Ecological Economics 164 (2019) 106346

Contents lists available at ScienceDirect

Ecological Economics

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

Analysis

Governing the Provision of Insurance Value From Ecosystems

Jouni Paavola[a,*], Eeva Primmer[b]

[a] Centre for Climate Change Economics and Policy (CCCEP), School of Earth and Environment, University of Leeds, Leeds LS2 9JT, United Kingdom
[b] Finnish Environment Institute, Finland

ARTICLE INFO

Keywords:
Ecosystem services
Risk management
Flood risk
Pest risk
Governance
Polycentricity

ABSTRACT

Ecosystems can buffer against adverse events, such as storms or pest outbreaks by reducing the probability of harm and magnitude of losses. We conceptualise factors involved in the governance of insurance value provision, drawing on the notions of protection and insurance, exogeneity and endogeneity, and allocation of rights and responsibilities. Using riverine floods and forest pest outbreaks as examples, we explore the challenges of governing ecosystem-based risk management. We suggest that such governance should build on existing institutions, because insurance value is jointly produced with provisioning ecosystem services and the governance arrangements for them importantly shape insurance value provision. However, existing institutional arrangements do not acknowledge involved actors' rights and responsibilities and they do not facilitate landscape level management of risks. While PES schemes and other market-like solutions may govern the provision of insurance value when transaction costs and trade-offs between the provision of insurance value and private goods are low, regulation or public provision is needed when transaction costs and trade-offs are high. The complexity of challenges in governing the provision of insurance value highlights the need for polycentric governance involving collaboration, knowledge creation and dissemination and the funding of activities needed for them.

1. Introduction

Ecosystems can buffer against sudden adverse events and incremental deterioration and losses, and thereby provide insurance value (Baumgärtner, 2007). For example, vegetation cover reduces surface water runoff and thus flood risk (Graves et al., 2015), and a diverse tree species and age structure can reduce forest pest outbreaks (Dymond et al., 2014). Some ecosystems, such as coastal marshes or forests on steep mountain slopes, could be managed primarily or entirely for their insurance value. Ecosystems such as oceans, mangroves and coral reefs that are not subject to intense management provide important insurance values such as protection from abrupt climate change, sea surges and storms, alongside other ecosystem services they provide. In modified ecosystems, such as in commercially managed forests and agricultural ecosystems, insurance value is typically a co-benefit of resource management.

Insurance value is poorly captured in the risk and cost-benefit calculations of land and resource managers and other actors seeking to derive economic benefits from ecosystems (Quaas and Baumgärtner, 2008), because the risk buffering capacity of ecosystems is typically a public good. Often the existing governance arrangements for environmental resources do not address the challenges of insurance value provision which results in societal losses through sub-optimal provision of insurance value. This is particularly the case with regard to modified ecosystems, which are primarily used and managed for benefits from provisioning ecosystem services. They merit attention because they are dominant ecosystem types in many places and because the trade-offs between different ecosystem services pose complex governance challenges.

The provision of insurance value is not just of academic interest – policy-makers and formal policy agendas increasingly acknowledge it because it has potential to make the benefits of environmental policies more tangible. For example, the European Union's (EU) 2013 Adaptation Strategy promotes insurance with an aim to improve risk awareness and prevention (EC, 2013b) and The Green Infrastructure Policy (EC, 2013a) supports ecosystem-based disaster risk management and spatial planning. The EU biodiversity strategy “Our Life Insurance, Our Natural Capital” similarly promotes ecosystem-based approaches to climate change mitigation and adaptation through conservation, restoration and sustainable management (EC, 2011). In the United States, ecological engineering has emerged as an approach to ecosystem restoration (e.g. Nesshöver et al., 2017), for enhanced resilience. The International Union for Conservation of Nature (IUCN) is also promoting nature-based solutions as an umbrella concept for a range of

* Corresponding author.
E-mail addresses: j.paavola@leeds.ac.uk (J. Paavola), eeva.primmer@ymparisto.fi (E. Primmer).

https://doi.org/10.1016/j.ecolecon.2019.06.001
Received 1 November 2018; Received in revised form 22 March 2019; Accepted 2 June 2019

ecosystem-related approaches for addressing societal challenges (Cohen-Shacham et al., 2016).

The problem is that the notion of insurance value is not yet conceptualised clearly enough for operationalisation. In particular, solutions for the governance of insurance value provision have received limited attention in the literature to date. One exception is the governance of the provision of green roofs reducing the risk of surface flooding and the impacts of heat exposure in cities, which has been shown to be promoted more successfully by regulatory policies combined with incentive schemes than by strategies relying on markets or information provision (Mees et al., 2013). Another example is the governance of mountain grasslands in Austria, France and Norway, where insurance value is a co-benefit of agricultural production: the diverse, extensively managed ecosystems provide a buffer against shocks and support the farmers' ability to adapt and transform their farming systems and involvement in tourism (Schermer et al., 2016).

In the reminder of this article we conceptualise and systematise the factors involved in, and constituting, the governance of insurance value provision in Section 2 and exemplify issues involved in modified agricultural and forest ecosystems in Sections 3 and 4. We suggest the interrelated notions of protection and insurance, exogeneity and endogeneity of risks as well as rights and responsibilities help map the landscape of governing the provision of insurance value and its challenges and to link the analysis of governance to economic and other theorizing of insurance value and its provision. For example, these notions help clarify the roles of actors in the provision of insurance value, and how its provision involves important issues of environmental justice such as whether beneficiary or polluter pays and whether protection against risk should be the responsibility of individuals or the state. In section 5, we relate our arguments and observations to the literature on risk management and ecosystem service governance, and in Section 6 we draw analytical and policy conclusions.

2. What Does Governance of Insurance Value Need to Address?

The provision of insurance value can be the sole or key purpose of land or resource management, for example in protected areas maintaining species diversity and resilience against pests, buffer zones protecting sources of public water supply, or forests on steep mountain slopes managed to reduce the risk of landslides. In these cases, insurance value provision trumps or constrains other resource uses. While it is easy to identify examples of above and other situations where insurance value provision can be the highest management priority, hardly any literature exists that would specifically examine the provision of insurance value and its governance in these settings. The situation with co-incidental insurance value provision from lightly managed ecosystems is comparable. For example the protection offered by mangroves and salt marshes against coastal erosion and storm surges has received attention in the literature (e.g. Danielsen et al., 2005; Gedan et al., 2011) but focus is on physical buffering capacity and provisioning, rather than on governance.

In modified agricultural and forest ecosystems, decisions about the provision of insurance value are made by land managers whose primary concern is the production of private goods such as timber, food or energy. These goods are provisioning ecosystem services which are often jointly produced with cultural ecosystem services for amenities or recreation, and regulating services contributing to ecosystem stability and resilience. It is the regulating services that typically provide insurance value. Provisioning services are often characterized by rival consumption and excludability and their provision is typically governed by private property rights and markets (Paavola, 2007, 2009). Cultural and regulating ecosystem services are often non-rival and difficult to exclude from. That is, they are usually either club goods and public goods. Both of them are amenable to non-rival consumption but because of lower exclusion costs club goods make cost-recovery possible and they can be self-provided or provided over the markets unlike public goods. Therefore, club goods and public goods pose different challenges for the governance of provision than private goods (Ostrom, 1990; Paavola, 2009).

