7 Nesshover, C., Assmuth, T., Irvine, K.N., Rusch, G.M., Waylen, K.A., Delbaere, B., Haase,
8 D., Jones-Walters, L., Keune, H., Kovacs, E., Krauze, K., Kulvik, M., Rey, F., Van Dijk, J.,
9 Vistad, O.I., Wilkinson, M.E., Wittmer, H., 2017. The science, policy and practice of nature-
10 based solutions: An interdisciplinary perspective. *Sci. Total Environ.* 579, 1215-1227.

11 Newton, A.C., Hodder, K., Cantarello, E., Perrella, L., Birch, J.C., Robins, J., Douglas, S.,
12 Moody, C., Cordingley, J., 2012. Cost-benefit analysis of ecological networks assessed through
13 spatial analysis of ecosystem services. *Journal of Applied Ecology* 49, 571-580.

14 Oliver, T.H., Isaac, N.J.B., August, T.A., Woodcock, B.A., Roy, D.B., Bullock, J.M., 2015.
15 Declining resilience of ecosystem functions under biodiversity loss. *Nature Communications*
16 6, 10122.

17 Paavola, J., Primmer, E., 2019. Governing the Provision of Insurance Value From Ecosystems.
18 *Ecol. Econ.* 164, 106346.

19 Pascual, U., Muradian, R., Brander, L., Gómez-Baggethun, E., Martín-López, B., Verma, M.,
20 Armsworth, P., Christie, M., Cornelissen, H., Eppink, F., 2010. The economics of valuing
21 ecosystem services and biodiversity, in: Kumar, P. (Ed.), *The Economics of Ecosystems and*
22 *Biodiversity*. Earthscan, London, pp. 183-256.

23 Pascual, U., Termansen, M., Hedlund, K., Brussaard, L., Faber, J.H., Foudi, S., Lemanceau,
24 P., Jorgensen, S.L., 2015. On the value of soil biodiversity and ecosystem services. *Ecosys.*
25 *Servs.* 15, 11-18.

26 Pearce, D.W., Turner, R.K., 1990. *Economics of natural resources and the environment*. JHU
27 Press, Baltimore.

28 Perrings, C., 1995. Biodiversity conservation as insurance, in: Swanson, T. (Ed.), *The*
29 *Economics and Ecology of Biodiversity Decline*. Cambridge University Press, Cambridge, pp.
30 71-72.

31 Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., Britten, N., Roen, K.,
32 Duffy, S., 2006. Guidance on the conduct of narrative synthesis in systematic reviews: A
33 product from the ESRC Methods Programme.

34 Primmer, E., Saarikoski, H., Vatn, A., 2018. An Empirical Analysis of Institutional Demand
35 for Valuation Knowledge. *Ecol. Econ.* 152, 152-160.

36 Pullin, A.S., Stewart, G.B., 2006. Guidelines for systematic review in conservation and
37 environmental management. *Conserv. Biol.* 20, 1647-1656.

38 Quaas, M.F., Baumgartner, S., 2008. Natural vs. financial insurance in the management of
39 public-good ecosystems. *Ecol. Econ.* 65, 397-406.

40 Raymond, C.M., Kenter, J.O., Plieninger, T., Turner, N.J., Alexander, K.A., 2014. Comparing
41 instrumental and deliberative paradigms underpinning the assessment of social values for
42 cultural ecosystem services. *Ecol. Econ.* 107, 145-156.

43 Raymond, C.M., Singh, G.G., Benessaiah, K., Bernhardt, J.R., Levine, J., Nelson, H., Turner,
44 N.J., Norton, B., Tam, J., Chan, K.M.A., 2013. Ecosystem Services and Beyond: Using
45 Multiple Metaphors to Understand Human-Environment Relationships. *Bioscience* 63, 536-
46 546.

47 Richert, E., Bianchin, S., Heilmeier, H., Merta, M., Seidler, C., 2011. A method for linking
48 results from an evaluation of land use scenarios from the viewpoint of flood prevention and
49 nature conservation. *Landscape Urban Plann.* 103, 118-128.

1 Rockstrom, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E., Lenton, T.M.,
2 Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der
3 Leeuw, S., Rodhe, H., Sorlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M.,
4 Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K.,
5 Crutzen, P., Foley, J., 2009. Planetary Boundaries: Exploring the Safe Operating Space for
6 Humanity. *Ecol. Soc.* 14, 33.

7 Royal Society, 2014. Resilience to extreme weather. The Royal Society Policy Centre report
8 01/14, London.

9 SAIFF, 2011. What is meant by restoration, enhancement, and alteration under the Flood Risk
10 Management (Scotland) Act 2009. Scottish Advisory and Implementation Forum for
11 Flooding., Edinburgh.

12 Schilling, K.E., Gassman, P.W., Kling, C.L., Campbell, T., Jha, M.K., Wolter, C.F., Arnold,
13 J.G., 2014. The potential for agricultural land use change to reduce flood risk in a large
14 watershed. *Hydrological Processes* 28, 3314-3325.

15 Schlapfer, F., Tucker, M., Seidl, I., 2002. Returns from hay cultivation in fertilized low
16 diversity and non-fertilized high diversity grassland - An "insurance" value of grassland plant
17 diversity? *Environ. Resour. Econ.* 21, 89-100.

18 Schmidt, K., Walz, A., Martin-Lopez, B., Sachse, R., 2017. Testing socio-cultural valuation
19 methods of ecosystem services to explain land use preferences. *Ecosys. Servs.* 26, 270-288.

20 Schulz, C., Martin-Ortega, J., Glenk, K., Ioris, A.A.R., 2017. The Value Base of Water
21 Governance: A Multi-Disciplinary Perspective. *Ecol. Econ.* 131, 241-249.

22 Shreve, C.M., Kelman, I., 2014. Does mitigation save? Reviewing cost-benefit analyses of
23 disaster risk reduction. *International Journal of Disaster Risk Reduction* 10, 213-235.

24 Speranza, C.I., 2013. Buffer capacity: capturing a dimension of resilience to climate change in
25 African smallholder agriculture. *Regional Environmental Change* 13, 521-535.

26 Steffen, W., Grinevald, J., Crutzen, P., McNeill, J., 2011. The Anthropocene: conceptual and
27 historical perspectives. *Philos. Trans. R. Soc. A-Math. Phys. Eng. Sci.* 369, 842-867.