The joint production of private and public goods is a key governance challenge for insurance value provision (Farley and Costanza, 2010: p. 2061), particularly in modified ecosystems in which provisioning ecosystem services are prioritised. Existing arrangements have been established primarily to govern the provisioning services, so insurance value provision is just a co-benefit of economic activities. If there are trade-offs between the provision of private goods of provisioning ecosystem services and the public good of insurance value, the level of insurance value provision will remain low. This is because insurance value is not formally recognised and there are no incentives for its provision. Land and resource managers are unable to recover the costs of public good provision in the absence of specific institutional arrangements supporting cost recovery. Particularly in settings with diffuse land-ownership resulting in many providers and beneficiaries, it is costly to establish and operate such institutions and therefore they often do not exist.

Insurance value provides economic benefit because it can reduce risk-related losses. Risk is often understood as the product of the probability and magnitude of adverse consequences. We can thus distinguish between *protection* – measures that reduce the likelihood of an adverse event – and *insurance* – measures that reduce losses caused by an adverse event (Pascual et al., 2015). For example, a flood plain provides 'natural protection' if it reduces the likelihood of a flooding event downstream. An example of 'natural insurance' (Quaas and Baumgärtner, 2008) is offered by urban green space, which can reduce the adverse consequences of a heat wave (Green et al., 2016). We suggest that both these risk management functions are captured by the notion of '*insurance value of ecosystems*'. Conceptually, insurance value is manifested as the reduction of the risk premium that a risk-averse agent would be willing to sacrifice to fully eliminate the risk (Baumgärtner, 2007).

Because the above conceptualisations of insurance value have implications for both land managers who provide and other actors who benefit from insurance value, explicit attention needs to be paid to the endogeneity and exogeneity of risk. A forest-owner or a farmer with monocultures of trees or crops is exposed to an endogenous risk of pest infestations which could be reduced by diversifying the species structure on their land, and thereby providin self-protection and -insurance (Pascual et al., 2015). Similarly, vegetation cover on the land-owner's or manager's land can increase the resilience against flooding and improve recovery, implying that the risk is endogenous. *Exogenous risks* occur when pest outbreaks originate in the neighbours' uniformly managed forests (Jactel et al., 2009; Bartkowski, 2017) and when flooding is caused or aggravated by actions of land managers in the upper catchment.

Understanding of both endogenous and exogenous risks as well as responses to them is affected by risk perception. Key factors influencing risk perception include: 1) previous (or direct) experience of events; 2) indirect experience such as information provided by the mass media or other communication channels, and; 3) trust in authorities and risk mitigation measures such as flood defences (see Wachinger et al., 2013; Cologna et al., 2017). Risk perceptions can vary widely even for the same risk, as actors' past experience of risk events differ, their exposure to, and capacity to obtain and use, information varies, and they have varying degrees of trust in authorities and technological interventions.

However, what endogenous and exogenous risks are is not given also for another reason: one land manager's exogeneous risk can become an endogenous risk to all similarly situated land managers at the landscape scale. The governance arrangements play a crucial role here: they can either leave individual actors to face and manage a risk individually, or the governance arrangements can involve varied collective strategies to manage the risks. At the same time, the choice of governance arrangements distributes the responsibility and costs of risk management in specific ways, and they also influence the level of residual losses and their distribution (see e.g. Eakin et al., 2009). That is, the governance arrangements determine the environmental justice outcomes with regard to risk exposure and management.

The existing rights and responsibilities regarding ecosystem management determine the combinations of ecosystem service flows that will be produced, as well as the relative volumes of the flows. Because these flows are jointly produced, the provision of insurance value is inextricably linked to the governance of other ecosystem services. Rights and responsibilities are most clearly defined for provisioning ecosystem services through property rights defining the right to extract resources and to manage them (Schlager and Ostrom, 1992). Therefore, it is important to consider these rights and responsibilities in the analysis of how insurance value provision is governed. This will also help identify the potential institutional changes required for better governance of insurance value provision.

Depending on the governance arrangements, the beneficiaries of insurance value could have a right to protection and insurance. This would entail management and precautionary responsibilities for land managers as providers. However, often rights and responsibilities are not explicitly or clearly defined. Insurance value may remain subject to only very general rights such as constitutional rights to sustainable environment, which does not create explicit responsibilities to providers. Insurance value provision could also rely on customary arrangements, and the beneficiaries hold mere informal rights (Ostrom, 1990; Gómez-Baggethun et al., 2013; Lockie et al., 2013). Finally, where explicit formalised rights and responsibilities exist, there can still be spatial mismatches between the jurisdictions and the scales at which insurance value provision decisions need to be made and implemented (Young, 2002; Vatn and Vedeld, 2012).

In what follows, we will exemplify the governance of insurance value provision and its challenges in flood risk management in the River Aire Catchment in the UK, and in forest pest management in Finnish managed forests. The examples illustrate the issues to be addressed when designing governance arrangements and help us ground our discussion to specific biophysical and institutional settings. Yet the observations are relevant for other settings as well, after accounting for differences in contexts. We examine the interrelated dimensions of governing insurance value provision: 1) protection against adverse events and insurance against losses; 2) endogeneity and exogeneity of insurance value provision; 3) rights and responsibilities of actors managing ecosystems and benefiting from insurance value, and; 4) existing governance mechanisms and their implications for insurance value provision. Based on the analysis, we discuss existing and potential governance arrangements, and draw conclusions on the governance of insurance value and its analysis.

3. Land Use and Flood Control

City of Leeds in United Kingdom is located in the catchment of the River Aire, which flows for 148 km from its source in the Yorkshire Dales to its confluence with the River Ouse. The catchment is 1100 km^2 in area (Environment Agency, 2010). The upper catchment is characterized by steep sided narrow valleys but to the South of Leeds the valleys become shallow and wide. The catchment is home to 1,050,000 people; three quarters of them living in the Leeds Metropolitan Area. Urban land use occupies 22% of the catchment (Environment Agency, 2010).

There have been significant floods in and around Leeds for ages (Leeds City Council, 2011) but they have been exacerbated by the sealing of natural surfaces, culverting and other modifications of watercourses as well as land conversion for agricultural and other uses. To control floods, there are over 120 km of raised defences in communities across the catchment. If current flood protection measures were not in place, over 13,000 properties would be at risk from a hundred-year flood (Environment Agency, 2010). But the current flood protection measures do not provide protection for all properties: for example, during the winter floods of 2015/16, over 1000 properties were flooded in the catchment. A substantial flood alleviation scheme is being constructed to protect the central parts of the City of Leeds and, to improve resilience, a catchment-wide programme of ecosystem-based flood risk reduction measures is being planned as a national pilot project.

Climate change is further increasing the flood risk, and is already affecting Leeds. Although the annual rainfall has not changed, extreme weather conditions causing flooding particularly in winter are increasingly frequent (Dadson et al., 2017). According to the UKCP09 Climate Projections, peak river flows could increase by 15–30% by 2025–2055, and by 20–50% after 2055, according to central estimates (Environment Agency, 2010).

3.1. Protection - Insurance

Urban and rural ecosystems can offer protection against the risk of riverine flooding by enhancing evaporation, absorbing water into the unsealed soil or by retaining and filtering water (Collentine and Futter, 2016). Water retention, flow retardation and water filtration are often produced jointly with other ecosystem services, such as food, recreation and cultural landscape, and provide co-benefits such as biodiversity, health and cultural identity (Dadson et al., 2017; Wilkinson et al., 2014).

Natural insurance against risk of riverine flooding can be provided by implementing nature-based solutions (NBS) (Nesshöver et al., 2017; Dadson et al., 2017; Farrugia et al., 2013; Green et al., 2016; Morris et al., 2016). NBS for flood risk management include establishing new woodlands or converting arable land to grazing in the upper catchments. Riverbeds can also be altered e.g. by building leaky dams or restoring meanders to enhance flow retardation, and excess water can be stored in ponds, wetlands and floodplains (Dadson et al., 2017). The upstream NBS lower the peak flows by reducing runoff or by spreading the runoff over a longer time. Therefore, they can reduce both the probability of flooding and losses when flooding occurs (Dadson et al., 2017). The evidence base on the effectiveness of NBS is still incomplete but at least the risk of losses due to small and frequent floods at small scales can be managed with NBS (Salazar et al., 2012; Iacob et al., 2014; Dadson et al., 2017; Morris et al., 2016). That is, NBS can increase the resilience in catchments with regard to small and moderate flood events.

3.2. Endogeneity – Exogeneity

Riverine flooding could be an endogenous risk at the catchment level. While water resources can be managed at catchment level under the Water Framework Directive, the management entities do not usually have the authority or control over all land uses affecting flood risk across catchments under existing governance arrangements. Therefore, riverine flooding remains an exogenous risk to downstream homeowners and farmers who cannot influence the probability and magnitude of flood events.

The actors that can manage the flood risk in terms of probability and magnitude are upstream land and water managers. The key dilemma is that the insurance value provided through nature-based flood control solutions is a public good. When natural insurance involves joint production of private and public goods (Baumgärtner and Quaas, 2010), there are likely to be at least some trade-offs that should be addressed. Private providers have little incentive to provide natural insurance if they cannot recover their costs. Therefore, the responsibility for flood risk management is often either assumed by the public sector or it is omitted entirely. Those exposed to flood risk can take measures to reduce losses when flooding occur, however: these measures can include defensive investments or insurance, for example.

3.3. Rights – Responsibilities

Landowners in the upper catchment of River Aire do not have any responsibility to undertake measures that reduce the risk of flooding downstream, nor to avoid actions that increase flood risk. Correspondingly, downstream farmers and landowners do not have right to natural insurance. Those at risk can take commercial flood insurance for example as a part of their buildings and contents insurance. However, a commercial insurance only covers asset losses. In the UK, building insurance is voluntary, which leads to low-income households not obtaining insurance, although they are often located in areas of high flood risk (Paavola, 2017). The availability of insurance can also weaken the incentives for the adoption of measures to avoid flood losses: insurance will enable the recovery of losses without trying to reduce the probability or magnitude of adverse outcomes.

The Department for the Environment, Food and Rural Affairs (Defra) has the national responsibility for policy on flood risk management, and it funds flood risk management through grants to the Environment Agency and local authorities. The Environment Agency has strategic responsibility for flood risk management and specific responsibility for managing the risk of flooding from the main rivers. Local authorities are responsible for developing and implementing a strategy for local flood risk management and for maintaining a register of flood risk assets (Kenyon et al., 2008). They also have the lead responsibility for managing the risk of flooding from surface water, groundwater and ordinary watercourses.

The jurisdictions of local authorities that are responsible for flood risk management do not spatially coincide with catchments. This means that the authorities cannot consider all risk reduction measures on the same footing. Measures within their own jurisdiction include plans and regulations but extra-jurisdictional concerns need to be addressed together with other authorities. These mismatches have led to localised defensive action to manage flood risk using grey infrastructure, often just relocating the flood risk, rather than catchment level considerations of nature-based solutions.

3.4. Governance

At the moment, there is no comprehensive governance framework in place to enforce or incentivise the provision of natural insurance against flood risk in the UK. Grey flood defences are mostly and at least partly publicly funded, and they are typically purpose-specific without co-benefits. Availability of commercial flood insurance for home owners and farmers is partly accentuating the problem, as it compensates for flood losses and removes the incentive to seek reduction of the probability and magnitude of losses.

Authorities responsible for flood risk management act as brokers between the potential providers and beneficiaries of insurance value, redefining or rearranging the rights and responsibilities concerning flood risk and its management, as well as (re)distributing the costs and benefits of insurance value provision. They have a range of institutional alternatives for doing so, including (see Morris et al., 2016):

- Purchase of upstream land for public ownership for flood risk management, without or with a lease back for compatible land uses;
- Regulation or planning standards to ensure the implementation of flood risk management measures on private land;
- Mandatory and compensated easements for flood water storage;
- Capital grants and annual payments to private landowners for the provision of flood risk management services;
- Other payment for ecosystem services (PES) schemes or auctions to incentivise the provision of flood risk management on private land, or taxes or charges for dis-incentivising risk increasing management.

Outright purchase, regulation and easements are suitable for ensuring long-term provision of flood risk management, and often to provide protection against major flood events. These solutions often need to be negotiated on a case-by-case basis. Capital grants and economic instruments suit shorter-term provision of additional flood risk reduction and control of recurrent smaller floods (Morris et al., 2016). Payments and auctions acknowledge land managers' rights when allocating new responsibilities to them. The choice of governance arrangements to enhance provision of insurance value thus defines rights and responsibilities and distributes the costs and benefits of provision in specific ways.

4. Forest Biodiversity and Pest Control

In Finland, over 20 million hectares of forest cover over three quarters of the country. These forests provide numerous ecosystem services, including carbon sequestration, nutrient cycling and water regulation, which are produced jointly with timber, berries, mushrooms, game, recreation and cultural identity (Saarikoski et al., 2015).

Over half a million mostly small-scale, non-industrial private forest holdings cover 61% of Finland's forest area, and generate about 75% of the country's timber growth. The forest owners have been a target of systematic regulation and guidance for over a century, with increasingly sophisticated information management and sharing systems (Hujala et al., 2007; Primmer and Wolf, 2009). The dominant forest management regime involves less than 100 year rotation – even less than 70 years – and clear-cuts, which results in even-aged forests. Typically one native conifer species, Norwegian spruce or Scots pine, dominates but naturally seeding native deciduous trees are retained during the rotation.

Finnish forest policy has tackled many challenges from sustainable yields to biodiversity degradation and social inclusion. Climate change has created the latest opportunities and threats (Ministry of Agriculture and Forestry, 2014a,b). Timber growth is expected to increase but extreme weather events and warm winters will create new risks (Lindner et al., 2010; Peltonen-Sainio et al., 2017; Seidl et al., 2017). New insect species will spread north, and pest damages increase. Windfalls concentrating on edges of clear cuts (Zeng et al., 2009) further increase pest outbreak risk.