28 Sukhdev, P., Wittmer, H., Schröter-Schlaack, C., Nesshöver, C., Bishop, J., Brink, P.t.,
29 Gundimeda, H., Kumar, P., Simmons, B., 2010. The economics of ecosystems and
30 biodiversity: mainstreaming the economics of nature: a synthesis of the approach, conclusions
31 and recommendations of TEEB. UNEP, Geneva, Switzerland.

32 The Nature Conservancy, 2018. Insuring Nature to Ensure a Resilient Future
33 [https://www.nature.org/en-us/what-we-do/our-insights/perspectives/insuring-nature-to-](https://www.nature.org/en-us/what-we-do/our-insights/perspectives/insuring-nature-to-ensure-a-resilient-future/)
34 [ensure-a-resilient-future/](https://www.nature.org/en-us/what-we-do/our-insights/perspectives/insuring-nature-to-ensure-a-resilient-future/).

35 Turner, R.K., Paavola, J., Cooper, P., Farber, S., Jessamy, V., Georgiou, S., 2003. Valuing
36 nature: lessons learned and future research directions. *Ecol. Econ.* 46, 493-510.

37 United Nations, 2016. Global Sustainable Development Report. Department of Economic and
38 Social Affairs, New York.

39 Walker, B., Meyers, J.A., 2004. Thresholds in ecological and social–ecological systems: a
40 developing database. *Ecol. Soc.* 9.

41 Walker, B., Pearson, L., Harris, M., Maler, K.-G., Li, C.-Z., Biggs, R., Baynes, T., 2008.
42 Incorporating resilience in the assessment of inclusive wealth: an example from South East
43 Australia. Discussion Paper 209. Beijer Institute. Available at www.beijer.kva.se.

44 Webbe, J., Sinha, I., Gale, C., 2018. Core Outcome Sets. *Archives of disease in childhood -*
45 *Education and Practice* 103, 163-166.

46 WHO, 2017. Vector Borne Diseases [http://www.who.int/news-room/fact-sheets/detail/vector-](http://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases)
47 [borne-diseases](http://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases). World Health Organisation, Geneva.

48 Williamson, P.R., Altman, D.G., Blazeby, J.M., Clarke, M., Devane, D., Gargon, E., Tugwell,
49 P.J.T., 2012. Developing core outcome sets for clinical trials: issues to consider. *Trials* 13, 132.

- 1 Zhai, G.F., Sato, T., Fukuzono, T., Ikeda, S., Yoshida, K., 2006. Willingness to pay for flood
- 2 risk reduction and its determinants in Japan. Journal of the American Water Resources
- 3 Association 42, 927-940.
- 4

Supplementary Material

Table S1. List of vector-borne diseases included in search terms (adapted from WHO 2017)

Chikungunya
Dengue fever
Rift Valley fever
Yellow fever
Zika
Malaria
Japanese encephalitis
Lymphatic filariasis
West Nile fever
Leishmaniasis
Sandfly fever
Phelebotomus fever
Haemorrhagic fever
Lyme disease
Relapsing fever
Borreliosis
Rickettsial disease
Spotted fever
Q fever
Tick-borne encephalitis
Tularaemia
Chagas disease
American trypanosomiasis
Sleeping sickness
African trypanosomiasis
Plague
Rickettsiosis
Onchocerciasis
River blindness
Schistosomiasis
Bilharzia

Table S2. Full list of the 154 papers for which data were extracted.

- Acosta, L.A., Eugenio, E.A., Macandog, P.B.M., Magcale-Macandog, D.B., Lin, E.K.H., Abucay, E.R., Cura, A.L., Primavera, M.G., 2016. Loss and damage from typhoon-induced floods and landslides in the Philippines: community perceptions on climate impacts and adaptation options. *International Journal of Global Warming* 9, 33-65.
- Ager, A.A., Vogler, K.C., Day, M.A., Bailey, J.D., 2017. Economic Opportunities and Trade-Offs in Collaborative Forest Landscape Restoration. *Ecological Economics* 136, 226-239.
- Agustsdottir, A.M., 2015. Ecosystem approach for natural hazard mitigation of volcanic tephra in Iceland: building resilience and sustainability. *Natural Hazards* 78, 1669-1691.
- Ascher, T.J., Wilson, R.S., Toman, E., 2013. The importance of affect, perceived risk and perceived benefit in understanding support for fuels management among wildland-urban interface residents. *International Journal of Wildland Fire* 22, 267-276.
- Babbar-Sebens, M., Barr, R.C., Tedesco, L.P., Anderson, M., 2013. Spatial identification and optimization of upland wetlands in agricultural watersheds. *Ecological Engineering* 52, 130-142.
- Baek, C.W., Lee, J.H., Paik, K., 2014. Optimal location of basin-wide constructed washlands to reduce risk of flooding. *Water and Environment Journal* 28, 52-62.
- Bagdon, B.A., Huang, C.H., Dewhurst, S., 2016. Managing for ecosystem services in northern Arizona ponderosa pine forests using a novel simulation-to-optimization methodology. *Ecological Modelling* 324, 11-27.
- Bagdon, B.A., Huang, C.H., Dewhurst, S., Meador, A.S., 2017. Climate Change Constrains the Efficiency Frontier When Managing Forests to Reduce Fire Severity and Maximize Carbon Storage. *Ecological Economics* 140, 201-214.
- Baker, J.M., Griffis, T.J., Ochsner, T.E., 2012. Coupling landscape water storage and supplemental irrigation to increase productivity and improve environmental stewardship in the U.S. Midwest. *Water Resources Research* 48, 1-12.
- Barbedo, J., Miguez, M., van der Horst, D., Marins, M., 2014. Enhancing ecosystem services for flood mitigation: a conservation strategy for peri-urban landscapes? *Ecology and Society* 19 (2): 54.
- Barbi, E., Denham, R., Star, M., 2015. Do improved grazing management practices lead to increased levels of ground cover? *Rural Extension Farming Systems Journal* 11, 114-121.
- Barth, N.C., Doll, P., 2016. Assessing the ecosystem service flood protection of a riparian forest by applying a cascade approach. *Ecosystem Services* 21, 39-52.
- Berger, F., Rey, F., 2004. Mountain protection forests against natural hazards and risks: New French developments by integrating forests in risk zoning. *Natural Hazards* 33, 395-404.