4.1. Protection – Insurance

Forest pest damage is controlled with salvage loggings and tree removals, to halt epidemic waves of damage (Ministry of Agriculture and Forestry, 2014b; Peltola, 2014). Yet, there is evidence that natural structural features such as species and age mix and presence of dead wood could provide ecosystem and landscape level resistance against large scale pest damage (Lindenmayer and Noss, 2006; Jactel et al., 2009; Brang et al., 2014). The insurance value generated by the recovery capacity of the ecosystem resulting in resilience would also contribute to the provision of other ecosystem services such as timber growth, water retention and recreation (Drever et al., 2006; Isbell et al., 2011; Saarikoski et al., 2015; Felton et al., 2016a, 2016b; Bartkowski, 2017). The resilience improving function of natural forest structure is recognised in the forest management guidelines (Tapio, 2014), a lightly enforced soft standard, but its relationship with removals as a control and preventive action is not clear.

Recent (2013) Finnish forest damage legislation de-emphasises natural insurance produced by natural structural features, by requiring forest owners to remove any dead or damaged spruce exceeding 10 m^3 and pine exceeding 20 m^3 per hectare, even if the trees are scattered. Before this change in law, requirements were less stringent, with only groups or heaps of dead trees exceeding 25 m^3 needing to be removed. The average amount of dead wood in managed forests is 4.7 m^3 per hectare and protected areas have twice as much. In contrast, natural Boreal forests have over ten times more dead wood (Siitonen, 2001). The change in law is likely to shift the perceptions about dead and damaged trees away from insurance value providing natural features toward creator of infestation risk, and further emphasize the need to salvage also the income from these trees.

Wind damage, which generates dead wood potentially triggering pest infestations, can also be controlled by silvicultural choices: avoiding heavy thinning, designing the clearcutting areas so that they do not face old stands, and using thinned buffers to reduce windfalls (Zeng et al., 2009; Kolström et al., 2011; Tapio, 2014). These measures add to logging costs but their benefits might be captured in a short period of time.

Insurance companies offer policies against insect damage but their primary product is insurance against storm damage. The dead trees are removed soon after the storm damage, to maximise timber revenue and to avoid pest infestations. The implications of commercial insurance on managing for natural diversity and insurance value through resilience remain unclear.

4.2. Endogeneity – Exogeneity

Finnish forest owners appreciate the ecosystem services their forests provide (Primmer et al., 2014) and forestry professionals acknowledge the importance of natural structural features that promote biodiversity in managed forests (Primmer and Karppinen, 2010). This suggests that pest risk management could be considered endogenous.

However, there is lack of understanding of the level of control that an individual has over pest outbreaks. It arises from the contradictory scientific evidence on natural diverse structural features contributing to resilience at a landscape level, yet at times increasing the pest infestation risk (Drever et al., 2006; Jactel et al., 2009). This is reflected in the forest management guidelines that promote natural pest resistance in the forest ecosystem but, on the other hand, suggest limiting the amount of damaged and dead wood to control outbreaks (Tapio, 2014). The new forest regulations provide a clear disincentive to promote diverse structural features, signalling control of an endogenous problem that can have negative externalities and hence be portrayed as exogenous for the neighbours.

4.3. Rights – Responsibilities

The right to a resilient landscape where pest outbreaks do not grow into uncontrollable infestations is with the neighbouring forest-owners and the entire community of forest-owners at the landscape level. This right is currently formally secured only by the salvage removals of damaged trees based on the Forest Damage Act (2013). However, the longer term landscape level resilience provided by natural diverse structural features is not formally secured. It is promoted only with the best management practice guidelines, a soft governance instrument.

The forest-owner is responsible for compensating infestation damage on neighbours' forests. In legally protected valuable habitats, more damaged trees can be retained, conditional on a formal notice to the authorities, but the liability to compensate pest damages remains the same. If a pest infestation starts in a protected area, the government compensates affected landowners. This tort law has not been applied to date in a pest infestation case between private forest-owners (personal communication with the Finance and Audit Manager of the Forest Centre over email 30.8.2017). The advice and control responsibility is with the Finnish Forestry Centre (Ministry of Agriculture and Forestry, 2014a), a node in the national forestry extension system implementing the best practice guidelines (Primmer and Wolf, 2009).

4.4. Governance

Biodiversity contributes to forest ecosystem resilience in complex and diffuse ways and it needs to be enhanced to secure a public good like insurance value. The diverse forest structure controlling pest outbreaks can be a “club good” (Ostrom, 1990), as the neighbouring forest-owners are dependent on each other in controlling the pest populations. The complex ecosystem processes and interactions that generate resilience at spatial and temporal scales beyond the forest owners' management unit and time-span are hard to motivate while the risk of sudden pest infestations speaks to risk aversion.

There are no markets or financial incentive mechanisms in place for governing natural insurance through diverse structural features across the landscape. The collective action opportunities of governing insurance value are not addressed in the current system, other than collaboration among authorities. The formally delineated risk governance for forest damages (Ministry of Agriculture and Forestry, 2014b) highlights risk management with control, placing the responsibility on controlling authorities, including:

- Legislation to generate a basis for forest damage prevention and readiness for action in case of damage: assigning mandates for organizations, supporting collaboration, and defining the precautionary and reactive activities.
- Risk management plans supported by continuous monitoring of forest health: relying on collaboration of forest, weather, environmental and other agencies.
- Preparedness rehearsals at national and local levels.

If more natural structures were to be generated on a voluntary basis, a more landscape-level approach would be required, to account for the club good character of resilience against pests. A payment for ecosystem services scheme could be applied; recent results indicate that forest owners are interested in such incentives (see Sheremet et al., 2018), and Finnish forest owners have experience with PES (Primmer et al., 2013). The legal liability for pest damages might also need to be re-interpreted because it dis-incentivises provision of natural insurance. However, even a narrower liability rule would be likely to weigh more than the voluntary soft standards supporting natural insurance because there is a tendency in the Finnish forest sector to comply with law (Similä et al., 2014).

5. Discussion

5.1. Insurance Value Governance Void

Although the insurance value of ecosystems has been acknowledged in the literature and in the policy agendas, the governance of its provision has received limited attention. Such governance is more straightforward when insurance value is the sole or priority purpose of resource management, as is the case with protected areas, buffer zones or forest cover in steep mountain slopes. It is co-incidental when lightly or non-managed ecosystems provide insurance value in conjunction with other ecosystem services. However, settings where an ecosystem is managed for provisioning services require more attention. Our analysis addresses the governance challenge of producing public good like natural insurance alongside private goods.

The insurance value of modified ecosystems is a public good produced jointly with private goods. That is, in modified ecosystems insurance value is provided as a co-benefit through varied governance arrangements the main purpose of which has been to govern the use and management of provisioning ecosystem services (Fisher et al., 2008; Primmer et al., 2015). In the presence of trade-offs between provisioning services and insurance values, the flows of the latter ones are likely remain sub-optimal, because the providers cannot recover the cost of public good provision in the absence of institutions supporting cost recovery.

Enhanced provision of insurance value would need new institutions that address the cost of provision (and knowledge management to take into consideration the diffuse co-benefit streams of resource use that relate to other policy areas, such as biodiversity, climate change or sustainable use of natural resources (Paavola, 2007; Primmer and Furman, 2012; Collentine and Futter, 2016; see also Farley and

Costanza, 2010; Chan et al., 2017). Despite potential synergies, these policy areas have their own legacies, which calls for institutional tailoring and new forms of information management when integrating them with insurance value provision.

The examples we examined help make several more detailed observations and arguments and identify how governance of natural insurance provision could be developed further. They indicate that nature-based solutions to risk management require the consideration of:

- Ecosystem functions that generate insurance value alongside other ecosystem services
- The spatial and institutional aspects of risk allocation, and;
- The institutional framework that implicitly and explicitly defines (or leaves undefined) the rights and responsibilities of beneficiaries and providers of insurance value.

Our examples suggest that legal and contractual rights and responsibilities are often assigned to those who can manage risks in the relevant spatial and temporal scales, e.g. by building artificial flood defences or by conducting salvage loggings. Yet reduction of the probability of harm and increasing resilience using nature-based solutions would require management on bigger spatial and temporal scales than current governance arrangements do (Wachinger et al., 2013; Fischer and Charnley, 2012). The relevant scales of political jurisdictions and ecosystems have been noted to seldom coincide (Young, 2002; Clement et al., 2017). Our examples indicate that this problem is exacerbated when the actors who could manage risks and those who are exposed to them operate at different scales.

Thus the current arrangements for coordination and collective action are not tuned to addressing landscape-level resilience or catchment-level flood risk management, nor to facilitating arrangements that would allow negotiation or trading of benefits across the landscape. Our analysis also indicates that often the emphasis in risk management is on a quick fix rather than on investing in resilience for natural insurance. For example, the removal of dead trees to control forest pest infestations is simpler than improving landscape level resilience. A dam construction to protect a specific area from flooding is more straightforward than developing retention upstream. The spatial mismatch also means that regulatory and planning based solutions for insurance value provision do not work when provision requires extra-jurisdictional measures.

The examples also indicate that existing governance arrangements for ecosystem service provision rarely define the rights and responsibilities of involved and affected actors. In particular, potential beneficiaries of reduced risks seldom seem to have rights to natural insurance. The payments for ecosystem services schemes have been noted to acknowledge the rights of potential providers but to omit the rights of beneficiaries (Vatn, 2010; Lockie, 2013; Primmer et al., 2013; Chan et al., 2017).

5.2. Insurance Value Governance Options

In our examples a complex set of institutions is already involved in the governance of insurance value provision, although mostly indirectly and unintentionally. A challenge is that the existing arrangements create trade-offs between the provision of insurance value and other ecosystem services because they mostly give effect to the already institutionalised rights. The existing institutions either need to be reformed, or new layers of institutions created to complement the existing ones, to foster the provision of insurance value. Several different strategies are available for this although we consider introduction of new layers as a most promising strategy giving rise to more polycentric forms of governance.

Private-to-private payments could be used for insurance value provision. Upstream-downstream payment arrangements are a classic example, although they have been found not to be able to fully address joint production of benefits (Kosoy et al., 2007). To function, private-to-private payments require clear definition of rights and low transaction costs, i.e. an understandable and measurable unit for trading, easily accessible information, as well as uncomplicated and frequently occurring transactions (Coggan et al., 2013). These conditions are rarely met for ecosystem services and our examples show that they are even more challenging to meet with insurance value.

Regulation and liability rules can also be used for governing insurance value provision (Glaas et al., 2016). For example, land management can be regulated to maintain landcover that generates insurance value. Such regulations could clarify or/and (re)define the rights and responsibilities of providers and beneficiaries. Regulation could be the most effective way in terms of transaction costs to secure insurance value provision in the high transaction cost context of numerous providers and beneficiaries when the connection between land management practices and risk reduction associated with them is well-known. This is because it reduces the costs of negotiating and contracting, although the transaction costs of seeking information, establishing rules and monitoring compliance with them and enforcing them remain (Paavola, 2007). Regulation may be particularly needed when actors cause exogenous risks and beneficiaries cannot be distinguished (Baumgärtner and Strunz, 2014).

Precautionary responsibilities (Glaas et al., 2016) and soft policy instruments such as voluntary guidelines and corporate social responsibility could also be used to govern the provision of insurance value. Pest risk reduction and gradual loss of nutrients and biodiversity are often addressed through best management practice guidelines and sustainability criteria designed and monitored by governments, certification systems or professional associations (Polasky et al., 2015; Turnpenny et al., 2014). However, the development of feedback signals between management and risk would be important for the functioning of these public-private governance arrangements, and to support the provision across the collective and the landscape.

The role of the insurance sector could also be harnessed for insurance value provision. At the moment, insurance providers are merely compensating for the losses. Yet they could also change their mode of operation and finance the implementation of measures that reduce the probability and magnitude of losses, such as the maintenance of specific vegetation cover to reduce flood risk or structural the maintenance of diverse forest structure to control pest infestations. There are some early signals of uptake of this kind of orientation in the area of climate change adaptation (Mills, 2009; Glaas et al., 2016).

Public ownership is an alternative when there are numerous beneficiaries of insurance value, risk-management driven land-use and nature-based solutions (see Wachinger et al., 2013; Morris et al., 2016). Landscape-level planning can support insurance value provision if large publicly owned areas are used for insurance value provision. While public schemes also face substantial transaction cost challenges, the larger scale they often have can render unit cost of information provision lower in comparison to market based solutions. Public provision can be further supported by private supply when public payment and funding schemes are used to contract landowners to change their land management practices. If payment solutions were developed further, payments for risk management could be seen as an investment in insurance value and could be channelled toward the provision of multiple jointly produced ecosystem services, and integrated with other payment schemes, for example for biodiversity and carbon (Corbera et al., 2009; Primmer et al., 2013).

5.3. Insurance Value as a Collective Action Challenge

Risk management is complex and requires combining multiple sources of knowledge. Our examples show that the challenges in insurance value provision do not focus only on the public-private axis but also across actors managing the landscape: in a fragmented privately-owned landscape, where the different users and beneficiaries of natural insurance depend on each other, the insurance value of ecosystems is a club good (Ostrom, 1990).

Public-sector led and private sector engaging market-like arrangements need to make use of, and encourage, collaborative efforts to address complex interactions across the landscape. This is partly because specific institutional interventions for the provision of insurance value would not function in isolation (see Vatn and Vedeld, 2012). Rather, they would interact with the existing institutional framework, which can be rigid in adapting to the needs of new resilience approaches (Abrams et al., 2017). Collaboration and network governance solutions are needed to include and link all relevant actors to address the mismatches and the spatial inter-connectedness (Paavola, 2016). This is likely to involve a combination of different kinds of institutions such as existing private property rights, arrangements that support the formation of landscape level partnerships of different stakeholders, as well as the funding of complementary activities of these partnerships, which together will amount to a polycentric form of governance (Ostrom, 2010). Although there is much evidence on the successfulness of institutional diversity and collaboration in risk management, collaboration faces a variety of barriers to do with resources, knowledge and professional cultures (Fischer and Charnley, 2012; Borg et al., 2015; Abrams et al., 2017; Sheremet et al., 2018; Paloniemi et al., 2018).

Collaboration of different stakeholders is crucial for new polycentric forms of governance that will have to build new layers of governance on top of the existing ones. There is some experience from the use of funding for collective action, which indicates that fostering of collaboration requires not only funding but knowledge support, coordination, engagement and interaction (Primmer et al., 2013; Primmer et al., 2014; Drechsler and Wätzold, 2017; Paloniemi et al., 2018). But land managers, forest-owners and home-owners could also team up and collaborate with their neighbours. In so doing, they could share the risks of for example temporary pest infestation increase, and the benefits of for example reduced flood risk after implementation of nature-based solutions.