- 1 Bernues, A., Rodriguez-Ortega, T., Ripoll-Bosch, R., Alfnes, F., 2014. Socio-Cultural and
2 Economic Valuation of Ecosystem Services Provided by Mediterranean Mountain
3 Agroecosystems. *Plos One* 9 (7), 1-11.
4
- 5 Biasi, R., Brunori, E., 2015. The on-farm conservation of grapevine (*Vitis vinifera* L.)
6 landraces assures the habitat diversity in the viticultural agro-ecosystem. *Vitis* 54, 265-269.
7
- 8 Biasi, R., Brunori, E., Smiraglia, D., Salvati, L., 2015. Linking traditional tree-crop
9 landscapes and agro-biodiversity in central Italy using a database of typical and traditional
10 products: a multiple risk assessment through a data mining analysis. *Biodiversity and
11 Conservation* 24, 3009-3031.
12
- 13 Birol, E., Hanley, N., Koundouri, P., Kountouris, Y., 2009. Optimal management of
14 wetlands: Quantifying trade-offs between flood risks, recreation, and biodiversity
15 conservation. *Water Resources Research* 45, 1-11.
16
- 17 Boughton, D.A., Pike, A.S., 2013. Floodplain Rehabilitation as a Hedge against
18 Hydroclimatic Uncertainty in a Migration Corridor of Threatened Steelhead. *Conservation
19 Biology* 27, 1158-1168.
20
- 21 Bouwer, L.M., Papyrakis, E., Poussin, J., Pfurtscheller, C., Thielen, A.H., 2014. The Costing
22 of Measures for Natural Hazard Mitigation in Europe. *Natural Hazards Review* 15, 1-10.
23
- 24 Braden, J.B., Johnston, D.M., 2004. Downstream economic benefits from storm-water
25 management. *Journal of Water Resources Planning and Management-Asce* 130, 498-505.
26
- 27 Bradshaw, C.J.A., Sodhi, N.S., Peh, K.S.H., Brook, B.W., 2007. Global evidence that
28 deforestation amplifies flood risk and severity in the developing world. *Global Change
29 Biology* 13, 2379-2395.
30
- 31 Brandolini, P., Cevasco, A., Firpo, M., Robbiano, A., Sacchini, A., 2012. Geo-hydrological
32 risk management for civil protection purposes in the urban area of Genoa (Liguria, NW
33 Italy). *Natural Hazards and Earth System Sciences* 12, 943-959.
34
- 35 Brang, P., 2001. Resistance and elasticity: promising concepts for the management of
36 protection forests in the European Alps. *Forest Ecology and Management* 145, 107-119.
37
- 38 Brody, S.D., Zahran, S., Maghelal, P., Grover, H., Highfield, W.E., 2007. The rising costs of
39 floods - Examining the impact of planning and development decisions on property damage in
40 Florida. *Journal of the American Planning Association* 73, 330-345.
41
- 42 Brookhuis, B.J., Hein, L.G., 2016. The value of the flood control service of tropical forests:
43 A case study for Trinidad. *Forest Policy and Economics* 62, 118-124.
44
- 45 Brouwer, R., Bliem, M., Getzner, M., Kerekes, S., Milton, S., Palarie, T., Szerenyi, Z.,
46 Vadineanue, A., Wagtendonk, A., 2016. Valuation and transferability of the non-market
47 benefits of river restoration in the Danube river basin using a choice experiment. *Ecological
48 Engineering* 87, 20-29.
49

- 1 Brown, A., Dayal, A., del Rio, C.R., 2012. From practice to theory: emerging lessons from
2 Asia for building urban climate change resilience. *Environment and Urbanization* 24, 531-
3 556.
- 4
- 5 Bryan, B.A., King, D., Wang, E.L., 2010. Potential of woody biomass production for
6 motivating widespread natural resource management under climate change. *Land Use Policy*
7 27, 713-725.
- 8
- 9 Buffin-Belanger, T., Biron, P.M., Larocque, M., Demers, S., Olsen, T., Chone, G., Ouellet,
10 M.A., Cloutier, C.A., Desjarlais, C., Eyquem, J., 2015. Freedom space for rivers: An
11 economically viable river management concept in a changing climate. *Geomorphology* 251,
12 137-148.
- 13
- 14 Butsic, V., Syphard, A.D., Keeley, J.E., Bar-Massada, A., 2017. Can private land
15 conservation reduce wildfire risk to homes? A case study in San Diego County, California,
16 USA. *Landscape and Urban Planning* 157, 161-169.
- 17
- 18 Cai, Y.P., Huang, G.H., Tan, Q., Chen, B., 2011. Identification of optimal strategies for
19 improving eco-resilience to floods in ecologically vulnerable regions of a wetland. *Ecological*
20 *Modelling* 222, 360-369.
- 21
- 22 Calkin, D.E., Cohen, J.D., Finney, M.A., Thompson, M.P., 2014. How risk management can
23 prevent future wildfire disasters in the wildland-urban interface. *Proceedings of the National*
24 *Academy of Sciences of the United States of America* 111, 746-751.
- 25
- 26 Carvalho-Santos, C., Nunes, J.P., Monteiro, A.T., Hein, L., Honrado, J.P., 2016. Assessing
27 the effects of land cover and future climate conditions on the provision of hydrological
28 services in a medium-sized watershed of Portugal. *Hydrological Processes* 30, 720-738.
- 29
- 30 Chapin, F.S., Danell, K., Elmqvist, T., Folke, C., Fresco, N., 2007. Managing climate change
31 impacts to enhance the resilience and sustainability of Fennoscandian forests. *Ambio* 36,
32 528-533.
- 33
- 34 Chen, C.Y., Huang, W.L., 2013. Land use change and landslide characteristics analysis for
35 community-based disaster mitigation. *Environmental Monitoring and Assessment* 185, 4125-
36 4139.
- 37
- 38 Chiang, L.C., Lin, Y.P., Huang, T., Schmeller, D.S., Verburg, P.H., Liu, Y.L., Ding, T.S.,
39 2014. Simulation of ecosystem service responses to multiple disturbances from an earthquake
40 and several typhoons. *Landscape and Urban Planning* 122, 41-55.
- 41
- 42 Colloff, M.J., Doherty, M.D., Lavorel, S., Dunlop, M., Wise, R.M., Prober, S.M., 2016.
43 Adaptation services and pathways for the management of temperate montane forests under
44 transformational climate change. *Climatic Change* 138, 267-282.
- 45
- 46 Colloff, M.J., Lavorel, S., Wise, R.M., Dunlop, M., Overton, I.C., Williams, K.J., 2016.
47 Adaptation services of floodplains and wetlands under transformational climate change.
48 *Ecological Applications* 26, 1003-1017.
- 49

- 1 Colloff, M.J., Lindsay, E.A., Cook, D.C., 2013. Natural pest control in citrus as an ecosystem
2 service: Integrating ecology, economics and management at the farm scale. *Biological*
3 *Control* 67, 170-177.
- 4
- 5 Connop, S., Vandergert, P., Eisenberg, B., Collier, M.J., Nash, C., Clough, J., Newport, D.,
6 2016. Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits
7 approach to urban green infrastructure. *Environmental Science & Policy* 62, 99-111.
- 8
- 9 Creutzburg, M.K., Scheller, R.M., Lucash, M.S., LeDuc, S.D., Johnson, M.G., 2017. Forest
10 management scenarios in a changing climate: trade-offs between carbon, timber, and old
11 forest. *Ecological Applications* 27, 503-518.
- 12
- 13 Croke, J., Thompson, C., Fryirs, K., 2017. Prioritising the placement of riparian vegetation to
14 reduce flood risk and end-of-catchment sediment yields: Important considerations in
15 hydrologically-variable regions. *Journal of Environmental Management* 190, 9-19.
- 16
- 17 Cross, J., Fountain, M., Marko, V., Nagy, C., 2015. Arthropod ecosystem services in apple
18 orchards and their economic benefits. *Ecological Entomology* 40, 82-96.
- 19
- 20 Dale, P.E.R., Connelly, R., 2012. Wetlands and human health: an overview. *Wetlands*
21 *Ecology and Management* 20, 165-171.
- 22
- 23 De Graff, J.V., Sidle, R.C., Ahmad, R., Scatena, F.N., 2012. Recognizing the importance of
24 tropical forests in limiting rainfall-induced debris flows. *Environmental Earth Sciences* 67,
25 1225-1235.
- 26
- 27 de Wit, M., van Zyl, H., Crookes, D., Blignaut, J., Jayiya, T., Goiset, V., Mahumani, B.,
28 2012. Including the economic value of well-functioning urban ecosystems in financial
29 decisions: Evidence from a process in Cape Town. *Ecosystem Services* 2, 38-44.
- 30
- 31 Dixon, S.J., Sear, D.A., Odoni, N.A., Sykes, T., Lane, S.N., 2016. The effects of river
32 restoration on catchment scale flood risk and flood hydrology. *Earth Surface Processes and*
33 *Landforms* 41, 997-1008.
- 34
- 35 Doblas-Miranda, E., Paquette, A., Work, T.T., 2014. Intercropping trees' effect on soil
36 oribatid diversity in agro-ecosystems. *Agroforestry Systems* 88, 671-678.
- 37
- 38 Drake, B., Smart, J.C.R., Termansen, M., Hubacek, K., 2013. Public preferences for
39 production of local and global ecosystem services. *Regional Environmental Change* 13, 649-
40 659.
- 41
- 42 Dumenu, W.K., 2013. What are we missing? Economic value of an urban forest in Ghana.
43 *Ecosystem Services* 5, E137-E142.
- 44
- 45 Dymond, J.R., Ausseil, A.G.E., Ekanayake, J.C., Kirschbaum, M.U.F., 2012. Tradeoffs
46 between soil, water, and carbon - A national scale analysis from New Zealand. *Journal of*
47 *Environmental Management* 95, 124-131.
- 48

- 1 Eigenbrod, F., Bell, V.A., Davies, H.N., Heinemeyer, A., Armsworth, P.R., Gaston, K.J.,
2 2011. The impact of projected increases in urbanization on ecosystem services. *Proceedings*
3 *of the Royal Society B-Biological Sciences* 278, 3201-3208.
- 4
- 5 Epanchin-Niell, R., Englin, J., Nalle, D., 2009. Investing in rangeland restoration in the Arid
6 West, USA: Countering the effects of an invasive weed on the long-term fire cycle. *Journal*
7 *of Environmental Management* 91, 370-379.
- 8
- 9 Erisman, J.W., van Eekeren, N., de Wit, J., Koopmans, C., Cuijpers, W., Oerlemans, N.,
10 Koks, B.J., 2016. Agriculture and biodiversity: a better balance benefits both. *Aims*
11 *Agriculture and Food* 1, 157-174.
- 12
- 13 Evans, R.O., Bass, K.L., Burchelt, M.R., Hinson, R.D., Johnson, R., Doxey, M., 2007.
14 Management alternatives to enhance water quality and ecological function of channelized
15 streams and drainage canals. *Journal of Soil and Water Conservation* 62, 308-320.
- 16
- 17 Everard, M., Jha, R.R.S., Russell, S., 2014. The benefits of fringing mangrove systems to
18 Mumbai. *Aquatic Conservation-Marine and Freshwater Ecosystems* 24, 256-274.
- 19
- 20 Everard, M., Quinn, N., 2015. Realizing the value of fluvial geomorphology. *International*
21 *Journal of River Basin Management* 13, 487-500.
- 22
- 23 Felton, A., Nilsson, U., Sonesson, J., Felton, A.M., Roberge, J.M., Ranius, T., Ahlstrom, M.,
24 Bergh, J., Bjorkman, C., Boberg, J., Drossler, L., Fahlvik, N., Gong, P., Holmstrom, E.,
25 Keskitalo, E.C.H., Klapwijk, M.J., Laudon, H., Lundmark, T., Niklasson, M., Nordin, A.,
26 Pettersson, M., Stenlid, J., Stens, A., Wallertz, K., 2016. Replacing monocultures with
27 mixed-species stands: Ecosystem service implications of two production forest alternatives in
28 Sweden. *Ambio* 45, S124-S139.
- 29
- 30 Fischer, J., Zerger, A., Gibbons, P., Stott, J., Law, B.S., 2010. Tree decline and the future of
31 Australian farmland biodiversity. *Proceedings of the National Academy of Sciences of the*
32 *United States of America* 107, 19597-19602.
- 33
- 34 Frank, S., Furst, C., Witt, A., Koschke, L., Makeschin, F., 2014. Making use of the ecosystem
35 services concept in regional planning-trade-offs from reducing water erosion. *Landscape*
36 *Ecology* 29, 1377-1391.
- 37
- 38 Galve, J.P., Cevasco, A., Brandolini, P., Soldati, M., 2015. Assessment of shallow landslide
39 risk mitigation measures based on land use planning through probabilistic modelling.
40 *Landslides* 12, 101-114.
- 41
- 42 Gilbert, L., 2013. Can restoration of afforested peatland regulate pests and disease? *Journal of*
43 *Applied Ecology* 50, 1226-1233.
- 44
- 45 Guo, E.H., Chen, L.D., Sun, R.H., Wang, Z.M., 2015. Effects of riparian vegetation patterns
46 on the distribution and potential loss of soil nutrients: a case study of the Wenyu River in
47 Beijing. *Frontiers of Environmental Science & Engineering* 9, 279-287.
- 48
- 49 Hayha, T., Franzese, P.P., Paletto, A., Fath, B.D., 2015. Assessing, valuing, and mapping
50 ecosystem services in Alpine forests. *Ecosystem Services* 14, 12-23.