When ecosystem dynamics are so complex that their insurance function remains partly or mostly unknown, adaptive governance and joint learning could be used (Armitage et al., 2008; Ruhl, 2016). Knowledge management in this kind of settings needs brokers who can reduce transaction costs and support the transition to more sustainable and socially optimal setting (Coggan et al., 2013; Kivimaa et al., 2018). Such brokers often are (but do not need to be) public sector organizations, who can raise funding from the beneficiaries and channel resources to the providers. Public sector or broker support may be particularly needed in arrangements where land-owners provide multiple public good like ecosystem services alongside natural insurance, such as climate regulation and recreation. Again this points the way toward more polycentric forms of governance for insurance value provision from modified ecosystems.

6. Conclusions

Although the insurance value of ecosystems has been acknowledged in the literature and in the policy agendas, the governance of its provision remains to be institutionalised. The arrangements for governing the supply of these provisioning ecosystem services are importantly shaping the provision of insurance. However, the existing institutions often ignore natural insurance due to the trade-offs between jointly produced ecosystem service flows. In particular, joint production of nature-based solutions requiring coordination across large spatial scales and collaboration among land owners and managers is overlooked. Narrowly construed solutions for e.g. shorter-term risk reduction such as grey infrastructure for flood control or removals of damaged trees also often undermine ecosystem-based insurance value generation.

Our analysis also shows that some existing governance arrangements, including commercial insurance and liability regulation can disincentivise precautionary long-term risk management with nature-based solutions, and steer land-owners and managers away from the provision of natural insurance. In general, existing institutional arrangements do not acknowledge potential beneficiaries' right to protection, nor potential providers' responsibility.

While there is enthusiasm about the potential of market-like arrangements in the provision of insurance value, our analysis suggests that they are unlikely to play a major role in insurance value provision. Insurance value is typically a public good, and organising markets for its provision entail high transaction costs due to the number of parties involved and the difficulty of determining units of objects of transactions and monitoring of their delivery. Public supply or provision, or regulation, is needed to buffer against risks when transaction costs and trade-offs are high. That said, public provision does not require public supply, as public payment schemes can help harnessing private supply of insurance value, and soft standards can also be used to enhance the provision of insurance value.

Governance arrangements for insurance value provision need to be built considering their interaction and fit with the existing institutions: new arrangements may entail redefining rights and responsibilities. Our analysis highlights the importance of addressing spatial scales and their incompatibilities and interdependences when designing governance responses. This will likely require new layers of institutions and polycentric governance involving collaboration and network arrangements also at the local level, as well as cross-levels, to address the interdependence of areas and actors in insurance value provision.

Acknowledgements

We would like to thank Rosalind Bark, Julia Martin-Ortega, Mikael Hildén and Arild Vatn for their valuable comments on earlier versions of this manuscript as well as the feedback from the participants in the special session Governing Insurance Value of Ecosystems at the European Ecological Economics Conference in Budapest in 2017. JP was supported by funding from the Economic and Social Research Council (ESRC) to the Centre for Climate Change Economics and Policy (CCCEP) (ESRC grant number ES/K006576/1). EP was supported by funding from the Academy of Finland (project number 275772).

References

Abrams, J., Huber-Stearns, H., Bone, C., Grummon, C., Moseley, C., 2017. Adaptation to a landscape-scale mountain pine beetle epidemic in the era of networked governance: the enduring importance of bureaucratic institutions. Ecol. Soc. 22 (4).
Armitage, D., Marschke, M., Plummer, R., 2008. Adaptive co-management and the paradox of learning. Glob. Environ. Chang. 18 (1), 86–98.
Bartkowski, B., 2017. Are diverse ecosystems more valuable? Economic value of biodiversity as result of uncertainty and spatial interactions in ecosystem service provision. Ecosystem Services 24, 50–57.
Baumgärtner, S., 2007. The insurance value of biodiversity in the provision of ecosystem services. Nat. Resour. Model. 20 (1), S.87–127.
Baumgärtner, S., Quaas, M.F., 2010. Managing increasing environmental risks through agrobiodiversity and agrienvironmental policies. Agric. Econ. 41, 483–496.
Baumgärtner, S., Strunz, S., 2014. The economic insurance value of ecosystem resilience. Ecol. Econ. 101, 21–32.
Borg, R., Toikka, A., Primmer, E., 2015. Social capital and governance: a social network analysis of forest biodiversity collaboration in Central Finland. Forest Policy Econ. 50, 90–97.
Brang, P., Spathelf, P., Larsen, J.B., Bauhus, J., Boncčina, A., Chauvin, C., Lexer, M.J., 2014. Suitability of close-to-nature silviculture for adapting temperate European forests to climate change. Forestry 87 (4), 492–503.
Chan, K.M., Anderson, E., Chapman, M., Jespersen, K., Olmsted, P., 2017. Payments for ecosystem services: rife with problems and potential—for transformation towards sustainability. Ecol. Econ. 140, 110–122.
Clement, S., Moore, S.A., Lockwood, M., Mitchell, M., 2017. Fit-for-purpose institutions? An evaluation of biodiversity conservation in the agricultural landscape of the Tasmanian midlands, Australia. Journal of Environmental Policy & Planning 19, 135–155.
Coggan, A., Buitelaar, E., Whitten, S.M., Bennett, J., 2013. Intermediaries in environmental offset markets: actions and incentives. Land Use Policy 32, 145–154.
Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., 2016. Nature-based Solutions to Address Global Societal Challenges. IUCN, Gland, Switzerland, pp. 97.
Collentine, D., Futter, M.N., 2016. Realising the potential of natural water retention measures in catchment flood management: trade-offs and matching interests. Journal