- Hess, T.M., Holman, I.P., Rose, S.C., Rosolova, Z., Parrott, A., 2010. Estimating the impact of rural land management changes on catchment runoff generation in England and Wales. *Hydrological Processes* 24, 1357-1368.
- Hinz, H.L., Schwarzlander, M., Gassmann, A., Bouchier, R.S., 2014. Successes We May Not Have Had: A Retrospective Analysis of Selected Weed Biological Control Agents in the United States. *Invasive Plant Science and Management* 7, 565-579.
- Holec, J., Hanewinkel, M., 2006. A forest management risk insurance model and its application to coniferous stands in southwest Germany. *Forest Policy and Economics* 8, 161-174.
- Holman, I.P., Hess, T.M., Rose, S.C., 2011. A broad-scale assessment of the effect of improved soil management on catchment baseflow index. *Hydrological Processes* 25, 2563-2572.
- Holstead, K.L., Kenyon, W., Rouillard, J.J., Hopkins, J., Galan-Diaz, C., 2017. Natural flood management from the farmer's perspective: criteria that affect uptake. *Journal of Flood Risk Management* 10, 205-218.
- Huang, C.H., Finkral, A., Sorensen, C., Kolb, T., 2013. Toward full economic valuation of forest fuels-reduction treatments. *Journal of Environmental Management* 130, 221-231.
- Huq, N., 2016. Institutional adaptive capacities to promote Ecosystem-based Adaptation (EbA) to flooding in England. *International Journal of Climate Change Strategies and Management* 8, 212-235.
- Hyberg, B.T., Riley, P., 2009. Floodplain Ecosystem Restoration: Commodity Markets, Environmental Services, and the Farm Bill. *Wetlands* 29, 527-534.
- Jackson, B.M., Wheeler, H.S., McIntyre, N.R., Chell, J., Francis, O.J., Frogbrook, Z., Marshall, M., Reynolds, B., Solloway, I., 2008. The impact of upland land management on flooding: insights from a multiscale experimental and modelling programme. *Journal of Flood Risk Management* 1, 71-80.
- Jackson, L.E., Pascual, U., Hodgkin, T., 2007. Utilizing and conserving agrobiodiversity in agricultural landscapes. *Agriculture Ecosystems & Environment* 121, 196-210.
- Jacobs, B., Boronyak-Vasco, L., Moyle, K., Leith, P., 2016. Ensuring Resilience of Natural Resources under Exposure to Extreme Climate Events. *Resources-Basel* 5, 20.
- Jellinek, S., Parris, K.M., Driscoll, D.A., Dwyer, P.D., 2013. Are incentive programs working? Landowner attitudes to ecological restoration of agricultural landscapes. *Journal of Environmental Management* 127, 69-76.
- Johnson, B.J., Munafo, K., Shappell, L., Tsipoura, N., Robson, M., Ehrenfeld, J., Sukhdeo, M.V.K., 2012. The roles of mosquito and bird communities on the prevalence of West Nile virus in urban wetland and residential habitats. *Urban Ecosystems* 15, 513-531.

- 1 Johnston, D.M., Braden, J.B., Price, T.H., 2006. Downstream economic benefits of
2 conservation development. *Journal of Water Resources Planning and Management-Asce* 132,
3 35-43.
4
- 5 Jones, N., Duarte, F., Rodrigo, I., van Doorn, A., de Graaff, J., 2016. The role of EU agri-
6 environmental measures preserving extensive grazing in two less-favoured areas in Portugal.
7 *Land Use Policy* 54, 177-187.
8
- 9 Jones, N., Fleskens, L., Stroosnijder, L., 2016. Targeting the impact of agri-environmental
10 policy - Future scenarios in two less favoured areas in Portugal. *Journal of Environmental*
11 *Management* 181, 805-816.
12
- 13 Josefsson, J., Berg, A., Hiron, M., Part, T., Eggers, S., 2013. Grass buffer strips benefit
14 invertebrate and breeding skylark numbers in a heterogeneous agricultural landscape.
15 *Agriculture Ecosystems & Environment* 181, 101-107.
16
- 17 Kadykalo, A.N., Findlay, C.S., 2016. The flow regulation services of wetlands. *Ecosystem*
18 *Services* 20, 91-103.
19
- 20 Kelly, C., Ferrara, A., Wilson, G.A., Ripullone, F., Nole, A., Harmer, N., Salvati, L., 2015.
21 Community resilience and land degradation in forest and shrubland socio-ecological systems:
22 Evidence from Gorgoglione, Basilicata, Italy. *Land Use Policy* 46, 11-20.
23
- 24 Kelt, D.A., Meserve, P.L., 2016. To what extent can and should revegetation serve as
25 restoration? *Restoration Ecology* 24, 441-448.
26
- 27 Kiedrzyńska, E., Kiedrzyński, M., Zalewski, M., 2015. Sustainable floodplain management
28 for flood prevention and water quality improvement. *Natural Hazards* 76, 955-977.
29
- 30 Kipkemboi, J., Van Dam, A.A., Ikiara, M.M., Denny, P., 2007. Integration of smallholder
31 wetland aquaculture-agriculture systems (fingerponds) into riparian farming systems on the
32 shores of Lake Victoria, Kenya: socio-economics and livelihoods. *Geographical Journal* 173,
33 257-272.
34
- 35 Koschke, L., Furst, C., Lorenz, M., Witt, A., Frank, S., Makeschin, F., 2013. The integration
36 of crop rotation and tillage practices in the assessment of ecosystem services provision at the
37 regional scale. *Ecological Indicators* 32, 157-171.
38
- 39 Kousky, C., Walls, M., 2014. Floodplain conservation as a flood mitigation strategy:
40 Examining costs and benefits. *Ecological Economics* 104, 119-128.
41
- 42 Kremen, C., Miles, A., 2012. Ecosystem Services in Biologically Diversified versus
43 Conventional Farming Systems: Benefits, Externalities, and Trade-Offs. *Ecology and Society*
44 17 (4): 40.
45
- 46 Kremer, P., Hamstead, Z.A., McPhearson, T., 2016. The value of urban ecosystem services in
47 New York City: A spatially explicit multicriteria analysis of landscape scale valuation
48 scenarios. *Environmental Science & Policy* 62, 57-68.
49