of Flood Risk Management 11, 76–84.
Cologna, V., Bark, R.H., Paavola, J., 2017. Flood risk perceptions and the UK media: moving beyond "once in a lifetime" to "be prepared" reporting. Climate Risk Management 17, 1–10.
Corbera, E., Soberanis, C.G., Brown, K., 2009. Institutional dimensions of payments for ecosystem services: an analysis of Mexico's carbon forestry programme. Ecol. Econ. 68 (3), 743–761.
Dadson, S.J., et al., 2017. A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. Proceedings of the Royal Society A 473, 20160706.
Danielsen, F., Sørensen, M.K., Olwig, M.F., Selvam, V., Parish, F., Burgess, N.D., Hiraishi, T., Karunagaran, V.M., Rasmussen, M.S., Hansen, L.B., Quarto, A., Suryadiputra, N., 2005. The Asian tsunami: a protective role for coastal vegetation. Science 310, 643.
Drechsler, M., Wätzold, F., 2017. Costs of uncoordinated site selection with multiple ecosystem services. Nat. Resour. Model. 30 (1), 10–29.
Drever, C.R., Peterson, G., Messier, C., Bergeron, Y., Flannigan, M., 2006. Can forest management based on natural disturbances maintain ecological resilience? Can. J. For. Res. 36 (9), 2285–2299.
Dymond, C.C., Tedder, S., Spittlehouse, D.L., Raymer, B., Hopkins, K., McCalllion, K., Sandland, J., 2014. Diversifying managed forests to increase resilience. Can. J. For. Res. 44 (10), 1196–1205.
Eakin, H., Winkels, A., Sendzimir, J., 2009. Nested vulnerability: exploring cross-scale linkages and vulnerability teleconnections in Mexican and Vietnamese coffee systems. Environ Sci Policy 12 (4), 398–412.
EC, 2011. Our life insurance, our natural capital: an EU biodiversity strategy to 2020. European Commission COM 2011, 244.
EC, 2013a. Green infrastructure (GI) - enhancing Europe's natural capital. European Commission COM 2013, 249.
EC, 2013b. An EU strategy on adaptation to climate change. Communication from the Commission to the European Parliament COM 2013, 216.
Environment Agency, 2010. Aire Catchment Flood Management Plan. Summary Report. Available on line at. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/289346/River_Aire_Catchment_Flood_Management_Plan.pdf.
Farley, J., Costanza, R., 2010. Payments for ecosystem services: from local to global. Ecol. Econ. 69, 2060–2068.
Farrugia, S., Hudson, M.D., McCulloch, L., 2013. An evaluation of flood control and urban cooling ecosystem services delivered by urban green infrastructure. International Journal of Biodiversity Science, Ecosystem Services & Management 9 (2), 136–145.
Felton, A., Gustafsson, L., Roberge, J.M., Ranius, T., Hjältén, J., Rudolphi, J., Felton, A.M., 2016a. How climate change adaptation and mitigation strategies can threaten or enhance the biodiversity of production forests: insights from Sweden. Biol. Conserv. 194, 11–20.
Felton, A., et al., 2016b. Replacing monocultures with mixed-species stands: ecosystem service implications of two production forest alternatives in Sweden. Ambio 45 (2), 124–139.
Fischer, A.P., Charnley, S., 2012. Risk and cooperation: managing hazardous fuel in mixed ownership landscapes. Environ. Manag. 49 (6), 1192–1207.
Fisher, B., Turner, K., Zylstra, M., Brouwer, R., Groot, R., Farber, S., Ferraro, P., Green, R., Hadley, D., Harlow, J., Jefferiss, P., Kirkby, C., Morling, P., Mowatt, S., Naidoo, R., Paavola, J., Strassburg, B., Yu, D., Balmford, A., 2008. Ecosystem services and economic theory: integration for policy-relevant research. Ecol. Appl. 18 (8), 2050–2067.
Gedan, K.B., Kirwan, M.L., Wolanski, E., Barbier, E.B., Silliman, B.R., 2011. The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm. Clim. Chang. 106, 7–29.
Glaas, E., Keskitalo, E.C.H., Hjerpe, M., 2016. Insurance sector management of climate change adaptation in three Nordic countries: the influence of policy and market factors. J. Environ. Plan. Manag. 1–21.
Gómez-Baggethun, E., Kelemen, E., Martín-López, B., Palomo, I., Montes, C., 2013. Scale misfit in ecosystem service governance as a source of environmental conflict. Soc. Nat. Res. Int. J. 26 (10), 1202–1216.
Graves, A.R., Morris, J., Deeks, L.K., Rickson, R.J., Kibblewhite, M.G., Harris, J.A., Farewell, T.S., Truckle, I., 2015. The total costs of soil degradation in England and Wales. Ecol. Econ. 119, 399–413.
Green, T.L., Kronenberg, J., Andersson, E., Elmqvist, T., Gómez-Baggethun, E., 2016. Insurance value of green infrastructure in and around cities. Ecosystems 19 (6), 1051–1063.
Hujala, T., Pykäläinen, J., Tikkanen, J., 2007. Decision making among Finnish non-industrial private forest owners: the role of professional opinion and desire to learn. Scand. J. For. Res. 22 (5), 454–463.
Iacob, O., Rowan, J.S., Brown, I., Ellis, C., 2014. Evaluating wider benefits of natural flood management strategies: an ecosystem-based adaptation perspective. Hydrol. Res. 45 (6), 774–787.
Isbell, F., Calcagno, V., Hector, A., Connolly, J., Harpole, W.S., Reich, P.B., Loreau, M., 2011. High plant diversity is needed to maintain ecosystem services. Nature 477 (7363), 199–202.
Jactel, H., Nicoll, B.C., Branco, M., Gonzalez-Olabarria, J.R., Grodzki, W., Långström, B., Santos, H., 2009. The influences of forest stand management on biotic and abiotic risks of damage. Ann. For. Sci. 66 (7), 1–18.
Kenyon, W., Hill, G., Shannon, P., 2008. Scoping the role of agriculture in sustainable flood management. Land Use Policy 25 (3), 351–360.
Kivimaa, P., Boon, W., Hyysalo, S., Klerkx, L., 2018. Towards a Typology of Intermediaries in Sustainability Transitions: A Systematic Review and a Research Agenda. (Research Policy).
Kolström, M., Lindner, M., Vilén, T., Maroschek, M., Seidl, R., Lexer, M.J., Marchetti, M., 2011. Reviewing the science and implementation of climate change adaptation measures in European forestry. Forests 2 (4), 961–982.
Kosoy, N., Martinez-Tuna, M., Muradian, R., Martinez-Alier, J., 2007. Payments for environmental services in watersheds: insights from a comparative study of three cases in Central America. Ecol. Econ. 61 (2), 446–455.
Leeds City Council, 2011. Preliminary Flood Risk Assessment Report. Available online at. http://www.leeds.gov.uk/docs/Leeds%20PFRA%202011.pdf.
Lindenmayer, D.B., Noss, R.F., 2006. Salvage logging, ecosystem processes, and biodiversity conservation. Conserv. Biol. 20 (4), 949–958.
Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Lexer, M.J., 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For. Ecol. Manag. 259 (4), 698–709.
Lockie, S., 2013. Market instruments, ecosystem services, and property rights: assumptions and conditions for sustained social and ecological benefits. Land Use Policy 31, 90–98.
Mees, H.L.P., Driessen, P.P.J., Runhaar, H.A.C., Stamatelos, J., 2013. Who governs climate adaptation? Getting green roofs for stormwater retention off the ground. J. Environ. Plan. Manag. 56 (6), 802–825.
Mills, E., 2009. A global review of insurance industry responses to climate change. The Geneva Papers on Risk and Insurance Issues and Practice 34 (3), 323–359.
Ministry of Agriculture and Forestry, 2014a. Maa- ja metsätalousministeriön varautumissuunnitelma metsätuhoihin. Helsinki. vol. 2014. http://mmm.fi/documents/1410837/1501861/Varautuminen_metsatuhoihin_2012_2014.pdf/c7fcfa86-a158-470d-914a-9c9cc07cd583.
Ministry of Agriculture and Forestry, 2014b. Finland's National Climate Change Adaptation Plan 2022 Government Resolution 20 November 2014. 978-952-453-862-6 (Electronic version).
Morris, J., Beedell, J., Hess, T.M., 2016. Mobilising flood risk management services from rural land: principles and practice. Journal of Flood Risk Management 9, 50–68.
Nesshöver, C., Assmuth, T., Irvine, K.N., Rusch, G.M., Waylen, K.A., Delbaere, B., Krauze, K., 2017. The science, policy and practice of nature-based solutions: an interdisciplinary perspective. Sci. Total Environ. 579, 1215–1227.
Ostrom, E., 1990. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, Cambridge.
Ostrom, E., 2010. Polycentric systems for coping with collective action and global environmental change. Glob. Environ. Chang. 20 (4), 550–557.
Paavola, J., 2007. Institutions and environmental governance: a reconceptualization. Ecol. Econ. 63, 93–103.
Paavola, J., 2009. From market failure paradigm to an institutional theory of environmental governance. Economia Delle Fonti di Energia e Dell'Ambiente 87–101.
Paavola, J., 2016. Multi-level environmental governance: exploring the economic explanations. Environmental Policy and Governance 26, 143–154.
Paavola, J., 2017. Health impacts of climate change and health and social inequalities in the UK. Environ. Health 16, 113 Supplement 1.
Paloniemi, R., Hujala, T., Rantala, S., Harlio, A., Salomaa, A., Primmer, E., Pynnönen, S., Arponen, A., 2018. Integrating ecological and social knowledge to support targeting of voluntary biodiversity conservation. Conserv. Lett. 11 (1), 1–10.
Pascual, U., Termansen, M., Hedlund, K., Brussaard, L., Faber, J., Foudi, S., Lemanceau, P., Jørgensen, S.-L., 2015. On the value of soil biodiversity and ecosystem services. Ecosystem Services 15, 11–18. https://doi.org/10.1016/j.ecolser.2015.06.002.
Peltola, A., 2014. Metsätilastollinen Vuosikirja 2014 (Finnish Statistical Yearbook of Forestry). SVT Maa- metsä- ja kalatalous 2014 (Official Statistics of Finland: Agriculture, Forestry and Fishery). Metsäntutkimuslaitos. (428 pp).
Peltonen-Sainio, P., Sorvali, J., Müller, M., Huitu, O., Neuvonen, S., Nummelin, T., Rummukainen, A., Hynynen, J., Sievänen, R., Helle, P., Rask, M., Vehanen, T., Kumpula, J., 2017. Sopeutumisen tila 2017: Ilmastokestävyyden tarkastelut maa-ja metsätalousministeriön hallinnonalalla. Luonnonvara- ja biotalouden tutkimus 18/2017.
Polasky, S., Tallis, H., Reyers, B., 2015. Setting the bar: standards for ecosystem services. Proc. Natl. Acad. Sci. 112 (24), 7356–7361.
Primmer, E., Furman, E., 2012. Operationalising ecosystem service approaches for governance: do measuring, mapping and valuing integrate sector-specific knowledge systems? Ecosystem Services 1 (1), 85–92.
Primmer, E., Karppinen, H., 2010. Professional judgment in non-industrial private forestry: forester attitudes and social norms influencing biodiversity conservation. Forest Policy Econ. 12 (2), 136–146.
Primmer, E., Wolf, S.A., 2009. Empirical accounting of adaptation to environmental change: organizational competencies and biodiversity conservation in Finnish forest management. Ecol. Soc. 14 (2), 27.
Primmer, E., Paloniemi, R., Similä, J., Barton, D.N., 2013. Evolution in Finland's forest biodiversity conservation payments and the institutional constraints on establishing new policy. Soc. Nat. Resour. 26 (10), 1137–1154.
Primmer, E., Paloniemi, R., Similä, J., Tainio, A., 2014. Forest owner perceptions of institutions and voluntary contracting for biodiversity conservation: not crowding out but staying out. Ecol. Econ. 103, 1–10.
Primmer, E., Jokinen, P., Blicharska, M., Barton, D.N., Bugter, R., Potschin, M., 2015. A framework for empirical analysis of ecosystem services governance. Ecosystem Services 16, 158–166.
Quaas, M.F., Baumgärtner, S., 2008. Natural vs. financial insurance in the management of public-good ecosystems. Ecol. Econ. 65 (2), 397–406.
Ruhl, J.B., 2016. Adaptive management of ecosystem services across different land use regimes. J. Environ. Manag. 183, 418–423.
Saarikoski, H., Jax, K., Harrison, P., Mononen, L., Primmer, E., Vihervaara, P., Barton, D., Furman, E., 2015. Appraising the cascade model to determine operational ecosystem service definitions: case boreal forest in Finland. Ecosystem Services 25 (7), 667–682.
Salazar, S., Francés, F., Komma, J., Blume, T., Francke, T., Bronstert, A., Blöschl, G., 2012. A comparative analysis of the effectiveness of flood management measures based on