- 1 Krysanova, V., Dickens, C., Timmerman, J., Varela-Ortega, C., Schluter, M., Roest, K.,
2 Huntjens, P., Jaspers, F., Buiteveld, H., Moreno, E., Carrera, J.D., Slamova, R., Martinkova,
3 M., Blanco, I., Esteve, P., Pringle, K., Pahl-Wostl, C., Kabat, P., 2010. Cross-Comparison of
4 Climate Change Adaptation Strategies Across Large River Basins in Europe, Africa and
5 Asia. *Water Resources Management* 24, 4121-4160.
- 6
7 Kulakowski, D., Seidl, R., Holeksa, J., Kuuluvainen, T., Nagel, T.A., Panayotov, M.,
8 Svoboda, M., Thorn, S., Vacchiano, G., Whitlock, C., Wohlgemuth, T., Bebi, P., 2017. A
9 walk on the wild side: Disturbance dynamics and the conservation and management of
10 European mountain forest ecosystems. *Forest Ecology and Management* 388, 120-131.
- 11
12 Lasco, R.D., Delfino, R.J.P., Espaldon, M.L.O., 2014. Agroforestry systems: helping
13 smallholders adapt to climate risks while mitigating climate change. *Wiley Interdisciplinary*
14 *Reviews-Climate Change* 5, 825-833.
- 15
16 Li, C., Zheng, H., Li, S.Z., Chen, X.S., Li, J., Zeng, W.H., Liang, Y.C., Polasky, S., Feldman,
17 M.W., Ruckelshaus, M., Ouyang, Z.Y., Daily, G.C., 2015. Impacts of conservation and
18 human development policy across stakeholders and scales. *Proceedings of the National*
19 *Academy of Sciences of the United States of America* 112, 7396-7401.
- 20
21 Lin, B.B., Philpott, S.M., Jha, S., 2015. The future of urban agriculture and biodiversity-
22 ecosystem services: Challenges and next steps. *Basic and Applied Ecology* 16, 189-201.
- 23
24 Locatelli, B., Catterall, C.P., Imbach, P., Kumar, C., Lasco, R., Marin-Spiotta, E., Mercer, B.,
25 Powers, J.S., Schwartz, N., Uriarte, M., 2015. Tropical reforestation and climate change:
26 beyond carbon. *Restoration Ecology* 23, 337-343.
- 27
28 Mancilla-Leyton, J.M., Mejias, R.P., Vicente, A.M., 2013. Do goats preserve the forest?
29 Evaluating the effects of grazing goats on combustible Mediterranean scrub. *Applied*
30 *Vegetation Science* 16, 63-73.
- 31
32 Mandal, D., Srivastava, P., Giri, N., Kaushal, R., Cerda, A., Alam, N.M., 2017. Reversing
33 land degradation through grasses: a systematic meta-analysis in the Indian tropics. *Solid*
34 *Earth* 8, 217-233.
- 35
36 Mariotte, P., Robroek, B.J.M., Jassey, V.E.J., Buttler, A., 2015. Subordinate plants mitigate
37 drought effects on soil ecosystem processes by stimulating fungi. *Functional Ecology* 29,
38 1578-1586.
- 39
40 Mariotte, P., Vandenberghe, C., Kardol, P., Hagedorn, F., Buttler, A., 2013. Subordinate
41 plant species enhance community resistance against drought in semi-natural grasslands.
42 *Journal of Ecology* 101, 763-773.
- 43
44 Marks, E., Aflakpui, G.K.S., Nkem, J., Poch, R.M., Khouma, M., Kokou, K., Sagoe, R.,
45 Sebastia, M.T., 2009. Conservation of soil organic carbon, biodiversity and the provision of
46 other ecosystem services along climatic gradients in West Africa. *Biogeosciences* 6, 1825-
47 1838.
- 48

- 1 Maroschek, M., Rammer, W., Lexer, M.J., 2015. Using a novel assessment framework to
2 evaluate protective functions and timber production in Austrian mountain forests under
3 climate change. *Regional Environmental Change* 15, 1543-1555.
- 4
- 5 Mathieu, A., Joannon, A., 2003. How farmers view their job in Pays de Caux, France -
6 Consequences for grassland in water erosion. *Environmental Science & Policy* 6, 29-36.
- 7
- 8 Mayor, A.G., Kefi, S., Bautista, S., Rodriguez, F., Carteni, F., Rietkerk, M., 2013. Feedbacks
9 between vegetation pattern and resource loss dramatically decrease ecosystem resilience and
10 restoration potential in a simple dryland model. *Landscape Ecology* 28, 931-942.
- 11
- 12 McVittie, A., Norton, L., Martin-Ortega, J., Siameti, I., Glenk, K., Aalders, I., 2015.
13 Operationalizing an ecosystem services-based approach using Bayesian Belief Networks: An
14 application to riparian buffer strips. *Ecological Economics* 110, 15-27.
- 15
- 16 Meadows, J., Herbohn, J., Emtage, N., 2013. Supporting Cooperative Forest Management
17 among Small-Acreage Lifestyle Landowners in Southeast Queensland, Australia. *Society &*
18 *Natural Resources* 26, 745-761.
- 19
- 20 Meldrum, J.R., Champ, P.A., Warziniack, T., Brenkert-Smith, H., Barth, C.M., Falk, L.C.,
21 2014. Cost shared wildfire risk mitigation in Log Hill Mesa, Colorado: survey evidence on
22 participation and willingness to pay. *International Journal of Wildland Fire* 23, 567-576.
- 23
- 24 Miguez, M.G., Verol, A.P., de Sousa, M.M., Rezende, O.M., 2015. Urban Floods in
25 Lowlands-Levee Systems, Unplanned Urban Growth and River Restoration Alternative: A
26 Case Study in Brazil. *Sustainability* 7, 11068-11097.
- 27
- 28 Miller, R., Nielsen, E., Huang, C.H., 2017. Ecosystem Service Valuation through Wildfire
29 Risk Mitigation: Design, Governance, and Outcomes of the Flagstaff Watershed Protection
30 Project (FWPP). *Forests* 8 (5), 142.
- 31
- 32 Morlando, S., Schmidt, S.J., LoGiudice, K., 2012. Reduction in Lyme Disease Risk as an
33 Economic Benefit of Habitat Restoration. *Restoration Ecology* 20, 498-504.
- 34
- 35 Morris, J., Beedell, J., Hess, T.M., 2016. Mobilising flood risk management services from
36 rural land: principles and practice. *Journal of Flood Risk Management* 9, 50-68.
- 37
- 38 Mueller, J.M., 2014. Estimating willingness to pay for watershed restoration in Flagstaff,
39 Arizona using dichotomous-choice contingent valuation. *Forestry* 87, 327-333.
- 40
- 41 Mueller, J.M., Swaffar, W., Nielsen, E.A., Springer, A.E., Lopez, S.M., 2013. Estimating the
42 value of watershed services following forest restoration. *Water Resources Research* 49, 1773-
43 1781.
- 44
- 45 Mukungu, N., Abuga, K., Okalebo, F., Ingwela, R., Mwangi, J., 2016. Medicinal plants used
46 for management of malaria among the Luhya community of Kakamega East sub-County,
47 Kenya. *Journal of Ethnopharmacology* 194, 98-107.
- 48
- 49 Myers, N., 1996. Environmental services of biodiversity. *Proceedings of the National*
50 *Academy of Sciences of the United States of America* 93, 2764-2769.

- 1
- 2 Nardini, A., Pavan, S., 2012. River restoration: not only for the sake of nature but also for
- 3 saving money while addressing flood risk. A decision-making framework applied to the
- 4 Chiese River (Po basin, Italy). *Journal of Flood Risk Management* 5, 111-133.
- 5
- 6 Newton, A.C., Hodder, K., Cantarello, E., Perrella, L., Birch, J.C., Robins, J., Douglas, S.,
- 7 Moody, C., Cordingley, J., 2012. Cost-benefit analysis of ecological networks assessed
- 8 through spatial analysis of ecosystem services. *Journal of Applied Ecology* 49, 571-580.
- 9
- 10 Ocampo-Penuela, N., Pimm, S.L., 2015. Bird conservation would complement landslide
- 11 prevention in the Central Andes of Colombia. *PeerJ* 3, 1-16.
- 12
- 13 Oliver, T.H., Isaac, N.J.B., August, T.A., Woodcock, B.A., Roy, D.B., Bullock, J.M., 2015.
- 14 Declining resilience of ecosystem functions under biodiversity loss. *Nature Communications*
- 15 6, 1-8.
- 16
- 17 Reddy, S.M.W., McDonald, R.I., Maas, A.S., Rogers, A., Girvetz, E.H., North, J., Molnar, J.,
- 18 Finley, T., Leathers, G., DiMuro, J.L., 2015. Finding solutions to water scarcity:
- 19 Incorporating ecosystem service values into business planning at The Dow Chemical
- 20 Company's Freeport, TX facility. *Ecosystem Services* 12, 94-107.
- 21
- 22 Richert, E., Bianchin, S., Heilmeier, H., Merta, M., Seidler, C., 2011. A method for linking
- 23 results from an evaluation of land use scenarios from the viewpoint of flood prevention and
- 24 nature conservation. *Landscape and Urban Planning* 103, 118-128.
- 25
- 26 Rovai, M., Andreoli, M., 2016. Combining Multifunctionality and Ecosystem Services into a
- 27 Win-Win Solution. The Case Study of the Serchio River Basin (Tuscany-Italy). *Agriculture-*
- 28 *Basel* 6 (4), 49.
- 29
- 30 Ryan, C., Elsner, P., 2016. The potential for sand dams to increase the adaptive capacity of
- 31 East African drylands to climate change. *Regional Environmental Change* 16, 2087-2096.
- 32
- 33 Sain, G., Loboguerrero, A.M., Corner-Dolloff, C., Lizarazo, M., Nowak, A., Martinez-Baron,
- 34 D., Andrieu, N., 2017. Costs and benefits of climate-smart agriculture: The case of the Dry
- 35 Corridor in Guatemala. *Agricultural Systems* 151, 163-173.
- 36
- 37 Salazar, S., Frances, F., Komma, J., Blume, T., Francke, T., Bronstert, A., Blöschl, G., 2012.
- 38 A comparative analysis of the effectiveness of flood management measures based on the
- 39 concept of "retaining water in the landscape" in different European hydro-climatic regions.
- 40 *Natural Hazards and Earth System Sciences* 12, 3287-3306.
- 41
- 42 Sarma, B., Sarma, A.K., Singh, V.P., 2013. Optimal Ecological Management Practices
- 43 (EMPs) for Minimizing the Impact of Climate Change and Watershed Degradation Due to
- 44 Urbanization. *Water Resources Management* 27, 4069-4082.
- 45
- 46 Schilling, K.E., Gassman, P.W., Kling, C.L., Campbell, T., Jha, M.K., Wolter, C.F., Arnold,
- 47 J.G., 2014. The potential for agricultural land use change to reduce flood risk in a large
- 48 watershed. *Hydrological Processes* 28, 3314-3325.
- 49

- Schlapfer, F., Tucker, M., Seidl, I., 2002. Returns from hay cultivation in fertilized low diversity and non-fertilized high diversity grassland - An "insurance" value of grassland plant diversity? *Environmental & Resource Economics* 21, 89-100.
- Schober, B., Hauer, C., Habersack, H., 2015. A novel assessment of the role of Danube floodplains in flood hazard reduction (FEM method). *Natural Hazards* 75, S33-S50.
- Schroth, G., Laderach, P., Dempewolf, J., Philpott, S., Hagggar, J., Eakin, H., Castillejos, T., Moreno, J.G., Pinto, L.S., Hernandez, R., Eitzinger, A., Ramirez-Villegas, J., 2009. Towards a climate change adaptation strategy for coffee communities and ecosystems in the Sierra Madre de Chiapas, Mexico. *Mitigation and Adaptation Strategies for Global Change* 14, 605-625.
- Sendzimir, J., Reij, C.P., Magnuszewski, P., 2011. Rebuilding Resilience in the Sahel: Regreening in the Maradi and Zinder Regions of Niger. *Ecology and Society* 16, 1.
- Shreve, C.M., Kelman, I., 2014. Does mitigation save? Reviewing cost-benefit analyses of disaster risk reduction. *International Journal of Disaster Risk Reduction* 10, 213-235.
- Smith, P., Olesen, J.E., 2010. Synergies between the mitigation of, and adaptation to, climate change in agriculture. *Journal of Agricultural Science* 148, 543-552.
- Speranza, C.I., 2013. Buffer capacity: capturing a dimension of resilience to climate change in African smallholder agriculture. *Regional Environmental Change* 13, 521-535.
- Thomas, R.J., 2008. Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. *Agriculture Ecosystems & Environment* 126, 36-45.
- Varela, E., Jacobsen, J.B., Mavsar, R., 2017. Social demand for multiple benefits provided by Aleppo pine forest management in Catalonia, Spain. *Regional Environmental Change* 17, 539-550.
- Vermaat, J.E., Wagtendonk, A.J., Brouwer, R., Sheremet, O., Ansink, E., Brockhoff, T., Plug, M., Hellsten, S., Aroviita, J., Tylec, L., Gielczewski, M., Kohut, L., Brabec, K., Haverkamp, J., Poppe, M., Bock, K., Coerssen, M., Segersten, J., Hering, D., 2016. Assessing the societal benefits of river restoration using the ecosystem services approach. *Hydrobiologia* 769, 121-135.
- Vojinovic, Z., Keerakamolchai, W., Weesakul, S., Pudar, R.S., Medina, N., Alves, A., 2017. Combining Ecosystem Services with Cost-Benefit Analysis for Selection of Green and Grey Infrastructure for Flood Protection in a Cultural Setting. *Environments* 4 (1), 3.
- Vollmer, D., Pribadi, D.O., Remondi, F., Rustiadi, E., Gret-Regamey, A., 2016. Prioritizing ecosystem services in rapidly urbanizing river basins: A spatial multi-criteria analytic approach. *Sustainable Cities and Society* 20, 237-252.
- Wahren, A., Schwarzel, K., Feger, K.H., 2012. Potentials and limitations of natural flood retention by forested land in headwater catchments: evidence from experimental and model studies. *Journal of Flood Risk Management* 5, 321-335.