the concept of “retaining water in the landscape” in different European hydroclimatic regions. Natural Hazards and Earth System Science 12 (11), 3287–3306.

Schermer, M., Darnhofer, I., Daugstad, K., Gabillet, M., Lavorel, S., Steinbacher, M., 2016. Institutional impacts on the resilience of mountain grasslands: an analysis based on three European case studies. Land Use Policy 52, 382–391.

Schlager, E., Ostrom, E., 1992. Property-rights regimes and natural resources: a conceptual analysis. Land Econ. 68, 249–262.

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., Wild, J., Ascoli, D., Petr, M., Honkaniemi, J., Lexer, M.J., 2017. Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., Wild, J., Ascoli, D., Petr, M., Honkaniemi, J. and Lexer, M.J., 2017. Forest disturbances under climate change. Nat. Clim. Chang. 7 (6), 395.

Sheremet, O., Ruokamo, E., Juutinen, A., Svento, R., Hanley, N., 2018. Incentivising participation and spatial coordination in payment for ecosystem service schemes: Forest disease control programs in Finland. Ecol. Econ. 152, 260–272.

Siitonen, J., 2001. Forest management, coarse woody debris and saproxylic organisms: Fennoscandian boreal forests as an example. In: Ecological Bulletins, pp. 11–41.

Similä, J., Pölönen, I., Fredrikson, J., Primmer, E., Horne, P., 2014. Biodiversity protection in private forests: an analysis of compliance. Journal of Environmental Law 26 (1), 83–103.

Tapio, 2014. Metsänhoidon suositukset. Metsätalouden kehittämiskeskus Tapion julkaisuja. http://tapio.fi/julkaisut-ja-raportit/metsanhoidon-suositukset-2/.

Turnpenny, J., Russel, D., Jordan, A., 2014. The challenge of embedding an ecosystems services approach: patterns of knowledge utilisation in public policy appraisal. Environ. Plan. C: Gov. Policy 32 (2), 247–262.

Vatn, A., 2010. An institutional analysis of payments for environmental services. Ecol. Econ. 69 (6), 1245–1252.

Vatn, A., Vedeld, P., 2012. Fit, interplay, and scale: a diagnosis. Ecol. Soc. 17 (4), 12.

Wachinger, G., Renn, O., Begg, C., Kuhlicke, C., 2013. The risk perception paradox—implications for governance and communication of natural hazards. Risk Anal. 33 (6), 1049–1065.

Wilkinson, M.E., Quinn, P.F., Barber, N.J., Jonczyk, J., 2014. A framework for managing runoff and pollution in the rural landscape using a catchment systems engineering approach. Sci. Total Environ. 468, 1245–1254.

Young, O.R., 2002. The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale. The MIT Press, Cambridge MA.

Zeng, H., Peltola, H., Väisänen, H., Kellomäki, S., 2009. The effects of fragmentation on the susceptibility of a boreal forest ecosystem to wind damage. For. Ecol. Manag. 257 (3), 1165–1173.