- 1
- 2 Wairore, J.N., Mureithi, S.M., Wasonga, O.V., Nyberg, G., 2016. Benefits Derived from
- 3 Rehabilitating a Degraded Semi-Arid Rangeland in Private Enclosures in West Pokot
- 4 County, Kenya. *Land Degradation & Development* 27, 532-541.
- 5
- 6 Walton, Z.L., Poudyal, N.C., Hepinstall-Cymerman, J., Gaither, C.J., Boley, B.B., 2016.
- 7 Exploring the role of forest resources in reducing community vulnerability to the heat effects
- 8 of climate change. *Forest Policy and Economics* 71, 94-102.
- 9
- 10 Wang, G.Q., Zhang, J.Y., Jin, J.L., Weinberg, J., Bao, Z.X., Liu, C.S., Liu, Y.L., Yan, X.L.,
- 11 Song, X.M., Zhai, R., 2017. Impacts of climate change on water resources in the Yellow
- 12 River basin and identification of global adaptation strategies. *Mitigation and Adaptation*
- 13 *Strategies for Global Change* 22, 67-83.
- 14
- 15 Watson, K.B., Ricketts, T., Galford, G., Polasky, S., O'Neil-Dunne, J., 2016. Quantifying
- 16 flood mitigation services: The economic value of Otter Creek wetlands and floodplains to
- 17 Middlebury, VT. *Ecological Economics* 130, 16-24.
- 18
- 19 Wiederholt, R., Lopez-Hoffman, L., Svancara, C., McCracken, G., Thogmartin, W.,
- 20 Diffendorfer, J.E., Mattsson, B., Bagstad, K., Cryan, P., Russell, A., Semmens, D., Medellin,
- 21 R.A., 2015. Optimizing conservation strategies for Mexican free-tailed bats: a population
- 22 viability and ecosystem services approach. *Biodiversity and Conservation* 24, 63-82.
- 23
- 24 Williams, A., Hunter, M.C., Kammerer, M., Kane, D.A., Jordan, N.R., Mortensen, D.A.,
- 25 Smith, R.G., Snapp, S., Davis, A.S., 2016. Soil Water Holding Capacity Mitigates Downside
- 26 Risk and Volatility in US Rainfed Maize: Time to Invest in Soil Organic Matter? *Plos One*
- 27 11, 1-11.
- 28
- 29 Worku, A., Pretzsch, J., Kassa, H., Auch, E., 2014. The significance of dry forest income for
- 30 livelihood resilience: The case of the pastoralists and agro-pastoralists in the drylands of
- 31 southeastern Ethiopia. *Forest Policy and Economics* 41, 51-59.
- 32
- 33 Wu, T., Kim, Y.S., 2013. Pricing ecosystem resilience in frequent-fire ponderosa pine forests.
- 34 *Forest Policy and Economics* 27, 8-12.
- 35
- 36 Wu, T., Kim, Y.S., Hurteau, M.D., 2011. Investing in Natural Capital: Using Economic
- 37 Incentives to Overcome Barriers to Forest Restoration. *Restoration Ecology* 19, 441-445.
- 38
- 39 Yao, L., Chen, L.D., Wei, W., Sun, R.H., 2015. Potential reduction in urban runoff by green
- 40 spaces in Beijing: A scenario analysis. *Urban Forestry & Urban Greening* 14, 300-308.
- 41
- 42 Zagas, T.D., Raptis, D.I., Zagas, D.T., 2011. Identifying and mapping the protective forests
- 43 of southeast Mt. Olympus as a tool for sustainable ecological and silvicultural planning, in a
- 44 multi-purpose forest management framework. *Ecological Engineering* 37, 286-293.
- 45
- 46 Zeng, X.T., Huang, G.H., Yang, X.L., Wang, X., Fu, H., Li, Y.P., Li, Z., 2016. A developed
- 47 fuzzy-stochastic optimization for coordinating human activity and eco-environmental
- 48 protection in a regional wetland ecosystem under uncertainties. *Ecological Engineering* 97,
- 49 207-230.
- 50

1

2 **Table S3. Number of studies classified according to CICES Regulation & Maintenance**
3 **Ecosystem Services.**

Code	CICES Regulation and Maintenance simple descriptor	Number
2.2.1.3	Regulating the flows of water in our environment	80
2.2.1.1	Controlling or preventing soil loss	26
2.2.1.5	Protecting people from fire	22
2.2.3.1	Controlling pests and invasive species	17
2.2.2.3	Providing habitats for wild plants and animals that can be useful to us	13
2.2.1.2	Stopping landslides and avalanches harming people	12
2.2.6.1	Regulating our global climate	12
2.2.5.1	Controlling the chemical quality of freshwater	10
2.2.4.2	Ensuring the organic matter in our soils is maintained	7
2.2.3.2	Controlling disease	6
2.2.6.2	Regulating the physical quality of air for people	5
2.2.1.4	Protecting people from winds	4
2.2.4.1	Ensuring soils form and develop	4
2.2.2.1	Pollinating our fruit trees and other plants	1
2.2.5.2	Controlling the chemical quality of salt water	1
5.2.1.2	Physical barriers to flows	1

4